PHOTONICA2015

V International School and Conference on Photonics
& COST actions: MP1204 and BM1205
& the Second international workshop "Control of light and matter waves propagation and localization in photonic lattices“
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Book of Abstracts

Editors
Suzana Petrović, Goran Gligorić and Milutin Stepić

Belgrade, 2015.

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24 August – 28 August 2015

Belgrade, Serbia

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Suzana Petrović, Goran Gligorić and Milutin Stepić

Vinča Institute of Nuclear Sciences, Belgrade, Serbia

Belgrade, 2015

ABSTRACTS OF TUTORIAL, KEYNOTE AND INVITED LECTURES AND CONTRIBUTED PAPERS

of

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1. Quantum optics
2. Nonlinear optics
3. Ultrafast phenomena
4. Laser spectroscopy
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10. Optical materials

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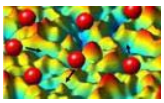

WORKSHOP
Control of light and matter waves propagation and localization in photonic lattices
(28-29 August)

The **International School and Conference on Photonics- PHOTONICA**, is a biennial event held in Belgrade since 2007. The first meeting in the series was called ISCOM (International School and Conference on Optics and Optical Materials), but it was later renamed to Photonica to reflect more clearly the aims of the event as a forum for education of young scientists, exchanging new knowledge and ideas, and fostering collaboration between scientists working within emerging areas of photonic science and technology.

A particular educational feature of the program is to enable students and young researchers to benefit from the event, by providing introductory lectures preceding most recent results in many topics covered by the regular talks. In other words, apart from the regular lectures, the plenary speakers will also give tutorial lectures specifically designed for students and scientists starting in this field.

The Conference consists of oral presentations and vibrant poster sessions. The wish of the organizers is to provide a platform for discussing new developments and concepts within various disciplines of photonics, by bringing together researchers from academia, government and industrial laboratories for scientific interaction, the showcasing of new results in the relevant fields and debate on future trends. This year our conference will contribute celebration of the International Year of Light as a global initiative which will highlight to the citizens of the world the importance of light and optical technologies. This PHOTONICA 2015 will include two COST Action meetings and one workshop with the main objective to promote knowledge in various disciplines of photonics. In additional to the lectures and seminars, a Round Table "Scientific publishing: Editors et altera" will be organized where the editors will present editorial and publishing policies of their journals and share their experiences. Following the official program, the participants will also have plenty of opportunity to mix and network outside of the lecture theatre with planned free time and social events.

This book contains 219 abstracts of all presentations at the **5th International School and Conference on Photonics, PHOTONICA2015**. Authors from 50 countries from all continents will present their work at the conference. There will be six tutorial and seven keynote lectures to the benefits of students and young researches. Twenty four invited lectures, five progress reports of young Serbian researchers and thirty one contributed talks will present most recent results in their research fields. Within the two poster sessions, students and young researches will present 146 poster presentations on their new results in a cozy atmosphere of the Serbian academy of science and arts.

Belgrade, July 2015
Editors

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Probing primary light-induced events in biomolecules with ultrafast multidimensional spectroscopies

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Many light-induced processes in biomolecules, such as energy relaxation, energy/charge transfer and conformational changes, occur on ultrafast timescales, ranging from 10^{-14} to 10^{-13} s. The speed of such elementary processes is intimately linked to their efficiency, making ultrafast optical spectroscopy an invaluable tool for their investigation. The simplest and so far more common spectroscopic technique is pump-probe, which makes use of two pulses: a "pump" pulse, which triggers the process and a broadband "probe" pulse, time-delayed by T, which acquires a snapshot of the transient absorption spectrum of the sample at time T. Pump-probe requires short pulses, in order to observe fast dynamics, and broad frequency tunability, to be able to excite a system on resonance and probe optical transitions occurring at different frequencies. A powerful recent extension of pump-probe is two-dimensional electronic spectroscopy (2DES), in which the system interacts with a sequence of three pulses, two phase-locked pump pulses delayed by τ and a probe pulse delayed by T [1]. By Fourier transforming the pump-probe data with respect to the delay τ, for a given value of T, one obtains a 2D spectrum as a function of "pump frequency" and "probe frequency". 2DES allows fundamentally new insights into the structure and dynamics of multi-chromophore systems, by measuring how the electronic states of chromophoric units within a complex molecular architecture interact with one another and transfer electronic excitations [2].
In this talk I will describe a state-of-the-art system for high time resolution pump-probe spectroscopy, based on two synchronized optical parametric amplifiers, providing sub-10-fs temporal resolution over a very broad spectral range, from 300 nm to 2 μm [3]. After reviewing the pulse generation and characterization techniques, I will present selected examples of applications to the study of ultrafast processes, such as energy/charge transfer in natural and artificial light-harvesting complexes [4, 5] and the isomerization of rhodopsin which triggers the primary event of vision [6]. I will then introduce a new system for ultra-broadband 2DES, which solves in a simple and elegant way the problem of generating a pair of phase-locked collinear pump pulses [7]. Finally I will show examples of application of 2DES to the study of energy relaxation pathways in photosynthetic complexes [8].

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Probes of quantum behaviour in organic molecules

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A growing body of evidence suggests that biological processes could be utilising quantum coherence, superpositions, and even, in some cases, quantum entanglement to perform various tasks with higher efficiency [1]. I will first briefly summarize how I see the case for the existence of genuine quantum effects, including two of the most famous examples of biological processes: photosynthesis and magneto-reception [2]. I will then present the key features of modeling the flow of energy in complex systems [3]. The main challenge is to experimentally obtain a handful of parameters believed to be important for describing the interplay between coherence (within the system) and noise (arising due to the interaction or the system with its environment) [4]. I will present single molecule spectroscopy experiments we are currently undertaking in our laboratory to obtain a better understanding of quantum effects in biomolecules. Finally, I will explain how to set up experiments to test both quantum coherence [5] as well as thermodynamical properties of energy transport [6].

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Optical and photocatalytical properties of solid and nanoporous nanostructures

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Solid and nanoporous gold nanoparticles with controlled particle size are produced from thin Au films and Ag/Au bilayer films by thermally mediated dewetting and dealloying processes. The pore size decreases to ten nanometers through dealloying by changing the Ag film thickness. The semi-spherical nanoporous Au nanoparticles exhibit greater size dependent plasmonic behaviour as compared to solid gold nanoparticles. The effects of optical extinction for different nanoscale porosity with particle size are investigated. The plasmon resonance of the nanoporous gold nanoparticles distributed over a large substrate is a promising candidate for plasmonic sensors for biological and organic molecules and other spectroscopic applications.

Hydrogenated TiO_2 (H-TiO_2) has triggered intense research interest in photocatalysis due to its substantially improved solar absorption and superior activity. However, the main factors that induce the enhanced photocatalytic performance of H-TiO_2 are still under debate. In order to clarify this issue, the structural properties of H-TiO_2, and their effects on photo-generated charges are comprehensively investigated in this study. H-TiO_2 nanoparticles with different hydrogenation degrees are rapidly synthesized through H_2 plasma treatment in several minutes; and their photocatalytic activities are evaluated by methylene blue (MB) degradation and CO_2 reduction in aqueous and gaseous media, respectively. The slightly hydrogenated TiO_2 (s-H-TiO_2) nanoparticles with the original white color exhibit enhanced photoactivity compared with the pristine TiO_2 (pristine-TiO_2) nanoparticles especially for CO_2 reduction; while the gray or black H-TiO_2 nanoparticles with higher hydrogenation degrees (h-H-TiO_2) display much worse catalytic performances. The presented results might provide new insights into the photoactivity of H-TiO_2, and pave the way for further studies of other hydrogenated metal oxides for photocatalytic applications.

In addition, the effects of two-dimensional photonic crystal surface pattern on the emission properties of the GaAs/AlGaAs based light emitting diode (LED) is demonstrated. For surface patterning of the LED, the interference lithography based on a double-exposure process by two-beam interference optical field was used. Prepared photonic crystal structure in the LED surfaces was analyzed by atomic force microscope and scanning electron microscope. Emitting properties of the LEDs were investigated by L(I) measurements. Effect of large and short period of two-dimensional photonic structure on light extraction efficiency was documented.

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Gas, glass and light: Light-matter interaction in microstructured optical fibres

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Microstructured fibres, in particular photonic crystal fibres, permit remarkable control over light-matter interactions, well beyond that possible in conventional single-mode fibre (SMF) [1]. For example, in PCFs with micron-sized cores surrounded by six hollow channels, the geometrical waveguide dispersion becomes strongly anomalous, which counterbalances the normal dispersion of the glass and shifts the zero dispersion wavelength into the visible, well μm below the canonical 1.3 of conventional SMF. The ability to engineer the group velocity dispersion has made possible the generation of octave-spanning supercontinua, revolutionising the brightness and bandwidth of white-light sources, and providing sources for frequency metrology based on fs frequency combs [2]. Recently PCF has been drawn from the fluorozirconate glass ZBLAN and used to construct supercontinuum sources with bandwidths μm in wavelength extending. from 200 nm to beyond 2 The fibre shows no sign of degradation in the UV, even after many hours of high brightness operation [3].

When solid-core PCF is twisted continuously (by thermal post-processing or by spinning the preform during fibre drawing), orbital angular momentum (OAM) states are created in the cladding that couple to the core light at certain resonant wavelengths, creating deep dips in the transmitted spectrum [4]. Twisted PCFs with "propeller"-shaped cores have the remarkable property of preserving the sign and magnitude of the orbital angular momentum over long distances [5].

GHz acoustic resonances in small-core PCF have been used to stably and passively mode-lock a fibre soliton laser at the 126th harmonic (2.1 GHz) of its round-trip frequency (16.8 MHz) [6].

Anti-resonant-reflecting (ARR) hollow core PCFs are particularly suited to ultrafast nonlinear optics because they guide over a very broad wavelength range (needed for fs pulses) with losses that range from 0.1 to a few dB/m. Gas-filled PCFs have been used for soliton compression to few-cycle pulses [7], and to generate widely-tunable deep-UV light sources [8] and multi-octave supercontinuum sources extending deep into the vacuum UV [9,10]. The ability to reach intensities of 10^{14} W/cm^2 or higher at the temporal focus of the self-compressed soliton means that ionization of the gas can play an important role, for example causing a soliton self-frequency-blue-shift [11] analogous

with the well-known Raman-related self-frequency red-shift.

A selection of scientific applications of photonic crystal fibres will be introduced in the talk.

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Superfluidity in ultracold atomic gases

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Thanks to the modern methods of magnetic and optical trapping and the manipulation of the interatomic forces it is now possible to explore a large variety of dynamic and superfluid phenomena in ultracold atomic gases. In this talk I will present an overview of major theoretical and experimental achievements concerning the superfluid behavior of these systems. These include the nature of quantized vortices, the quenching of the moment of inertia, the absence of viscosity, the collective oscillations of irrotational nature, and the propagation of first and second sound.

Quantum optics and quantum information using cold Rydberg atoms and polaritons

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In recent years various quantum communication protocols have been proposed by using non-Gaussian states of the light, such as the generation of entangled “Schrödinger's cat states” [1, 2].

For applications to quantum information processing, it is interesting to use these techniques together with “giant” optical non-linear effects, that can be obtained from large interactions between Rydberg atoms, known as Rydberg blockade [3, 4].

We will present a review about the use of non-Gaussian states of the light, and of recent results towards the possible realization of non-linear optical effects that are large enough to induce photon-photon interactions [5, 6]. Such effects would be a signicant step forward for quantum information processing and communications, including the implementation of an efficient two-photon phase gate.

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Carbon nanomaterial for ultrafast fiber lasers in near and mid infra-red

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Single Wall carbon NanoTubes (SWNT) and graphene are efficient saturable absorbers for mode-locking and Q-switching of fibre and solid state lasers [1, 2]. SWNTs can be both metallic and semiconducting with energy band depended from a diameter of SWNT. Importantly, the SWNT has a sub picosecond absorption recovery time due to non-radiative relaxation through the excitonic energy levels [1,3]. Same time graphene is a 0-band semiconductor material with an easy adjustable energy band to the excited light. The absorption recovery in graphene is even faster than in SWNT due to carrier thermalization processes [2]. Both materials provide a unique platform for advanced pulse generation regimes: high power, tenability, harmonic mode locking, etc.

In our report, we will review the general procedure of development of carbon nanomaterials based saturable absorbers via a wet chemistry route [1]. The materials were used either as a variety of polymer nano-composite films sandwiched in a fibre connector or as a nanomaterials liquid dispersion filled up a fibre microchannel [4-6]. The saturable absorption properties of materials were examined by Z-scan, pump-probe and power depended transmission techniques [1,3]. Finally, the carbon nanomaterials were used for ps and sub ps pulse generation of Yb, Er, Tm doped fibre lasers in the optical range of 1000- 1900 nm [5-9].

The demonstrated lasers can be applicable in telecom, bio-medical treatment and environmental monitoring.

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"Optical meta-atom": localization of light with quantized energy

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In open systems the energy associated with a photonic mode continuously leaks away in the form of a radiated wave, and hence the lifetimes of all natural oscillations are invariably finite. This property is strictly linked to the fact that accelerated charged particles emit light as they transit through inertial reference frames. This is the origin of the Rutherford atom stability problem, wherein electrons orbiting around the nucleus eventually collapse into the nucleus. Nevertheless, even in the pioneering times of atomic physics it was realized that the radiation loss can be significantly suppressed in systems formed by a large number of particles. In particular, Larmor observed that "when steady orbital motions in a molecule are so constituted that the vector sum of the accelerations of all its ions or electrons is constantly small, there will be no radiation, or very little, from it, and therefore this steady motion will be permanent" [1].

Surprisingly, it was recently theoretically demonstrated that in the limit of vanishing material loss plasmonic materials offer the opportunity to have light localization in *open bounded* systems with no radiation loss [2]. Under some strict conditions, volume plasmons – i.e. charge density waves in metals – may enable the formation of "embedded eigenvalue" states in finite sized cavities, such that in the absence of material loss the light oscillations can have infinite lifetime, notwithstanding that the resonator is penetrable by an incoming electromagnetic wave at the pertinent frequency. This property is absolutely unique, and there are no other examples in the literature of bounded resonators with such characteristics. Besides being of theoretical interest, mechanisms that prevent radiation loss and permit light localization can have important applications in light emitting devices, enhanced nonlinearities, and chemical or biological sensing [3-4].

A limitation of our proposal in Ref. [2] is that because of the Lorentz reciprocity theorem the trapped light state cannot be pumped by an external source. Indeed, structures made of reciprocal materials are intrinsically bi-directional, and hence if the trapped light mode cannot leak out then it is also impossible to feed its oscillations with an external excitation. Here, it is shown that the interplay of volume plasmons with a nonlinear material response may provide the means to pump the embedded eigenstate using an external source [5]. Notably, we prove that the trapped state energy is quantized, such that self-sustained oscillations are only possible for specific stored energy values. Because of the obvious parallelisms with the energy quantization of bound electronic states in atoms, we refer to the proposed resonator as an "optical meta-atom". It is envisioned that the developed ideas may find applications in optical switching and optical memories.

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Nanophotonics for holographic applications

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Advances in nanoscale fabrication allow for the realization of artificial materials with properties such as metamaterials. They are composed of subwavelength electromagnetic structures, placed at close proximity to each other. Due to mutual coupling between individual structures, they present properties to incident electromagnetic radiation that are different from those associated with the material from which the structures are comprised of. In this paper we demonstrate the use of multiwalled carbon nanotubes (MWCNTs) as shown in Fig 1 (a) and silver nano-rods as shown in Fig 1(b), as subwavelength holographic structures to produce optical metamaterials that exhibit artificial dielectric properties[1], polarisation[2] and wavelength[3] control through band gaps within the optical regime. Furthermore, if a liquid crystal (LC) material is added to this geometry [4] it provides a variable refractive index pathway between the resonant elements and alters the plasmonic frequency in a complex way. This is not a simple process to model or measure as the interaction at the surface of the plasmonic element with the liquid crystal has a dominant effect in this geometry and is very difficult to observe experimentally, however the addition of the LC materials allow us to electrically tune the properties of the metamaterials.

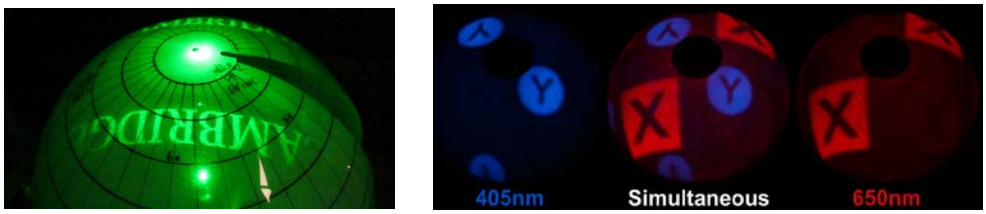

Figure 1. Plasmonic nano-holograms. a) Replay filed from a MWCNT hologram. b) Replay field from a Ag nano-rod hologram at different wavelengths.

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Dipolar QED: an alternative paradigm for quantum optics, sensors, and non-equilibrium dynamics

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In dipolar QED (dQED) the effect of neighbouring dipoles dominate the interaction between an emitter and the electromagnetic field (similar to the effect of a cavity in cavity QED). The strong coupling regime of dQED is characterised by the hopping of excitations (photons) between dipoles and for regular arrays maps onto a XY spin model [1]. The hopping of virtual photons can also be detected as a level shift which for an ensemble is referred to as the *N* atom 'Lamb' shift. In terms of applications, by mixing optical and microwave dipoles in the dQED regime it is possible to realise large single photon non-linearities [3] and detect weak fields by inducing optical bistability [4].

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Plasmonic Stopped-Light Nanolasing

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Lasers all have two vital components: a (laser) gain material and coherent feedback of the emitted light. In normal lasers feedback is provided by placing the gain material between mirrors – i.e. inside a cavity. Going beyond traditional cavity-concepts, recently conceived nanolasers employ plasmonic resonances for feedback, allowing them to concentrate light into mode volumes that are no longer limited by diffraction [1]. A particularly successful design for lasers with strongly confined fields on the nanoscale is based on semiconductor nanowires [2,3].

The use of localized surface plasmon resonances as cold-cavity modes, however, is only

one route to lasing on subwavelength scales. Lasing, in fact, does not require modes predefined by geometry but merely a feedback mechanism [4].

Here we demonstrate that the concept of dispersion-less stopped-light allows by combination of nanoplasmonics with quantum gain materials *stopped-light lasing* in hybrid nanoplasmonic heterostructures. Thereby, photons are trapped and amplified in space just at the point of their emission. It will be shown that at the stopped-light point, a stable lasing mode can form over a finite region of gain material due to the arising local (cavity-free) feedback in the form of a sub-wavelength optical vortex [5].

The remarkable spatio-temporal dynamics of nanoplasmonic stopped-light lasing is studied on the basis of a Maxwell-Bloch Langevin approach [5]. Moreover, a new rate-equation framework is shown to grasp the particular physics of stopped-light lasing involving singularities in the density of states [6]. The observed high-β characteristics and ultrafast relaxation oscillations of cavity-free stopped-light lasing can potentially allow for the design of thresholdless plasmonic laser diodes that are thinner than the wavelength and localized on the nanoscale but also potentially extended over large areas and can be modulated with THz speeds. A novel quantum model provides fundamental insight into the strong coupling between quantum emitters and localized nanophotonic modes and simulations reveal the ultrafast dynamics of nonequilibrium surface-plasmon polaritons that are condensed at stopped-light singularities.

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New generation of compact semiconductor based lasers in biomedical applications

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In recent years, there has been a growing interest in the development of compact and low-cost, versatile, broadly tunable CW and ultra-short pulse laser sources generating light across the near-infrared and visible spectral ranges. In this talk we are presenting the recent progress on the development of novel compact laser sources generating light across broad spectral ranges in CW and ultra-short pulse regimes. We also will demonstrate applicability of such lasers in Biomedical Photonics.

Dielectric metasurfaces with optically induced dielectric response: control of wavefront and nonlinearities

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Resonant dielectric metasurfaces can provide an efficient and superior way for manipulation of light fields. However, only the interplay of electric and magnetic resonances of all-dielectric metasurfaces can enable the complete polarization-independent control of the transmission and reflection of light [1,2]. This has opened a new way for the realization of low-loss flat optics with wide-range of practical applications. This talk will present our activities on the design, fabrication and characterisation of all-dielectric metasurfaces based on silicon nanodisks. In such metasurface we can independently engineer the spectral positions and widths of their electric and magnetic Mie-type resonances by altering the nanodisk geometry [1]. This engineering has enabled us to demonstrate experimentally efficient wavefront control of optical beams as well control of light emission and nonlinearities.

Wavefront control: We show that by spectrally overlapping the electric and magnetic resonances of the silicon disks we can completely suppress the reflection from the metasurface, while the absorption in the surface is negligible for wavelengths above the Silicon bandgap. Under these conditions, the dielectric metasurface operates as an efficient Huygens metasurface, allowing for the manipulation of optical wavefronts with 100% transmission efficiency and zero losses [2]. Using this concept we have demonstrated functional holographic metasurface for wave shaping, including vortex beam generation and tunable holographic devices [3].

Nonlinearity enhancement: Silicon is the material of choice for many nonlinear photonic devices. We show that the nonlinear response of such silicon metasurfaces can be dramatically enhanced, resulting in strong third harmonic generation in the vicinity of the magnetic resonance of the surface [4,5].

Our results suggest a novel approach for functional ultra-thing metadevices, including wavefront engineering and advanced light sources.

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Interacting topological quantum states of ultracold atoms

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Recent experiments in ultracold atoms and photonic analogs have implemented synthetic gauge fields and opened up the possibility to study topological states of quantum many-body systems, such as interacting Chern insulators. One major open issue is whether topological transitions can be driven by interactions. I will discuss two recent theoretical results:

1) We consider a non-abelian and time-reversal invariant version of the Hofstadter problem - a quantum particle on a lattice in a synthetic magnetic field - which has recently been realized in ultracold atoms. Without interactions, the system exhibits various phases such as topological and normal insulator, metal as well as semi-metal phases with multiple Dirac cones. Using a combination of dynamical mean-field theory and analytical techniques, we investigate and establish the stability of topological insulator phases in the presence of strong interactions.

2) We investigate the Haldane honeycomb lattice tight-binding model, for bosons with local interactions at filling one. We analyze the ground state phase diagram and uncover three distinct phases: a uniform superfluid (SF), a chiral superfluid (CSF) and a plaquette Mott insulator with local current loops (PMI).

Nonlinear graphene plasmonics and photonics: manipulating light on a surface

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Graphene, a single layer of carbon atoms arranged in hexagons, is an atomically thin representative of a new class of materials – two-dimensional crystals. Because of the restricted dimensionality and crystal symmetry, graphene has very interesting physical properties. In particular, it has been recently recognized, that graphene possesses possibly the strongest nonlinear optical response among all known optical materials [1-4]. This discovery has encouraged many research groups to develop new photonic setups incorporating graphene as the major nonlinear element and boost the overall nonlinear performance of conventional photonic devices, such as waveguides [5, 6] and cavities [7]. However, graphene is conceptually different from the usual, three-dimensional bulk

materials. New theoretical tools and experimental setups must be developed to explore and utilize its unique optical properties.

In this talk, I will present my recent work on theoretical analysis of nonlinear optical effects in graphene-based plasmonic and photonic structures. I will discuss the newly developed approach, whereby optical response of graphene is incorporated via nonlinear boundary conditions in Maxwell equations. I will describe the asymptotic expansion procedure and derivation of pulse propagation equation for various nonlinear guiding plasmonic and photonic structures, and present general expressions for effective linear and nonlinear contributions due to graphene. I will discuss basic nonlinear effects including self-focusing and nonlinear switching in planar structures which support surface graphene plasmons, nonlinear pulse propagation and parametric frequency conversion in graphene-clad photonic waveguides and micro-fibers.

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TERA-MIR Radiation: Materials, Generation, Detection and Applications II

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In this talk, I start by summarizing the main goals and recent achievements of COST ACTION MP1204 [1], whose main objectives are to advance novel materials, concepts and device designs for generating and detecting THz and Mid Infrared radiation using semiconductor, superconductor, metamaterials and lasers and to beneficially exploit their common aspects within a synergetic approach. We use the unique networking and capacity-building capabilities provided by the COST framework to unify these two spectral domains from their common aspects of sources, detectors, materials and applications. We are creating a platform to investigate interdisciplinary topics in Physics, Electrical Engineering and Technology, Applied Chemistry, Materials Sciences and Biology and Radio Astronomy. The main emphasis is on new fundamental material properties, concepts and device designs that are likely to open the way to new products or to the exploitation of new technologies in the fields of sensing, healthcare, biology, and industrial applications. End users are: research centres, academic, well-established and

start-up Companies and hospitals.

Results are presented along our main lines of research: *Intersubband materials and devices with applications to fingerprint spectroscopy; Metamaterials, photonic crystals and new functionalities; Nonlinearities and interaction of radiation with matter including biomaterials; Generation and Detection based on Nitrides and Bismides.*

Next I summarize research results in which I have been directly involved including: *valence band THz polaritons and antipolaritons* [2,3], *a microscopic approach to dilute semiconductor optics* [4], *simulations of quantum cascade lasers* and *THz generation by frequency multiplication in semiconductor superlattices and a numerical study of high impedance T-match antennas for THz photomixers* [5]. The theoretical results outlined are intended to stimulate further cooperation between theory and experimental teams.

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Light-Matter Interactions in Graphene and Heterostructures made of 2D Crystals

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When one writes by a pencil, thin flakes of graphite are left on a surface. Some of them are only one angstrom thick and can be viewed as individual atomic planes cleaved away from the bulk. This strictly 2-dimensional (2D) material called graphene was presumed not to exist in the free state and remained undiscovered until a few years ago. In fact, there exists a whole class of such 2D crystals. The isolation of various 2D materials, and the possibility to combine them in vertical stacks (as LEGO bricks), allows making heterostructures based on 2D crystals. Such a concept provides the opportunity to fabricate devices with novel functionality.

Graphene is currently attracting lot of attention because of its unusual electronic, optical and mechanical properties, which make this material very attractive for several applications. However, before thinking about developing a graphene-based technology,

we have to be able to identify graphene and to probe its changes in properties while processing. Being “all surface”, graphene is extremely sensitive to the environment and to external perturbations. Raman Spectroscopy is the most used technique to probe the properties of graphene. In the first part of this talk I will give an overview on the use of this technique to identify graphene [1], and to probe amount of defects, doping, strain and superlattices [2-5].

If time allows, in the second part of this talk I will show example of photoactive devices based on 2D crystals heterostructures, composed of semiconducting transition metal dichalcogenides/graphene stacks [6-7].

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Photonics Meets a Modern Transistor: Building High-performance Electronic-Photonic Systems with Integrated Silicon-Photonics

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Today's chips suffer from a large mismatch between internal computational capability and inability of the input/output interface links to deliver the required data from the outside environment, both in terms of energy-cost and bandwidth-density. Silicon-photonic technology is well positioned to overcome these two fundamental difficulties of electrical links, but proper integration strategies need to be applied to preserve its advantages.

In this talk we'll present the latest results on the integration of silicon-photonic interconnects in both the 45nm SOI logic process [1-3] (the process in which many advanced processors like Power 7, Cell, and Espresso are built) and a bulk CMOS memory periphery process [4-5]. We also illustrate some critical aspects of this technology that need to be addressed from integration, circuits and systems side. These results present a culmination of a 10-year multi-university program between Massachusetts Institute of Technology, University of California, Berkeley and University

of Colorado, Boulder, aiming to integrate photonics monolithically into processes with advanced transistors.

Moreover, just like integrating the inductor into CMOS chips at the end of 1990s revolutionized the radio design and enabled mobile revolution, the integration of silicon-photonic active and passive devices with modern CMOS transistors is greatly positioned to revolutionize a number of systems beyond computers and data-centers – sensor platforms (ultrasound, bio-screening), imaging (portable LIDAR systems), as well as the wireless communications infrastructure with photonic-assisted phase-arrays, low-phase noise signal sources and large bandwidth, high-resolution ADCs, to name a few.

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How Quantitative confocal fluorescence microscopy without scanning for the study of fast dynamical processes *via* massively parallel Fluorescence Correlation Spectroscopy (FCS)

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Quantitative confocal fluorescence microscopy without scanning is developed for the study of fast dynamical processes *via* massively parallel Fluorescence Correlation Spectroscopy (FCS). Simultaneous excitation of fluorescent molecules across the specimen is achieved using a Diffractive Optical Element (DOE). Fluorescence from 1024 illuminated spots is detected in a confocal arrangement by a matching matrix detector consisting of the same number of single-photon avalanche photodiodes (SPADs). Software was developed for data acquisition and fast auto- and cross-correlation analysis by parallel signal processing using a Graphic Processing Unit (GPU). Using aqueous suspension of quantum dots and live cells, we show quantitative mapping of local concentration and mobility across the specimen with a sub-millisecond temporal resolution (21 μs/frame).

Real-time measurements of intensity spatio-temporal dynamics in fiber lasers

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Physical systems with co-existence and interplay of processes featuring distinct spatio-temporal scales are found in various research areas ranging from studies of brain activity to astrophysics. Complexity of such systems makes their theoretical and experimental analysis technically and conceptually challenging. We will show that radiation of partially mode-locked fibre lasers, while being stochastic and intermittent on short time scale, exhibits periodicity and long scale correlations over slow evolution from one round trip to another. The evolution mapping of intensity autocorrelation function allows us to reveal variety of spatio-temporal coherent structures and to experimentally study their symbiotic co-existence with stochastic radiation. Our measurements of interactions of noisy pulses
over a time scale of thousands of non-linear lengths demonstrate that they have features of incoherent temporal solitons. Real-time measurements of spatio-temporal intensity dynamics are set to bring new insight into rich underlying nonlinear physics of practical active- and passive-cavity photonic systems.

Optomechanics with cold rubidium atoms

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Inducing mechanical action on atoms by continuous wave (cw) laser excitation has been the central topic in atomic physics for decades. Laser cooling and trapping of atoms, a

technique that enables production of dense (ultra)cold atomic samples, was made available by employing the radiation pressure force. Furthermore, atomic self-organization and collective cavity cooling have been demonstrated in cavity-optomechanical systems with cold atomic ensembles. Yet, in contrast to the rich and fruitful field of cw-laser-induced optomechanics, the investigations of mechanical action on atoms due to interaction with trains of ultrashort laser pulses (i.e. frequency combs) are scarce in literature.

I will present our recent results on the investigation of the frequency-comb (FC) induced radiative force on cold rubidium atoms, which indicate that in a specific excitation geometry an entirely new type of FC-atom interaction emerges that calls out for further experimental and theoretical investigation [1].

The second part of the talk will be devoted to the design and experimental demonstration of the optomechanical forces that drive the motion of neutral atoms in a way analogous to the Lorentz force driving the motion of charged particles. I will present our investigation of the synthetic Lorentz force in cold (but still classical) rubidium atomic gas. The force arises as a result of the atom-light interaction using radiation pressure and Doppler effect [2]. I will present the first experimental results of the radiation pressure force which depends on the velocity of the cold atomic cloud, and is perpendicular to it [3]. This research could trigger many intriguing novel experiments which hold potential to emulate complex classical systems in magnetic fields with highly controllable and well understood cold atoms systems.

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Ramsey spectroscopy for high performance Rubidium vapour cell frequency standards

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In the area of ultra-stable vapor cell Rubidium clocks, our research has focused on the laser-pumped microwave-optical Double Resonance (DR) scheme using low-Q magnetron-type microwave cavities ensuring a sufficiently homogeneous RF field while enabling compact physics packages (≤ 3 liters, including the frequency-stabilized laser head), with excellent short and medium term frequency stabilities (~ $2 \cdot 10^{-13}\ \tau^{-1/2}$). As a

result, this type of atomic clocks are ideal for applications such telecommunication and global navigation satellite systems (GPS, Galileo, Glonass, Compass, etc.).

In Rb frequency standards operating in the Continuous Wave (CW) mode, the laser and microwave fields are applied continuously and simultaneously. The laser-induced AC Stark (or light-shift) effect sets stringent constraints on the laser medium and long term intensity and frequency stability [1]. In the pulsed optical pumping (POP) scheme [2], a Ramsey-type sequence may be used, and the laser and microwave fields are not applied simultaneously, which suppresses the light-shift effect and allows a separate optimization of the laser pumping and detection parameters. However, to fully take advantage of these possibilities, a greater homogeneity of the microwave field inside the resonance cell is necessary [3].

Our talk will first present our developments and latest results in terms of improved short and medium term frequency stability, including a quantitative comparison of the CW and POP schemes using the same physical configuration. We will then discuss into more details selected relevant physical effects such as the microwave power-shift and the light-shift versus laser intensity and frequency. Finally, we will present how the Ramsey schemes also make possible in-situ measurements of relevant physical quantities such as the DC and microwave magnetic fields as well as the longitudinal and transverse relaxation times, with sub-mm scale spatial resolution [4].

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Characterization of atherosclerotic arterial tissue using multimodal non-linear optical (NLO) microscopy

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Atherosclerosis is among the most widespread cardiovascular diseases and one of the leading cause of death in the Western World. Characterization of arterial tissue in atherosclerotic condition is extremely interesting from the diagnostic point of view. Routinely used diagnostic methods, such as histopathological examination, are limited to morphological analysis of the examined tissues, whereas an exhaustive characterization requires a morpho-functional approach. Multimodal non-linear microscopy has the potential to bridge this gap by providing morpho-functional information on the examined tissues in a label-free way. Here we employed multiple non-linear microscopy techniques, including CARS, TPF, SHG, and FLIM to provide intrinsic optical contrast from various tissue components in both arterial wall and atherosclerotic plaques. CARS and TPF microscopy were used to respectively image lipid depositions within plaques and elastin in the arterial wall. Cholesterol deposition in the lumen and collagen in the arterial wall were selectively imaged and discriminated by means of SHG microscopy [1]. Image pattern analysis of SHG images allowed characterizing collagen organization in different tissue regions. Further, the analysis of collagen fluorescence decay contributed to the characterization of the samples based on collagen fluorescence lifetime [2]. Different values of collagen fiber mean size, collagen distribution, collagen anisotropy, and collagen fluorescence lifetime were found in normal arterial wall and within plaque depositions, prospectively allowing for automated classification of atherosclerotic lesions and plaque vulnerability. The presented method represents a promising diagnostic tool for evaluating atherosclerotic tissue and has the potential to find a stable place in clinical setting as well as to be applied *in vivo* in the near future.

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Photonic Topological Insulators and Topological Anderson Insulators

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The recent experiments on photonic topological insulators signified a new direction. We present the progress in this area, including also the first observation of topological Anderson insulators, with an emphasis on universal ideas common to optics, cold atoms and quantum systems.

The discovery of topological insulators relying on spin-orbit coupling in condensed matter systems has created much interest in various fields, including in photonics. In two-

dimensional electronic systems, topological insulators are insulating materials in the bulk, but conduct electric current on their edges such that the current is completely immune to scattering. However, demonstrating such effects in optics poses a major challenge because photons are bosons, which fundamentally do not exhibit fermionic spin-orbit interactions (i.e., Kramer's theorem). At microwave frequencies, topological insulators have been [1] in magneto-optic materials, relying on strong magnetic response to provide topological protection against backscattering – in the spirit of the quantum Hall effect. However, at optical frequencies the magneto-optic response is extremely weak, hence a photonic topological insulator would have to rely on some other property. Indeed, numerous theoretical proposals have been made for photonic topological insulators [2], but their first observation [3], made by our group, relied on a different idea: Floquet topological insulators [4]. Later that year, another group reported imaging of topological edge states in silicon photonics [5]. These experiments have generated much follow up, among them – as the arguably most intriguing one the area of "topological photonics" – our first experimental observation of topological Anderson insulators (predicted in [6]], where a system becomes topological only when disorder is introduced [7]. The purpose of this talk is to review these developments, discuss new conceptual ideas, and suggest applications.

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Silicon photonics for the mid-infrared

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Silicon and germanium photonics integrated circuits offer a range of applications in biochemical and environmental sensing, medicine, astronomy and communications as Si and Ge are transparent up to wavelengths of approximately 8 μm and 15 μm, respectively [1]. Silicon-on-insulator (SOI), can be used only up to 4 μm due to the high absorption loss of silicon dioxide, and therefore alternative material platforms have to be utilized for longer wavelengths. Also, to fully exploit the transparency range of SOI, 400 or 500 nm thick overlayers need to be used rather than the most popular 220 nm platform [2]. To further extend the transparency range of this platform we can use suspended Si or Ge-on-Si.

SOI rib, strip and slot waveguides and Ge on Si waveguides were modelled using Photon Design FIMMWAVE software package with complex FMM solver and also with Lumerical software package. We have also used other methods such as the Finite Element Method (FEM) to check validity of the results. Other passive devices such as MMIs and MZIs, have been simulated by Photon Design FIMMPROP FMM complex solver. The SOI structures were fabricated on 500 nm SOI wafers, whilst Ge-on-Si devices were fabricated on 3 μm Ge top layer, by e-beam lithography and ICP etching. The propagation loss for 500 nm strip waveguides was as low as 1.3 dB/cm, whilst slot and Ge-on-Si waveguides showed 1.6 dB/cm and 0.6 dB/cm, respectively, at a wavelength of 3.8 μm. The MMI insertion loss was 0.1-0.2 dB/MMI, whilst MZIs showed ERs of up to 30 dB.

We have developed a new concept for suspended Si waveguides where only one etch step is required for the creation of subwavelength gratings on both sides of the waveguide, that serve both as lateral claddings and access points for oxide removal by HF. The waveguide core and the sub-wavelength claddings were designed using Bloch-Floquet mode calculations with a Fourier Eigenmode Expansion Method (F-EEM) simulator. These structures were also fabricated by e-beam lithography and ICP etching, and were undercut by HF etching. The propagation loss was 3.5 dB/cm [3]. Work is underway to develop other passive devices based on this platform.

We have reported boron implanted silicon detectors based on large rib waveguides that had responsivity at 2.5 μm reduced by a factor of 10 compared to 1.55 μm, while for 2.0 μm it was approximately 80% of that for 1.55 μm [4]. These results were very encouraging as it was expected that for smaller waveguides, larger responsivities and speeds could be achieved. We have recently demonstrated responsivities ~1 A/W, and bandwidths of ~10 Gbps for such waveguides when operated in the avalanche regime.

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Prospects for Monolithic Electronics-Photonics Integration: Silicon Photonics as a More-than-Moore Device Technology in Sub-100nm CMOS

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Scalable semiconductor manufacturing has enabled Moore's Law and the exponential growth of the complexity of microelectronic circuits, enabling billion-transistor microprocessors on a single chip. Due to its economy of scale, complementary metal-oxide semiconductor (CMOS) microelectronics technology has gone beyond digital logic, however, and has spawned a number of "More than Moore" technologies, including radio and high-frequency RF circuits that are important in mobile wireless applications. Meanwhile, silicon photonics has been developing separately as an on-chip technology for optical signal processing, starting with applications in optical fiber communication, but today reaching into many others. Today, the limitations of CMOS technology in applications like computing are calling for a convergence of state-of-the-art CMOS microelectronics and silicon photonics [1].

In this talk, we review the results of a decade-long collaborative effort of teams at MIT, University of California Berkeley and University of Colorado Boulder to enable the merger of these two technologies on a single chip, bringing photonics into CMOS [2,3] as a More-than-Moore device technology enabling new capabilities. This talk will focus on the design of photonic devices within CMOS technology used to manufacture advanced microprocessors [2] and memory chips [3], with the goal of enabling processors and memory with natively integrated light interfaces on chip. Although CMOS technology imposes extensive constraints on design to ensure the yield of billions of transistors on a single chip, we show that photonic devices can be designed within native CMOS that not only are not heavily impacted by these design constraints, but indeed benefit from some of the unique features of advanced CMOS. We present approaches to low loss waveguiding [2], efficient fiber-to-chip coupling based on array nanoantenna couplers (losses approaching 0.2dB in design) [4,5], efficient modulators based on microdisk resonators using transistor well implants to enable efficient modulation (5fJ/bit) [6], and record-efficiency thermally tunable wavelength filters (2uW/GHz) [6]. All of these passive and active devices [4-8] are realized in the transistor crystalline silicon body and polysilicon gate layers, alongside transistor circuits, in a standard 45nm silicon-on-insulator CMOS process used to build commercial microprocessors used in computing platforms from the Sony Playstation 3 and Nintendo Wii to the IBM BlueGene/Q class of supercomputers. We will also describe some of the unique photonic device designs [8] needed to enable a suite of photonic devices in bulk silicon CMOS processes of the kind used to manufacture DRAM memory chips.

This work has led to the demonstration of record-energy transmitters, and the highest complexity electronic-photonic circuits demonstrated to date with thousands of photonic

devices and over 70 million transistors on a single die. The potential applications extend beyond processor-to-memory interconnects to other systems on chip that require high bandwidth, sensitivity, timing precision, etc. A follow-up talk to this one will describe recent system demonstrations enabled by this technology.

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Ultrafast magnetization control at high- gain Free Electron Laser(s)

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The new class of free-electron laser (FEL) X-ray sources generates radiation with unprecedented parameters in terms of pulse length, photon flux, and coherence in extremely wide spectral range (from THz to X-rays). This makes FELs ideal tools for studying ultrafast dynamics (fs-ps) in matter on its intrinsic length- scales (nm-um).
In contrast to previous pump- probe experiments where magnetic maze-domain structured Co/Pt multilayer samples have been demagnetized by optical radiation [1], we employ high- field THz pulses with low photon energies. Where, with optical excitation magnetization is manipulated by heating of the spin system, pumping with THz gives opportunity to control the system by directly coupling magnetic field component of the THz pulses.

Here, we present results from THz driven pump– probe X-ray FEL experiments on structured magnetic-domain Co/Pt samples and show that a change in asymmetry of the resonant magnetic small-angle X-ray scattering signal can be detected on a picosecond

time scale and with much shorter recovery times than the optically induced demagnetization.

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Biophotonics and Molecular Imaging: looking at biological function and disease from cells to whole organisms

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Modern tools in biophotonics have offered the field of molecular imaging new possibilities for exploration of biological function, as well as detection and treatment of disease in living organisms. Innovations like super resolution and light sheet microscopy, micro and fluorescence tomography, intravital microscopy and optoacoustics have completely changed the paradigm of biological and ultimately clinical research. Furthermore, the development of pioneering approaches for the production, manipulation and delivery of light radiation, such as pulse and beam shaping and wavefront adaptive modifications have been used for better manipulation and processing of biologically significant specimens. These innovations have succeeded to overcome the limitation set by traditional microscopic imaging and high resolution images deeper than a few micrometers can be obtained [1-3].

Here, a novel, hybrid imaging methodology is presented, involving light sheet microscopy and bright field micro-tomography in a single prototype. This hybrid approach combines deep penetration of light into the specimen, minimal phototoxicity, high imaging speed with the increased resolution offered by the multiple projections and novel reconstruction algorithms.The system is capable of measuring small model organisms such as Caenorhabditis Elegans or 3D live cell cultures (e.g. cancer cell spheroids) with single cell resolution and at various time points. The multispectral capabilities of the system employing the use of different laser sources and appropriate optics allow the detection and following of multiple biological functions or the study of the response to different chemotherapeutics, simultaneously. Tumor spheroids are *in vitro* cancer models of increasing interest, as they more closely resemble real tumours compared to conventional monolayer cultures. The technology thus, offers high resolution, quantitative assessment of the distribution and cytotoxicity of new therapeutic agents in a well-controlled, live disease model and can serve as a useful tool in pre-clinical drug development and testing.

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Si-based Monolithically Integrated Polychromatic Interferometers: a new enabling tool for food safety applications

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Optical sensors based on integrated waveguides are one of the most elegant and sensitive approaches to biological and chemical sensing. The employment of photons for probing and monitoring bio/chemical reactions is a contactless method, and offers thus the ability to galvanically isolate the sensing element from the excitation and detection electronics, and allows at the same time a harmonious interplay between the detection and fluidic components. Despite the recent advances in integrated optical devices, and the impressive limits of detection achieved, optical sensors face a major hurdle that has so far hindered their evolvement into truly viable products for Point-of-Need applications, and has mostly bound them to the laboratory. The main hurdle is how to couple light to the waveguides in a way that is effective, reliable, cost efficient and that allows for small size and portability.

To overcome this fundamental issue, a radical photonic lab-on-a-chip platform, has been designed and developed comprising planar waveguides self-aligned to VIS-NIR light-sources, and detectors, all monolithically integrated on the same *silicon chip* and fabricated with standard microelectronic/micromachining processes. Even though Si is an indirect bandgap semiconductor, light emission has become possible through the use of avalanche diodes biased beyond their breakdown voltage and emitting in the VIS-NIR region of the spectrum. The LEDs are coupled to individually functionalized optical interferometric waveguides. The integrated nature of the basic biosensor scheme and the ability to functionalize each transducer independently with different recognition biomolecules allows for the development of miniaturized optical transducers tailored towards multi-analyte tests.

In this work, an overview of the fabrication aspects will be presented [1], but most importantly the nature of broad-band interferometry will be analyzed. Given the fact that standard interferometers, like Mach-Zehnder and Young interferometric devices are based on monochromatic light sources, the monolithic silicon platform must deal with the broad-band nature of the silicon based light sources. In this respect, we will present a unique Mach-Zehnder and Young interferometer photonically engineered to

accommodate broad-band light [2-3]. Furthermore, particular applications for label-free optical detection related to human health and food safety will be presented [4].

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Pulsed Laser Assisted Generation of Novel Materials and Related Applications

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This paper will review our recent work on the application of pulsed laser processing for novel materials production. Two distinct approaches are reviewed including laser materials modification in controlled gas and liquid media respectively. In particular, it is shown that the artificial surfaces obtained by femtosecond laser texturing of solid surfaces in reactive gas atmosphere exhibit roughness at both micro- and nano-scales that mimics the hierarchical morphology of natural surfaces [1]. Depending on the functional coating deposited on the laser patterned three dimensional structures we can achieve artificial surfaces that are: (a) of extremely low surface energy, thus water repellent and self-cleaned; (b) responsive, i.e., show the ability to change their surface energy in response to different external stimuli such as light, electric field and pH [2]. Moreover, the behaviour of neural cells cultured on laser engineered substrates of specially designed morphologies was investigated [3]. The second part of the paper is focused on the pulsed laser assisted synthesis and functionalization of graphene and related two-dimensional (2D) materials. In particular we report on a rapid and facile method for the simultaneous reduction [4], doping [5] and functionalization [6] of GO. This technique is compatible with flexible, temperature sensitive substrates and was initially applied for the efficient production of highly transparent and conductive flexible graphene-based electrodes. It is based on the use of femtosecond laser irradiation for the in-situ, non-thermal, reduction of spin coated GO films on flexible substrates over a large area [4]. Furthermore, we present a fast, non-destructive and roll to roll compatible photochemical method for the simultaneous partial reduction and doping of GO nanosheets through ultraviolet laser irradiation in the presence of reactive Cl2 precursor molecules [5]. By tuning the laser exposure time, it is possible to control the doping and reduction levels and therefore to tailor the work function (WF) of the GO-Cl derivatives from 4.9 eV to a maximum value of 5.23 eV, a WF value that matches the HOMO level of most polymer donors employed in organic photovoltaic devices. Moreover, we demonstrate the pulse UV laser - assisted photochemical functionalization of GO with small molecules as an efficient technique to

realize efficient electron acceptors [6]. Potential applications of pulsed laser synthesized and modified materials in electronics, particular to bulk heterojunction organic solar cells are demonstrated and discussed.

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Superradiance in electrically pumped semiconductor laser structures: Myth or reality?

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Since a long time, cooperative superradiance (SR) has been observed in highly excited atomic and molecular gases. Characteristic quadratic growth of SR pulse peak power with the number of excited atoms is an attractive feature from a practical point of view. In particular, application of SR emission in electrically pumped semiconductor light emitting devices may open a way to produce optical pulses with peak power levels unattainable in conventional lasing regimes. However the possibility of SR emission in electrically pumped semiconductor devices is a very controversial topic. This is because at first glance, the short carrier dephasing time T_2~100fs should inhibit any macroscopically coherent processes in semiconductor medium, including cooperative recombination. In this talk I will critically review a set of assumptions leading to a conclusion that superradiance should be impossible in semiconductors. After that I will present our experimental results obtained for multi-section InGaN QW laser diodes. Studying a transition from amplified spontaneous emission to Q-switched lasing operation in these devices, we find a narrow region of driving parameters that requires us to evoke the cooperative recombination of carriers. More specifically, to explain experimentally observed red shift of SR emission, I consider pairwise recombination of two electron-hole pairs in either X or Π configuration. I will conclude with a conjecture that the uncertainty caused by two possible recombination schemes may lead to a quantum effects in photon statistics.

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Fluorescence and photocatalytic properties of hybrid nanostructures that comprise inorganic nanoparticles and biomolecules

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Hybrid nanostructures were prepared by functionalization of gold and silver nanoparticles with tryptophan and/or riboflavin biomolecules. The obtained bioconjugates were investigated by TEM and HRTEM and various spectroscopy methods (XPS, FTIR, UV-vis and photoluminescence). The biomolecule functionalized nanoparticles were introduced in different cells (bacteria, *Escherichia coli*, fungi *Candida albicans* and HuH-7 wt human cancer cells). The process of accumulation of the nanoparticles within the cells was followed by means of synchrotron excitation deep ultraviolet (DUV) fluorescence imaging. The DUV imaging showed that it was possible to distinguish the fluorescent signal pertaining to functionalized nanostructures from the autofluorescence of the cells. Also, a high spatial resolution of the deep UV fluorescence images (one pixel ~154 nm) enabled us to probe nanoparticle accumulation with single cell resolution. Photocatalytic properties were studied on ZnO/Ag heterostructures. ZnO nanocubes were prepared using alginate biopolymer as a controlled environment for the particle growth. ZnO/Ag heterostructures were prepared by reduction of silver salts in the presence of nanocubes. High resolution scanning electron microscopy showed that the spherical silver nanoparticles were formed at nanocubes edges and vertices. UV–vis and photoluminescence spectroscopy measurements revealed that the surface plasmon resonance peak of the silver nanoparticles dominates the absorption spectra of the ZnO/Ag hybrid particles, while at the same time the Ag nanoparticles quench the ZnO emission. The photocatalytic activity of the ZnO/Ag heterostructure was faster than that of the pure ZnO and further improved with increasing the concentration of silver. Both the alginate-ZnO and alginate-ZnO/Ag nanostructures showed strong antimicrobial activities against gram-positive (*Staphylococcus aureus*) and gram-negative (*Escherichia coli*) bacteria.

Controlling Rydberg atoms in dense gases

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Rydberg atom excitations in dense clouds alter the medium to be highly non-linear for single photon absorption, making possible all-optical quantum computing [1], single photon transistors [2], and single photon absorbers [3]. However, in order to utilize Rydberg excitations in dense clouds for quantum optics, the rich physics and chemistry of Rydberg atoms interacting with a dense neutral-atom background gas, via low-energy electron-neutral and ion-neutral scattering, must be well understood. Collisions between the Rydberg electron and background neutral atoms, lead to a mean field density shift for Rydberg atoms, which is of the order 10MHz/ 10^{14} cm^{-3} for ^{87}Rb triplet s-wave scattering. We exploit this density shift to characterize the mean density of our quantum gas, a Bose-Einstein Condensate (BEC), and to monitor the dynamics of the BEC phase transition, by analyzing the center of gravity of Rydberg spectra. We report how the mean field density shift, in combination with a density gradient, can also be used to localize Rydberg excitations in density shells with a spatial resolution less than optical wavelengths. This control of spatial excitation allows us to study the density-dependent quantum chemistry between a Rydberg atom and neutral atoms in a BEC. We discuss the implications of these results on experiments on charged impurities in quantum gases as well as wavefunction imaging based on electron-phonon coupling in a BEC.

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Witnessing Multipartite Entanglement without Entanglement Witness Operators

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The experimental demonstration and quantification of the multipartite entanglement present in a quantum state is a building block for quantum science and technologies. Most

of the current approaches are based on the implementation of suitable Hermitian witness operators. These, however, require critical assumptions on the fidelity of their experimental realization and constraints on the investigated quantum states. Here we propose an alternative method of witnessing entanglement that is based on the Fisher information and is closely bound to the distinguishability of quantum states [1,2,3]. The key idea is that entanglement can enhance the statistical speed with respect to parametric changes. The implementation of our approach is particularly simple: it only requires to access probability distributions obtained after applying collective operations and measurements, without any assumptions on the quantum state and on the efficiency of the measurement implementation. Our ideas have been recently experimentally demonstrated with Bose-Einstein condensates and used to witness entanglement beyond spin-squeezing [4]. With trapped ions and photonic systems, we can witness genuine multipartite entanglement by solely analyzing published data on parity oscillation visibilities. Entanglement-enhanced statistical speed is the key ingredient of quantum metrology [1,5].

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Quantum magnetometry using single spins in diamond and cold atomic ensembles

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Nitrogen-vacancy (NV) center in diamond is a promising quantum metrology tool finding applications across disciplines. The spin sensor measures magnetic fields, electric fields and temperature with nano-scale precision and is fully operable under ambient conditions. Moreover, it achieves precision scaling inversely with total measurement time $\sigma B \approx 1/T$ (Heisenberg scaling) rather than as the inverse of the square root of T, with $\sigma_B = 1/\sqrt{T}$ the Shot-Noise limit. This scaling can be achieved by means of phase estimation algorithms (PEAs), in combination with single-shot read-out. Despite their accuracy, the range of applicability of PEAs is limited to sensing single frequencies with negligible temporal fluctuations. Nuclear Magnetic Resonance (NMR) signals from molecules often contain multifrequency components and sensing them using PEA is ruled out. In this talk, I will present an alternative method for precision magnetometry in frequency multiplexed signals via compressive sensing (CS) techniques focusing on nanoscale NMR. We show that CS can provide for precision scaling approximately as $\sigma B \approx 1/T$, as well as for a 5-fold increase in sensitivity over dynamic-range gain, in addition to reducing the total

number of resources required. We illustrate our method by taking model solid-state spectra of Glycine acquired under Magic Angle Spinning conditions [1].

Finally, in this talk I will also present recent results toward quantum magnetometry using planar squeezed states via quantum non-demolition measurements in cold atomic ensembles [2].

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Stability of Microresonator Soliton Frequency Combs

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Optical frequency comb generation based on femtosecond mode-locked lasers has revolutionized high-precision clock generation and optical metrology. In recent years there has been a significant research interest in the possibility of generating stable and coherent optical frequency combs via cascaded four-wave mixing occurring in a continuous-wave (cw) pumped nonlinear optical microresonator. This may eventually lead to chip-based, inexpensive frequency comb sources that would be of great interest in a host of applications ranging from medical and environmental spectroscopy, astronomy, and coherent communication systems.

In essence, the nonlinear microresonator is a miniature version of the synchronously pumped passive nonlinear fiber cavity that was extensively investigated since more than 20 years ago. The master equation describing the generation of periodic temporal structures (hence frequency combs in the frequency domain) is the path-averaged driven and damped nonlinear Schrödinger (NLS) equation, also known in optics as the Lugiato-Lefever equation (LLE) [1]. In that context, it was shown that stable dissipative cavity solitons exist, which result from the balance between cavity loss and phase-sensitive parametric gain from the injected cw. These cavity solitons are stable against soliton-soliton interactions [2-3], as well as random noise induced frequency or timing jitter [3]. A stable or phase coherent frequency comb is generated, whenever a single cavity soliton (or a train of a few, non-interacting solitons) is generated from the cavity modulational instability process [1,4].

In this presentation, we will overview the stability of cavity solitons in optical microresonators under the action of several perturbing factors, which are of importance in practical microresonator structures. First we consider the case of a strongly nonlinear and dissipative system such as the silicon microresonator, where the cavity soliton dynamics is strongly affected by the presence of nonlinear loss processes such as two and three-photon absorption, as well as the free-carrier induced loss and dispersion [5]. Next we

consider the stability of cavity solitons in weakly dissipative microresonators, where the first-order perturbing terms are retained in the LLE. Finally, we will discuss novel and intriguing soliton stability and multistability effects that occur in the high-power regime of microresonators. In this case the LLE approach is no longer a valid model, and it should be replaced by the Ikeda map coupled with the generalized NLS equation [6].

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100 W-class fs laser system based on hybrid laser technologies

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Ultrashort laser pulses enable the cold ablation materials processing, because the energy is deposited in shorter time duration than the thermal diffusion time. This results in the high surface quality with precise patterning depth, without grooves, rims or visible melting damage [1]. The commercially available laser systems offer either longer picosecond pulses (>15 ps) with high average power (50-100 W) or shorter sub-picosecond pulses (0.5-1 ps) with up to ~30 W of average power. High throughput of industrial processes drives the demand for even higher laser average power. Shorter, sub-ps pulses increase the ablation efficiency and etch (material removal) rate for some materials (e.g. steel) [2]. In this work, we present the state-of-the-art >100 W 800 fs laser system, which is ideally suited for high speed surface processing.

Our customized Yb-based oscillator delivers 400 fs pulses, centred at 1030 nm, with 2.8 W of average power, at 83 MHz pulse repetition rate. The oscillator output is directly seeded into the two-stage power amplifier, avoiding the standard chirped pulse amplification technique, typically used in high power fs lasers. This reduces the complexity and allows more compact foot print, lower cost and increased robustness. The amplifiers are based on the novel Yb:YAG single crystal fiber technology that provides efficient thermal management and a good overlap between the pump and the signal beams [3]. The first stage is pumped by a high brightness 100-μm fiber-coupled laser diode emitting up to 140 W at 940 nm. The signal is double passed using a reflective mirror and the Faraday rotator. The output is extracted by a polarizing cubic beam splitter. The small signal gain of the first stage amounts to remarkable 32 dB, while the maximum output power is 42 W. The second stage is bi-directionally pumped by the 100-μm and 200-μm

fiber-coupled laser diodes, emitting at 940 nm, with 140 and 210 W, respectively. The signal is single passed in the second stage amplifier and the output is extracted by a dichroic mirror.

The maximum output power is 160 W with pulse duration of 800 fs. For an average output power of 100 W, we measured M_x^2=1.2 and M_y^2=1.3. This is to the best of our knowledge more than 10 times higher small signal gain compared to previously published results [4], and the highest average power of sub-picosecond pulses achieved with single crystal fibers. In addition, it is the first time that a bi-directional pumping scheme is used.

The laser system details, spectral, temporal and spatial (beam profiles and M^2 measurements) characterization of the laser output will be presented.

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Counting atoms with single-atom resolution

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For hyperfine-state-selective measurements on ensembles containing 100 or more atoms, a single-atom resolution has been demonstrated [1], along with detection sensitivity that is 21 dB below the quantum projection noise limit. The demonstrated measurement resolution is expected to provide the readout capability necessary for atomic interferometry substantially below the standard quantum limit (SQL). Measurements are performed on laser-cooled ^{87}Rb atoms confined at the antinodes of a standing-wave dipole trap at 852 nm in an optical cavity. Atoms in the cavity change the refractive index of a medium and hence induce a shift of the resonance frequency of the optical resonator by an amount proportional to the atom number. In order to measure this atom-induced frequency shift, and consequently the atom number, we introduce 780-nm probe laser to the cavity and observe the dispersive Pound-Drever-Hall (PDH) signal, which detects the phase of the probe light reflected from the cavity. Resolution of the "detection system" is determined by the atom number variance extracted from a large number of repeated measurements.

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Connection between stationary and transient electromagnetically induced transparency and slow light in Rb buffer gas cell

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Here we report on recent progress on investigation of electromagnetically induced transparency (EIT), slow light and connection between these two phenomena in Rb buffer gas cell [1]. The EIT resonances, formed among Zeeman coherences of hyperfine state $5^2S_{1/2}$ $F_g = 2$, were studied by using a laser beam which frequency was stabilized on the hyperfine transition $F_g = 2 \rightarrow F_e = 1$ on D_1 line in ^{87}Rb isotope. The influence of the laser beam intensity, diameter (1.3 mm or 6.5 mm) and radial intensity distribution (Gaussian or Π profile) on the contrast, linewidth and line shape of EIT resonances is examined. Resonances were obtained by measuring the transmitted laser beam intensity through Rb

cell when longitudinal magnetic field was changing slowly, under the conditions of constant laser beam power and polarization. For the 1.3 mm diameter Gaussian laser beam, EIT resonances have non-Lorentzian line shapes with Ramsey narrowing of the central peak, induced by the diffusion of coherently prepared atoms in the dark, and then back to the beam. In case of a wide Gaussian beam with 6.5 mm diameter, the EIT line shape is Lorentzian when laser intensity is small, otherwise it can not be described by Lorentzian function due to contribution of the atoms in the wings of a beam. The laser beam with Π intensity profile and 6.5 mm diameter always gives Lorentzian EIT resonances.

Time development of EIT resonances was examined from σ^- transmission signal. For that purpose, two rectangular σ^- pulses separated in time were propagating through Rb cell, together with a strong σ^+ control field. The laser beam was turned off between two σ^- pulses in order to enable a free evolution of Zeeman coherences in the dark. In a repeated interaction of two σ^- pulses with Rb atoms, the Raman-Ramsey fringes were measured, both on σ^- transmission signals and temporal EIT resonances. Ramsey oscillations, appearing at the beginning of the second σ^- pulse, are dumped during pulse duration and disappear at later moments due to Zeeman decoherence. It was noticed that the linewidth of the central peak was independent on the dark time, in contrary to the fringes of higher order which got narrower when time separation between two pulses was prolonged [2].

The slow and stored σ^- pulse were measured in the Rb cell, based on stationary and temporal EIT analysis. It was experimentally ascertained that the most efficient slow light process is obtained in the medium with the most contrasted and narrowest EIT resonances. Once the optimal laser beam parameters were set, the delay of the Gaussian σ^- pulse was measured as a function of the pulse duration and laser beam intensity. The measured group velocities are in the range from 1.7 km/s to 23 km/s, while the fractional time delay is in the interval from 3.5 % to 20 % [3]. Higher transmission and higher group velocity of the Gaussian σ^- pulse were obtained when rectangular preparation pulse of the same polarization had previously prepared the dark states [4].

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Modeling and applications of Quantum Cascade in external magnetic field

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The rapidly emerging field of nano-optoelectronics is based on the understanding and control of intersubband transitions in nano-dimensional systems. One of the most striking outcomes of intersubband transitions engineering is the quantum cascade laser (QCL) – an efficient and reliable unipolar semiconductor laser source [1], with the possibility to operate from the mid-infrared (MIR) to the THz range of frequencies. These powerful devices are particularly appreciated for such wide scope of operating wavelengths which can be achieved by using the same heterostructure combination, but changing the design of the active region, i.e. 'tailoring' the layers' widths and composition. This renders QCLs suitable for numerous applications, including free-space communications, medical diagnostics and in particular, chemical sensing and monitoring [2].

In the MIR part of the spectrum, QCLs are of great interest for gas sensing and monitoring. We explore the possibilities of using advanced tools for global optimization, namely the genetic algorithm, to obtain structural parameters of gain-maximized QCL emitting at specified wavelengths, suitable for detection of pollutant gasses, such as SO_2, HNO_3, CH_4 and NH_3, in the ambient air. Then we introduce a strong external magnetic field perpendicular to the epitaxial layers, to fine tune the laser output properties [2]. This magnetic field alters the electron energy spectrum by splitting the continuous energy subbands into discrete Landau levels whose arrangement influences the magnitude of the optical gain. In addition, strong effects of band nonparabolicity result in subtle changes in the lasing wavelength at magnetic fields which maximize the gain, thus allowing us to explore the prospects of multi-wavelength emission of the given structure.

THz frequencies belong to the quite under-utilized part of the electromagnetic spectrum, despite their significant application potential. This is mostly due to the lack of coherent solid-state THz sources. The so called „THz gap" falls between two frequency ranges that have been well developed, the microwave and millimeter-wave frequency range. THz QCLs are great candidates to fill in this gap [3]. We have analyzed two structures lasing in this region (both of them reported in the literature, but not studied under the influence of an external magnetic field), the three- and four-well (per period) based structures that operate at 3.9THz and 1.9THz, respectively, implemented in $GaAs/Al_{0.15}Ga_{0.85}As$. Numerical results are presented for magnetic field values from 1.5 T up to 20 T, while the band nonparabolicity is carefully accounted for.

Because of their high output gain, QCLs are suitable to be used as active media in metamaterial unit cells, thus enabling evasion of metallic inclusions present in conventional metamaterials [4]. We analyze a quantum cascade structure lasing at 4.6THz, placed under the influence of a strong magnetic field. We first solve the full

system of rate equations for all the relevant Landau levels, and obtain the necessary information about the carrier distribution among the levels, after which we are able to evaluate the permittivity component along the growth direction of the structure, as well as the range of frequencies at which the structure exhibits negative refraction for a predefined total electron sheet density.

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Dissipation through localised loss in lattice bosonic systems

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In the recent years, controlled dissipation has proven to be a useful tool for probing of a quantum system in the ultracold setup [1]. We consider dynamics of lattice bosons induced by a dissipative local defect [2]. We address superfluid and supersolid phases that are ground states of an extended Bose-Hubbard Hamiltonian. To this end, we solve the master equation using the Gutzwiller approximation and find that in the usual homogeneous superfluid phase repulsive interactions lead to enhanced dissipation process. On the other hand, our mean-field approach indicates that the effective loss rates are significantly suppressed deep in the supersolid phase where repulsive nearest neighbour interactions play a dominant role. Our numerical results are explained by an analytical insight and in particular, in the limit of strong dissipation we recover the quantum Zeno effect.

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Stationary localization in driven and dissipative Bose-Hubbard chains

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In Bose-Hubbard models with and without dissipation beyond the mean-field approximation any localized state is predetermined to decay [1-4]. An additional gain may be able to recover stationary and dynamically stable localized states as well as a localized oscillating type of solution. We demonstrate the existence of these states in one-dimensional Bose-Hubbard lattices with gain and loss in a semi-classical regime. As the full problem is intractable analytically, we will include quantum fluctuations up to second order. The resulting equations are beyond the dissipative and driven DNLS limit. The study is compared with the results of a Gutzwiller ansatz. Stationary modes of dissipative equation sets have an important advantage over exact solutions of conservative equations. If they are stable, they can be obtained via the dissipative dynamics no matter the initial state (belonging to the basins of attraction). Therefore their preparation is easier and more robust. Losses, unavoidable in experiments, are not a drawback, but a necessary ingredient for their existence.

For quantum lattices the single site solution has to be unique [5], therefore localized modes do not have an anti-continuous limit: For the decoupled sites the homogenous mode is the only solution. We find [6], that the symmetry-breaking transition from homogenous to discrete periodic states, the bifurcations to localized static and periodic modes, and the symmetry-breaking transition back to the homogenous mode mark novel phases without a counterpart in the Hamiltonian limit (zero dissipation, zero gain) of the Bose-Hubbard where the well-known Mott-superfluid phase transition has been widely described.

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Role of real and virtual photons in the temporal and spectral modifications of one photon wave packet propagating in a 1D waveguide

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A recent issue in quantum optics is the study of the interaction of photons and atoms in one-dimensional (1D) waveguide. These devices have been shown to be efficient in the experimental implementation of quantum information operation schemes. Among these studies, is the diffusion of a single photon wavepacket by an array of atoms. Rotating wave approximation (RWA) is generally used to simplify the complex interaction process. We show here that non-RWA terms cannot be neglected in the case of one photon interacting with two separated atoms in 1D waveguide [1]. We relate the temporal and spectral properties of the transmitted and reflected wavepacket to the nature –real or virtual- of photons exchanged between atoms and we clarify the role of each [1-2]. Moreover, we establish the expression of the effective coupling between atoms and we show that it results from a subtle interference effect between parts of virtual photons.

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Tuning the quantum phase transition of bosons in optical lattices

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This talk reviews three concrete examples how the quantum phase transition of bosons in optical lattices from the Mott to the superfluid phase can be tuned. In the first example we consider anti-ferromagnetically interacting spin-1 bosons loaded into a three-dimensional cubic optical lattice [1]. There the different superfluid and Mott phases are tunable due to the presence of an external magnetic field. The second example deals with bosons in an optical lattice, where the s-wave scattering length is periodically modulated [2,3]. It turns out that this time-dependent lattice system can be approximately mapped for large enough driving frequencies to an effective time-independent Hamiltonian with a conditional hopping and that the resulting quantum phase boundary depends quite sensitively on the driving amplitude. Finally, we study an optical Kagome superlattice which is generated by enhancing the long wave length laser in one direction [4]. Due to the delicate interplay

between on-site repulsion and artifical symmetry-breaking also non-superfluid phases with fractional filling as well as an anisotropic superfluid density do appear.

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Photoreflectance study of InAs-InGaAs dots-in-a-well heterostructures

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Self-assembling InAs/GaAs quantum dots (QDs) have been used for optoelectronic devices, such as QD infrared photodetectors (QDIPs), exploiting intraband electronic transitions between the bound-state of QD and continuum. In recent years, an advanced InAs/InGaAs dots-in-a-well (DWELL) quantum heterostructure was implemented. This novel QDIP concept is then based on intraband optical transitions between the bound-states of QD and quantum well (QW). This QDIP design thus allows a spectrally adaptive optical response through adjusting QD/QW parameters and/or applying a bias voltage [1]. However, better understanding of electronic structure and optical properties in a wide temperature range is essential for optimization and further development of these novel photodetectors.

In this work, the properties of electronic states of InAs QDs grown with and without InGaAs capping layer (CL) within GaAs/AlAs QW are investigated. Photoreflectance (PR) spectroscopy [2, 3] is used to probe the QD- and QW-related interband optical transitions over the temperature range 3–300 K. Also, room temperature contactless electroreflectance (CER), phototransmittance (PT), photoluminescence (PL), and PL excitation (PLE) spectra were measured for comparison. Photomodulated signal intensity variation with temperature was analyzed through Arrhernius expression, while the temperature-dependent transition energies were evaluated using semi-empirical Varshni formula. To identify the observed spectral features, numerical calculations of interband transition energies and intensities for the InAs QDs and complex QW structure, consisting of InAs/InGaAs binary-QW embedded into GaAs/AlAs QW, were carried out using nextnano[3] software [4].

For the first time, the evidence for the influence of back-surface reflection effects on the PR spectra of DWELL structures is provided. The interband optical transition energies of ground-state and four excited-states were established in 3–300 K temperature, indicating a high uniformity of QD ensemble. It was found that PR lineshape is influenced by variation of photomodulation mechanism with temperature. In particular, at high temperatures, lineshape is governed by the quantum-confined Stark effect, whereas, at low temperatures, PR lineshape indicates state-filling effects [3]. This suggests that QD composition is partially changed due to Ga/In interdiffusion. Furthermore, QD-related optical transitions follows the Varshni relation with parameters in between that of a bulk InAs and GaAs, owing to a strain-driven partial decomposition *in situ* of the InGaAs CL [3, 5]. Arrhenius analysis yields activation energy ~320 meV at high temperatures, suggesting that signal intensity quenching is governed by exciton thermal emission from dot-to-well bound-states.

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Dynamic tuning of the optical emission of InGaN nanowire quantum dots by surface acoustic waves

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We report on the dynamic spectral modulation of the quantum dot (QD) energy levels in GaN/InGaN heterostructure nanowires by the elastic field of a surface acoustic wave (SAW). This allows to periodically tune the QD emission energy at frequencies determined by the SAW, which is crucial for the realization of high-repetition-rate single photon sources.

The samples investigated consist of InGaN QDs embedded in hexagonally packed GaN nanowires grown on (0001) GaN-on-sapphire templates by plasma-assisted molecular beam epitaxy (PA-MBE). The QDs are formed by fluctuations of the indium content in the topmost nanowire region containing a nano-disk-like InGaN section. The InGaN disks display narrow and almost fully linearly polarized QD-like emission lines in micro-photoluminescence (μ-PL), as well as a strong antibunching in photon correlation

measurements, thus indicating unambiguously single photon emission [1]. By varying the indium content and the growth conditions, the emission covers the blue-green spectral range. For SAW experiments, the nanowires are mechanically transferred from their native substrate onto a SAW delay line defined by optical lithography on a piezoelectric lithium niobate crystal.

When individual nanowires are subject to the SAW's strain and piezoelectric fields, the emission energy is periodically modulated causing an alternating shift in the QD transition energy within a bandwidth up to 1.5 meV and at the acoustic frequency of ~330 MHz. This is evidenced by the SAW-induced splitting of both the QD exciton (X) and biexciton (XX) emission energy observed in the time-averaged μ-PL spectra. This energetic splitting reflects the sinusoidal modulation of the InGaN band gap induced by the SAW. The splitting scales almost linearly with the acoustic amplitude, which implies that the QD response is dominated by deformation potential coupling induced by the SAW strain field [2]. Both the X and XX lines of a given nanowire QD undergo the same modulation amplitude, thus indicating that the SAW strain field does not affect the XX binding energy. In addition, the emission intensity of these excitonic complexes integrated over many SAW periods is independent of the SAW amplitude, suggesting that the SAW does not change the overall emission efficiency and the QD's excitonic occupancy state. However, the decay times of both X and XX increase with increasing the SAW amplitude. These effects are discussed in terms of the hydrostatic component of the SAW strain field. As these nanowire heterostructures can be grown in ordered two-dimensional arrays [1], the present results are an important step towards the development of both spatially and time-controlled InGaN-based linearly polarized single photon emitters for advanced quantum light applications.

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Stationary and transient properties of photon condensates

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A seminal experiment in Bonn has presented convincing evidence of both a Bose-Einstein distribution and a macroscopic occupation of the lowest mode for a gas of photons confined in a dye-filled optical microcavity [1]. Furthermore, these equilibrium

properties could recently be understood within the framework of a non-equilibrium model of photons in terms of a steady state solution [2,3]. Here we utilize this non-equilibrium model in order to study in detail the stationary photon distribution in the respective modes of the dye-filled cavity. It turns out that, depending on the dye pumping rate and the cavity decay rate, different modes become macroscopically occupied. In particular, we present the corresponding phase diagrams and describe the transitions between the phases analytically. Using a linear stability analysis we demonstrate that the stationary states are always unconditionally stable. Finally, we examine how the relaxation times toward equilibrium depend on the respective system parameters and compare them with the thermalization times obtained experimentally from the corresponding transient dynamics [4].

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Modeling of Light Emitters Based on Nitride Quantum Dots and Nanowires

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Nanostructures based on III-nitride semiconductors offer certain advantages for realization of single-photon sources and classical light emitters. Larger band offsets and effective masses lead to strong quantum-confinement effects which enable the operation of devices at higher temperatures. Wide band gap of III-nitrides leads to the emission in the blue and ultraviolet spectral range, which is not accessible with most of the other materials. In this work, simulation insights into the light emitting properties of III-nitride quantum dots and nanowires will be presented.

We performed the calculations of excitonic and biexcitonic states in self-assembled GaN/AlN quantum dots with special emphasis on the use of these dots for single-photon source applications [1]. Theoretical methodology for calculation of single-particle states was based on 8-band strain-dependent envelope function Hamiltonian, with the effects of spin-orbit interaction, crystal-field splitting, and piezoelectric and spontaneous polarizations taken into account. Exciton and biexciton states were found using the configuration-interaction method. Optimal dot heights for their use in single-photon emitters were determined for various diameter-to-height ratios.

Next, we investigated the electronic properties of InGaN quantum structures embedded in site controlled GaN nanowires [2]. The InGaN structures under consideration consist of two sections: the middle one, which is formed on the polar c-facet, and the side one, which is formed on the semi-polar r-facets. These structures exhibit two-color emission at 384 nm and 488 nm. We identified that the main origin of two-color emission is higher In incorporation on the nanowire polar c-facet, while the influences of internal electric field and strain are less significant.

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Bounded dark-state polaritons in atom-cavity arrays

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The investigation of coupled atom-cavity systems, known as Jayne's-Cummings Hubbard (JCH) lattices, provides insight in the behaviour of strongly interacting photons and polaritons. Strongly interacting polaritons in JCH lattices possess some of the features typically present in strongly correlated condensed-matter systems, among them Mott-insulator to super-fluid quantum phase transition [1]. In case of two excitations in the JCH lattice, two-polariton bound states may be possible [2].

We theoretically investigate the nature of eigenstates in the two-excitation subspace of an array of coupled cavities, where each contains a three-level atom in a Λ-configuration. One of the atomic transitions is driven by an external classical field, while another is influenced by a far off-resonant cavity mode field. The two fields are in two-photon Raman resonance. Atom-cavity coupling leads to the formation of three bands, whose width increases with inter-cavity hopping. In addition, we find two bounded dark-state polaritons (BDSPs). Since the energies of the BDSPs lie within the band gaps, we show that due to the presence of BDSPs the system behaves as an extrinsic semiconductor with them as dopants. Without inter-cavity hopping, analytical expressions for two band gaps are provided. It shows that the size of band gaps can be tuned by the Rabi-frequency of the classical field and the common detuning from the respective atomic transitions. In the presence of hopping, three regimes are identified with respect to the Rabi-frequency where the system behaves either as a semiconductor or as a conductor. In case of semiconducting behaviour, we have determined critical effective atom-cavity coupling strength above which one or both gaps vanish.

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Fibonacci superlattice in the aqueous solution of $Co(NO_3)_2(H_2O)_6$

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In this work, the transmission spectrum of 1% aqueous solution of $Co(NO_3)_2(H_2O)_6$ is measured in the spectral region 400-600 nm. The spectra logT(E) and $G/G_0(E)$ are also presented. The Fermi energy [1] is calculated by the theory of Fermi liquids for the investigated solution. The ions Co^{2+} occur as defects with beneficial effect on the optical properties of the Fibonacci superlattice [2]. Thus, this superlattice finds good application in the regulation of the processes of cobalt electrons in the aqueous solution of cobalt nitrate.

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Relaxation time measurements in a 25 mm Rb vapor cell for high-performance Rb atomic clocks

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We are studying the physics of compact atomic frequency standards (atomic clocks) based on Rb vapor cells, in view of the development of novel high-performance atomic clocks for applications such as satellite navigation systems or industrial metrology applications.

In our studies we use a clock physics package based on the compact magnetron-type cavity (external volume of only 45 cm^3) and a buffer-gas vapor cell of 25 mm diameter and length [1]. The magnetron-type cavity has been extensively studied (both in theory and experiment) and demonstrated an excellent microwave magnetic field orientation and a sufficiently uniform microwave field distribution inside the cavity [3]. We apply laser and microwave interrogation to this system, and have successfully achieved state-of-the-art short-term stability performances for the laser pumped Rb clocks based on both

continuous-wave (CW) and pulsed optical pumping (POP) schemes [2,3]. Using the pulsed technique with Ramsey scheme, high-contrast fringes were observed for our experimental clock setup. Rabi oscillations demonstrate a sufficiently uniform microwave magnetic field distribution inside the cavity. We could observe Ramsey signals with a contrast of up to 35% with a linewidth of 160 Hz and a typical short-term clock stability of $2.1\times10^{-13}\tau^{-1/2}$ [2,3].

Here we report the measurements about 25 mm vapor cell's relaxation time (T1 and T2) which can seriously affect the Rb clock's short-term stability. The traditional Franzen [4] method of evolution in the dark is used to measure population relaxation time T1. Spin echo [5] method is used to measure coherence relaxation time, by creating an atomic spin polarization with a laser pulse and then applying two separated $\pi/2$ and π microwave pulses. This scheme removes the effects of dephasing due to residual inhomogeneities of the magnetic field inside the Rb vapor cell. Extrapolation to zero microwave results in coherence relaxation time T2 $\approx$ 3 ms which is consistence with the theoretical calculation.

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Composite localized modes in discretized spin-orbit-coupled Bose-Einstein condensates

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The use of ultracold quantum gases, in particular bosonic and fermionic condensates, for simulating fundamental effects originating in condensed-matter physics has drawn much interest [1]. One of these effects is the spin-orbit coupling (SOC). This effect plays a major role in many phenomena and applications, including spin and anomalous Hall effects [2], topological insulators [3], spintronics [4], etc. In contrast to the complex picture found in solids, the experimental and theoretical description of SOC effects in

Bose-Einstein condensate (BEC) is much simpler [5]. This has motivated our study of the impact of SOC on the immiscibility-miscibility transition in the localized complexes in BEC, which can emulate the phase transition between insulating and conducting states in semiconductor. For this purpose, we introduce a discrete model for binary SO-coupled BEC trapped in a deep one-dimensional optical lattice [6]. We consider two different types of coupling, with spatial derivatives acting inside each species, and between the species. Stable localized composite states of miscible and immiscible types are found to exist for both types of coupling. We also study how the transition between miscible and immiscible type of localized complexes depends on the SOC strength. Particularly interesting are the applications of our model to the SOC binary condensates built of infinitely heavy atoms and the binary BEC with effective atomic masses which have opposite signs.

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Electromagnetically induced transparency in four-level Y-type atom with degenerated and quasidegenerated excited levels

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Electromagnetically induced transparency is an effect in which, by using electromagnetic influence, some opaque medium can be made transparent for radiation which is otherwise resonantly absorbed [1,2]. Research in the area of EIT effect was extensively conducted on quantum systems with three levels, however during the last decades, some generalizations to bigger number of energy levels have been made. Although papers concerning these systems show some new effects, only limited number of them take degeneracy of the atomic levels into consideration [3].

We consider four-level Y-type atom, which first excited state contains the manifold of three sublevels, interacting with probe and two control fields. Probe field drives the transition between the ground level and particular sublevel. Control fields couple the given sublevel with closely spaced upper excited levels.

Absorption and dispersion of the probe and coupling fields are investigated (plotted) as the functions of spontaneous emission coefficients, the Rabi frequencies and detunings of the fields. Electromagnetically induced transparency in the fields is achieved (realized)

with properly chosen values of the parameters in two-photon and off two-photon resonance regimes [4]. Effects of relative phase of the driving fields and spontaneously generated coherence between the upper levels on the width of transparency window in field absorption are investigated in detail. Finally, the analysis of observed dependence in dressed-state picture is given.

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Double-double electromagnetically induced transparency in the four-level Y-type atom with spontaneously generated coherence

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Theoretical and experimental studies of quantum interference and quantum coherence in multi-level atomic systems have led to the discovery of novel, remarkable phenomena. Notable example includes electromagnetically induced transparency (EIT), the phenomenon that makes a medium, opaque under normal circumstances, transparent to an applied laser field [1,2].

The system studied in our work is a four-level Y-type atom interacting with three coherent laser fields – one probe and two control fields. The probe field induces the transition from the ground state to the intermediary, first excited state. Two control fields induce transitions from the intermediary state to the two highest nearly degenerated excited states. Realization of double EIT has been studied for the system in given geometry in the absence of spontaneously generated coherence [3]. Here, we analyze the appearance of double-double EIT [4] in the Y-type system with spontaneously generated coherence and its dependence on the probe and control fields amplitudes through their Rabi frequencies, their detunings, the relative phase among the control fields, spontaneous emission coefficients, as well as the relative orientations of atomic dipoles induced by control fields.

It has been determined that the variation of relative orientation of electric dipoles which correspond to transitions induced by control fields can lead to a slight change of minima positions, as well as their depth. Also, this variation affects the size of absorption peaks, both in the absolute and relative sense – if, for a given set of other parameters, there exist three absorption peaks, the middle peak size change is always in the opposite direction than the two side-peaks. Whether the two side-peaks gain or lose in size with the increase

of the relative angle between the dipoles depends on the values of the rest of the parameters. All of this is also true for the variation of the relative phase between the applied control fields, as it produces the same kinds of effects. Note that when the amplitudes of control fields are the same, and their detunings are of the same absolute value, but of the opposite sign, the line profile of absorption is symmetric and the middle peak is exactly at zero probe detuning. Whether or not the middle peak exists or not depends on the control fields detunings – if they are both zero, the middle peak does not exists, and there is one window of low absorption. For any non-zero control field detunings, there is a middle peak and two absorption windows. The widths of the absorption windows depend on the amplitudes of control fields. The values of the absorption peaks have also been shown to depend upon spontaneous decay coefficients for the two transitions which are induced by the control fields – the larger the coefficients, the smaller the side-peaks are and, hence, the middle peak is the higher.

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Atomic and Nuclear quantum optics: Multiphoton and autoionization resonances in a strong DC electric and laser field

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We present an advanced combined relativistic operator perturbation theory (PT) and energy approach [1,2] and apply it to studying interaction dynamics of the finite Fermi systems (heavy atoms, nuclei, molecules) with an intense external (DC electric and laser) field. The approach allows uniform, consistent treating the strong field and quasistationary and collisional problems. It is based on the Gell-Mann and Low adiabatic formalism and method of the relativistic Green's function for the Dirac equation with complex energy. The essence of the operator PT is the inclusion of the well-known method of "distorted waves approximation" in the frame of the formally exact PT. Results of the calculation for the multi-photon resonance and ionization profile in Na,Cs, Ba atoms are listed [2]. We have studied the cases of single-, multi-mode, coherent, stochastic laser pulse shape. An account for stochastic fluctuations in a field effect is of a great importance. It is also studied the phenomenon of the above threshold ionization. Efficiency of method is demonstrated by QED perturbation theory calculations for the two-photon ionization cross-sections for extended photon energy range (including above-threshold ionization) in Mg. Comparison with the R-matrix calculation of Luc-Koenig et al and othere avalable theoretical and experimental data is given. New data on the DC,

AC strong field Stark resonances, multi-photon and autoionization resonances, ionization profiles for a few heavy atoms (Eu, Tm, Gd, U) are presented. It has been firstly studied earlier discovered a giant broadening effect of the autoionization resonance width in a sufficiently weak electric (laser) field for uranium It is declared that probably this effect is universal for optics and spectroscopy of lanthanides and actinides and even superheavy elements.

The direct interaction of super intense laser fields in the optical frequency domain with nuclei is studied within the operator PT and the relativistic mean-field (plus Dirac-Woods-Saxon) model [2,3]. The ac-Stark shifts of the same order as in typical quantum optical systems relative to the respective transition frequencies are feasible with state-of-the-art or near-future laser field intensities. A nuclear dynamic (AC) Stark shift of low-lying nuclear states due to off-resonant excitation by laser field ($I \sim 10^{25}$-10^{35} W/cm^2) is studied and is described within the operator perturbation theory and the relativistic mean-field (RMF) model for the nucleus [2]. We present the results of AC Stark shifts of single proton states in the nuclei ^{16}O, ^{168}Er and compared these data with known results by Keitel et al [3]. New data are also listed for the ^{57}Fe and ^{171}Yb nuclei. Shifts of several keV are reached at intensities of roughly 10^{34} W/cm^2 for ^{16}O, ^{57}Fe and 10^{32} W/cm^2 for heavier nuclei. It is firstly presented a consistent relativistic theory of multiphoton-resonances in nuclei and first estimates of energies and widths for such resonances are presented for ^{57}Fe and ^{171}Yb nuclei

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Hydrogenic impurity states in the opened spherical core-shell quantum antidot

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Controlling the physical properties of quantum antidots (QAD) is interesting from the fundamental point of view and also for its potential application in the development of semiconductor optoelectronics devices. To study the optical properties of a medium with an ansamble of QADs it is necessary to clarify properties of a single dot.

We investigated the influence of increasing core and shell size on the states energy for single CdSe/ZnS/CdSe core-shell QAD, in the presence of the hydrogenic impurity. Calculations of the hydrogenic impurity discrete states in the opened spherical

semiconductor multilayered QAD are performed under effective mass approximation by assuming a spherically symmetric confining potential of finite depth. On the basis of the analytical solutions of the Scrödinger and Poisson equations for QAD with hydrogenic impurity located in the center, energy of states and corresponding wave functions for CdSe/ZnS/CdSe QAD are determined.

Energies of 1*s*, 2*s*, 3*s*, 2*p*, 3*p*, and 3*d* states, and radial probabilities, that illustrate spatial charge distribution, are presented in this paper. These results enable obtaining linear and non-linear optical intraband transitions coefficients changes. Behavior of 1*s* is the most prominent. For small core radius 1*s* orbital expands out of the dot with energy below the bottom of the outer material conduction band i.e. core material in this particular case. When core radius increases energy increases and at characteristic core dimension, 1*s* orbital contracts into the core region and the ground state energy decreases till it reaches constant value, characteristic for core material.

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Driven Bose-Hubbard Model with Impurity

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We consider two aspects of a single-band Bose-Hubbard Hamiltonian with an additional impurity fixed at a lattice site. In a time-independent model we generalize the atomic limit of Ref. [1] to the case that the impurity dislocates an arbitary number of bosons depending on the boson-impurity interaction strength. Afterwards, we follow Refs. [2,3] and study a time-dependent generalization where the periodic modulation of the boson-impurity interaction strength and the boson-boson interaction leads effectively to a conditional hopping.

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Improving Ginzburg-Landau theory for bosons in optical lattices via degenerate perturbation theory

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Bosons in an optical lattice yield a paradigmatic quantum phase transition between a Mott insulator and a superfluid. Recently, a Ginzburg-Landau theory for the underlying Bose-Hubbard model has been developed, which allows to determine the location of this quantum phase transition quite accurately [1-3]. Here we extend the validity range of this Ginzburg-Landau theory with the help of a degenerate perturbation theory. This allows to study also harmonically confined optical lattices, where a wedding cake structure of insulating Mott shells with superfluid regions between the Mott shells emerge [4].

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Parametric non-degenerate four wave mixing in hot potassium vapor

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Parametric non-degenerate four wave mixing (4WM) is a nonlinear process in which two photons mix in order to create photons with different frequencies. This process is realized via double lambda scheme by stimulating a four-stage cyclical transition resulting in the emission of amplified probe and conjugate photons. Photons created by this process are time-correlated and produce relative intensity squeezed beams [1] enabling measurements beyond the shot-noise limit [2].

In our experiment double lambda scheme is realized at D1 line of potassium isotope ^{39}K. We have investigated the influence of the density of potassium atoms, intensity of the pump beam, intensity of the probe beam, angle between the pump and the probe beam, one photon detuning and two photon detuning on the 4WM gain. The laser frequency is locked at various detunings (250 MHz to 2500 MHz) from the $4S_{1/2}F_g=1$ -> $4P_{1/2}$ transition. The probe is detuned at 460 MHz (ground state hyperfine splitting) in respect to the pump beam and scanned around the Raman resonance. The vacuum potassium

vapor cell,is heated up to 150^{o}C. The pump and probe beam intersect at small angle (2 - 10 mrad) determining the phase matching condition.

The efficiency of 4WM process is studied by simultaneously measuring the conjugate and the probe beam amplification. The highest gain we measured is 80 and to the best of our knowledge it is the highest gain obtained in FWM process in alkaline vapor cells. The maximal gain was achieved at 120^{o}C and for -6 MHz two photon detuning. We believe this will significantly improve the results in further investigation on relative intensity squeezing.

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Strong coupling regime of semiconductor quantum dot embedded in the nano-cavity

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Self-assembled quantum dots on semiconductor substrate have found many applications in optoelectronic devices such as single photon emitters, qubits for quantum computers, etc [1,2]. In this work, we study the interaction of the electron in nano-dot embedded in the nano-cavity with photons of a incident beam. Theoretical framework of our study is the semi-classical model Hamiltonian, which describes nano-dot interacting with the electromagnetic field. For the practical calculations we have employed rotating wave approximation. The influence of both, decay rates of cavities and quantity of coupling constant to level shift of electrons in a quantum dot have been analyzed. The boundary between strong coupling and weak-coupling regimes has been presented.

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Quantum yield vs photon energy dependence of colloidal Pb quantum dots

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One of the most important parameters for standardization of novel light-emitting materials is the photoluminescence quantum yield (QY). The QY is defined as the number of emitted photons per 1 absorbed photon. For the large variety of fluorophores the Kasha-Vavilov rule, which states the independence of both the luminescent spectral shape and its QY on the excitation photon energy, is fulfilled. However, some advanced materials (e.g. some QDs) with it's complex size and surface-dependent optical properties violate the KV rule and measuring of PL QY over extend excitation range is necessary.
In addition, it is commonly considered that PL QY doesn't depend on the concentration of QD solution in the reabsorption-free concentration range. However, strongly dilute suspensions of QDs could suffer from instability of QDs and reveal perturbations of PL QY values. This makes the investigation of PL QY depending on the concentration of suspensions is of practical importance. Up to now the understanding of these phenomena is very poor and needs complex study.

The 3 different sizes of oleic-acid (OA) capped PbS QDs were purchased from MK Nano (mean diameter d = 2.4 nm and 3.3 nm) and Strem Chemicals (d = 3 nm) and dispersed in toluene at different concentrations. We determined the absolute external PL QY directly by using a set-up based on an integrating sphere (IS) with diameter of 10 cm. A set (about 30) of various LEDs emitting in the range from UV to NIR region were used to excite PL. The PL QY was calculated as the ratio of the number of emitted photons and the number of absorbed photons [1]. The PL QY of QDs is commonly expected to decrease with increasing excitation photon energy because various non-radiative pathways (surface and other trap states) could participate in the relaxation of generated hot carriers. Indeed, for all investigated sizes of PbS QDs the non-resonantly excited PL QY was approximately linearly decreasing with increasing photon energy. Consequently, one-wavelength excitation measurement is not enough to characterize the PL QY of PbS QDs and at least set of excitation wavelengths (resonant and non-resonant) should be used.

The QY values for big QDs (3 nm and 3.3 nm) reveal concentration independency for concentrations 1 – 5 μM/L. At higher concentrations, PL QY is dropping down due to the well-known effect of reabsorption [1]. However, in the case of small PbS QDs (2.4 nm) it was observed the decrease of PL QY even for highly diluted samples (< 5 μ M/L). The ligands desorption and surface oxidation of QDs are the most probable origins of such behaviour as the surface quality could be perturbated for very dilute suspensions. The effect of surface modification at low concentrations of QDs is expected to be more pronounced for smaller QDs because of their higher surface-to-volume ratio that is in agreement with above mentioned observations. However, according to the concentration-selective ligand desorption hypothesis, the QY dependence on concentration should be observed also for larger QDs, but for lower concentrations than for smaller QDs [2]. The

two set of 3.3 nm PbS QD suspensions with different concentrations were prepared to support the idea. Into one set we added 10 μL of OA in toluene (1:4 OA in toluene). Expectedly, for concentrations lower than 0.5 μM/L a small reduction of QY has been observed. On the other hand, almost no decrease of QY with decreasing concentration were observed for samples with added OA, so revealing that the origin of the abnormal QY concentration dependence is the ligand desorption from surfaces of QDs in quite dilute suspensions. That points out the importance of measuring PL QY for different concentrations to avoid possible ligand desorption and PL reabsorption effects [3].

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Energy light pulse localization in layered photonic crystal with non-instantaneous nonlinear response

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As it well known, a problem of optical pulse interaction with photonic crystal (PC) has great interest, in particular for data processing by optical methods. In [1], light energy localization in layered photonic structure due to soliton formation in several PC layers was predicted if the nonlinear medium response was instantaneous. Below we consider the non-instantaneous response of medium. In this case, laser pulse propagation is described by following set of equations

$$\varepsilon(z)\frac{\partial A}{\partial t}+iD\frac{\partial^2 A}{\partial z^2}+i\beta\left(\varepsilon(z)+\alpha(z)\,p\right)A=0,$$
$$\frac{\partial p}{\partial t}+\frac{p}{\tau_p}=|A|^2,\ 0<z<L_z,\ 0<t\le L_t.$$

Above, a function $A(z;\,t)$ is a complex amplitude, slowly varying in time (t) only; z is a spatial coordinate; L_t, L_z are maximal values of time and space coordinate, p describes nonlinear medium response and α characterizes its strength, which depends from incident pulse intensity, in particular. Function $\varepsilon(z)$ describes a dielectric permittivity of ambient medium and the PC layers; D, β are real coefficients, which satisfy the conditions $D=(4\pi\chi)^{-1},\beta=\pi\chi$. Parameter χ describes the laser pulse propagation direction. τ_p characterizes relaxation time of medium response on the laser pulse action.

The main aim of our investigation consists of clarifying the relaxation time influence on the light energy localization process. We are of interest the total amount of this energy, and order number of layers, and maximal intensity in the corresponding layer. For example, in the Table these characteristics are shown for interaction of the incident Gaussian pulse with its duration $a=3$ with PC, containing alternating layers, which possess the nonlinearity $\alpha_1=-59.21,\alpha_2=59.21$, and thickness $d_1=0.2,d_2=0.4$, and dielectric permittivity $\varepsilon_1=5.29,\varepsilon_2=2.25$. Other parameters are the following $D=-0.021,\beta=-11.84$. The distance between the PC and initial beam centre position is equal to 12.

Table 1.

τ_p	Layer of laser energy localization	Maximal intensity in layer	Localization energy (%)
0.01	2	14.7	35.32
	4	13.9	24.93

0.05	2	11.6	9.00
	4	8.0	7.025
	6	0.6	2.74
	10	0.9	3.606
0.25	10	20.2	47.45
0.5	4	7.0	30.77
	6	26.3	37.30
1	2	17.8	42.32
	4	8.1	26.42

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Sum-frequency generation of multi-line carbon monoxide laser in $AgGaSe_2$ crystal

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Carbon monoxide laser (CO laser) has high laser efficiency and an unusual wide spectrum of generation numbering hundreds of ro-vibrational lines in fundamental (from 4.7 μm to 8.2 μm) and overtone (from 2.5 to 4.2 μm) bands [1]. Frequency conversion of CO laser radiation in nonlinear crystals enables one to cover almost full mid-IR range from 2.5 μm to 17 μm [2, 3]. In [2] spectral interval from 12 μm to ~17 μm was covered by difference frequency generation of CO laser and CO_2 laser radiation in GaSe and $AgGaSe_2$ crystals, longest wavelengths and highest conversion efficiency being obtained in $AgGaSe_2$ crystal. Second harmonic and sum frequency generation (SFG) of CO laser radiation is also possible in $AgGaSe_2$. However, only one publication [3] reported about second harmonic generation of CO laser radiation in this crystal, and there is no information on conversion efficiency. In this study SFG (including second harmonic generation) of multi-line CO laser radiation in $AgGaSe_2$ was examined.

In the experiment we used a low-pressure cw CO laser with cryogenically cooled active medium pumped by dc discharge. The CO laser operated in Q-switch mode by rotating mirror. The FWHM pulse duration of CO laser was ~0.5 μs at Q-switch frequency of ~100 Hz. Peak power of radiation reached ~1 kW at average power of ~40 mW. The spectrum of the CO laser consisted of about 80 spectral lines in wavelength range from 5.0 μm to 6.1 μm. CO laser radiation was focused by CaF_2 lens (focal length 12.5 mm) into uncoated $AgGaSe_2$ crystal with the length 8 mm. Maximum average power of SHG was 0.13 mW at 43^o phase-matching angle. External conversion efficiency reached 0.5%, that corresponded to internal efficiency of ~0.9% (taking into account Fresnel losses on

uncoated facets of crystal). The spectrum of SFG consisted of about 140 lines in wavelength range from 2.55 μm to 2.9 μm. The wide spectrum of SFG was due to non-critical spectral phase matching. A great number of spectral lines of converted emission was due to simultaneous SFG of different pairs of CO laser lines.

Obtained energetic and spectral parameters of SFG are close to results obtained under similar conditions in $ZnGeP_2$ crystal [4]. To enhance conversion efficiency in $AgGaSe_2$ crystal we are going to apply high power nanosecond CO laser [5]). Moreover, phase-matching angles of sum and difference frequency generation in $AgGaSe_2$ were calculated. It was found that two-stage frequency conversion (including sum and difference frequency generation) under optical pumping by a multi-line CO laser radiation is possible in single $AgGaSe_2$ crystal, like in $ZnGeP_2$ crystal [6,7].

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Light guidance properties of kagomé hollow-core photonic crystal fibres

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When the fibre's geometry has a periodicity in the cladding, the photonic bandgap and/or the low density of states effects can appear, leading to light guidance in the fibre's core [1, 2]. In this paper we analyse the light propagation characteristics of kagomé hollow-core photonic crystal fibres (HC-PCFs). We consider the case of kagomé fibres whose hollow-core is filled with noble gases.

In order to study the fibre's cladding properties, we show our computation results for the photonic energy bands of kagomé fibres, and then we determine the corresponding diagrams of the projected bandgaps and of the density of states. We relate those data of the photonic bands of the fibre's cladding with field distributions of fundamental propagating modes. Finally, after studying the nonlinear and dispersive characteristics of kagomé HC-PCFs, we show selected results of nonlinear propagation of light on these

fibres: effects such as the ultraviolet light generation and the supercontinuum will be addressed.

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Light shift averaging in antirelaxation-coated atomic cells

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Antirelaxation-coated cells filled with hot atomic vapours are commonly used in nonlinear and quantum optics experiments. Of a particular interest are nonlinear magneto-optical effects that enable ultra-precise magnetic- field measurements. These effects are based on optically-induced anisotropy that evolves due to magnetic field. The anisotropy stems from optical polarization of atomic spins. In the simplest case polarized atoms precess around the field direction with the Larmor frequency [1]. As a result, the properties of light transmitted through the vapour are modulated and detection of the modulation frequency provides a direct measurement of the magnetic field.

While light is used for generation and probing of the polarization and hence detection of magnetic field, it may also affect readings of atomic magnetometers. This problem arises from the AC Stark effect, which shifts energy levels of atoms. This can result in a shift of spin-precession frequency (light shift) [2] and hence may lead to incorrect determination and deterioration of sensitivity of magnetic-field measurements. With this respect, the necessity of precise measurements calls for determination of the AC Stark shift due to the employed light.

Although the AC Stark effect can be detrimental for operation of atomic magnetometers, there are various examples of its beneficial use. For instance, it may be used to compensate for the nonlinear Zeeman effect [3,4], i.e., the effect of nonlinear magnetic splitting of Zeeman sublevels that may also compromise the operation of atomic magnetometers. Specifically, application of circularly polarized laser light can generate purely Zeeman- type energy level shift (generation of fictitious magnetic field) [5]. In a recent work, two orthogonal light beams were used in a standard scalar magnetometer to generate fictitious magnetic field, enabling operation of the device as an all-optical vector

magnetometer [6]. This configuration has important advantages, including the ability to operate in close proximity to other sensor. Importantly, the analogous configuration of a scalar magnetometer using two magnetic-coils generated fields does not offer such capabilities.

The above-mentioned experiments [3,4,6] exploited atoms enclosed in paraffin-coated cells. In all these experiments, the authors assumed that the light shift can be averaged over the whole cell volume. This brings the question of the independence of the light shift on light-beam diameter. While this assumption seems to be consistent with the experimental results, no direct proof of this effect has been obtained so far.

The goal of this contribution is to investigate the light shift averaging in paraffin-coated cells. The broadening of resonance signal due to a small light-shift beam size is also expected. The experiment was conducted along with simplified Monte Carlo simulations that confirm observations. The setup is similar to standard atomic magnetometer with additional laser beam introducing the light shift responsible for the fictitious magnetic field Zeeman splitting.

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Self-focusing and plasma generation of linear polarized laser pulse in optical schemes with preferential directions

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Ultrashort laser pulse with peak power above critical one propagates in filamentation regime in transparent media and consists in pulse energy localization [1-3]. Filamentation is a result of nonlinear optical interactions between high-power laser pulse and propagation media like Kerr self-focusing and plasma defocusing of the beam. Studies of self-focusing and filamentation dependence on laser pulse polarization began early in 1966, when authors of papers [4, 5] provided theoretical and experimental study on this topic and demonstrated strong influence of linear and circular pulse polarization on self-focusing. Later, similar studies were conducted with femtosecond laser pulses in [6-8]. Most of the papers discussed axisymmetric optical schemes regardless of pulse

polarization orientation. However, linear polarization orientation can crucially influence upon nonlinear processes in case of non-axisymmetric optical systems. For instance, laser beam in paper [9] formed the plasma channel with density distribution profile of two maxima of different values in meridional and sagittal focal planes for conditions of strong astigmatism. Therefore the influence of linear polarization orientation on the beam filamentation for optical schemes with preferential directions was studied in this work.
A femtosecond Ti:Sapphire laser facility (100 fs FWHM, 6 mm e^{-1}, 744 nm of 0.1 to 2.5 mJ and 248 nm of 0.1 mJ) was used as the source of light. We conducted experiments with tree different optical schemes: astigmatic beam propagation, two beam superposition and beam propagation through a slit. In the first experiment on study of laser pulse filamentation in astigmatic optical scheme laser beam in IR domain was horizontally reflected at angle of 22.5 degrees by a spherical mirror with focal distance of 50 cm and formed plasma channel with two maxima of density distribution. The plasma density in the first focus was higher for vertical pulse polarization as compared to horizontal one and vice versa in the second focus of astigmatic beam. This effect was more evident for lower energy pulses (1.2 mJ compared to 2.5 mJ); such a difference can be explained by various self-focusing conditions. In the second experiment the initial IR or UV laser beam was divided in two by a diaphragm with two holes of 3.5 mm in diameter, which were focused by lens of 50 cm. Varying orientation of beams superposition plane relative to polarization plane lead to different plasma density profiles. In the case of both wavelength domains (1 mJ for IR and 0.1 mJ for UV) beams superposition in the plane perpendicular to the polarization plane resulted in an increase of plasma density in contrast to the other orientation, but in case of UV beam this effect was strongly demonstrated. Third experiment concluded in preferential direction formation by IR beam of 0.6 mJ propagating through a slit of 1.5 mm width and lens of 50 cm focal distance. Plasma density decrease and slight plasma channel elongation in the case of pulse polarization collinear to the slit orientation were obtained. So, considerable influence of laser pulse linear polarization orientation on its filamentation for non-axisymmetric optical schemes was experimentally demonstrated.

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Observation of flat band properties in photonic lattices

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Localization of light waves in periodically perfect photonic lattices is possible by means of nonlinearity what, however, usually demands large level of power [1]. In the linear regime localization requires extra ingredients as, for example, disorder or local impurities, resulting on non-controlled or too controlled light patterns, respectively. This is the general scenario for conventional systems where linear bands show a dispersive nature, allowing waves to travel across the lattice while transporting energy through the system. However, there is class of systems presenting an unconventional linear spectrum where, at least, one band is perfectly flat [2]. For example, in Lieb lattices [3] the energy spreading is highly determined on the input excitation region. Depending on the particular site excited, the observation of transport, transport and localization, or simple localization is possible, as a manifestation of the band structure. Additionally, linear modes belonging to this flat band are localized in space and occupy only few sites of the lattice.

In this talk, I will present our recent results on flat band systems showing the possibility to observe numerically and experimentally the predicted phenomenology from tight-binding models. We will review results on two-dimensional lattices (Kagome [4] and Lieb [3,5]) as well as in quasi one-dimensional lattices (Sawtooth [6] and Stub [7]). We will show that the excitation of ring localized structures is possible as well as to observe their linear combination forming more complex patterns. Our experiments were implemented in femtosecond laser written waveguide arrays [8], where different waveguide patterns can be fabricated. To study transport properties, we performed different experiments injecting a 633 nm laser beam on individual lattice sites. Additionally, we prepared complex input conditions using a combination of Spatial Light Modulators to modulate in amplitude and phase a 532 nm wide laser beam. In this way, we were able to excite fundamental localized excitations originated in the flat band of these systems, confirming the discrete approach used to describe weakly coupled waveguide arrays.

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Charge Flipping Vortices in DNLS trimer and hexamer

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We examine the existence and properties of Charge Flipping Vortices (CFVs), rtices which periodically flip the topological charge, in three-site (trimer) and six-site (hexamer) discrete nonlinear Schrödinger (DNLS) lattices. We demonstrate numerically that CFVs exist as exact quasiperiodic solutions in continuous families which connect two different stationary solutions without topological charge, and that it is possible to interpret the dynamics of certain CFVs as the result of perturbations of these stationary solutions. The CFVs are calculated with high numerical accuracy and we may therefore accurately determine many of their properties, such as their energy and linear stability, and the CFVs are found to be stable over large parameter regimes.

We also show that, like in earlier studies for lattices with a multiple of four sites, trimer and hexamer CFVs can be obtained by perturbing stationary constant amplitude vortices with certain linear eigenmodes. However, in contrast to the former case where the perturbation could be infinitesimal, the magnitude of the perturbations for trimers and hexamers must overcome a quite large threshold value. These CFVs may be interpreted as exact quasiperiodic CFVs, with a small perturbation applied to. The concept of a charge flipping energy barrier is introduced and discussed.

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Formation of optically induced photonic waveguides in a bulk of lithium niobate with a pyroelectric response

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Propagation of light beams in nonlinear optical media is accompanied by the spatial self-action effects. It results in the possible regimes of the spatial solitons which can form optical waveguides in these media. The diameters of two-dimensional (2D) or thicknesses of one-dimensional waveguide elements formed in experiments with spatial solitons range from tens to few microns [1]. Channel optical waveguides and more complicated waveguide circuits may be optically induced in some crystalline materials. The special interest among all materials is attracted in this way to the photorefractive crystals with

huge nonlinear optical response at low light intensity [2]. Some of such crystals demonstrate the strong pyroelectric effect. The electric field is generated in these crystals at the change of the temperature accompanied with variations of their spontaneous polarization [3]. The self-trapping of light beams with obtaining of spatial soliton regime exploiting the pyroelectric properties has been recently demonstrated for undoped lithium niobate ($LiNbO_3$) crystal [4]. The channel waveguides have been formed in those experiments as in the bulk of this crystal as in the $LiNbO_3$ - based planar waveguide. The ability to optically reconfigure the topology of waveguide components and circuits in nonlinear optical materials opens the way to formation of micro- and nano-scaled components suitable for the applications in modern photonics and optical communication systems [5].

In this work we experimentally investigate formation of 2D waveguide channels and more complicated waveguide circuits due to the pyroelectric mechanism of the nonlinear response in nominally undoped $LiNbO_3$. The characteristics of these circuits are studied at wavelengths of 532 and 633 nm.

We study characteristics of waveguide elements and circuits formed in a bulk of lithium niobate crystals with low photorefractive sensitivity exploiting their pyroelectric properties. Channel waveguides, waveguide directional couplers and waveguide arrays are generated in undoped crystals of congruent composition and in stoichiometric lithium niobate crystals. We use in experiments the laser radiation with wavelengths of 532 and 633 nm. The crystal samples are heated to involve into play the pyroelectric effect using the Peltier element. To provide the necessary configuration of photonic waveguide circuits, we form the required profile of light fields at the input surface of the crystal samples with phasing and diffraction elements. The waveguide and diffraction properties of elements and circuits obtained are studied with optical microscopy and with excitation of light within waveguide structures. The light trapping within waveguides, the storage time of waveguide circuits formed and characteristics of the discrete diffraction effects demonstrate the usability of pyroelectrically induced waveguide elements and systems for the needs of waveguide photonics.

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Optical properties of spherical quantum dot with on-center hydrogen impurity in magnetic field

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The progress in nanofabrication in the last decades has contributed to the growing interest for the theoretical study of the structures and properties of low-dimensional systems. Therefore, the investigation of the optical properties of the semiconductor heterostructures, like quantum wells, wires and dots, is of great significance, considering their potential applications in different optoelectronic devices of the novel generation [1].

In this article, we consider GaAs/AlGaAs spherical quantum dot, containing on-center hydrogenic impurity under the static magnetic field. Energy levels and dipole transition matrix elements of the impurity electron for different magnetic field strengths have been computed by the numerical solving of the Hamiltonian eigenproblem. Computation has been performed in the effective mass approximation, with confining potential modeled by the impenetrable spherical wall, using the Lagrange mesh method. The numerical results have then been used to obtain the linear and third-order nonlinear optical absorption coefficients [2-6].

Finally, we discuss the behavior of the absorption coefficients as the functions of the quantum dot radius, as well as the applied magnetic field strengths. It has been observed that, for the given quantum dot radius and laser intensity, the increase in magnetic field strength results in the shifting of the linear and nonlinear coefficient maxima to the lower laser frequencies. A similar conclusion is valid when the quantum dot radius increases at given values of the magnetic field and laser intensity.

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On localized modes in nonlinear binary kagome ribbons

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One of the attractive two-dimensional [2D] lattice configurations is characterized by kagome geometry. The specific arrangement of its elements, i.e. waveguides, in the form of periodic hexagons renders completely flat the first energy band in linear case. As a consequence, the localized ring-like eigenmodes belonging to the lowest energy state propagate without diffraction through the system [1, 2]. Here we study kagome ribbon [3], which can be interpreted as one-dimensional counterpart of the standard 2D kagome lattice, and can be fabricated by dint of the direct femtosecond laser inscription [4, 5].

The existence, stability and dynamical properties of various localized modes in binary kagome ribbon with defocusing Kerr type of nonlinearity have been explored, both numerically and analytically. We derived the corresponding dispersion relation and the bandgap spectrum, confirmed the opening of mini-gaps in it and found several types of stable ring-like modes to exist: staggered, unstaggered and vortex. Beside these nonlinear mode configurations occurring in a semi-infinite gap, we investigated features of "hourglass" solutions, identified in [3] as interesting structures when kagome lattice dimensionality is reduced to 1D. In nonlinear binary kagome ribbon dynamically stable propagation of unstaggered rings, vortex modes with certain topological charge and hourglass solutions are observed, while the staggered ring solutions are destabilized. In addition, we examined possibility to generate stable propagating solitary modes inside the first mini-gap and found that these mode patterns localize within sites mutually coupled by smaller coupling constant. The last feature is opposite to the nonlinear localized solutions found in the semi-infinite gap.

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Interference structures in nonlinear processes in strong infrared laser fields

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With the advent of high-power lasers, many interesting nonlinear phenomena have been observed when exposing atoms and molecules to strong laser fields (see review articles [1,2] and references therein). High-order harmonic generation (HHG) and high-order above-threshold ionization (HATI) on molecular targets are the two processes that recently have attracted more attention [3,4]. This paper is devoted to the above mentioned processes with emphasis on homonuclear diatomic molecules that are exposed to strong infrared linearly polarized laser fields.

Both HHG and HATI may be described by the so-called three-step model [5,6]. The first two steps are the same for both processes. In the first step, the considered molecular target absorbs more photons from the laser field than is necessary for ionization. Influenced by the laser field, the ionized electron may return to parent ion (the second step). In the third step of the HHG process, the electron recombines with the parent ion and one high-energy photon is emitted whereas the third step of the HATI process is characterized by the rescattering of the ionized electron off the parent molecular ion.

We apply the molecular strong-field approximation (MSFA) in the frame of the S-matrix theory. By analyzing the HHG and HATI spectra for different orientations of molecular axis with respect to the direction of the laser polarization vector we have observed interference structures. The positions of the interference minima are in accordance with our previous theoretical predictions, i.e. the positions of the minima depend on the internuclear distance and on the relative contributions of the atomic orbitals in the linear combination of the atomic orbitals (LCAO) of the highest occupied molecular orbitals (HOMO) [7-10]. Our HHG and HATI spectra have been obtained for laser wavelengths of 1250-1300 nm. Our results may also provide additional information about molecular structure.

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Light propagation through the composite linear photonic lattice containing two nonlinear defects

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Photonic lattices represent suitable systems for investigation of wave propagation in periodic structures [1]. However, different unavoidable defects may arise either during their process of fabrication or as result of misusage, accidental damage, etc. Although undesirable in the first place, these imperfections enable the existence of different types of stable, localized defect modes [2].

In this paper, we investigate light propagation through composite photonic lattice composed of two identical linear and lossless lattices. The interface between them represents a geometric defect, while each lattice contains a single nonlinear defect that is placed symmetrically with respect to the interface. Depending on the input light beam parameters (its position, width and transverse tilt), the width of geometric defect, strength and position of the nonlinear defects, different dynamical regimes have been identified. These dynamical regimes are caused by the balance of photonic lattice potentials' contributions originating from the presence of the geometric and two nonlinear defects.

We have found numerically conditions under which dynamically stable bounded modes can exist in the area between nonlinear defects or between a nonlinear and a geometric defect. Various types of localized modes such as: two-hump, multi-hump, one- and multi-component moving breathers localized at a certain area among defects have been observed. The parameters can be adjusted to capture light and to prevent light launched inside the area among defects to leave it, i.e. this corresponds to the appearance of the modes trapped inside this area. Since the configuration of the lattice prevents transmission of the light through the area confined by defects, these modes can formally be related to Fano resonances and Fano- blockade [3, 4]. When light is launched outside

the area among defects, different dynamical regimes have been distinguished: total reflection, single and double partial reflection and full transmission through the area among defects.

These numerical findings may lead to interesting applications such as blocking, filtering and transporting light beams through the optical medium. Photonic devices based on resonant tunneling such as waveguides interacting through the area between defects, may be applied as add-drop filters.

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On high power dynamically stable vortices in multicore optical fibers

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Vortex structures are widespread in nature (tornadoes, the Great Red Spot of Jupiter, and microscopic objects in quantum physics) [1]. Optical vortices are characterized by a wave field with zero intensity, undefined phase in the vortex center, a screw dislocation of the wave front and conservation of the topological charge. The vortex property most significant for applications, such as in optical traps, information transmission, multiplexing in communications and amplification of power in multi-core-fiber (MCF) based lasers, is their ability to carry orbital angular momentum and energy [2].

The mathematical model of the circularly coupled MCF without and with the central core is based on the general complex difference-differential Ginzburg-Landau equation. Here we considered its linear variant with identical small number of periphery cores including loss and gain, as well as, the nonlinear one without the loss-gain mechanisms [2,3].

The most significant finding is the stable propagation of high power vortices in the MCFs. They appeared as eigenvalue solutions of linear MCFs in both the configuration without and with central core [3]. In certain circumstances propagation of 'frozen' vortex

structures (the ones that propagate with unchanged phase in cores) is shown, too. The presence of small material losses in cores has not affected stable vortex propagation [3]. In the linear case, the system has no limitations regarding the optical power that is being transmitted, which is not the case in reality, since there are obvious physical restrictions [4]. Although the nonlinearity, in general, shrinks the region of existence of dynamically stable vortices, the huge region of dynamically stable ones with high power is confirmed to prevail [2]. The amplitude of nonlinear vortices is an active parameter, in contrast to the linear system.

In conclusion, our results indicate a possibility of stable coherent propagation of high power though MCFs by the means of vortices. A new degree of freedom in the system can be introduced by the presence of the loss-gain mechanisms which can be arranged to 'use' the central core as an energy channel for the energy exchange in the system, therefore allowing destabilization of the vortex structure by localization of a huge power into one core or a small number of cores.

The steady-state coherent propagation in MCFs opens new opportunities for the multicore waveguide system applications, such as in spatial division multiplexing. This emerging technology of transmitting information over separate spatial channels – cores in MCF, altogether increasing the total capacity per fiber, is of utmost importance in modern optical communications systems.

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The nonlinear optical properties and electronic transitions of thienylpyrroles−containing chromophores: A DFT study

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In this study, the linear and nonlinear optical parameters (the molecular static polarizability (α), and the first-order static hyperpolarizability (β_0), the orientational second-order static hyperpolarizability (γ_{orient})), UV-vis spectra and HOMO and LUMO energies of dicyanovinyl-thienylpyrroles **2** compounds [1] were investigated by using the HSEh1PBE/6-311G(d,p) and 6-311++G(d,p) levels of density functional theory [2]. The UV-vis spectra were simulated using TD/HSEh1PBE/6-311G(d,p) level, and the major

contributions to the electronic transitions were obtained. The molecular hardness (η) and electronegativity (χ) parameters [3-5] were also obtained by using molecular frontier orbital energies. The NLO parameters of the title compound were calculated, and obtained data were compared with that of para-Nitroaniline (pNA) which is a typical NLO material and the corresponding experimental data [1,6]. The β_0 value (18.68×10^{-30} esu) calculated by using HSEh1PBE/6-311G(d,p) for compound **2a₂** is 1.49 times lower than the experimental value (28×10^{-30} esu), and 2.21 times greater than pNA value (8.45×10^{-30} esu). Data of these chromospheres display significant molecular second nonlinearity and provide the basis for future design of efficient nonlinear optical materials having the dicyanovinyl-substituted compounds. So as to investigate intra and intermolecular bonding and interaction among bonds, and present a practical basis of investigating charge-transfer or conjugative interaction in the title compounds NBO analysis were carried out.

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Stable temporal dissipative solitons in resonant gases confined in PBG fibers

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Propagation of light in resonant atomic gases with an electromagnetically induced transparency configuration benefits from high nonlinearities and the possible engineering of the linear properties. Solitons are among the nonlinear manifestations that have been predicted in those systems, as optical beams [1,2] or as slow optical pulses [3,4]. The spatial solitons in those systems were already experimentally demonstrated [5,6]. Most of the predictions of solitons in such systems were done by neglecting the dissipative terms which are supposedly very small when compared with the conservative ones. However, we have recently obtained a modified version of the cubic complex Ginzburg-Landau equation (CGLE) when considering the propagation of an optical pulse whose frequency is in resonance with a three level gas confined in a hollow core photonic band-gap (PBG) fiber [7]. The analysis was done using a multiscale approximation up to third order. This equation admits stable solitons if there is net linear gain as is the case with the cubic CGLE.

We have also found a PBG fiber and a gas configuration whose characteristics permit the propagation of such stable solitons. Nevertheless, the linear gain, that is possible because the gas is only confined in the hollow core but not in the cladding holes, brings background instability.

Here, we systematically address the configurations of gases confined in PBG fibers that are more suitable for stable dissipative solitons, studying the dependence of sign and magnitude of the equation parameters with the experimental conditions. Moreover, we will obtain a propagation equation in fourth order which introduces a delayed Raman scattering term. This new term creates a new branch of solutions that exist and are stable in a limited range of the parameter space for which there is linear loss, so that, the background is stable.

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Light propagation in deterministic aperiodic Fibonacci waveguide arrays

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During the 1980s quasi-crystallographic structures in solid state physics fundamentally amazed the scientific community [1], and inspired a new field of research in optics and photonics. Owing to the analogy of photonic lattices to solid state systems, the first optical experiments were implemented analyzing aperiodic media [2]. Irregular photonic lattices are of great interest as these structures offer proper band gaps where propagation is forbidden while translation invariance and thus the general scheme of Bloch wave propagation within periodic arrangements are broken. Asking for aperiodic structures rapidly the nomenclature of Fibonacci grating came up for this often is referred to as the embodiment of irregularity [3,4]. Generally spoken, the research field of aperiodic lattices is a fertile topic [5] as these structures offer the possibility of light localization in deterministic disordered structures that are settled between periodic and disordered systems [6]. Light localization in quasi-periodic photonic lattices is observed in Aubry André model and also realized experimentally in AlGaAs substrate [7].

We extend these concepts to quasi-periodic Fibonacci waveguide arrays, considering light propagation along waveguides. We fabricate the array of identical waveguides (identical refractive index profile) in Fe:$LiNbO_3$ crystal. The distance between successive waveguides is modulated in Fibonacci manner. This means that the sequence of separations consists of two elements, A and B, lined in such a way to make Fibonacci word. We have analyzed experimentally and numerically how various incident beam positions influence propagation and localization characteristics and compare it with appropriate periodic waveguide arrays. In general, we find the beam expansion is slowed down in quasi-periodic Fibonacci waveguide arrays, and localization properties in such lattice are closer to a random than periodic lattice. However, with a modification of the refractive index variation, the localization effects are observed for shorter propagation distances by increasing refractive index variation.

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Counterpropagating optical solitons in PT symmetric photonic lattices

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We construct solitonic solutions for the system of two optical beams propagating in opposite directions [1, 2] in parity-time (PT) symmetric [3, 4] photonic lattices by using modified Petviashvili method [5]. Our system support PT symmetric fundamental solitons, as well as solitary vortices. We propagate them and investigate their basic characteristics. We report power transfer between counterpropagating beams and symmetry breaking (or split-up) transition.

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Quench Dynamics for Trapped Dipolar Fermi Gases

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A recent time-of-flight expansion experiment for polarized fermionic erbium atoms managed to detect a Fermi surface deformation which is due to the dipolar interaction [1]. Here we perform a systematic study of quench dynamics of trapped dipolar Fermi gases at zero temperature, which are induced by a sudden change of the magnetic field, which enforces the polarization of the magnetic moments of the erbium atoms. As this modifies the equilibrium configuration, oscillations of the fermionic erbium cloud emerge around the new equilibrium, which are characteristic for the presence of the dipole-dipole interaction. In order to analyze the emergent dynamics we follow Ref. [2] and solve analytically the underlying Boltzmann-Vlasov equation wihtin the relaxation approximation in the vicinity of the new equilibrium configuration by using a suitable rescaling of the equilibrium distribution [3]. The resulting ordinary differential equations of motion for the scaling parameters are solved numerically for experimentally relevant parameters all the way from the collisionless to the hydrodynamic regime. A comparison with a corresponding linear stability analysis reveals that the resulting quench dynamics can be understood in terms of the low-lying collective modes due to the smallness of the dipolar interaction strength. All our theoretical and numerical calculations can be tested in current experiments with ultracold dipolar fermionic atoms.

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Trapped Bose-Einstein Condensates with Strong Disorder

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We work out a non-perturbative approach towards the dirty boson problem at zero temperature that is based on a Gaussian approximation for correlation functions of the disorder problem and the condensate wave function solving the Gross-Pitaevskii problem. For harmonically trapped Bose-Einstein condensates we apply, in addition, the

semiclassical approximation and derive with this self-consistency equations between the disorder ensemble-averages of particle density and condensate density. Invoking, furthermore, the Thomas-Fermi approximation we obtain results that reproduce for weak disorder the seminal results of a Bogoliubov theory of dirty bosons [1-3], but do not yield for strong disorder a Bose-glass phase. Afterwards, we go beyond the Thomas-Fermi approximation and perform a full numerical treatment of the self-consistency equations based on the Crank-Nicolson split-step semi-implicit imaginary-time propagation [4], which yields a quantum phase transition to a Bose-glass phase for strong disorder [5].

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Faraday Waves in Dipolar Bose-Einstein Condensates

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We present the emergence of Faraday waves in cigar-shaped ^{52}Cr and ^{164}Dy Bose-Einstein condensates. These density waves are induced by periodic modulation of the frequency of the trapping potential. We study through extensive numerical simulations and detailed variational treatment the effects of the strong dipolar interaction on the spatial and time-period of the Faraday waves. Unlike in the case of homogeneous [1] or inhomogeneous contact interactions [2], the emergence of Faraday waves is found to further destabilize the condensate in the presence of strong dipolar interaction. The interesting effect of spatial period variation of generated density patterns is observed numerically and studied within the Gaussian variational approach.

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Linear modulational stability analysis of Ginzburg-Landau dissipative vortices

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Two-dimensional dissipative solitons are well described by the complex Ginzburg-Landau equation with cubic-quintic nonlinearity compensating diffraction. Linear and nonlinear losses are simultaneously balanced by the gain [1]. Vortex solitons contain zero electric field in center corresponding to topologic singularity called charge [2]. Vortices are particularly sensitive to azimuthal modulational instability causing filamentation for some parameters [3]. We perform linear stability analysis in order to determine for which value of parameters dissipative vortex either splits into filaments or becomes stable, hence, becomes dissipative vortex soliton. The increment value of different mods shows how strong is modulational instability.

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Spectral Method for Numerical Solution of the Nonlocal Nonlinear Schrödinger Equation on the GPU

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An important characteristic of many nonlinear media is their nonlocality, that is, the property that the size of the response of the medium is different from the size of the excitation. High nonlocality is of special interest, because it is observed in many media. These include nematic liquid crystals [1], materials with thermal nonlocality [2], photorefractive crystals [3], and Bose-Einstein condensates [4], among other. Essential part in the analysis of nonlocal phenomena is an accurate and efficient numerical simulation. Nonlocal models are generally represented by the system of two coupled equations; the first one is the nonlinear wave equation while the second one describes the nonlocality. There are many proven ways to perform the simulation of wave equation, while simulating the nonlocal equation can be challenging, as a result of different

physical and boundary conditions that have to be satisfied. In this paper we implement a spectral method for simulating both equations, but due to delicate numerical nature of nonlocal equation the simulation of that equation is done using a modified spectral method. Moreover, the algorithm is implemented on a GPU, in order to get high efficiency and to address more computationally demanding problems. Obtained results are discussed in terms of performance and accuracy.

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Control of power-dependent walk-off in bias-free nematic liquid crystals

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In this paper we investigate numerically how to control and reduce power-dependent walk-off [1, 2] by using a full three-dimensional model for beam propagation in highly nonlocal bias-free nematic liquid crystals (NLCs). We calculate the fundamental soliton profiles using modified Petviashvili method [3, 4]. We have investigated soliton propagation with different initial momenta and rest angles. Owing to the highly nonlocal character of the dielectric response of NLC, we demonstrate various soliton trajectories.

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Spatio-temporal general Jacobi elliptic function expansion method applied to the generalized (3+1)-dimensional nonlinear Schrödinger equation

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We generalize the Jacobi elliptic function (JEF) expansion method which first used in [1,2] for the case of the (3+1)-dimensional Nonlinear Schrödinger Equation ((3+1)-D NLSE). In this paper we use an expansion function which is a solution to a differential equation in which the square of the derivative is equal to a general fourth order polynomial of the original function, instead of the standard JEF used in [1,2] for which the derivative is equal to a polynomial containing just the zeroth, second and fourth order terms. Another generalization compared to [1] and [2] is that in addition to the parameter functions next to the expansion function and its inverse the ansatz also contains a free parameter function, which allows for a larger range of potential solutions. By plugging in this more general ansatz into the standard (3+1)-D NLSE, solving the obtained system of algebraic and ordinary differential equations, and using suitable matching conditions for the streingth of the nonlinearity and other parameters we obtain novel forms of solutions to the (3+1)-D NLSE previously undiscovered by [1] and [2]. Some of the novel solutions obtained include solutions based on the Weierstrass elliptic function [3] and solutions which use the inverses of Carlson's elliptic integrals [4]. These solutions can potentially be generalized to other systems containing the basic NLSE with additional terms added, such as the Gross-Pitaevskii equation [5,6] or the NLSE with a linear potential [7].

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Parity non-conservation effect in atomic optics and observation of the P and PT violation using NMR shift in a laser beam

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During the past decade, first of all the optical experiments, including the Mössbauer spectroscopy measurements, to detect the parity non-conservation or violation effect have progressed to the point where the parity violation weak amplitudes can be measured with accuracy on the sufficiently high accuracy to provide a low-energy test of the Standard model [1-3]. It is obvious that the experiments for an electro-weak interaction parameters measurements, comparison of the measured amplitudes with theoretically determined ones are required. Now days the parity non-conservation effect in atomic and nuclear systems has a potential to probe a new physics beyond the Standard Model. In our paper we systematically apply the formalism of the nuclear-QED many-body perturbation theory [4-6] to precise studying a parity violation effect in heavy atoms with account for the relativistic, nuclear and radiation QED corrections. The nuclear block of theory is presented by the relativistic mean field model (the Dirac-Woods-Saxon model). Earlier an efficiency of this approach has been demonstrated in the precise calculation of the energy spectra, the hyperfine structure constants, E1, M1 transition probabilities for some heavy atoms and heavy ions [4-6].

As a test, we present the results of computing the energy levels, hyperfine structure intervals, E1,M1 radiation transitions amplitudes in the heavy atoms such as ^{133}Cs, ^{173}Yb, ^{205}Tl (test for the further atomic violation computing). Further we have computed the parity violation radiative amplitudes for a number of the atomic and nuclear systems, namely: ^{133}Cs, ^{173}Yb, ^{205}Tl (atomic parity violation) and ^{119,121}Sn (nuclear parity violation). Accuracy of accounting for the inter electron exchange-correlation corrections, the Breit and weak inter electron interactions, radiation and nuclear (magnetic moment distribution, finite size, neutron "skin") effects, nuclear spin dependent corrections due to an anapole moment, Z-boson [(A_nV_e) current] exchange, the hyperfine-Z boson exchange [(V_nA_e) current] have been analysed.

Besides, the weak charge has been calculated for the ^{133}Cs, ^{205}Tl atoms and firstly ^{173}Yb and comparison of the theoretical results with the Standard Model data has been done. Using the experimental parity non-conservation parameter value ΔE_1^{PNC} /β==39mV/cm (Berkeley, 2009; Tsigutkin et al) and our value $9.707\cdot10^{-10}ea_B$, it is easily to determine the weak charge value Q_W=-92.31 for ^{173}Yb (Z=70, N=103) that should be compared with the Standard Model value Q_W=-95.44. Besides, the obtained theoretical data have been compared with the known earlier and recent results by Flambaum-Dzuba et al, Johnson-Sapirstein-Blundell, Safronova et al [2,3]. At last, we discuss a new improved possibility for observing

P and PT violation using a nuclear magnetic resonance frequency shift in a laser beam [7]. The corresponding shift is provided by a correlation of the a nuclear spin with the momentum of the photon (***Ik***).

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New nonlinear optics and dynamics of quantum and laser systems with elements of a chaos

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The work is devoted to carrying out new approaches to the universal quantum-dynamic and chaos-geometric modelling, analysis and prediction of a chaotic dynamics of nonlinear processes in atomic and molecular systems in intense electromagnetic fields and quantum-generator and laser systems. The latter include a single-modal laser with an absorbing cell, a fiber laser, a semiconductor laser coupled with feedback with delay, the system of semiconductor quantum generators, combined through a general cavity. The computing code includes a set of numerical quantum-dynamic models and such non-linear analysis methods as the correlation integral approach, multi-fractal analysis, average mutual information, surrogate data, false nearest neighbours algorithms, the Lyapunov's exponents and Kolmogorov entropy approach, spectral methods and nonlinear prediction (predicted trajectories, neural network etc) algorithms [1]. We present new approach to modelling a chaotic dynamics of atomic and molecular systems in a uniform magnetic and crossed magnetic and AC electric fields. It includes the combined finite-difference solution of the Schrödinger equation, optimized operator perturbation theory, the model potential method for atomic systems in a field [2].

As application we present the results of studying regular and chaotic dynamics of the GeO molecule in an electromagnetic (linear polarization) filed of the intensity of 25 GW cm^2. We list the results of computing the correlation dimension D (2.73), embedding dimension, Kaplan-York dimension (2.51), the Lyapunov's exponents (the first two exponents are positive, +, +), Kolmogorov entropy etc for the polarization polarization time series. The same data are computed for hydrogen and alkali atoms in a uniform magnetic and crossed magnetic and AC electric fields.

Further we present the results of the complete numerical investigation of a chaos generation in the low- and high-attractor time dynamics of the semiconductor GaAs/GaAlAs laser system with delayed feedback (the governing parameter: feedback strength or current injection). It has been numerically shown that firstly arising periodic states of the system transform into individual chaotic states and then global chaotic attractor with a chaos generation scenario through period-doubling bifurcation, which is significantly modified. We present firstly computed original data on the Lyapunov's exponents (+, +), correlation (chaos – 2.2; hyperchaos – 7.4), embedding (correspondingly 4 and 8), Kaplan-York (correspondingly 1.8 and 7.1) dimensions, the Kolmogorov entropy (0.15-0.71). Besides, It has been presented new model of forecasting the low-attractor time dynamics for the first time.

We present the results of the complete numerical investigation of a chaos generation in the low- and high-attractor time dynamics of the erbium one-ring fibre laser (EDFL, 20.9mV strength, λ= 1550.190nm) with the control parameters: the modulation frequency *f* and dc bias voltage of the electro-optical modulator. It has been numerically shown that there are realized the one-period (*f* = 75MHz, V = 10V and *f* = 60MHz, V = 4V), two-period (*f* = 68 MHz, V = 10V or *f* = 60MHz, V = 6V) and chaotic (*f* = 64MHz, V = 10 V and *f*=60MHz, V=10V) dynamical regimes in dependence upon the *f, V* values. The Lyapunov's exponents (+, +), correlation, embedding, Kaplan-York dimensions, the Kolmogorov entropy have been computed. It has been numerically shown that a chaos in the EDFL is generated via intermittency by increasing the DC bias voltage and period-doubling bifurcation by reducing the frequency modulation computers.

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Vortex necklace beams: Self-focusing and guiding properties in SBN crystal

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Particular interest in singular dark beams (optical vortices (OVs), one-dimensional dark beams and ring dark waves (RDWs)) is motivated by their ability to propagate as dark spatial solitons or dark solitary waves and to induce gradient optical waveguides in bulk self-defocusing nonlinear medium (NLM) [1-3]. Necessary (but not sufficient) condition for this is to propagate them in a NLM of negative nonlinearity, in which the dark beam diffraction is compensated for by the medium's nonlinearity. In contrast, the positive (e.g. Kerr or photorefractive) nonlinearity leads to accelerated dark beam broadening and energy density redistribution on the host background beam. As a result, controllable initiation of self-focusing of the bright structures on the host background can be expected [4-7].

In this work we show experimentally that the presence and the evolution of singular necklace beams (with 5 or 10 peaks) and quasi two-dimensional dark beam nested on a bright background beam noticeably perturb the host background. In a photorefractive nonlinear medium (crystal SBN) these perturbations can initiate self-focusing of the background which will lead to induction of bulk waveguides in the SBN crystal. Further we investigated experimentally the time stability and the photosensitivity of these optically-induced waveguides to a probe beam from a Ti:Sapphire laser and the quality of the guided beams. In view of the ordering of the waveguides along a ring and on their number, the best matching probe beam was found to be a single or a twofold-charged optical vortex beam. As expected, the results indicate that parallel all-optical guiding of optical signals at wavelengths, for which the NLM is not photosensitive, appear feasible.

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Transport of extended and localized waves in linear and nonlinear one-dimensional N-mer lattices

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We use the discrete nonlinear Schroedinger equation (DNLS) to investigate the conditions for tuning the transmission resonances in one-dimensional systems with correlated disorder [1]. More specifically, we study the random symmetric N-mer case, in both, linear and non-linear regimes. When the tunability conditions are met, we study numerically the propagation of extended and localized waves for four different kinds of N-mer [2]; The random trimer [3], tetramer, pentamer and hexamer cases. We found that the effective width of the resonances when the tuning condition is met is larger for the pentamer than for the well-case case of the symmetric random trimmer.

For the propagation of extended waves, we found exponential decay in the transmission of plane waves for samples with size no longer that 200 sites, while for longer chains we found a power-law decrease.

For delta-like initial condition we examined the propagation of the light by studying the exponent of the mean square displacement at long propagation times. For the four different kinds of N-mer examined, we found in the linear case, a diffusion exponent larger than the conventional super diffusive exponent 3/2. In the nonlinear regime we did not observe any change on the diffusion exponent for long time evolution.

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Ultrafast dynamics and imaging of laser-generated nano-acoustic waves in metal/substrate layered systems

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The generation and characterization of very-high frequency nano-acoustic waves in metal/substrate layered systems has been a subject of primary interest in the field of ultrafast laser-matter interaction [1-3]. After ultrafast laser excitation very-high frequency nano-acoustic waves are generated that propagate at all directions outward the interaction region. Various laser-based optical experimental techniques have been implemented for the study the dynamics [2] and for spatio-temporal imaging [3] of said waves. We have used 6ns and 35fs laser pulses to generate nano-acoustic waves of few MHz up to sub-THz frequencies in metal/insulator and metal/semiconductor layered systems. We have employed a variety of experimental laser-based techniques and have developed appropriate theoretical simulation models to study and understand the spatio-temporal dynamics and physical mechanisms following ultrafast laser excitation. More specifically, we have used 6ns laser pulses to excite surface nano-acoustic waves in metallic thin film/glass substrate layered systems [4-5]. We have employed an experimental dynamic imaging interferometry technique combined with a numerical model based on finite element analysis to study the generation and propagation of these waves. The experimental technique provided excellent spatial resolution of ~1nm vertical to the film's surface and direct whole-field imaging with nanosecond temporal resolution. The developed three dimensional finite element model simulated the laser matter interaction in the thermoelastic, melting, and ablation regimes. This approach provided unique insight in the spatio-temporal dynamics and thermo-mechanical characteristics of the generated waves. Furthermore, we have used 35fs laser pulses to excite metal thin-film transducers deposited on Si (100) monocrystal thick substrates [6]. We have used a degenerate femtosecond pump-probe transient reflectivity technique to detect giant nano-mechanical strains transferred in Si substrates, manifested experimentally as strong Brillouin oscillations. The experimental findings are supported by a theoretical thermo-mechanical approach based on a revised two-temperature model and elasticity theory.

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Photoemission electron microscopy as a tool for the investigation of advanced optical nanoantenna dynamics

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Plasmonic nanoantennas are a subject of great interest in nanooptics due to their applicability for directional emission, sensing, or enhancement of nonlinear interaction. We present here an advanced antenna concept. The plasmonic resonance of a gold disc can be regarded as a standing wave interference of in- and outward propagating Hankel plasmon solutions [1]. The reflection of the outward propagating plasmon mode at the circumference of the disc is the important parameter. This quantity can be influenced by surrounding the disc with a Bragg mirror structure for Hankel plasmons, enhancing the modal reflection and hence the resonance strength of the antenna [2]. Moreover, if the period of the grating rings is chosen as $p = 2\pi/k_{spp}$, the structure also provides phase matching from incident plane wave radiation to Hankel plasmons. This makes the enhancement mechanism twofold, leading to a nanoantenna with higher Q factor and tailored angular behavior.

To investigate this concept, we first performed full-wave FDTD simulations which promise an approximate sevenfold enhancement of the electric field strength. We then designed the optimal structure based on our simulation data and fabricated it by milling it into a thick gold layer using a focused ion beam. The resulting sample was placed in a photoelectron emission microscope (PEEM) [3]. As illumination we used a 30 fs ultrashort Ti:Sa laser system at 800 nm wavelength under 4° incidence. The high photon

density on the sample during the pulse is able to trigger the photoelectric effect in a 3-photon process.

The photoelectron emission microscope provides detailed information about the plasmonic excitation of the structure with high spatial and temporal resolution, without the need for any interacting probe as in near-field microscopy. We observe a strong dipolar resonance in the middle of the advanced antenna. Outside the structure, outward propagating Hankel plasmons are excited. To understand the fringe period and contrast decay, we developed a pulsed Hankel plasmon interference model. A detailed analysis needs to take into account the pulse lengths of the plasmon and driving laser pulse as well as their group velocities. The developed model is shown to be in excellent agreement with our measurements. The spatio-temporal extent of the pulse is found to be the main factor that influences the fringe visibility instead of the plasmon damping, which is orders of magnitudes weaker. This enables to take temporal snapshots of the optical process using PEEM.

In conclusion, we have demonstrated that photoelectron emission microcopy is able to provide detailed insight into the physics of optical nanoantennas. Spatio-temporal information is available with very high resolution without the need for any disturbing interacting probe. The resulting electron emission images directly relate to the optical properties of the nanoantenna. We demonstrated the dipole mode operation of a gold disc-ring antenna and the enhancement of the corresponding resonance. The observed excitation of Hankel-type plasmon solutions was shown to be in excellent agreement with our spatio-temporal model of the PEEM yield. This technology promises to become one of the experimentally most informative techniques to investigate nanooptical structures with advanced optical functionalities.

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Generation of terahertz radiation in quantum-dot based ultrafast photoconductive antennae.

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Photoconductive antennae (PCAs) were the first successful technique for coherent THz signal generation and detection [1]. Since that initial demonstration there is still a great deal of research dedicated to the design of THz antennas in almost every aspect of the device.

Semiconductor quantum dots (QDs) were introduced by Ekimov et.al. [2] about the same time ago and since then have found themselves involved in many applications such as diode lasers, amplifiers, saturable absorbers[3] and photovoltaic devices [4]. All these applications take advantage of QD's high thermal and optoelectronic efficiency and short charge carrier lifetime, which are necessary for effective photoconductive THz emitters.
Here we present a QD-based THz PCAs capable of being pumped at very high optical intensities of higher than 1 W optical mean power, i.e. about 50 times higher than the conventional PCAs that are commercially available at present.

Apart from high thermal tolerance, defect-free GaAs crystal layers in an InAs:GaAs QD structure allows high carrier mobilities and ultrashort photocarrier lifetimes simultaneously, thus combining advantages and lacking disadvantages of GaAs and low-temperature grown (LT) GaAs, that are the most popular PCA materials so far. By changing QD size, QD composition, density of dots and number of QD layers, the optoelectronic properties of the overall structure, can be set over a reasonable range – compact semiconductor pump lasers that operate at wavelengths in the region of 1-1.3 μm can be used.

Antennae electrodes are lithographically printed over a semiconductor InAs:GaAs QD substrate. The substrate includes layers of implanted InAs:GaAs QDs. The QD antenna is optically pumped using a femtosecond Ti:Sapphire laser (M Squared Lasers model Sprite-XT, pulse duration 120 fs at 80 MHz repetition rate) focussed onto the photogap of the antenna achieving a spot diameter of approximately 30 μm.

Our antennae samples show no saturation in THz generation for all pump powers up to 1.2 W. Generated THz power is superlinearly proportional to laser pump power. Generated spectrum spans from 150 GHz up to 1.2 THz. Taking into account the efficient operation in both pulsed and CW regimes and the ability to use compact semiconductor lasers as pump sources for such antennae, we aim these sources for all kinds of biomedical applications, from evaluation and diagnostics to, possibly, treatment.

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Impact of Seidel aberrations in high harmonic generation: Theoretical and experimental results

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We present a theoretical study of the effects produced by lens aberrations when ultrashort light pulses are focused to produce High Harmonic Generation (HHG). We analyze the effects of spherical aberration, coma, astigmatism, andfield curvature in the focusing of ultrashort light pulses for Gaussian illumination. Predominates aberration in the focusing lens is determined experimentally. We also present the effects on the spatial profile of the HHG.

The effects produced in the spatiotemporal profile of ultrashort light pulses have been studied in several works [1]. But they have not studied the effects of lens aberrations produced in HHG. This work is the first to formally study these effects.

The electric field distribution of an ultrashort pulse in the focal plane of a lens is determined by the following diffraction integral

$$U(x_2, y_2, z, \bar{u}; \Delta\omega) \propto \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} U_0(x_1, y_1, \bar{u})\, P(x_1, y_1)\, A(\Delta\omega)\, e^{-i\Theta(x_1, y_1; \eta)}\, e^{i\phi(x_1, y_1)} \times e^{\frac{ik_a}{2z}\left[(x_2 - x_1)^2 + (y_2 - y_1)^2\right]}\, dx_1\, dy_1$$

Spatiotemporal profile is obtained by numerically solving equation 1. To determine the spatial distribution of the HHG, another theoretical analysis is realized considering the distribution of electrical field in the focal plane.

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Ultrafast dynamics of a cyanine dye near liquid-liquid interface

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We have explored ultrafast dynamics of a near infra-red (NIR) cyanine dye, IR775 dissolved in dimethyl sulfoxide (DMSO) solvent that is interfaced with neat diethyl-ether using degenerate pump-probe technique [1] at 800 nm. Our time resolution is 30 fs. This study provides insight into the penetration dynamics of the neat-solvent diethyl ether into the DMSO dye solution. The dynamical process occurring near the interface towards the bulk solution was examined. The dye is soluble in both the solvents but is intentionally dissolved in DMSO only which is the lower layer and the upper layer is the neat diethyl-ether solvent. The dye dissolved in the DMSO layer was shown to penetrate through the interface and the process continued until the system reached an equilibrium condition. The transient absorption signal decreases on moving the position of the pump-probe experiments from the bulk dye solution in DMSO towards the interface with neat-diethyl ether. We used a multi-exponential decay function for fitting our experimental results. We have found that the dynamical time constant mainly depends on the excitation position of the pump-probe experiments with respect to the interface of the dye solution with neat diethyl-ether layer. We deduced four time constants from these fittings and assigned them as: coherent artifact (τ_1), vibrational cooling time (τ_2), intermediate state time [2] (τ_3) and ground state recovery time (τ_4). Coherent artifact is the coherent interaction of identical pump and probe pulses in the sample, which corresponds to the instrument response function. The vibrational cooling time is the heat dissipation of excited dye molecules to the surrounding solvent molecules. The intermediate state time is the growth and survival time of the intermediate state of the dye molecule in the solvent which is characterized in our case by the growth in the time-resolved trace after vibrational cooling and followed by ground state recovery time. The ground state recovery time is the ground state population recovery of the dye molecules after the pump has depopulated the ground state of the IR775 dye. The vibrational cooling time, τ_2 increases and τ_3 decreases as we move from bulk to near the interface (Z = 0) up to Z= - 0.2 mm indicating that system gets more heterogeneous near the interface. We noticed the most drastic changes in decay constants closest to the interface at Z < -0.2 mm (more towards interface) where the intermediate state is not formed and this we attribute to the maximum penetration of diethyl ether into the DMSO layer resulting in spatial heterogeneity [3]. As the penetration of diethyl ether decreases from near the interface to the DMSO dye solution, the viscosity of the medium also gradually increases. The viscosity of DMSO (2.14 cp at 20°C) is ~9 times higher than the viscosity of diethyl ether (0.2448 cp at 20°C). With two such solvents with high viscosity difference that are separated by an interface, we show that solvent penetration dynamics affects the viscosity of solution at different positions.

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Ultrafast processes for H_2ATPP-LuDTPA and its complexes with transient metals

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Porphyrins are substances with a key role in a number of biological processes and technological applications [1,2], in particular in catalysis [3], therefore they are in spotlight of various research efforts. The photophysical study of porphyrins is important both for practice and for fundamental science because of porphyrins are the fine model substances due to the stability of the porphyrin complexes with most metals in periodic table, characteristic electronic spectra in visible region, and dependence of luminescent properties on the nature of metal [4]. A detailed understanding of relaxation processes in excited porphyrins plays the key role in clarifying the character of photophysical processes and literate application of the prominent porphyrin properties.

In this work photophysics of ethanol solutions of the Cu^{2+}, Ni^{2+}, Zn^{2+} and H^+ complexes of novel stable tetraphenylporphyrin modified by strong chelating agent aminopolycarboxic acid with lutetium ion (Lu^{3+}) [5] were studied by femtosecond pump-probe spectroscopy (Ti:Sapphire laser, 100 fs, 400 nm).

$$\Delta A(\lambda, t) = A_1(\lambda)e^{-\frac{t}{\tau_1}} + A_2(\lambda)e^{-\frac{t}{\tau_2}} + A_3(\lambda)e^{-\frac{t}{\tau_3}} + A_4(\lambda)e^{-\frac{t}{\tau_4}} \qquad (1)$$

For all complexes multiexponential kinetics of transient absorption decay was observed. The kinetics is connected with sequential population and decay of (π,π*)-, (π,d)- and (d-d*)-type excited states. Global fit of an array of kinetic curves (formula 1) together with known literature data allows one to determine the nature, characteristic lifetimes and spectral properties of the excited states of studied complexes.

Table 1. Spectral properties and lifetimes of excited states of studied complexes in ethanol

Complex	λ_{max} (A_1), nm	λ_{max} (A_3), nm	λ_{max} (A_4), nm	τ_1, ps	τ_2, ps	τ_3, ps	τ_4, ps
H_2ATPP-DTPA	460	440	440	0.4	7	210	3100
ZnATPP-LuDTPA	460	460	460	1.6	-	150	1800

NiATPP-LuDTPA	460	430	425	0.6	6	90	320
CuATPP-LuDTPA	460	455	430	1.1	-	53	100

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Time behavior of NO absorption in gas mixtures excited by pulsed electric discharge

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Nitric oxide molecules were excited in gas mixtures NO:He=1:5, NO:Ar=1:5 and NO:N_2=1:10 by pulsed e-beam sustained electric discharge (EBSD) with pulse duration of ~100 μs. To study vibrational excitation of NO molecules in the ground electronic state, as a probe we applied a cw CO laser operating on more than 200 spectral lines. We chose several CO laser lines which coincided with ro-vibrational transitions of NO molecule within detuning frequency range <0.1 cm^{-1}.

At initial gas temperature of T=293 K for all the gas mixtures an absorption for the lowest NO transition $\Pi_{1/2}$ 2-1 R(8.5) appeared almost immediately with the start of the EBSD (t=0). We observed well-defined maximum of absorption at t=100 μs for NO transition $\Pi_{1/2}$ 2-1 R(8.5) with time duration of ~180 μs (FWHM) and then slowly falling tail up to 3 ms. The maximum absorption coefficient for NO transition $\Pi_{1/2}$ 2-1 R(8.5) was 5 times higher for nitrogen-reach gas mixture at specific input energy of Q_{in}=250 J/(l*atm) than for argon-reach mixture at Q_{in}=50 J/(l*atm). NO absorption for gas mixtures NO:N_2=1:10 and for higher vibrational transitions of NO from 3-2 to 13-12 band peaked almost

simultaneously at t=160-200 μs. After this moment NO absorption for these transitions decreased slowly for a few milliseconds.

A numerical model of vibrational kinetics in an ensemble of NO molecules and buffer gases was developed by comparing the experimental and calculated data on absorption dynamics of vibrationally excited NO molecules. The theoretical model includes a self-consistent numerical solution of equations of vibrational kinetics in mixtures of NO:He, NO:Ar and NO:N_2 and Boltzmann equation for the distribution function of electron energy of pulsed EBSD. In our calculations, we used data [1] on rate constants of VV exchange between N_2 molecules. To calculate the rate constants of VV exchange between NO molecules in processes: $NO(u) + NO(v) \rightarrow NO(u+1) + NO(v-1)$, we used an analytical expression that included the role of long-range dipole-dipole interaction between NO molecules. The structure of this expression is similar to that proposed in [2] for the calculation of the rate constants of VV exchange between diatomic molecules with the dominance of long-range part of the interaction potential. Processes of VV' exchange between NO and N_2 molecules are also poorly understood. In the first stage, the VV' exchange rate constants between NO and N_2 molecules were described by an analytical formula that was previously used to calculate the rate constants in the case of VV' exchange between N_2 and CO molecules. Data on the rate constants for the VT relaxation of NO were taken from paper [2, 3]. The calculated temporal behavior of the absorption coefficients on NO transitions is in good agreement with the measured absorption.

Another time behavior was observed when probing the NO absorption in mixtures NO:Ar=1:6 and NO:N_2=1:10 cooled down to T=122±2 K. Dynamics of absorption slowed down with decreasing of gas temperature. Absorption for NO transition $\Pi_{1/2}$ 2-1 R(8.5) and higher transitions was observed for about 3 s at the level 0.1 of maximum. This fact suggests that under these conditions the mixture accumulates a sufficiently large amount of vibrational energy and the energy relaxes very slowly to heat due to VV' exchange between N_2 and NO molecules and VT-relaxation of the NO molecules.

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Photoacoustic frequency and spectroscopy technique for evaluation opto-thermal properties of macromolecular nanostructures

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The knowledge of energy transport mechanisms across macromolecular nanostructures is of great importance both from fundamental and applied points of view because these materials are promising in the field of nanowire materials in nano-optics and nanoelectronics. Theoretical investigations, which have recently done for macromolecular nanostructures, indicate different absorption properties as well as heat transport mechanisms for infra-red and visible incident beams. In order to enable experimental proving of theoretical models, we have suggested modification of optical pump part in classical photoacoustic frequency techniques and calculated matched electronic part. We have presented the technique for measurement optical coefficient of absorption and thermal diffusivity of macromolecular nanostructures at large range of infra-red and visible wavelength of pump beams.

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Dipol-dipol energy transfer in CdSe/ZnS quantum dot – Eosin molecule system doped into the polymer matrix

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We aimed to investigate not only the quantum dots fluorescence direct quenching by eosin molecules and the corresponding dipole-dipole energy transfer, which has been studied in several papers before, but quenching rate constants estimation and quantum dots fluorescence quenching mechanism obtaining on dye molecules photo-excitation.

The absorption spectra were studied by Shimadzu UV-2600 spectrophotometer; fluorescence spectra and fluorescence kinetics were studied by means of the spectrofluorimeter Fluorolog-3 (Horiba). Fluorescence intensity correlation functions were measured by means of Photocor-Complex equipment. These functions allowed us to estimate the quantum dots sizes and their distributions.

We studied spectral-kinetic properties of eosin molecules and quantum dots after laser excitation on the wavelength of 405 nm. We noticed quantum dots fluorescence intensity decrease on 520 nm and eosin fluorescence intensity increase on 560 nm [1]. With these data use we estimated Stern-Volmer constant [2] which appeared to be 38 ns^{-1} and the same order as the diffusive constant in liquid solution [3]. We also estimate the transfer constants, quantum yields and fluorescence rate constants for eosin and quantum dots. It was shown that rate constants had the same order as ones in liquid solutions.

It was interesting to notice that the quenching constants had different values when estimated by means fluorescence kinetics and quantum yield investigation. It was assumed that quantum dots may be aggregated in polymer which results in the fluorescence lifetime and quenching probability difference. Our assumption has been proved by the sample imaging by means of scanning confocal microscope Centaur. It was shown that quantum dots were non-homogeneously distributed in the polymer matrix and formed fluorescent clusters with 1 – 4 nm size.

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Rb-based stabilized laser at 1560 nm

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We have developed a compact fiber-connectorized rubidium-based laser system for CO_2 monitoring at 1572 nm [1]. The beam of a fiber-pigtailed DFB laser emitting at 1560 nm is frequency doubled to reach the region of 780 nm and is frequency-locked to a rubidium saturated absorption transition [2]. An optical frequency comb generator is used to fill the gap of 12 nm between the CO_2 line and the laser at 1560nm; it is realized by modulating part of the DFB laser light with a waveguide electro-optical modulator enclosed in a Fabry-Pérot cavity.

This system has a stability, in terms of the overlapped Allan deviation, of 10^{-10} between 1 s and 10 second integration time. The present work is devoted to a detailed study of the phenomena causing the difference between the measured stability and the S/N limit. The

studies are conducted by analyzing each block of the device, starting with the control loop of the DFB laser at 1560 nm.

In the optical part of the DFB laser stabilization loop, we demonstrate the existence of two etalon-like cavities. The associated optical interferences lead to frequency instabilities, of the DFB laser frequency, in the order of $2\text{-}6\cdot10^{-11}$ for averaging times between 5 and 60 seconds. We will also report on our spectroscopic studies to evaluate the accuracy and systematic frequency shifts due to, for instance, the Doppler-broadened component of the signal. Depending on the selected sub-Doppler transition, these shifts may be at the 10^{-9} level or higher and must therefore be well characterized in order to guarantee the overall system level specifications.

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Surface enhanced Raman spectroscopy of thiacyanine dye J-aggregates on single silver nanoaggregates

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Dye-coated colloidal metal nanoparticles (NPs) exhibit interesting optical properties originating from the interaction between metal core and dye shell. Depending on the interaction mechanism between the two, optical properties of dyes or NPs can be changed separately or jointly within the dye-NP assembly [1]. Many of the recent studies are focused on dyes which are able to self-assemble in highly oriented structures called J-aggregates on the surface of metallic NPs [2,3]. Owing to the variety of mechanisms by which dyes and their J-aggregates can interact with metallic NPs, dye-NP assemblies can lead to applications ranging from nanoscale sensing [4] to advanced composite materials for novel active and nonlinear optical devices [5].

Here we study the influence of TC concentration on its J-aggregation on the surface of AgNPs assemblies using Raman mapping and atomic force microscopy (AFM). Aqueous solutions (colloids) of citrate stabilized AgNPs with an average diameter of ~10 nm are mixed with TC dye solution and then deposited onto freshly cleaved highly oriented pyrolytic graphite and mica surfaces. The spectral signature of citrate ions is identified by (i) the O-H band around 220 cm^{-1}, (ii) the C-H band around 2950 cm^{-1} and (iii)

pronounced blinking in the 1000-1800 cm^{-1} range. In contrast, dye molecules adsorbed on nanoparticles are recognized by several stable Raman bands between 200 and 1600 cm^{-1}. In situ AFM measurements show that SERS 'hot spots' are formed either on large single nanoparticles (diameter > 100 nm) or within assemblies of small nanoparticles (with diameters in the 10 - 50 nm range). However, only the latter are found to yield a citrate or TC dye SERS signal. We find that the TC dye adsorbed on the surface of AgNP nanoassemblies always forms J-aggregates when the dye concentration in the TC-AgNP solution is varied between 0.5μM and 17μM. Even though, a clear SERS spectra of dye J-aggregates can be acquired for high dye concentration (17μM) the citrate ions always exist on the AgNP surface and so does their SERS signature in form of O-H (220 cm-1) and C-H (2960 cm-1) bands. Assemblies with low TC concentration (0.5μM) do not have a clear dye SERS spectra, but rather spectra similar to the one of citrate ions meaning that either not all AgNPs are dye coated, or rather that the amount of TC molecules adsorbed on the surface of the nanoparticle is small and hence not detectable.

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Measurements of Rb hyperfine splitting with a femtosecond optical frequency comb

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The femtosecond laser frequency comb spectrum is composed of many thousands equidistantly spaced modes [1]. One could simply imagine it as a ruler consisting of narrow modes at known optical frequencies. It has provided us with optical clocks which use optical frequency standards and a clock operating at a higher frequency is more precise.

The advent of precision femtosecond optical combs brings a new set of tools for precision atomic and molecular spectroscopy. For example, it can be used for precision spectroscopy of electronic transitions [2]. The absolute frequency can be determined by

the knowledge of frequency rate, offset frequency and a beat note frequency. Additionally, the frequency combs cover a broad spectral interval allowing spectroscopy of different atomic or molecular systems to be done using the same laser system.

We use Erbium-fiber-based optical frequency comb synthesizer that covers a broad optical spectrum 530...1000 nm emitting 150 fs pulses with 250 MHz repetition frequency. The broad emission spectrum of the frequency comb laser makes it a robust tool Together with a 780 nm ECFL diode laser and a Rb vapor saturation setup we are attempting to measure the hyperfine splitting of Rb atoms. GNNS receiver and the signal from satellites is used for long term stabilization of the oscillator in the Rb standard necessary for the frequency comb. This takers approximately 10000-100000 s to assure a long term stability. We continue to gather data and keep monitoring the operation of both the Rb standard and the GNSS.

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Laser-induced features at Titanium implant surface in vacuum ambience

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Nowadays, titanium and its alloys have numerous applications, e.g., in industrial processes, aerospace engineering and bio-medicine. Due to its good mechanical and chemical characteristics, including corrosion resistivity, relatively low density, as well as biocompatibility, of special importance is the use of titanium as implant material [1]. For bio-applications of titanium, optimal surface topography is of prime importance. In spite of that, laser generated modifications of Ti-surface in a controlled atmosphere have been only sporadically studied [2], while data regarding modifications induced under reduced air pressure are lacking.

The present work studies the interaction of TEA CO_2 laser with Ti target, under reduced air pressure of 0.1 mbar. The influence of the laser irradiances (ranging from 40-70 $MWcm^{-2}$), and the number of applied laser pulses (10, 50, 100, 200, 500 and 1000) on surface morphology and plasma parameters of titanium have been investigated.
In summary, the observed phenomena leading to surface modifications may be described as follows: (i) Creation of craters with conically cross-section and maximal depth of ~ 4 μm (after 10 pulses) up to ~ 20 μm (after 1000 pulses); (ii) Resolidification of droplets in

the periphery region (hydrodynamic effects); (iii) Creation of plasma in front of the target.

In order to correlate the plasma parameters with the surface modification time-integrated space-resolved laser induced plasma spectroscopy (TISR-LIPS) [3] has also been performed. Spectral lines of Ti I and Ti II were used for plasma diagnostics. The presence of plasma strongly affects the ablation process and plays a key role for surface modification of the irradiated Ti target.

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Spectroscopy of lanthanides atoms: Relativistic theory of autoionization resonances in spectra of some atoms

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The paper is devoted to application of the a relativistic many-body perturbation theory [1] with Dirac-Kohn-Sham (DKS) zeroth approximation combined with the generalized energy approach to studying the autoionization resonances spectra for heavy atoms, in particular, spectra of lanthanides (Eu, Yb) atoms, and search of the unusual futures in behaviour of the autoionization resonances in sufficiently weak dc electric field that can be detected by a laser spectroscopy methods. The wave function zeroth basis is found from the Dirac equation with a potential, which includes ab initio (the optimized DKS potential, the electric potential of a nucleus). The correlation corrections of the PT high orders are taken into account within the Green functions method (with using the Feynman diagram's technique). All correlation corrections of the second order and dominated classes of the higher orders diagrams (electrons screening, particle-hole interaction, mass operator iterations) are taken into account. As example, in table 1 we list the experimental (compilation) and theoretical data for energies (accounted from the ground state: $4f^{14}6s^2\ ^1S_0$) of some YbI singly excited states: MCHF-BP – data, obtained on the basis of multiconfiguration Hartree-Fock (MCHF) method within the framework of Breit-Pauli (BP) relativistic corrections developed by Fischer (A, B+D, D different sets of configurations considered in MCHF-BP calculation]); HFR – data, , obtained on the basis of Cowan's relativistic Hartree-Fock method; WC- data of analysis by Wyart-Camus; EA-MMBPT - data by Ivanov et al obtained on the basis of the model many-body perturbation theory and energy approach (EA-MMBPT) [2,3].

Table 1. Energies E (cm^{-1}) of the YbI singly excited states.

Config.	J	MCHF+ BP(A)	MCHF+ BP(C)	MCHF+ BP(BD)	HFR	EA-MMBPT	WC	This work	[2]
$6s_{1/2}^{2}$ *	0	0	0	0	0	0	0	0	0
$6s_{1/2}6p_{1/2}$	0	18087	17262	18730	17320	17400	17312	17310	17288
$6s_{1/2}6p_{1/2}$	1	18174	17568	18813	17954	18100	17962	18008	17992
$6s_{1/2}6p_{3/2}$	1	24614	26667	25257	25069	25500	25075	25094	25068
$6s_{1/2}6p_{3/2}$	2	18357	18249	18999	19710	19800	19716	19715	19710
$6s_{1/2}5d_{3/2}$	1	24094	28871	23740	24489	23900	24489	24410	24489
$6s_{1/2}5d_{3/2}$	2	24505	28973	24172	24484	24600	24751	24824	24752
$6s_{1/2}5d_{5/2}$	2	26984	29633	26841	27677	26100	27654	26970	27678
$6s_{1/2}5d_{5/2}$	3	25860	29374	25500	25271	24900	25270	25098	25271

Note: * [2] E=-148710cm^{-1}; $E1$=-148700cm^{-1}; $E2$=-148695cm^{-1};

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The interaction between variously shaped TiO_2 nanoparticles with UV laser determines the quality of the mass spectra of carbohydrates

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The important factor that determines the process of the laser-induced desorption and ionization of molecules for the mass spectrometric analysis is the interaction between the laser light and the substrate. It is of importance that substrate efficiently absorbs laser energy, which will be further rapidly transferred to the analyte. The overall goal in this process is to obtain good quality mass spectrum with low degree of fragmentation. Whereas the application of organic matrices instead of substrates results in the numerous undesired polymerization reactions, which complicate the spectra, and in some cases, even prevent the detection of the ions of interests, nanoparticles as substrates are convenient due to a lower number of background signals and low onset of fragmentation reactions in the gas phase.

Titanium dioxide (TiO_2) is semiconductor-based and widely used substrate for laser desorption and ionization ((SA)LDI), and when it is in the excited state it transfers an electron or energy into the ground state molecule. This process is called sensitized photoreaction [1]. The desorption/ionization processes on TiO_2 nanoparticles are related to the physical properties of the substrate such as ability to absorb and dissipate energy

from the irradiating laser light source [2]. TiO_2 has a large band gap (bulk anatase: 3.2 eV), and can therefore be used as a SALDI matrix with the N_2 laser (337 nm) [3].

The aim of our study is to investigate the influence, which the interaction of the UV laser with TiO_2 nanoparticles of various shapes and size has on the quality of the mass spectra of carbohydrates: D-(+)-glucose, D-(+)-maltose, raffinose, arabinose, β-ciclodextrine, substances which are otherwise difficult for mass spectrometric analysis. For this purpose, we used small, nearly spherically shaped colloidal TiO_2 nanoparticles (average diameter ~ 5 nm), prolate nanospheroids (length: 40–50 nm, the lateral dimension: 14–16 nm) and nanotubes (length: 100-150 nm, average diameter 11 nm). For comparison, the spectra are acquired also with traditionally used organic matrices.

The spectra of carbohydrates with organic matrices are overloaded with matrix signals, in which case the signals arising from the analyte of interest are suppressed, or it is possible to detect only adducts with matrix. Laser-induced ionization on nanostructures offers alternative ionization pathways through the formation of Na^+ and K^+ adducts with appreciable yield [4].

TiO_2 nanotubes showed extraordinary properties for detection of carbohydrates. Arabinose was detectable only with TiO_2, and D-(+)-glucose and D-(+)-maltose were detected in negative ion mode, which was not the case with other organic matrices and substrates. Not only the highest intensities of mass peaks but also the smallest coefficient of variation was achieved with TiO_2 nanotubes. Taken toghether, TiO_2 nanotubes, due to their size and the shape, have the most suitable physical properties for the substrate in the SALDI technique.

The laser intensity was kept as low as possible in order to prevent fragmentaion. Higher laser intensity is required for the process of desorption/ionization when TiO_2 NPs are used (2400 i.u.), but for TiO_2 PNSs and TiO_2 nanotubes were lower and nearly the same 1950 and 2000 i.u., respectively.

In conclusion, larger, tube-shaped TiO_2 substrates more efficiently absorb the laser energy and transfer it to the carbohydrates, enabling their desorption/ionization and preventing their fragmentation.

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Photothermal response of a double-layered semi-transparent sample

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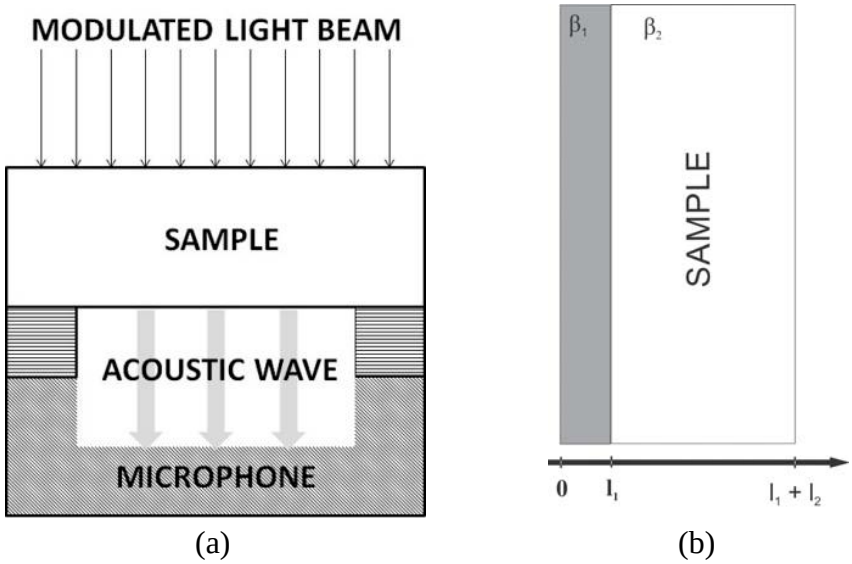
In this work, a double-layered sample is considered. One layer of the sample is assumed to have high optical absorption coefficient ($\beta_1>>1$, surface absorber) while the other layer's optical absorption coefficient, β_2 is low, which is a common situation in transmission photothermal experiments with optically transparent samples [1-5] (Figure 1). The expressions are derived for surface temperature variations due to the absorption of excitation EM radiation and its conversion into heat within the sample. The study focused on two experimental cases: In the first, the surface absorber is considered to be exposed to the excitation EM beam, while in the second, the other layer is the one to be exposed. The differences in amplitude and phase characteristics, predicted by theory in these two cases, are discussed.



(a) (b)

Figure 1. a) Transmission experimental configuration, b) Two-layered sample.

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The influence of multiple optical reflections on the photoacoustic frequency response

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The influence of multiple optical reflexions (Fig.1) on the photoacoustic (PA) response has scarcely been considered throughout the literature, except for a few works [1,2]. Recent experimental results, obtained on very thin films [3,4], show the disagreement with theoretical predictions of amplitude and phase characteristics of the PA response and require more detailed consideration of the influence of multiple optical reflections.
In this work, a model of optically generated heat sources in the sample with low optical absorption coefficient is derived. Multiple reflexions are considered at both surfaces of the sample exposed to the intensity-modulated laser beam. The impacts of the reflexion coefficient, the absorption coefficient and the thickness of the sample on the amplitude and phase characteristics of the photoacoustic response are discussed.

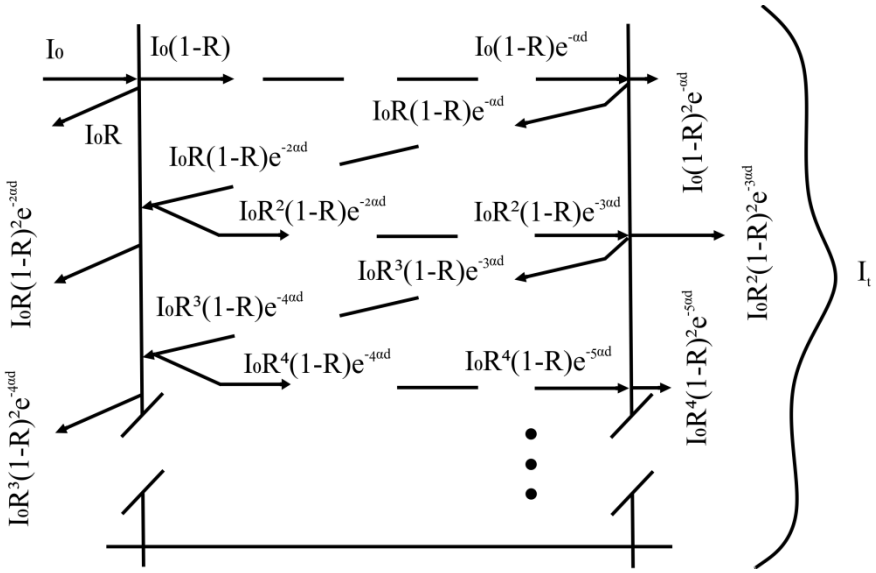

Fig.1. Illustration of multiple optical reflections effect.

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Characterisation of High Contrast Gratings (HCGs) by means of micro-reflectance spectroscopy

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The development of surface-normal emitting photonic semiconductor devices like VCSELs (Vertical Cavity Surface Emitting Lasers) requires very high reflectivity mirrors. Due to the sophisticated heat management in the case of the DBRs (Distributed Bragg Reflectors), the research aimed at a new solutions were desirable [1]. That was the reason why high refractive index contrast gratings have drawn great attention for several years.

HCG is one-layer photonic structure composed of periodically repeated stripes made of high refractive index material and low refractive index material gaps between them. It has to be surrounded by low refractive index media. In spite of the simple construction of this kind of structures, they have extraordinary properties. The gratings are designed to have almost 100% reflectivity for surface-normal incidence with strong polarization discrimination [2-4]. These features with the sub-micron thickness of the HCG made the planar devices very interesting candidates to substitute DBRs in VCSELs. The solution can allow to facilitate significantly heat dissipation from the active region of the devices without loss of high reflectivity.

In this work we report results of examination of HCG by means of optical spectroscopy. For this aim the method of micro-reflectance was applied and specialist measurement system was implemented. We have investigated optical features of HCG, for example polarization dependence of reflectance spectra. The experimental results have been compared with theoretical predictions. The good agreement between them has been observed. So we have received empirical confirmation for extraordinary optical properties of high contrast gratings that is a key issue in case of future applications of the planar devices.

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Reverse analysis of mid-infrared laser beams with large divergences on the basis of goniometric far field measurements

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Physical processes occurring in laser resonators affect the electric field distribution on the laser mirrors and thereby affect the optical beam shape. Therefore, the beam parameters give us valuable information about the state of the active region of the laser. Thus, the knowledge of both the far field and the near one is desired. However, the transformation between field distribution in the near field (on the mirror) and the far field (in the space) is usually performed only in one direction – from the near to the far field – and is based on paraxial approximation [1]. To get the reverse transformation, in this work we present a novel approach to the problem of calculation of the near field from the results of the far-field measurements.

Paraxial approximation was firstly applied to the analysis of gas lasers which have low-divergent beams. Because such an approximation is convenient for analytical calculations, it is also commonly used in description of the beams of the semiconductor lasers which, however, are highly-divergent. So, in the case of semiconductor lasers such an approach is not precise.

In this work we present an exact numerical method for transformation between the near and the far field, back and forth, based on the basic Huygens principle. The reverse transformation – estimation of the field distribution on the laser mirror based on the far field measurements – is made by the least squares method combined with the effective index method.

To illustrate the general method, we present results of the reverse analysis of the beams of mid-infrared quantum cascade lasers based on gallium arsenide and indium phosphide [2]. The far field measurements were made by using a wide-angle goniometric profilometer [3].

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Near-field terahertz spectroscopy of anisotropic dielectric micro-resonators

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Highly-dielectric subwavelength micro-resonators support both electric and magnetic resonance modes at terahertz (THz) frequencies. Arranged in periodic arrays, they offer an advantageous alternative to conventional metal-based metamaterials making them polarization-independent and reducing the intrinsic absorption related to Ohmic losses in metallic meta-atoms [1]. Anisotropic dielectric materials used in periodic structures add a new degree of freedom for engineering the geometrical structure and electromagnetic response of metamaterials. Unlike at optical frequencies, in the THz range, some dielectric materials naturally possess high refractive indices and strong electromagnetic anisotropy. The low-loss TiO_2 can be synthesised in a variety of sizes, degrees of crystallinity and porosity. Poly-crystalline TiO_2 micro-spheres are isotropic, and their first Mie resonance (magnetic dipole) lies in the THz range [2]. On the other hand, mono-crystalline TiO_2 (rutile) exhibit strong anisotropy at THz frequencies with the ordinary and extraordinary values of its dielectric permittivity equal to $\varepsilon_o \approx 85$ and $\varepsilon_e \approx 170$, respectively.

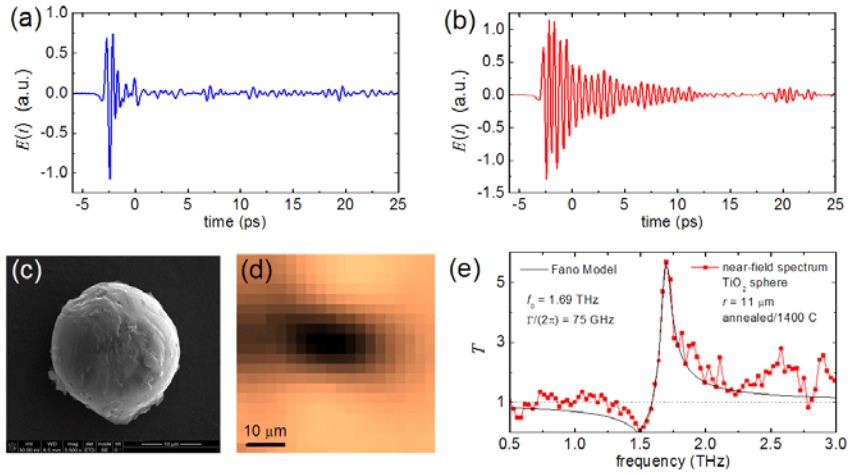

Fig.1. (a) Reference THz pulse waveform, (b) waveform measured at ≈1μm distance from a 22μm TiO2 micro-sphere. (c) Scanning electron micrograph of the sample and (d) a THz image of the first magnetic mode of the sphere. (e) Near-field spectrum of the sphere showing its ordinary magnetic dipole resonance, the experimental data is fitted by a Fano line-shape.

We study individual highly anisotropic mono-crystalline TiO_2 micro-spheres through near-field terahertz time-domain spectroscopy at different orientations of the crystallographic axes with respect to the incident field polarization. We experimentally observe the excitation of their magnetic and electric Mie modes (Fig.1). We discuss the nature of the observed Fano signatures of the resonances in the spectra, and analyse the potential use of mono-crystalline TiO2 micro-resonators for all-dielectric THz metamaterials.

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Time-resolved FT-IR spectroscopy of rare earth ions in fluoride crystals

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Rare earth crystals have extraordinary optical properties. They possess hundreds of well-defined electronic levels (crystal-field levels), whose associated spectroscopic lines span the UV, visible, infrared, and THz bands of the electromagnetic spectrum. Some of the visible and near infrared excited states are so long-lived that colour changes may be observed with the naked eye.

To date, rare earths have been mainly exploited in solid-state lasers and in fiber amplifiers. The erbium-doped fiber amplifier (EDFA) is perhaps one of the best-known examples [1], [2]. Very recently, another exciting potential application has emerged: quantum technologies. It is known that the quantum state of atomic defects such has the NV^- centre in diamond [3], or the phosphorus donor centre in silicon [4], can be manipulated with short laser pulses. The unique spectroscopic properties of rare earth ions might too also be harnessed for solid-state quantum computing. Electrons in these well defined crystal-field levels can be conveniently be addressed with bench-top laser sources. Since many of these excited states are particularly long-lived, there is then sufficient time to perform coherent quantum manipulations of the system.

Advances in Fourier Transform infrared (FT-IR) spectroscopy have now made it possible to study time-resolved dynamics on a broad range of timescales from seconds to nanoseconds. In this talk we will describe in detail a time-resolved FT-IR pump-probe experiment that we have used to characterise the excited state lifetimes of Ho^{+3} ions in a $YLiF_4$ crystal matrix. Using our pump-probe technique, we have characterised the

excited state lifetimes of several spectral features across the visible, near infrared (NIR), and mid infrared (MIR) bands, on timescales ranging from nanoseconds to milliseconds. A number of these long-lived electronic states have the potential to be coherently manipulated using nanosecond laser pulses.

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Ordered InGaN/GaN nanowires as arrays of classical and quantum light sources: growth, characterization and modeling

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With the realization of (In)GaN based blue light emitting diodes (LEDs) in the early 90s, the set of primary color LEDs was completed, revolutionizing the market of solid state lighting [1]. Due to a high lattice mismatch with the underlying substrates, the full exploitation of III-nitride semiconductors is still constrained by their limited crystal quality, when grown as compact (3D) epitaxial layers. In that sense, the strain-free GaN nanowires (1D), characterized with a virtually perfect crystal quality, offer a plenty of possibilities for further technological improvements.

The realization of efficient phosphor-free LEDs with only one family of materials, would lead to further design simplifications and energy savings. Due to their exceptionally high band offsets, the III-nitrides are also convenient for room temperature single photon emission [2], whereas their bandgap tunability (from near UV to near IR) facilitates their employment in fiber- and/or free-space quantum communications. In this work, we address growth, characterization and modeling of InGaN nanodisks, fabricated on pencil-like GaN nanowires (NWs), emphasizing the potential of this particular nanostructure for classical and quantum light generation.

The studied NWs, grown by selective area growth homoepitaxy [3], are: site-, diameter-, height- and shape-controlled and exhibit exceptional crystal quality. They are grown in hexagonal matrices with 280 nm pitch, 180 nm diameter, 600 nm height and with a truncated pyramidal top, consisting of one top *c*- and six side *r*-facets. The InGaN nanodisks are grown with varying thickness (10 - 30 nm) and InGaN compositions (10 – 25%), and capped with a 50 nm thick GaN. The InGaN nanodisk consists of polar (on *c*-facet) and semipolar (on *r*-facets) sections. The two sections are characterized by different: composition, internal electric field and strain. These differences lead to the nanodisk two-color emission, as evidenced by the combination of scanning electron microscopy and cathodoluminescence measurements [4]. Micro photoluminescence experiments performed on single NWs reveal sporadic appearance of intense and narrow (< 500 μeV) quantum-dot-like emission lines, originating from the InGaN nanodisks. This light, tunable over blue and green spectral range, is strongly linearly polarized (polarization ratio >90%). Photon correlation measurements performed on these emission lines, show pronounced antibunching. We find the $g^{(2)}(0) < 0.3$, which is a clear signature of the quantum nature of the emitted light [5].

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Design and analysis of diffractive surfaces in lens for optical disk system

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The presented research is devoted to the design of diffractive surfaces and their influence on the optical aberrations in the optical disk lens. Considering that diffractive optical elements have the known disadvantages, like possible parasitic diffraction orders and probable decrease of the transmission, we analyzed the optical disk lens with combined aspherical and diffractive surfaces. By using aspheric and diffractive surfaces the correction of optical aberrations was investigated in the lens for optical disk systems. The characteristics of designed diffractive surfaces were controlled in Software DIFSYS 2.30 which can show profile and fabrication limits of diffractive optical element (DOE).
Performances required on an optical disk lens are originally diffraction-limited performances represented by Marechal's criterions, which was to make the wave front aberration to be 0,07 λ. When aberration up to a certain image height also needs to be eliminated, it is necessary to make both surfaces of the single lens to be aspherical. In the case of a diffractive element, on the other hand, spherical aberration turns out to be under-corrected when wavelength dependency of the spherical aberration is larger and the wavelength is longer. When a 650 nm wavelength is used for DVD and 780 nm is used for CD, the degree of under-correction is higher for CD [1]. Nevertheless it is possible to make the sum total of spherical aberration of both the refraction and diffraction system to be satisfactory value by utilizing this wavelength difference. These so-called hybrid achromats exploit the fact that the dispersion of refractive elements is opposite that of diffractive elements, so they can neutralize each other [2, 3]. We investigated a design of the disk lens for 780 nm, which is an application for DVD optical system with NA (numerical aperture) = 1. The starting point for aspheric disk lens is limited by technology on 2 variable parameters, radii and thicknesses. By using default merit function for best focus using the RMS Spot Radius, Centroid RA 18x18 and additional parameters for decreasing spherical aberration, the starting point of disk lens was optimized. The conic and 6^{th} order aspheric coefficients were defined additionally on both surfaces of disk lens. We used Zemax's Even Asphere to define aspheric surfaces in our design. With additional 7 more parameters (2 coefficients for conic, 5 coefficients for

Even-Asphere) the performances of disk lens were improved. Longitudinal aberration of primary wavelength is in range 0.002 mm. In the next step diffractive micro-structure was added on the first aspheric mother surface number 1 in data editor. It was defined as a binary 2 surface, defined by 3 coefficients. In this way, longitudinal aberration of disk lens was significantly decreased. Longitudinal aberration is in range 0.0001 mm for investigated range of wavelength. Advantages of diffractive surface are obvious in this design. The MTF curve of designed lens is showing a diffraction-limited system while the geometric spot radius is 0.045 microns on the spot diagram.

The designed diffractive surface has 18 zones, with minimum radial change 0.01055 mm between two zones, feasible for manufacturing when the value is higher than 10 microns. We have presented advantages of DOE in design of the lens for optical disk system, and by using the software DIFFSYS we have shown that DOE which we have designed, can be fabricated.

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Rapid Electron Beam Patterning of Concentric Nano-rings for Nanoplasmonics

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We demonstrate electron beam lithography (EBL) technique for rapidly producing arrays of concentric metallic nano-rings. Rather than defining the dimensions of the rings themselves, the raster beam exposure system of the EBL software is exploited to produce concentric arrays of pixel-like spots as described before for more simple features [1-4]. The sub-optimal exposure dose inherent to this method has the additional benefit of producing minimal line width. With this method, software resources can be reduced significantly, allowing larger arrays than traditional EBL methods and patterning time is reduced by a factor of 3 or more. This approach can be useful for producing large arrays of conducting rings for applications in nanophotonics and -plasmonics.

To demonstrate the possibilities we fabricated continuous metallic nanorings down to a minimum inner radius of 30 nm. The annular width, or difference between inner and outer radius, can be adjusted from approximately 10 nm up to 50 nm. A minimum

separation of approximately 40 nm between the concentric rings has been achieved for up to ten rings.

Concentric rings allow tailoring of the optical resonances by coupling of the resonances in consecutive rings according to plasmon hybridization principle [5]. Resonance tuning from visible to mid-IR wavelength is possible merely by changing the diameters of the rings. We shall present the optical characteristics and applications of these nanopatterns in the conference.

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Experimental demonstrations of efficient composite broadband polarization retarders, polarization filters and rotators

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A new type of broadband polarization half-wave retarder and narrowband polarization filters are described and experimentally tested. Both, the retarders and the filters are designed as composite stacks of standard optical half-wave plates, each of them twisted at specific angles. The theoretical background of the proposed optical devices was obtained by analogy with the method of composite pulses, known from the nuclear and quantum physics. We show that combining two composite filters built from different numbers and types of waveplates, the transmission spectrum is reduced from about 700 nm to about 10 nm width. We experimentally demonstrate that this method can be applied to different types of waveplates. [1]

The experimental demonstrations of the broadband and ultra-broadband polarization rotators are under preparation. The results are based on the investigations in the articles [1, 2, 3].

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Segmented Slot waveguide modulator for InP membranes on Silicon (IMOS) with electro-optical polymer and highly doped InGaAsP layer

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In the development of the InP membranes On Silicon (IMOS) platform [1], electro-optical modulators are a key device for optical interconnects. Slot waveguide based modulator with highly nonlinear electro-optical (EO) polymer has shown to be an attractive solution [2]. The small dimensions of the structure, the characteristics of a high overlap of the optical mode due to boundary conditions, and presence of the electric field of the microwave signal in the low refractive index region give the possibility to realize devices with small footprint (hundreds of μ^2), high bandwidth (>100 GHz) and low V_π x L value (~ 0.7 V mm). This solution is suitable to be integrated with passive devices already developed for this platform, and with new active devices which are under development.

The most common configuration for a slot waveguide modulator using EO polymers consist of a slot waveguide (~300 nm thickness) of two layers, one consisted on n-doped material (~50nm) covered by an intrinsic layer (~250 nm). The n-doped layer works as a strip loaded layer which electrically connects the slot waveguide with the contacts. This design faces several difficulties because it requires highly demanding characteristics. One of the most important is a need on providing a high-frequency electrical driving signal to the slot. To face this problem, a tradeoff has to be made between a low resistivity of the strip loaded layer, which can be obtained by increasing the doping of the material; and low optical losses which require low doping levels. The second difficulty consists of the fabrication of such a small geometry and the high accuracy needed in the etching to reach the correct dimensions of the strip loaded layer. In this work we present a different configuration, consisting of a quasi-continuous electrical contact based on subwavelength segmentation lines [3] with the addition of a highly doped InGaAsP layer used as the conductive layer. In this case, the layer stack consist of an intrinsic layer of InP (250nm) covered by a thin layer (~50nm) of highly doped InGaAsP material (~$2x10^9$). This higher doped layer reduces the resistivity to a level around 0.00049 Ω cm and with capacitance around 15 fF result in a RC bandwidth of several hundreds of GHz. The optical losses

with high doped material are usually high, but due to the small thickness of this conductive layer, and a high presence of the optical field in the low refractive index material, it leads to acceptable losses; around 10 dB/cm. The main advantages of this segmented connection layers are: only one step height fabrication is required and due to high doping levels, the contact resistance is extremely low ($\sim 10^{-6}$) which effectively removes the RC limitation of the modulator. Furthermore the highly doped layer can be removed with selective wet etching in the sections where it is not needed, reducing the total losses of the complete device.

The subwavelength dimensions required can be realized in our facilities using Electron-Beam Lithography (EBL) and Hydrogen Silses Quioxane (HSQ) as negative tone resist material and hard mask, due to its high resolution characteristics. Fabrication of these devices is planned soon.

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Multimode RNGH instabilities of Fabry-Perot cavity QCLs: Impact of diffusion

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Quantum Cascade Lasers (QCLs) producing picosecond pulses of high peak power will find numerous novel applications for time-resolved MIR spectroscopy, free space communication, remote atmosphere sensing *etc*. The short upper state lifetime (~1 ps) in QCLs prohibits passive mode-locking or Q-switched operation because the gain recovers much faster than the pulse repetition rate. Gain switched pulse production has been attempted yielding 120 ps pulse width [1] and active mode-locking was achieved in QCL utilizing diagonal transition [2]. Unfortunately, diagonal transition rendered QCL operation temperature out of the practical use. Experiments reported in [3] evidence that some QCL structures exhibit features of multimode Risken-Nummedal-Graham-Haken (RNGH) instabilities [4,5] at low excess above lasing threshold ($p_{th2}<1.1$). The onset of such RNGH instabilities and excitation of regular self-pulsations may provide practical means to produce picosecond pulses in the MIR spectral range.

Conventional RNGH analysis [4,5] predicts that the second threshold p_{th2} is in the range of 9 to 16 times above lasing threshold, does not take the spatial grating of population inversion into account and barely agrees with experiments in unidirectional ring fiber

lasers [6]. Here we consider Fabry-Perot (FP) cavity QCLs and conventional semiconductor quantum well (QW) LDs. Like in reference [3], we take into account the effect of the induced grating of population inversion, but we also incorporate the grating of the medium polarization and its relaxation due to carrier diffusion. This allows us to explain low second threshold in QCLs without inducing the ambiguous assumption of Ref. [3] of a built-in saturable absorber and Kerr lensing-effect in the waveguide of QCL. We further elucidate the importance of unipolar diffusion in QCLs and ambipolar diffusion in conventional LDs: without diffusion, the second threshold would be too low and independent of the lasing wavelength. Time domain simulations utilizing travelling wave rate equation model of Ref. [7] show irregular self-pulsations, in agreement with experiment in [3]. Shortening of the cavity length down to L=100μm results in the increase of the second threshold up to 2.3-2.5. Above RNGH threshold, steady state regular self-pulsations can be established, preceded by a high-amplitude burst, which might be attributed to Dicke superradiance (SR) [8]. Very high p_{th2} in conventional LDs is predicted by the model, attributed to ambipolar diffusion. Just like QCLs above the RNGH threshold, FP cavity LDs would exhibit SR emission burst followed by regular RNGH self-pulsations.

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Graphene based optical modulators and sensors

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Tunable conductivity is one of the most important property of graphene. It can be controlled electrically and chemically. In the first approach, charge carriers in graphene are induced by applying a gate voltage due to the electric field effect. In the chemical doping of graphene, adsorbed molecules serve as charge carrier donors or acceptors. By coupling graphene to optical devices, they can be made tunable. The electrical doping of

graphene can be applied for electro-optic modulators, whereas the chemical doping of graphene can be used for a very efficient sensing.

Here we shortly review our recent work on graphene based optical modulators [1,2,3] and sensors [4] and focus on the modulation [3] and sensing with the Fabry-Perot resonators. The proposed modulator consists of the Bragg top mirror, the cavity with graphene, and the metallic bottom mirror. Reflectance from the cavity is electrically controlled by adjusting the Fermi level in the graphene. At near-infrared and terahertz frequencies, the amplitude modulation of the reflectance is dominant. On the other hand, the tuning at mid-infrared frequencies is based on the spectral shifting of the cavity resonances. The proposed sensor consists of the metallic mirror, the dielectric spacer and graphene on a top of the structure. Chemical doping due to adsorbed molecules on the graphene results in the amplitude change of the reflectance which can be used for an efficient sensing at terahertz frequencies.

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Optical properties of organic-inorganic hybrid structures doped with graphene nanoparticles

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Graphene, owing to its high optical transmittance, low resistivity, high chemical stability and mechanical strength, has been defined as the next generation material for electronic and photonic devices [1,2].

We present the effect of graphene nanoparticle addition on optical and electrical properties of liquid crystals (LC) or polymer dispersed liquid crystals (PDLC). Three different sizes of graphene nanosheets (nanoplatelets) in different concentrations have been added into the organic compounds and the influence of graphene addition on the electro-optical behavior of hybrid structures has been studied.

The optimization of driving operating voltage and electrical conductivity of selected organic compounds as well as enhancement of the LC alignment properties will allow us to combine highly birefringent LC molecules with the excellent photoconductivity of inorganic crystals into a single, functional device with enhanced functionality.

The studied hybrid structures are assembled by LC or PDLC film, Ru-doped BSO photoconductive substrate and glass substrate. The proposed nanoparticle doped organic-inorganic hybrid devices will play important role as light-valve shutters, spatial light modulators, in display technology and related photonic applications.

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Efficient grating couplers for the 5um wavelength range implemented on a Ge on Si or Ge on SOI waveguide platform for midIR sensing applications

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Coupling light to and from an integrated photonic chip by means of a grating coupler is an important step towards high yield compact integration of photonic devices [1]. The most basic way of coupling light to and from a chip via end-fire coupling is often hampered by the need of cleaving, and the fact that the input and output of every device have to be routed towards the edge of the chip impacting the chip's size.

Our work is aimed at realizing the first grating couplers in the 5um wavelength range implemented on a Ge on Si or Ge on SOI waveguide platform. These waveguide platforms are emerging as CMOS compatible platforms for the midIR wavelength range [2]. We are considering second order gratings in advanced configurations to enhance the fiber-to-chip coupling efficiency, such as freestanding Ge gratings on SOI and gratings with gold (Au) back reflector. In case of second order grating structures the simulated coupling efficiency goes up to 40-45%, while for some of our advanced structures an efficiency beyond 50% and 3dB bandwidth of more than 150nm is expected. Simulations are carried out using a 2D FDTD tool.

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One-dimensional hybrid photonic crystals for sensing applications

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In this work we present the fabrication and characterization of one-dimensional hybrid photonic crystals (1D-hPhC) in form of quarter-wavelength multilayered stack comprising alternatively deposited spin-coated polymer films (PMMA) as low-refractive index material and metal oxide films (Nb_2O_5 and V_2O_5) prepared by sol-gel method as high refractive index material. Sol-gel deposition conditions were optimized in order to obtain good quality films with small absorption. Surface morphology and structure of the films were studied by Transmission Electron Microscopy (TEM) and Selected Area Electron Diffraction (SAED). Optical properties of layers including refractive index (*n*), extinction coefficient (*k*) and thickness, (*d*) were determined through measurements of transmittance and reflectance spectra followed by modeling. The optical properties of the multilayered stacks were studied at normal and oblique incidence of linearly polarized light. Surface roughness of the films and stacks was determined through optical measurements of their profile. The possibility of using the 1D photonic crystal as an omnidirectional reflector was exploited theoretically and confirmed experimentally. Besides, the prospect of using the studied structure for chemical sensing with optical read-out is demonstrated and discussed.

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Optical properties of zinc oxide nanostructures prepared by laser assisted technique

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Due to the physical and chemical stability, low toxicity in combination with direct wide band gap (3.37 eV) and large exaction binding energy (60 meV) zinc oxide based nanomaterials are considered as promising candidates for applications in blue/UV light emitting diodes, piezoelectric transducers, gas sensors, photocatalysts, optical coatings, varistors, etc. Usually, as-grown ZnO exhibits n-type conductivity due to native defects such as zinc interstitials and oxygen vacancies. The reliable p-type doping is still a major

problem, although there have been some reports on the realization of p-type ZnO using a dual-acceptor doping method, where two acceptors such as Li–N, N–As and N–Ag could be simultaneously introduced.

In the present paper to prepare doped ZnO NPs we used laser irradiation processes in two different ways. First, ZnO NPs were synthesized by two step process which involved a sequential laser ablation of Zn (N1) and Ag (N2) targets in the 0.01 M ammonium nitrate solution followed by the additional laser irradiation of the formed colloid with the second harmonic of the Nd:YAG laser (532 nm, 90 mJ). Second, laser ablation of Zn target in the mixture of Ag colloid in ethanol and NH_4NO_3 (N3) was used. The laser ablation experiments were carried out by focusing of radiation of the Nd:YAG laser (LOTIS TII, LS2134D), operating in a double-pulse mode at 1064 nm, on the surface of a target placed in the cell filled with a solvent (repetition rate 10 Hz, pulse duration 10 ns, pulse energy 50 – 80 mJ). The resulting NPs were characterized by TEM, XRD, SAED and UV-vis optical absorption, Raman and FTIR spectroscopy.

It was shown that laser ablation of Zn target in 0.01 M NH_4NO_3 solution (N1) resulted in the formation of two types of particles: rod-like and spherical with a size of 30-50 nm. However, the phase composition of both types of particles is analogous. The major phase was polycrystalline ZnO with the hexagonal zincite structure. The ablation of Ag target in the solution N1 resulted in the transformation of rod-like particles into spherical ones (N2). The analysis of SAED patterns of the N3 sample showed that the NPs are composed of ZnO in zincite structure and of cubic Ag. Laser irradiation of NPs in the third sample resulted in the distortion of the lattice and disappearing of Ag reflections that may be the consequence of doping of ZnO or alloying of Ag and Zn NPs.

Raman and FTIR spectra of the formed NPs confirmed the formation of ZnO in zincite structure after laser ablation. The FT-IR spectrum of the prepared ZnO NPs showed the broad peak at 435 – 544 cm^{-1}, that is characteristic to zinc oxide and is related to the stretching vibrations in Zn–O. Raman analysis of the samples showed that for the sample N3 the fundamental optical modes A1 (TO) and A1 (LO) were observed at 381 and 553 cm^{-1}, respectively. The A1 (LO) mode is known to be related to the defects such as oxygen vacancy, interstitial Zn in ZnO. Moreover the line at 493 cm^{-1} is observed that can be used to confirm the incorporation of Ag in the ZnO lattice [1].

The absorption spectra of the as-synthesized nanocrystals revealed two prominent absorption bands in the UV-visible region. The peak at 360 nm can be attributed to the excitonic absorption of ZnO while the peak around 415 nm corresponds to the plasmon absorption band of Ag NPs. The appearance of two kinds of characteristic absorption bands also confirms that the as-synthesized samples are composed of zero valent Ag and ZnO. Additional laser irradiation of the N3 colloidal solution resulted in the merging of the bands resulting in a weak excitonic peak and a broad absorption in the range of 400–600 nm. This can be indicative of the formation of the ZnO/Ag nanocomposite.

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Formation and precise geometry control of SNAP microresonators by external electrostatic fields

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In SNAP (Surface nanoscale axial photonics) resonators propagation of a slow whispering gallery mode along an optical fiber is controlled by nanoscale variation of the effective radius of the fiber [1]. Similar behavior can be realized in so-called nanobump microresonators in which the introduced variation of the effective radius is asymmetric, i.e. depends on the axial coordinate [2]. The possibilities of realization of such structures "on the fly" in an optical fiber by applying external electrostatic fields to it is discussed in this work. It is shown that local variations in effective radius of the fiber and in its refractive index caused by external electric fields can be large enough to observe SNAP structure-like behavior in an originally flat optical fiber.

Theoretical estimations of the introduced refractive index and effective radius changes and results of finite element calculations are presented. Various effects are taken into account: electromechanical (piezoelectricity and electrostriction), electro-optical (Pockels and Kerr effects) and elasto-optical effect. Different initial fibre cross-sections are studied. The aspects of use of linear isotropic (such as silica) and non-linear anisotropic (such as lithium niobate) materials of the fiber are discussed.

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Optically addressed spatial light modulator assembled by organic-inorganic hybrid structure

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An optically addressed hybrid structure assembled in a way to combine the excellent photoconductivity of an inorganic photorefractive crystal and the strong birefringence of a liquid crystal (or polymer dispersed liquid crystal (PDLC)) is proposed and experimentally demonstrated as a phase only spatial light modulator (SLM).

In the proposed light-valve device, all optically controlled effect comes from the photo generated space-charge field in the photorefractive substrate of Ru-doped $Bi_{12}SiO_{20}$ crystal, which can rise strong enough to act as a driving force for the liquid crystal molecules realignment inside the molecule droplets. The differences in the refractive indexes between the liquid crystal droplets and polymer matrix change as a result of the different intensity illumination into the hybrid device, thus it works as a light-valve [1].

Two beam-coupling experiments performed at Bragg match regime at 1064 nm show prospective amplification values and high spatial resolution. Furthermore, using the proposed hybrid structure, converting of intensity pattern into a phase modulated pattern is demonstrated by computer generated holograms (CGH) reconstruction [2].

Such optically addressed SLM device has the advantages of easy fabrication, no need of polarizers and high spatial resolution which open possibilities for further non-linear applications in a wide spectral range.

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Terahertz wave scanned imaging system for threat detection at standoff distances

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Due to their non-ionizing nature and penetration capabilities, terahertz to millimeter waves have been attracting attention for security applications such as threat and concealed object detection, along with material characterization and non-destructive imaging applications. Due to limited number of array detection schemes operating within this range, imaging schemes with scan architectures are typically employed, where the optical design which accompanies transceiver electronics plays an important part.

Single pixel, scanned imaging systems also depend on image processing and reconstruction steps to compensate optical distortions and limited resolution characteristics. Moreover, various post processing techniques are being used for detection of threat/concealed objects within the imaged scene.

In this work, we present a terahertz active scanned imaging system for threat detection at standoff distances. The system design incorporates two separate transceiver units, hence it is capable of operating at two different frequencies by switching from one to the other. A

preliminary work reporting early development stages of this study has been reported before, where characteristics of the optical system have been tested by constructing image of a metal object at a distance of ~1m [1].

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Liquid crystal reflection modulators based on coupled terahertz resonant cavities

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Liquid crystal (LC) based devices are promising cheap alternatives for terahertz wave modulators and electrically tunable components in applications that do not require high-speed switching. Examples include several securities, safety or material science applications, in which millisecond response times are sufficient.

Conventional nonresonant LC cells, widely used in display technology, have typical thicknesses of few λ_0, amounting to few micrometers or less for operation at visible frequencies. In the terahertz, however, a conventional LC cell would need to be few millimeters thick [1] leading to a range of practical problems, including low quality of the LC alignment, operating voltages in the kilovolt range and, most importantly, slow response times of the order of a second.

As a way around the thick-LC-cell problem in the terahertz, the use of resonant metallic structures and metamaterials for enhancing the light-LC interaction has recently been considered [2] and found to be promising [3], especially if the resonant cavity is designed so that an optimal balance [4] between the various cavity mode decay rates [5] is achieved.

In this work, we consider the use of an array of coupled terahertz cavities for enhancing the performance of resonant LC-cells [4]. We analyze the coupling mechanism by employing the temporal coupled-mode theory for multimodal optical resonators [6]. For

proof-of-concept numerical simulations, we numerically solve Maxwell equations in the frequency domain in conjunction with a rigorous tensorial formulation [7] of the Landau-de Gennes theory for describing the microscopic details of nematic molecule switching dynamics under applied bias. We find that, by wisely choosing the geometry of cavities, terahertz LC cells can be designed to have few-micron thicknesses and millisecond response times, while retaining high modulation efficiency.

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Tunable dispersion filters based on liquid crystalline systems

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The method for tunable filtration and modulation of infrared (IR) radiation, based on a combination of the Freedericksz effect and the Christiansen effect was proposed in the report. The latter effect arises if particles are dispersed in a sufficiently transparent medium and the particle sizes are comparable with the wavelength of the incident light. In this case, the system transmits light in a narrow range of wavelengths, where the refractive indices are close for the particle material and the medium in which the particles are dispersed. In this work, aluminum oxide is used as a material of particles because of strong change of its refractive index in the mid-IR spectral region. At this case, the liquid crystal acts as a matrix because its refractive index easy changes along light propagation at application of the electric field.

The optical transmission of small aluminum oxide particles in liquid crystal 4-methoxybenzylidene-4'-butylaniline (MBBA) and the dual-frequency liquid crystal (DFLC) mixture consisting of 4-n-pentyl-4'-cyanobiphenyl (5CB), 4-hexyloxyphenyl

ester 4'-hexyloxy-3-nitrobenzoic acid (C2), 4-n-pentanoyloxy-benzoic acid-4'-hexyloxyphenyl ester (H 22) has been investigated.

It has been observed that the transmission band is shifted toward high wavenumbers at application of a voltage and depends on temperature for the Al_2O_3-MBBA system [1]. The study of transmission spectra of the Al_2O_3 particles-DFLC system in the ordinary electro-optic cell has been shown that for certain changes in the frequency of the applied electric field at the same voltage, a transmission region maximum of the Al_2O_3 particles-DFLC ordinary cell switches from one wavenumber to the other [2-3]. While the twist-structure of the system at low frequencies passes the light at the same wavenumbers but it becomes practically opaque at high frequencies [4].

The experimental results are explained by reorientation of the liquid crystal molecules as the value and the frequency of the applied electric field change.

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Numerical Estimation of the Minimum Resolvable Temperature Difference of the Third Generation Thermal Imagers

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To completely specify a thermal imaging system and produce a good thermal imagery, two parameters are measured: thermal sensitivity and spatial resolution [1]. Spatial resolution is assessed by the MTF (Modulation Transfer Function) which indicates how small an object can be resolved by the thermal imaging system [2], whereas thermal sensitivity is expressed by the NETD (Noise Equivalent Temperature Difference) that provides information about the minimum temperature difference discerned above noise level [3, 4]. MRTD (Minimum Resolvable Temperature Difference) is a better system-performance descriptor than the MTF alone because the MTF does not take into

consideration the noise level. MRTD is also a more complete measurement than the NETD because it accounts for both spatial resolution and noise level [1]. For this reason, this paper proposes a graphical user interface for numerical estimation of the MRTD which allows the user to see and check the effect of each thermal imager parameter. The developed tool is based on a mathematical model designed to estimate the MRTD for 1st and 2nd generation thermal imagers which is modified to estimate the MRTD for 3rd generation thermal imagers. As a demonstration, two models of thermal imagers of the third generation are tested. The obtained results are compared with the declared values given by the producers. Moreover, the developed calculator could be used as an educational tool for examination and demonstration of thermal imager properties.

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Determination of RNGH round-trip gain using bi-orthogonal perturbation approach

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An interesting new possibility to generate short mid-infrared pulses using quantum cascade lasers (QCLs) stems from experimental observations [1] that certain QCLs, at a low pump excess above threshold, exhibit features of Risken-Nummedal-Graham-Haken (RNGH) instabilities [2,3] and therefore might produce self-pulsations [4]. In order to explain the origin of low-threshold RNGH instabilities in QCLs we take into account the effect of the induced grating of population inversion, like in [1]. However, we also incorporate the induced grating of the medium polarization and diffusion of polarization terms and examine the impact on the continuous wave (CW) lasing stability. The aim of this communication is to report on our efforts of finding the approximate analytical solution of the eigenvalue with the largest real part of the stability matrix.

Continuous wave (CW) lasing stability was examined by linear expansion of Maxwell-Bloch equations regarding small perturbations in the field *E*, medium polarization *P* and carrier density *N* as well as their spatial harmonics. The spectrum of the Lyapunov exponent of the resulting 9x9 matrix may show only one mode with positive increment. The analysis shows that the matrix can be tailored to block-diagonal form with 4x4 block being responsible for RNGH instabilities. The system becomes unstable when the

eigenvalue of the 4x4 matrix with the largest real part becomes positive. Since attaining the exact analytical expression for the eigenvalues is quite cumbersome and assumes solving the fourth-order equation with complex coefficients, we pursued the approach of finding the approximate expressions using second-order bi-orthogonal perturbation theory [5]. As model systems we examine 4 mm and 100 μm long QCLs, both operating at the wavelength of λ=10 μm. We used typical QCL relaxation time constants T_1=1.3 ps and T_2=140 fs. The "exact" (numerical) solution and the perturbation method are in very good agreement, particularly in case of long cavities and low p around instability threshold value which is slightly above one (p_{th2}=1.05). Increasing pump excess above threshold p results in small deviation between two curves, especially for lower perturbation frequencies. Predictions of the Lyapunov stability analysis were verified via numerical simulations with the travelling wave rate equations model of Ref. [6]. In a long cavity the round-trip time of 88ps significantly exceeds the upper state lifetime. Above the RNGH instabilities threshold, it will exhibit irregular self-pulsations or spiking. In a short cavity with round-trip time of 1.1 ps, the memory effect will persist in the active region before the arrival of each subsequent pulse, and hence the system may exhibit regular self-pulsations.

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Interplay of disorder and PT symmetry in one-dimensional optical lattices

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We study light propagation through a one-dimensional binary optical lattice in the presence of diagonal disorder and alternating gain and loss, and examine the light transport phenomena for localized and extended input beams [1]. In the pure PT -

symmetric case, we derive an exact expression for the behavior of light localization in terms of typical parameters of the system. Inside the PT -symmetric region, the light localization becomes constant as a function of the strength of the gain and loss parameter, but outside the PT -symmetric window, light localization increases as the gain and loss parameter increases. When disorder is added, we observe that the presence of gain and loss inhibits (favors) the transport for localized (extended) excitations.

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Terahertz Wave Sensitive Superconducting Bolometric Detector

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There is the unexplored region and growing interesting area by having frequency region as 0.3-10 THz due to their variety of application areas in medical and biological sciences, including imaging, information technology medical diagnosis and the detection of explosives [1]. Terahertz detectors which are cryogenic detectors having NEP approximately 10^{-12}–10^{-14} W/sqrt(Hz) and pyroelectric detectors, golay cells schottky diodes belong to room temperature detectors as having NEP 10^{-10}–10^{-12} W/sqrt(Hz). Several instructive ideas have been proposed for the detection of THz waves and tried to construct different types of bolometers [2,3] but they require costly cryogenic spending and have slow response times. Hot electron bolometer (HEB) which is belong to cryogenic detectors holds a great potential because of their fast response time. About HEB, many different works have been studied and published [4]. Intense, coherent and tunable THz radiation from intrinsic Josephson junctions (IJJs) in layered high temperature superconductor has been reported recently [5]. Additionally, emitting Josephson junctions made from Bi2212 provide enough power to allow room temperature THz detectors, such as Golay cells and pyroelectric detectors, due to the high emitted power [6]. It's not easy to get the thinner Bi2212 single crystal on substrate that's why, we used epoxy to transfer Bi2212 crystal on sapphire substrate and cleaved sample to take thinner thickness. Then antenna structure pattern by electron beam lithography on sample to fabricate hot electron bridge bolometer for efficient THz detection by using Bi2212. In our measurements, resistance v.s. temperature and resistance v.s. time behaviors were measured and response time was calculated in liquid nitrogen cryostat controlled by Labview program.

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Terahertz Wave Metametarial Filters Based on Superconducting Bi2212 Thin Films

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Terahertz (THz) frequency range lying between 0.1 to 10 THz, and its technology has attracted vast interests due to its wide application areas [1]. The importance of developing passive and active devices which work in terahertz wave frequencies is ever more increasing in this popular field [1-2]. Superconducting devices are excellent candidates due to their distinctive advantages of extremely low noise, low power consumption and high frequency operation [3-4]. In addition to these, although high-Tc superconducting low-loss metamaterial devices have been designed, thin films based on (Bi2212) $Bi_2Sr_2CaCu_2O_{8+x}$ have not been utilized. In this study, we present two types of filters for the terahertz (THz) frequency range. Our goal is to develop narrow band THz band-pass filters based on superconducting metamaterials. In contrast to metals, the complex conductivity of superconductors intrinsically depends on the magnetic field, temperature, and applied optical fields. Active metamaterial structures can therefore be realized by directly controlling the conductivity of the superconducting elements without introducing additional elements. ITO, Ti and Cu were chosen as the metallic layer due to their good attachment to the substrate. These films were grown in high vacuum magnetron sputtering system. Terahertz resonant filters were lithographically fabricated from 90-300 nm metal films grown on a 1 mm thick quartz substrate. After fabrication, the samples were measured using a Bruker Vertex V80 FTIR spectrometer. Transmission measurements have shown center frequencies and bandwidths close to the design predictions. The measured results of metal mesh filters showed an insertion loss, which is due to the finite conductivity of the metal films and some loss in the substrate. Finally the created structures were also characterized using time-domain THz spectroscopy (THz-TDS) and CW-THz measurement systems. CST microwave program is used for simulation studies of transmittance properties of filter structures and compared with

experimental results. Furthermore, superconducting Bi2212 thin films will be used for fabrication of filter structures.

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Microcavity with DBR Mirrors for Efficient THz Emission from Optically Pumped GaP Layer: Numerical Analysis by the Method of Single Expression

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The terahertz (THz) band of electromagnetic (EM) waves is of high interest during last decades since considerable number of new phenomena of EM wave - matter interaction in this range has been found [1]. There exist different ways of exciting THz waves [1,2]. Our analysis considers THz wave emission technique using non-linear optical effect in semiconductors known as THz wave rectification [2].

An influence of 1D microcavity on THz emission from semiconductor layer of GaP at optical pump (THz wave rectification [2]) is analysed. Fabry – Perot type microresonator with DBR mirrors of SiO_2/Air bilayers is analysed. For the numerical analysis the method of single expression (MSE) is used [3-5].

It is obtained, that emission intensity from "DBR – GaP layer – DBR" structure strongly depends not only on the number of layers in DBRs but also on their outermost layers' permittivity. For efficient emission of THz waves from GaP layer an adjacent to semiconductor layers of DBRs should be of low dielectric permittivity. An enhancement of THz emission from the considered multilayer structure is possible by an increase of microresonator's Q – factor, which requires an increase of bilayers number in DBRs.

Electromagnetic modelling by the MSE permits to obtain also electric and magnetic fields and Poynting vector distribution within the structure that gives clear explanation of physics of specific frequencies emission from the microcavity. Resonant emission takes place at frequencies coinciding with resonant transparency of microcavity with GaP as a spacer.

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TE and TM THz Intervalence Band Antipolaritons

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The coupling of THz radiation with intersubband transitions in microcavities has attracted strong interest recently, notably within the context of polariton emitters [1]. As in the case of conduction band transitions, polaritons and antipolaritons [2,3] can be investigated with either absorptive (passive) or gain (inverted) media.

The interaction of THz cavity modes with intervalence transitions can improve the quantum efficiency of THz-polaritonic devices. These devices have strong potential for applications in spectroscopy, imaging and improved data transmission in communications and ultra-strong coupling of THz radiation with intersubband transitions which can further improve the applicability of polaritonics. Conduction band-based polariton coupling is restricted to the TM mode.

Valence subband transitions can be coupled with both TE and TM modes polarized cavity modes, which has stimulated us to extend our studies of TE valence band polaritons [3] by comparing results obtained for THz polaritons and antipolaritons for the two possible modes. Both cases are investigated for different cavities and excitation conditions and the possibility of switching between one mode to the other with a large change in resonant frequency and polariton splittings are discussed. The strong nonparabolicity and k-dependence of the transition dipole moment has a very strong role in the shifting of

effective resonance frequencies between TE and TM modes for the same transition. It has also been shown to have potential for THz lasing without inversion [4].

The numerical results presented can stimulate further experimental investigations for a deeper understanding of the valence band coupling scenario and have potential for applications in which a simple design with two possible outputs with different polarizations and resonant frequencies could be of relevance and can further advance applications in the TERA-MIR range [5].

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Simulations of a THz Transmission Line Resonator for Heterodyne Photomixing

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Impressive progress has been achieved in the area of CW terahertz sources over the last decade, including Quantum Cascade Lasers [1,2], negative differential resistance devices and terahertz multipliers, but heterodyne THz photomixers have become commercially available for CW spectroscopy applications and are samong the simplest methods for THz-generation in terms of device complexity and fabrication. Furthermore, stacked InGaAs and InAlAs quantum well structures have been shown to have a low carrier lifetime and a band gap of 1.55um enabling the use of less expensive optical sources.
Using the simulation method presented in [3], we summarize results for a novel and very simple THz photomixer structure based on a conventional photoconductor driving a coplanar stripline (CPS) terminated with a multilayer capacitance and RF-chokes doubling as bond pads for the photoconductor bias circuit. The transmission line is a more efficient reactance element than a comparable uniplanar meander structure and contributes to a higher radiation resistance of the resonant circuit.

The design leads to a predicted a radiated power with a fivefold improvement over the output of the conventional design described in Ref. [4]. The current distribution on the transmission line indicates a linear polarisation of the radiated power.

The layout features of the design are intentionally simple and can be produced with conventional, inexpensive photolithographic methods. This design can potentially for further progress in applications in the TERA-MIR range [5].

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3D model of bladder cross-section tissue for visualisation of optical properties

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Bladder cancer (BC) is the fourth most common malignant disease worldwide, accounting for 4 % of all cancer cases [1]. As such, early diagnosis of the disease can improve both the outlook of treatment for patients as well as reduce the costs associated with the disease [2]. Many current photonics based devises are available for potential application in BC detection, but their effectiveness remains unproven [3]. The purpose of the study is to create an optical cross-section model of a bladder, capable of visually representing the passage of photons through the tissue layers [4]. Fresh pig bladders were dissected into 2 cm^2 sections and subjected to spectrophotometric analysis. The absorption, transmission and reflectance data, along with the dimensions of the analysed sections and complimentary literature data were used in the creation of a "generic" cross-section optical property model simulating the passage of thousands of photons through the tissue at different wavelengths. Fluorescence data gathered by the multifunctional laser non-invasive diagnostic system "LAKK-M" (SPE "LAZMA" Ltd, Russia) from pig bladders was further applied to the model for a specific representation of the photon passage through the tissues [5]. Ultimately, this model can be employed to simulate the effects of different laser wavelength and energy inputs to bladder tissue and to determine the effectiveness of potential photonics based devices for BC diagnosis.

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Sunscreen nanoparticles titanium dioxide and zinc oxide thermal influence on skin at sunlight radiation

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Skin protection against excessive doses of solar radiation causing skin cancer is a challenging task. Skin is a multilayered structure consisting of layers with specific physical properties [1]. The superficial skin layer (stratum corneum) serves as a natural protecting barrier for deeper-located layers containing living cells. From the optical point of view, its function is to prevent penetration of ultraviolet (UV) radiation into epidermis and dermis. In order to increase intrinsic protection of these layers by the upper-located stratum corneum, sunscreens containing chemical light-absorbing components were developed [2, 3].

A mathematical model developed by authors was applied to simulate sunlight radiation absorption and heat transfer processes in the sunscreen-treated skin [4]. The focus was on the effect of size and concentration of TiO_2 and ZnO nanoparticles for UV protection. Energy of the absorbed light released mainly in the form of heat, making consideration of heat loads an important issue.

In this research, we consider the effect of nanoparticles (of various sizes) embedded into the superficial layer of skin on distribution of absorbed light density and skin surface temperature dynamics at sunlight irradiation. The optimum nanoparticles sizes for each wavelength were selected accounting for size-dependent absorption and scattering of light by nanoparticles of various sizes. The wavelengths of 310, 318, 360, 400, 500, 514, 600, 700 and 800 nm chosen as the representatives of the UV, visible and infrared (IR) spectral regions, respectively, in order to account for the wide solar spectrum. This causes overestimation of the heat load due to exclusion of longer wavelengths from the consideration.

In the present paper, a 1-cm^2-large area of the skin surface is considered, with corresponding incident solar radiation power equal to 100 mW (integral over the wavelengths of 280-4000 nm); skin thickness is 620 μm. Accounting for the constant blood circulation in bottom layers of the skin, we simulated various values of heat release on the skin surface: 2.5-100 W/m^2. The temperature of the skin in the steady heat transfer process exceeds 0.05 ^0C (in case of 1% of TiO_2 nanoparticles) and 0.1 ^0C (in case of 5% of TiO_2 nanoparticles). A minor difference in temperature can be explained by the presence of strong thermal conductivity on the surface and blood perfusion in the bottom layers, providing a sufficiently powerful thermoregulatory mechanism in skin. TiO_2 nanoparticles have more pronounced sunscreen properties than ZnO, including, reduced the amount of thermal load on the irradiated skin.

It has been shown that a considerable part of incident solar radiation is absorbed in the stratum corneum layer containing nanoparticles. The skin temperature in presence of sunscreen nanoparticles decreases in addition to surface thermal conductivity and blood perfusion. The calculations show that nanoparticles of TiO_2 and ZnO substantially prevent penetration of UV radiation deep into the skin, screening the underlying layers and internal organs from UV radiation.

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Web-based applications for simulations by Monte-Carlo ray tracing method

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Propagation of laser radiation in heterogeneous medium has been studied for many years. This study helps to simulate some physical phenomena in atmosphere, turbid media, as well as problems associated with the use of laser diagnostics and therapy in medicine. The interaction between light and turbid-like medium can be described using the concept of radiative transport. The simulation of such phenomena is based on Monte Carlo method. To share our modeling software with other scientific groups, simplify the procedure of simulation, and result processing, we have adapted the architecture of the software for online using.

Let us consider the concepts of the Monte Carlo method on the example of the laser radiation interaction with multilayer medium (e.g., human skin). Coordinate of entering to the medium is randomly selected for every photon. Mathematical modeling based on Monte Carlo algorithms is used to calculate the density of absorbed light energy distribution in the skin [1]. This method simulates the "random walk" of photons in the human skin tissue volume considering light absorption and scattering. In Monte Carlo simulation, the skin is treated as a five-layer medium. For each layer, the optical properties are assumed to be invariable, i.e., the model is symmetric in relation to a shift in a plane parallel to the layer interface [2].

The package of applied software was developed for calculation of the photon distribution in turbid medium [3]. The software allows calculating temperature field of complex system, temperature dynamics and distribution of absorbed light energy. Now one of the trends in computation science is web-based applications that allow using the software

regardless of the user platform. There are two approaches to building architecture of web-application: client-server architecture allows running application on a client side and performing all calculation on a server side (e.g. on cloud server). Client architecture is using a web-browser for perform for all kind of calculation. Web applications are popular due to the ubiquity of web browsers, and the convenience of using a web browser as a client. The ability to update and maintain web applications without distributing and installing software is a key reason for their popularity, as is the inherent support for cross-platform compatibility.

Web applications based on cloud architecture can be automatically scaled to the required performance. The technology of hardware virtualization permits to create the required number of servers, each of them is run on own operating system and each of them is allocated the same resources such as the memory, CPU/GPU [4] and disk space. Thus, the usage of cloud architecture eliminates the need to keep physical servers.
We conducted an analysis of CPU/GPU and web-based approaches and compared the performance of each of them for the biophotonics simulation. Each of the architectures is significantly different in overall computation approach, but each of the methods can be successfully used for relative class of computational tasks. The highest performance was achieved by GPU applications. Web application based on JavaScript/NodeJS engine showed best adaptability and interactivity. A performance of web application was twice as less than native CPU applications.

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Plasmon-resonant nanoparticles with variable morphology for optical imaging

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Advances in development of plasmon-resonant nanoparticles (PRNPs) provide wide possibilities for researchers to apply PRNPs of variable forms in major biophotonics-

based applications. This is because of the unique physical and chemical properties of PRNPs, specifically by the ability of plasmon resonance (PR) [1]. PR results in highly localized field enhancement at the PR wavelength as well as intense absorption and scattering of incident light. Absorption and scattering properties are of high importance for PRNPs integration into biophotonics applications [2]. The main studies have been devoted to absorption properties of plasmonic nanoparticles. Herewith, scattering component of the PRNPs spectrum, despite its importance for sensor and photonics, attracts much less attention of the researchers.

Here, we developed nanostructures as contrast agent for real-time visualization of nanoparticles uptake and localization within cells. For the first time to our knowledge scattering and absorption coefficients of the pristine and silica coated nanostars with variable sizes were separated by means of collimated transmittance and diffuse reflectance/transmittance analyses and were compared with scattering and absorption abilities of nanospheres.

We pioneered application of conventional laser confocal microscopy in combined scattering and transmitted light modes to detect the backscattering signal of gold nanostars, nanocubes and nanospheres, which is useful for the direct real-time observation of nanoparticle uptake by and localization in living cells. Scattering properties of PRNPs were investigated using optical coherence tomography (OCT) by imaging of nanoparticle suspensions in glass capillary to significantly increase visibility of capillary flow. The plasmon resonance of nanostructures corresponded to the central emission wavelength of the light source of the employed OCT. We investigated the opportunity of cells transfection by the use of optoporation – generation of transient pores on the cell membrane. The cells were irradiated by a continuous-wave laser (wavelength 808 nm) and a fibre-optic nanosecond laser (wavelength 1064 nm, pulse duration 5 ns) in presence of nanospheres or nanostars of comparable sizes for enhanced cell membrane permeabilization and more efficient penetration of nanostructures and biomaterial into cells.

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Experimental study of the influence of blood flow on the fluorescence signal of biological tissue

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In recent years, fluorescence spectroscopy (FS) has been successfully used in studies of biological objects at the micro level, which allows the monitoring of temporal and spatial dynamics of molecular processes. This method is based on analyzing the characteristics of induced endogenous fluorescence in probed biological tissues with low-intensity optical radiation at certain wavelengths. However, in general, one of the main problems with this method so far, is the correct interpretation of the data. It is known that changes in blood flow can affect the fluorescence spectra: it may result from signal attenuation due to the absorption capacity of the blood and the change in the concentration of fluorescent coenzyme occurring during concomitant changes in metabolism. In this study, we tried to experimentally study the effects of blood flow on the NADH and FAD fluorescence signals in biological tissues.

Experimental studies were conducted on the palmar surface of the skin of the middle and ring fingers of the right hand of healthy volunteers. To evaluate the intensity of blood flow, perfusion was recorded by laser Doppler flowmetry (LDF) with a "LAKK-02" laser analyzer (sensing wavelength – 1064 nm). The fluorescence spectrum of biological tissues was detected by means of non-invasive diagnostic FS channel complex "LAKK-M" (SPE "LAZMA", Moscow) for 2 excitation wavelengths of endogenous fluorophores NADH and FAD – 365 and 450 nm, respectively. The main idea of the research was the implementation of provocative actions (functional tests) on blood flow through changes in extremity temperature (heat and cold pressor test) and application of the brachial arterial occlusion cuff with pressure of 200-220 mm Hg (occlusion test). Special tooling designed and printed on a 3D-printer, allows the placement of the measuring LDF and FS channel fibre along the arm, as well as the ability to secure additional 2-channel temperature sensors specially developed for the temperature measuring instrument. One study recorded the fluorescence of either NADH or FAD. The study consisted of 7 stages, during which the fluorescence spectra and the perfusion of biological tissues are registered at the same time: background recording when placing your hands in the air – 2 min; in warm water (42 °C) – 4 min (heat test); in cold water (15-20 °C) – 10 min (cold pressor test); occlusion of the brachial artery in cold water – 3 min (in conjunction with occlusive cold pressor test); relaxation step in cold water – 10 min; heating of hot water (42 °C) – 11 min (final thermal break). The duration of the experiment was a full 40

minutes, during which about 70-90 fluorescence spectra of biological tissues were recorded. A total of 37 experiments were performed on 10 volunteers.

With the help of non-invasive methods LDF and FS, we have shown the relationship between blood flow (perfusion) and recorded fluorescence signals. All volunteers displayed a high inverse correlation (~0.4-0.8) between registered back reflected radiation and the intensity of fluorescence from biological tissue perfusion and temperature for both fluorophores investigated. Thus, we can assume that factors affecting the absorption of the blood change the fluorescence spectra of biological tissue.

The results obtained must be considered in fluorescence spectroscopy research to determine the concentrations of various fluorophores in biological tissue and the development of new diagnostic criteria and normalizing factors. Also, the results of these experiments indicate a need for further studies, since this generally leads to improved methodology and instrumentation technology for use in medical fluorescence spectroscopy.

Apoptotic changes visualization in cisplatin-treated leukemic cells using second-harmonic generation imaging

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Apoptosis, or programmed cell death type I, is a process in which sequence of events leads to degradation of cell content, cell shrinkage, membrane changes and fragmentation of nucleus. In the execution phase of apoptosis, breaking down of cell cytoskeleton causes the cell membrane to bulge outward - phenomenon known as membrane blebbing. The end result is formation of apoptotic bodies, membrane-bound vesicles containing organelles, sometimes with nuclear fragments. Induction of apoptosis is considered as best approach in anticancer therapy with cytotoxic drugs [1]. Therefore, detecting morphological features of tumor cells under the influence of cytotoxic agents is of great scientific importance. One of the obstacles is to visualize and analyze morphological changes in living suspension cells (e.g. leukemic cells) using conventional light and/or fluorescence microscopy. Therefore, transmission electron microscopy is often used. Although this gives deep insight into subcellular morphology and changes, methodology employed is often time-consuming, expensive and involves usage of multiple toxic substances.

Given all of the above, we analyzed apoptotic changes in commercial human acute promyelocytic leukemic (HL-60) cell line treated with well known apoptosis- inducing antitumor agent cisplatin [2], using second-harmonic generation (SHG) imaging, using

femtosecond laser microscopy homemade nonlinear laser scanning microscope [3] in **T**wo **P**hoton **E**xcitation **F**luorescence (TPEF) mode. Cells were grown under standard conditions [4], seeded in 12-well plates, and treated with cisplatin for 48h in the IC_{50} value concentration range (the IC_{50} value is a concentration that decreases cell viability for 50 %, compared to untreated cells). After the treatment, cells were incubated in dark with supravital fluorescent dye acridine orange (AO) for 30 minutes. The≈10 μl drop of cells was then placed on microscope slides and covered with glass cover slips. Control (untreated cells) and cells treated with cisplatin were visualized and photographed using TPEF SHG imaging. Sections of cells 1,6 μm thick were made, and 3D image reconstruction was performed.

Untreated cells were seen as round, with intact cell membrane and clearly visible nucleus and nucleolus, as expected. On the other hand, leukemic cells treated with cisplatin showed changes in the morphology. They were smaller in diameter, and cell nucleus was fragmented. Furthermore, cell membrane changes were also seen, numerous protrusions, suggesting membrane blebbing and initial phases of apoptotic bodies formation. 3D image reconstruction further confirmed observed morphological cell changes typical for apoptosis.

Performed experiments and obtained results suggest that SHG TPEF imaging could be used for the detection of morphology phenomena related to cell apoptosis, which can be of importance in cancer research, especially in the area of understanding cytotoxic mechanism of action of novel potential antileukemic agents.

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Ellipsometric and AFM Study of Adsorption Properties of Model Lipid Membranes with Biological Molecules

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Cholesterol's interaction with the lipid membrane is very important for understanding of the reasons for the public important neurological diseases like Alzheimer und Parkinson.

The presented work considers the absorption properties of the model lipid membranes in interaction with biologically important molecules like cholesterol.

Lipid layer's formation kinetics has been obtained by using ellipsometry. The absorption of cholesterol on lipid films in medium has been studied. Dependence between lipid concentration and cholesterol/lipid film growth has been observed. The topology of the absorbed cholesterol and lipid surface has been obtained using AFM.

Obtained results are a very good beginning for investigation of the adsorption properties of the model lipid membranes with biological important molecules.

Ultra-short laser induced nanofoam analysis of biopolymer - based thin biofilms

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During the last few years, the naturally – derived biocompatible and biodegradable hydrogen polymers such as collagen, elastin and gelatin three – dimensional self – standing scaffolds are used for an advanced biomedical applications. The laser surface modification of biopolymer thin films represent an alternative technique to conventional chemical – based methods allowing effective control of material processing with minimal thermal damages. Previous studies and reports by other groups have revealed that surface morphological changes affect to the cell behavior such as: growth, proliferation, differentiation and adhesion. The nanostructure analysis shows cells migration in time towards the laser irradiated surfaces and lower cells density into non – irradiated zones.

In this paper, collagen – elastin surface modifications after femtosecond laser irradiation have been shown. The thin films were treated by CPA Ti:Sapphire laser (Femtopower – Compact Pro) emitting at 800 nm central wavelength with 30 fs pulse duration and 1 kHz repetition rate. A process of nanoporous scaffold creation by ultrashort laser interaction with transparent biopolymer films has been observed. The single and multi – shot ablation threshold F_{th} (N=1), F_{th} (N>1), the incubation coefficient ξ, and the ablation rate d which describe the laser ablation processes were determined. Besides the fundamental interest concerning the physical processes in laser – matter interaction zone, initial estimations of growth dynamic and kinetics of cavitation phenomena formation were performed by the so – called “pressure wave model”. The basic consideration of the model is related to the pressure influence of the ablation gas which is responsible for the cavitation bubbles expansion and stability.

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Colorectal cancer stage evaluation with synchronous fluorescence spectroscopy

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Colorectal cancer is the third most common cancer and cause of cancer related deaths worldwide [1, 2]. Early diagnosis and accurate staging of the colorectal cancer are critical for a successful curative treatment. Some optical spectroscopic techniques are investigated for implementing in the clinical diagnostic procedure in order of achieving a greater accuracy of the diagnosis.

In our study we were investigating the characteristic difference, with diagnostic meaning, in the fluorescence spectra of cancerous and healthy colorectal tissues, ex vivo. The samples were excised during standard cancer removing surgical procedure. The measurements were performed with spectrofluorimeter FluoroLog 3 (HORIBA Jobin Yvon, France). The fluorescence of the sample was evaluated through synchronous fluorescence spectroscopy that allows highly sensitive and accurate analysis of multi-compound biological samples. We applied synchronous fluorescence measurements with excitation in the spectral range of 280-720 nm and wavelength interval in the range of 10-280 nm with increment of 10 nm.

The resulted spectra are presented in three dimensional graphics with two axes presenting the excitation wavelength and the maintained wavelength interval during the scan, and color contour map scheme, which represents the intensity of the observed fluorescence. The main observed fluorophores whose fluorescence has a diagnostic meaning are the amino acids tyrosine and tryptophan, the coenzymes NADH and FAD and the structural proteins collagen and elastin. In the synchronous fluorescence spectra of three colorectal tumours and healthy tissue originated from one patient we can examine the formation of specific alterations in the fluorescence, which can be addressed to specific dysplastic alterations in the tissues and can be used for determining the tumour, which has evolved for the longest period of time.

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Two-photon excitation fluorescence microscopy analysis of porcine erythrocytes and erythrocyte ghosts

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Recently it has been shown that hemoglobin emits high energy Soret fluorescence when two-photon excited by the near infrared and visible femtosecond light sources[1].This feature of hemoglobin was used for label-free imaging of porcine erythrocytes and residual hemoglobin in erythrocyte membranes (i.e. ghosts) intended to be used like controlled drug delivery systems.

The packed porcine erythrocytes and erythrocyte ghosts were prepared as described in Kostić et al. [2]. The samples for TPEF microscopy were prepared by introducing the following protocol: 20μL of erythrocytes (hematocrit 5%) and ghosts were allowed to settle onto cover glasses and dry on air. Coverslips were put and fixed onto the dried samples. Visualization of the examined erythrocytes was performed at excitation wavelength 730 nm.

The TPEF image of porcine erythrocytes confirms the presence of echinocyte or acanthocyte morphology, previously observed with scanning electron microscopy [2]. This kind of morphology is common artifact in handling with the porcine blood [3]. It was also observed that distribution of hemoglobin, which is dominant component of erythrocytes, follows the cell morphology and it is localized close to membrane. Its lowest density is observed to be in the central area. For some erythrocytesa significant accumulation was revealed in cells' protrusions. Even though in bulk UV/VIS spectrophotometric analysis confirmed the presence of residual hemoglobin (in low amount) in the erythrocyte ghosts suspension after applied gradual hypotonic hemolysis process and washing out procedure, visualization of empty erythrocyte membranes was not possible. Since no fluorescence of any membrane's constituent was detected, it may be concluded that in case of erythrocytes fluorescence originates only from hemoglobin.

Further investigation involving labeling will clarify whether the amount of residual hemoglobin in suspension of empty erythrocyte membranes is below the limit of detection of TPEF or it is predominantly localized in buffer phase but not on membranes themselves. Visualization and quantification of residual hemoglobin on membranes is important from the aspect of estimation of membranes' purity level, especially due to an indication that residual hemoglobin might affect encapsulation efficiency [2]. Performed investigation opens the possibility to use TPEF in quality assessment of applied process for empty erythrocyte membranes production.

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The application of laser scanning microscopy in the research on an amyotrophic lateral scerosis rat model

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An original labframe nonlinear laser scanning microscope (NLM) setup was tested on samples of cells and neural tissue slices from the amyotrophic lateral sclerosis (ALS) $SOD1^{G93A}$ transgenic rat model. ALS is a neurodegenerative disorder characterized by progressive and selective loss of motor neurons in the motor cortex, brainstem and spinal cord [1].NLM offers better axial resolution, and is also capable to restrict photobleaching and photodamaging of the biological specimens. The NLM technique, two photon excitation imaging (TPEF), was tested by comparing it to confocal laser scanning microscopy on the ALS and control astrocytes cell samples. Autofluorescence images were obtained on 30μm-thick brain slices derived from the ALS rat model and compared to age-matched wild type (wt) animals. Coronal brain slices of brainstem and motor cortex were used. Additionally, it was tried to detect SHG (Second-harmonic generation) signals on brainstem slices. In NLM excitation was obtained by mode-locked Ti:Sapphire laser (Coherent, Mira 900) at the wavelength of 840 nm and average power of ~40 mW or 10 mW. Astrocytes were also scanned with the confocal LSM 510 microscope (Carl Zeiss) at the wavelength of 488nm.The main observation was that the NLM technique offers more sensitive detection of isolated ALS and control autofluorescent astrocytes. Also, the brainstem region *nucleus facials* presented a more intense autofluorescence signal in ALS as compared to wt. tissue slices. Further research is expected to reveal exact relationship between fluorescence signals for corresponding brain slices and also to reveal the molecular origin of the autofluorescent signal. Possible targets are lipofuscin,

nicotinamide adenine dinucleotide phosphate and, most notably, ALS-specific protein aggregations [2].

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Synchronous fluorescence spectroscopy for analysis of vegetable oils

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Fluorescence spectroscopy is widely used analytical tool. It is often used in food analysis because it is rapid and reliable technique. Fluorescence analysis of vegetable oils takes advantage in presence of natural fluorophores such as phenols, chlorophyls, tocopherols and their oxidation products. These oils are multicomponent systems and standard fluorescence spectroscopy can be insufficient for their analysis. To reveal the whole potential of fluorescence techniques other type – synchronous fluorescence spectroscopy (SFS), is applied in oils research. SFS is relying on simultaneously scanning of excitation and emission wavelength while a constant difference between them is maintained. This is how better discrimination between particular fluorophores is obtained and the precision of the analysis is increased.

This research presents the obtained results after oils oxidation – thermal treatment and photooxidation. Potentially toxic compounds for human body are generated during heat treatment or exposure to light. It also shows that discrimination between different types of oil can be made.

Using FluoroLog3 spectrofluorimeter (HORIBA Jobin Yvon, France) and excitation at wavelength region of 220-800 nm, measurements on a set of vegetable oil samples were made. Emission spectra were detected in the wavelength region of 220-800 nm and $\Delta\lambda$ from 10 to 100 nm, with step of 10 nm, was applied for the need of synchronous scanning.

This study was designed to show that synchronous fluorescence spectroscopy is proper for analysis of vegetable oils and can be used for monitoring of oil quality. Obtained results show that oils oxidation is very serious issue and should be controlled.
Further studies are foreseen with increasing of the database.

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Compact diffraction phase microscope for biomedical applications

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Nowadays there are over1.6 billion smartphone users in the world – just a little less than a quarter of the world's population. This number of own smartphone holders is progressively growing up, and expected to reach 34.3% of the world population by 2018 [1, 2]. The advantages of lab-on-a-chip technology provide an opportunity to use cell phone cameras and minimal addition of optical components to monitor non-invasively various parameters of biological tissues in everyday live. We develop a diffraction phase microscopy (DPM) and combine it with the cell phone camera. DPM is a combination of light microscopy and micro-interferometry techniques. Whereas the light microscopy provides quality information about objects, the information from DPM is quantitative. The advantages of this method are well documented [3-5], demonstrating an ability to use DPM in real-time for the biological objects with dynamic changes, such as skin blood flow and blood microcirculation. In current presentation parameters of the DPM combined with the cell phone camera, procedure of image processing and the results of phantom studies are presented and discussed.

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Investigation of biopolymers thin films transformations, induced by ultra-short laser interaction in the 10-fs regime, for advanced applications

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The use of ultra-short pulses for nanoengineering of biomaterials opens up new approaches for creation of nanoplatforms with different mechanical, structural and adhesion characteristics for biological, medical and tissue engineering applications. Structuring the surface of a biomaterial into arrays with micro- and nanoscale features and architectures, defines new roadmaps to advanced applications of biomaterials. It is hypothesized that by varying the composition and architecture of the scaffold matrix could be induced changes in cells behaviour.

In this study novel interaction regime of laser pulses sub10fs duration with biomaterial surface has been observed and thoroughly investigated. This interaction regime allows the generation of well defined nanoporous surfaces. Thin films of novel collagen/elastin composite and gelatin were irradiated by Ti:sapphire fs laser in air at central wavelength 800nm, with pulse durations in the range of 10-30fs. The size and shape as well as morphological forms occurring in the resulted areas of interaction were analyzed as a function of irradiation fluence, number of pulses and pulse duration. By shortening the pulse duration is achieved improved reproducibility of surface modification. The 10fs interaction regime allows generation of well defined nano porous surface arrays.

In this study we have examined a novel composite consisting of the combination of collagen and elastin in order to provide a biodegradable matrix to serve as a biomimetic surface for cell attachment. Confocal microscopy images of modified zones reveal formation of surface fringe patterns with orientation direction alongside the area of interaction.

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Monitoring of temperature-mediated response of biological tissues *in vitro* by administered luminescent ZnCdS nanoparticles

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Monitoring of local temperature in biological tissue is of particular importance e.g. for development of new methods of selective cancer treatment and reduction of body fat [1]. Semiconductor nanoparticles through their luminescent properties provide a new attractive tool for the local temperature monitoring within the tissues [2, 3]. We demonstrate the temperature dependence of the intensity and position of the luminescence spectra of ZnCdS nanoparticles in water. Heating of the sample by 25 °C resulted in the shift of the luminescence maximum by 5 nm [4, 5]. We also investigated the spectral response of ZnCdS nanoparticles sandwiched between two layers of fat and muscle tissue on the local temperature. Luminescence quenching has been observed during heating of the both tissue types. The observed changes in nanoparticle luminescent intensity are attributed to phase transitions of lipid components in case of the adipose tissue and coagulation of proteins in case of the muscle tissue. We show that ZnCdS nanoparticles are perspective nanotechnological tool for measuring temperature of biological tissue upon heating. This new diagnostic approach, we believe, opens new horizons for more accurate treatment in therapeutic procedures and cosmetology, as well as in environmental monitoring.

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Cell morphology alterations quantified within adipose tissues at different physical action by 3D Optical Coherence Tomography

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A high-resolution 3D optical coherence tomography (3D OCT) imaging diagnostic modality is widely used for visualization of an internal structure of various biotissues in a number of applications in biology and medicine [1, 2]. In the current study, 3D OCT has been applied to visualize cell morphology alterations quantified within adipose tissues at different physical action *in vitro*. Hyperthermia is one of the ways to provide a controllable physical impact on fat cells [3-5]. The spatial distribution of intra abdominal fat in the body depends on the lifestyle, genetic predisposition, individual characteristics, as well as the presence of the disease, in particular endocrine and digestive system [6, 7]. The knowledge of morphology of the adipose tissue is essential for reliable layer by layer dosimetry of laser radiation used for treatment of obesity and cellulite [8-10]. We demonstrate that 3D OCT is an excellent non-invasive method that can be applied to quantify intra abdominal fat and its distribution within tissues. We report the results of imaging cell morphology alterations within adipose tissues by using 3D OCT. Representing author has performed a pilot study, developed a technique, and carried out data processing by computer, taken part in the discussion of the results and interpretation of the observed effects.

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Calculations of optical properties of some molecules suitable for coating of nanoparticles for biological applications

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Coating of nanoparticles by various bioactive molecules is a way to modify their surfaces and extend their bio-functionality [1-3]. Infrared (IR) and spectroscopy of electronic transitions in the ultraviolet and visible (UV/VIS) range of wavelengths are the most suitable techniques to investigate the details of functional groups attachment at nanoparticles surface [4, 5]. From that reason we have investigated the optical properties of citric acid, dextran, chitosan, oleic acid and poly(ethylene glycol) by semi-empirical quantum mechanics, and ab-initio Hartree-Fock calculations using the HyperChem software package [6]. The equilibrium conformations, IR, and UV/VIS spectra of the pristine molecules of various lengths, before and after their attachment to the magnetite (Fe_3O_4) surface have been determined. The vibrational IR modes and electronic UV/VIS transitions that change the most upon the molecules attachment have also been identified. The results have been compared to the existing experimental data and the results of similar calculations, and the possible implications for biological applications of nanoparticles coated with the investigated molecules have been discussed.

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Application of laser confocal microscopy for investigation of neurodegenerative diseases

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Combination of immunohistological staining using antibodies conjugated with fluorescent dyes, and confocal microscopy has been established as an invaluable tool for investigation of neurodegenerative and neuroinflammatory phenomena. By employing immunofluorescent stainings we aimed to examine cellular markers of these processes in 3 different models of neurodegenerative disorders: 1) transgenic rat model of amyotrophic lateral sclerosis (ALS) [1], a fatal neurodegenerative disease characterized by dysfunction and death of neurons in the motor pathways of the brain and spinal cord; 2) rats treated with a neurotoxicant, 3 methyltin, which causes specific degeneration of neurons in the hippocampus and development of Alzheimer's disease like symptoms [2] and 3) rats surgically subjected to 10 min. global cerebral ischemia by cardiac arrest, and left to survive for another 1 and 2 years [3].

For registration of immunofluorescence we used a confocal laser scanning microscope LSM 510, (Carl Zeiss GmbH) with three laser units: Ar laser with multiple spectral lines (457 nm, 478 nm, 488 nm, and 514 nm) and two He-Ne lasers (543 nm and 633 nm, respectively). This combination of lasers enables excitation of fluorochromes (fluorescent indicators) that absorb light in the blue, green and red parts of the visible spectrum. Two, three, and up to four channel registration is in the range form 475nm, over green and red parts of the visible spectrum, to infra red light. By using immunofluorescent staining we investigated markers of lymphocytes (TCR), microglia (OX42 and Iba1), astrocytes (GFAP) and neurons (NeuN and NeuroTrace). Signal intensities of used cellular markers in acquired confocal images were then analyzed for gaining insight into quantitative and morphological changes of examined cell types. Furthermore, for better visualization of cell interactions acquisition of serial optical sections was performed using z-filters, which were then reconstructed into 3D images using the Zeiss software.

Investigation on the hSOD1^{G93A} rat model of ALS revealed activation of both astrocytes and microglia in the brainstem and hippocampus, as well as infiltration of lymphocytes into the brain tissue. Furthermore, degeneration of motor neurons characterized by disruption of the cell nucleus, as well as interaction of neurons with microglial cells was noticed. In animals treated with TMT immunochistochemistry and confocal microscopy revealed a massive activation and redistribution of microglia and astrocytes in the hippocampus, and around the dilated lateral ventricles. In rats subjected to global cerebral ischemia, microglial and astroglial activation, interaction of neurons with both types of

glial cells, as well as lympocytes infiltration were found in the hippocampus, cerebral cortex, striatum and thalamus, both 1 and 2 years after ischemic insult. These results give important insight into neuroinflammatory mechanisms of these three types of neurodegenerative disorders, and give a base line of glial and immune responses for further experiments on putative therapeutic approaches.

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Imaging glial activation and tissue metal composition in amyotrophic lateral sclerosis

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Amyotrophic lateral sclerosis (ALS) is a fatal neurodegenerative disorder characterized by death of neurons in motor pathways of the brain and spinal cord. 20% of familial forms are caused by mutations in the Cu,Zn-superoxide dismutase (SOD1) which are suspected to increase its susceptibility to form insoluble intracellular aggregations and cause loose copper and zinc binding to the mutated apoprotein [1], leading to glial activation, increased reactive oxygen species production and neuroinflammation [2]. Therefore, we examined the markers of glial activation and metal imbalance in the brainstem and hippocampus of the SOD1 G93A rat model of ALS.

Immunohistochemistry for Iba1 and GFAP as markers of microglia and astrocytes, and SOD1, was performed on brainstem and hippocampus tissue slices of presymptomatic and symptomatic SOD1 G93A rats, as well as control animals. Images of stained sections were made using the confocal laser scanning microscope LSM 510 (Carl Zeiss GmbH) equipped with the Ar laser with multiple spectral lines (457 nm, 478 nm, 488 nm, and 514 nm) and He-Ne laser (543 nm) which were used for excitation of fluorochromes that absorb light in the blue and green parts of the visible spectrum. Acquisition of serial optical sections was performed using z-filters, which were then reconstructed into 3D images using the Zeiss software. The voxel signal intensity of Iba1, GFAP and SOD1 in 3D images was analyzed using the IMARIS software (Bitplane, Switzerlad) for reconstruction of morphology of glial cells and investigation of signal colocalization between SOD1 and either Iba1 or GFAP.

Analysis of 3D confocal images with IMARIS software revealed an activated morphology of both astrocytes and microglia in the brainstem of ALS rats, notably

already at presymptomatic stage. In addition to an expected increased aggregation of SOD1 in astrocytes, its subcellular organization towards astrocytes soma was revealed, while in microglia SOD1 was located more peripherally, in the cell processes, implying possible SOD1 excretion. In the hippocampus, astrocytes showed a similar activated profile (also already in presymptomatic animals), while microglia was unaffected. SOD1 aggregation profile in hippocampal astrocytes was also directed to the soma, while microglia showed a more diffuse, but progressive aggregation.

Investigation of tissue elemental composition was performed on brainstem and hippocampus tissue slices of control and SOD1 G93A rats by hard X-ray microscopy on the micro-XAS beamline at 10 keV. Analysis of mean pixel intensity in X-ray fluorescence images revealed increased copper and nickel accumulation in both investigated regions of ALS animals, while presence of zinc was higher in the brainstem but lower in the hippocampus. These results bring new incite to the metal imbalance and related early glial biomarker detection in ALS.

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Two-photon excitation autofluorescence study of two cave-dwelling insects

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We performed a study of the nonlinear optical properties of chemically purified chitin and insect cuticle using two-photon excited autofluorescence (TPEF) and second-harmonic generation (SHG) microscopy. Excitation spectrum, fluorescence time, polarization sensitivity, and bleaching speed were measured. We have found that the maximum autofluorescence signal requires an excitation wavelength below 850 nm. At longer wavelengths, we were able to penetrate more than 150-μm deep into the sample through the chitinous structures. The excitation power was kept below 10 mW (at the sample) in order to diminish bleaching. The SHG from the purified chitin was confirmed by spectral- and time-resolved measurements. Two cave-dwelling, depigmented, insect species were analyzed and three-dimensional images of the cuticular structures were obtained. Cave-dwelling insects, including the two species analyzed herein, are regarded as models for evolution and biogeography, as their reduced aboveground dispersal produces phylogenetic patterns of area distribution that largely matches the geological history of

mountain ranges and cave habitats. It should be mentioned that other model organisms have been analyzed using nonlinear microscopy (NLM): nematode Caenorhabditis elegans (Maupas 1900), as a model in molecular and developmental biologies, and insect D. melanogaster as an important model in genetics. Apart from insects, the results of our study are applicable to a wide range of other biological taxa possessing chitin (algae, fungi, mollusks, other arthropods, and so on). Thanks to the high penetration depth, NLM could enable studying of both morphological (external) and anatomical (internal) structures of a variety of living organisms. Such analyses are possible without any sample destruction or dissecting. The additional advantage of the technique is that either dead or living biological models could be experimentally observed.

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Nanoparticles for Cancer Cell Diagnostics and Ablation Modelling the Interaction of Nanoparticles with Radiation

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There is a strong interest in thermal ablation after absorption of radiation (visible, NIR, TERA-MIR, GHz). This technique permits precise and targeted treatment through thermal damage caused to the affected tissues, leaving intact the surrounding healthy cells. Ultrafast excitation of electrons may via electron-phonon coupling transfer the energy deposited by the photons to the vibrating modes of the crystal [1, 2]. The heat thus generated at microscale may in turn be transferred to the surroundings of the nanoparticles: the targeted cells. The development of a simulation tool would be beneficial to gain insight into the physical processes at work during the ultrafast transduction of light radiations into thermal energy. In this paper we present the results of the application of a transfer-matrix based numerical algorithm for both phantom and actual cell materials including the specific resonances of nanoparticles. We are particularly interested in silica coated ferrite nanoparticles NiFe2O4SiO2 [3]. To the best of the authors' knowledge, these nanoparticles have not been used for medical diagnostics and cancer cell ablation so far. The interest for these particular systems is based on the one hand on the biocompatibility of silica and its mechanical properties, and on the other hand on the fact that ferrites have resonances in a frequency domain where electromagnetic waves present no biological risks. Note that as ferrites have magnetic

properties, the magnetic dipole interactions may affect the dispersion of the nanoparticles in the biological system. The silica coating has the additional advantage of screening these interactions. The software will be further developed to investigate the effects of both thermal and cryo ablation per Raman, optical and FTIR absorption and predict how much irradiation is converted into heat and how far the new particles can burn cancer cells.

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Microresonator Frequency Combs in Visible and mid-IR

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Diamond's high linear (n ~ 2.4) and nonlinear (n_2 = 1.3x10^{-19} m^2/W) refractive index, wide bandgap (5.5eV) and negligible nonlinear loss mechanisms due to multi-photon processes, as well as excellent thermal properties (high thermal conductivity in excess of 2000W/mK at room temperature, low thermal expansion coefficient, and small thermo-optic coefficient) make it well suited for realization of stable microresonator combs that operate over wide wavelength range with low threshold powers. We will present our recent result on frequency comb generation at telecom wavelengths using high Q factor (>10^6) diamond ring resonator[1], realized using our thin-film approach[2]. Threshold powers as low as 20 mW are measured, and up to 20 new wavelengths are generated from a single-frequency pump laser. We will also discuss our efforts towards realization of diamond comb in visible range using both thin-film and angled-etching approaches[3-4]. Our theoretical results indicate that an octave-spanning comb (450-900nm) could be obtained with ~100mW pump powers.

We will also discuss our ongoing efforts aimed at realization of mid-infrared (mid-IR) frequency combs based on silicon-on-sapphire (SOS) platform. The high transparency of silicon from 1.2 to ~6.5 μm wavelength makes it suitable candidate for this application. The mid-IR frequency combs have the potential to revolutionize mid-IR spectroscopy, providing high brightness, large bandwidth and high speed parallel detection of multiple spectral features. We have recently demonstrated SOS micro-ring resonators that feature intrinsic quality factors of Q≈279,000 [5]. Using these devices we were able to demonstrate four-wave mixing (FWM) between pump and signal beams in 4.5 μm wavelength range, having optical powers of 100mW and 13mW, respectively (measured before grating coupler with efficiency ~3%). In addition, we were able to demonstrate cascaded FWM process, a precursor for frequency comb generation.

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Optical switching in dual injection-locked Fabry-Perot laser diodes

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The technique of injection-locking is a general physical concept which realizes unidirectional coupling of two self-sustained oscillators, meaning that one (slave) oscillatory system can adjust its frequency and phase according to the frequency and the phase of another (master) one, due to the certain coupling between them. In the laser technique, in order to achieve injection-locking, light from the master laser is injected into the cavity of the slave one. Provided that the external light is in the certain range of injection power and frequency detuning, slave laser stably locks its wavelength and phase to the wavelength and the phase of the external light signal [1]. This technique has been attracting more and more attention in the fields of all-optical communications and all-optical signal processing, especially due to the bistability experienced with injection-locked lasers [1]. Different kinds of all-optical memories [2], regenerators [3], flip-flops [4] wavelength switching [5] or advanced modulation formats conversion [6] have been proposed on the basis of the bistability in injection-locked semiconductor lasers.

In this paper we focus on less investigated dual injection-locking scheme, in which we simultaneously inject two external optical signals. We describe the dynamics of the Fabry-Perot semiconductor slave laser under the dual injection-locking by using the multimode rate equation system. We conduct our investigation in the range of tristability, where we investigate switching between three stable states of the slave laser. We classify switching mechanisms to variation of the injection power, which provides amplitude controlled switching, variation of the frequency detuning, which provides phase controlled switching, and on the combination of both mechanisms, by simultaneous variation of both injection power and frequency detuning. For all three mechanisms we present switching trajectories in the dn/dt versus n phase space, where n stands for the carrier concentration. By the means of the phase space plots we explain and classify available and unavailable switching directions in dual injection-locked semiconductor lasers. For available switching directions we numerically investigate switching times with respect to the amplitude and period of injection power or frequency detuning variation of the master laser, and show that there is an optimal period for which the switching time is minimized. In addition to this, we show that, in terms of switching time, there is discrepancy between switching directions, which can be modified by changing the initial conditions of the slave laser. As a result of particular interest, we show that simultaneous variation of injection power and frequency detuning can significantly improve switching characteristics, i.e., make switching time up to four times shorter.

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Monitoring of the laser wavelength in modern fiber-optic communication systems using dual photodetectors

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Fiber-optic communication systems enable very fast access to the large amounts of data to almost the all users of the information and communications systems. Monitoring and control of such fiber-optic based information and communications systems is of the crucial importance for the very large data rate traffic over the internet. DWDM systems became a standard in order to maximize utilization of existing resources of the fiber-optic systems. These systems use large number of laser light sources with adjacent wavelengths and therefor constant monitoring and control of all lasers in the system is of vital importance [1]. There is a relatively large number of different methods for the determination of the wavelength of lasers such as optical spectrometers with a monochromator, a Fabry-Perot interferometer, etc [2-6]. In this paper a simple and cost effective solution for laser light wavelength monitoring in DWDM L-band with two different photodetector is presented. Different sensitivities of Ge and InGaAs photodiodes in the L-band, i.e. in the wavelength range from 1570 nm to 1610 nm, has been used for the simple sensor realization for the monochromatic light source wavelength measurement. By illuminating simultaneously both photodiodes with the help of the fiber-optic coupler and corresponding signal processing a linear dependence between the output sensor signal and light wavelength has been obtained. While the distance between two adjacent channels in DWDM systems in the L-range is equal to 0.82 nm, measurement accuracy achieved using proposed method was around 0.3nm. Acquired accuracy is considered as sufficient for monitoring of laser wavelength since the accuracy of the proposed method is less than half the distance of adjacent channels.

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Assistant procedures for Quantum Key Distribution in future Optical Communication Systems

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From cryptographic point of view, quantum key distribution (QKD) [1] is important cryptographic methodology for key exchange. In the context of our work, we obtained fully quantum QKD. From information security point of view, QKD can be seen as a necessary and useful security tool. In that light, we have used its properties to make authentication mechanism more practical and to improve future authentication related services. Current state of the art attacks have been analysed. Security claim of our protocol is: we have come up with the weakest possible primitive which enables efficient key growing in the scope of QKD.

QKD assistant procedures have the function to bridge the gap between the ideal model and practical systems. On source side, as a consequence of the lack of the ideal photon sources, we have used almost fair random number generator (model) [2] which is based on probabilistic algorithm. There is a strong point in use of both XoR and quantum encoder, given the structure of our scheme. By minimizing the influence of correlation between authentication key bits on encoding with these two successive operations, we are also minimizing Eve's knowledge about quantum encoded tag. Our analysis, taking into account finite key effects, provides assistant procedure for the losses in quantum channel. In order to take into account complete influence of quantum channel on qubit transmission, the maximum allowed level of losses is estimated, such that already established results from statistical communication theory for communication efficiency bound is still satisfied.

We have designed provable secure one-way authentication primitive for the two state B92 protocol [3]. Although only provable secure, due to obtained high security level for known-plaintext attacks, presented scheme still presents major progress beyond what can be obtained with classical ciphers. On the other hand, our authentication scheme provides highly exponential bounds for eavesdropper detection. In order to find the minimal price for obtaining authentic quantum channel, the size of the initial secret has been estimated. As a consequence, we have come up with authentication scheme which is optimal against denial of service attacks. Therefore, we have provided successful assistant procedure for the current lack of single photon detectors. Proposed secure authentication scheme fits better to B92 than BB84 [4], given mentioned security claim. Moreover, total efficiency of B92 protocol is improved. Finally, asymmetric quantum scheme which consumes as less key bits as possible is obtained.

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Simulation analysis of energy efficient WDM Ethernet Passive Optical Network

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In order to obtain the energy saving WDM (Wavelength Division Multiplexing) Ethernet Passive Optical Network (WDM EPON) it is necessary to reduce an Optical Network Unit's (ONU's) electrical power consumption to the lower level. It is very important to do without any compromising the implemented Quality of Service (QoS). In this paper we present energy efficient WDM EPON model which is based on WDM EPON - FWPBA (Fixed Wavelength Priority Bandwidth Allocation) model [1] and which supports QoS implementation.

In this model ONUs are able to send and receive packets in defined time slots; while one ONU exchanges traffic packets with Optical Line Terminal (OLT) other ONUs are inactive. In that inactive period, called *sleep mode* [2][3], it is possible to turn off some optoelectronic blocks, like optical photo-detectors and lasers with associated electronic circuits, and put ONU CPU in idle state. Furthermore, by using *batch-mode* transmission [3] more energy can be saved during sleep mode. For implementation of these energy saving mechanisms it is necessary to perform an extension of Multi-Point Control Protocol (MPCP). The presented model will allow incremental upgrade from EPON to energy efficient WDM EPON.

We were simulating the presented WDM EPON using C programming. The bandwidth allocation algorithm, which was used in these simulations, is mathematically described in paper. The results have been presented in terms of packet delay (caused by ONU and OLT packet buffering), packet delay variation, packet loss rate, throughput, buffers queue occupation as a function of the number of ONUs, traffic structure and traffic load. The results from simulations of energy efficient WDM EPON have been compared with corresponding values from unmodified WDM EPON - FWPBA model [1]. The most important results are data about overall ONU inactive and active period and these results present energy efficient improvement of WDM EPON - FWPBA model.

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On the outage performance of generalized mixed RF/FSO transmission system

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Free space optics communication (FSO) has recently received great interest as an attractive solution particularly when fiber optics installation is costly or not existing [1,2]. FSO can guarantee a Line of Sight (LOS) high bit rate communication over long distances and up to several kilometers. A possible scenario is where FSO and Radio Frequency (RF) transmission systems are deployed together as a last mile solution for the connectivity gap between RF access network and the backbone network.

In this context, we study the outage performance of a dual-hop transmission system with a fixed gain amplify and forward relay and heterogeneous technologies composed of a radio frequency and free space optics links [3,4]. We assume that the RF link has the Nakagami-m fading channel and the FSO link has the M distributed fading channel. Importantly, we adopt in the relay a subcarrier intensity modulation (SIM) scheme to convert the RF signal to optical signal [4]. We derive exact closed-form analytical expressions for the outage probability in term of the Meijer's G function. We also investigate the effects of the pointing errors in the FSO links. We demonstrate that the existing results in the literature are special cases of our derived analytical expressions. The exactness of our results is verified by Monte Carlo simulations.

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Techno-economic analysis of NGNs implementation in rural areas based on the geographic and socio-demographic characteristics of Serbia

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In the last decade the role of broadband infrastructure has been revised and it is widely considered that the existence, or absence of this infrastructure, is parameter that is used to classified certain area as development or underdevelopment. As a result almost all EU countries in last years have launched different strategic plans for in roll of broadband infrastructure that will be widely reachable and will improve the different segments of life as health, education, and new job openings among others. However, the most of this growth is related to urban/suburban areas since the investment costs in these areas are much lower in comparison with rural areas [1]. Consequently, the return of investment is much slower and raise the question that still remains unanswered – what is the future of broadband access networks in rural areas?

In this paper we present techno-economic analysis of coax networks and multichannel EPONs as two main technologies for next generation of access networks implementation (NGAN). The paper present in-depth comparison of HFC, based on DOCSIS 3.0, and multichannel WDM EPON as, in authors opinion, the most competitive NGAN technology which are able to deliver supreme service to end users in the terms of the all SLA/QoS parameters [2]. In order to make the analysis as much realistic as possible authors consider the two generation of both systems. In the case of the coax system authors analyze HFC based on DOCSIS 3.0 with integrated (I-CMTS) and the following generation that include modular (M-CMTS) solution [3]. In the case of the multichannel solution authors provide analysis of hybrid TDM/WDM EPON based on DWBA algorithm, and its successor that is based on DWPBA-FS system [4].

As previously mentioned, analysis of both systems rely on socio-demographic infrastructure of Serbia in which the broadband access in rural areas is under-develop and should be improved in future period. For presented analysis authors use currently available information related to implementation of HFC systems [5]. Since this type of data is generally considered private we provide only relative measures and use well known information. For the evaluation of WDM EPON system and related cost we refer to previous works and built the hypothetical network model [6] in order to evaluate the main characteristics related to in roll and/or migration strategy of discussed solutions and give an insight in the further access network development.

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Electro-Optical Modulation Bandwidth Analysis for Traveling-Wave and Reflective Semiconductor Optical Amplifiers

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For nearly three decades, semiconductor optical amplifiers (SOAs) continuously inspire researchers to design novel SOA-based photonic devices, come up with new applications and push the limits of their performance. Aside from being used as standalone amplifiers, SOAs found themselves as a building block for numerous complex photonic devices [1]. A particularly promising application is as a colorless transceiver in optical network units of wavelength-division multiplexed passive optical networks [2]. Superb properties such as design simplicity, tunability, nonlinearity, wide amplification spectrum, compact size and easy integration with other optical components on a single optical chip, place them in preferred position for future access optical network design.

Years of research led to a significant number of steady-state and dynamic models with a different level of complexity both for traveling-wave (TW-), and reflective (R-) SOAs. In using SOAs for modulation and remodulation purposes, small-signal modulation bandwidth proves to be a very useful figure of merit. Up to this date, very little research has been done regarding the RSOA small-signal electro-optical modulation bandwidth [3], although several research groups had been studying TW-SOA modulation response [4], [5].

In this manuscript we set to investigate the small-signal electro-optic modulation bandwidth of both TW- and RSOA, and provide analytical results for several special cases and different operating regimes. The analytical results are benchmarked with the numerical ones, obtained using the model presented in [3]. We provide simple and useful means for determining bandwidth dependence on SOA material and structural parameters. We confirm previous conclusions that the bandwidth generally increases with active region length and bias current density. We also analyze its dependence on confinement factor, carrier lifetime, and internal loss of the active region.

Although the results obtained via analytical approach slightly deviate from the numerical ones, we find them highly useful, especially when quick analysis of the system is required. The modest time and resource requirements allow reliable guidance in selecting the optimal SOA parameters.

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An analysis of W-shaped plastic optical fibres by WKB approximation

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The graded-index plastic optical fiber, because of its relatively large bandwidth and core diameter, is the type of the fiber that is used in a majority of the fiber optic systems in existence today [1]. A specially type of optical fiber known as a W-fiber has some desirable properties and unique characteristics not found in matched-cladding fibers. In this work, by Wentzel–Kramers–Brillouin (WKB) method, the total mode numbers of the graded-index W-shaped plastic optical fiber is theoretically reviewed. The obtained formula for total mode numbers of W-shaped optical fibers arises from an approximation of the WKB integral, which preserves the general validity requirements of the method [2]. Also, by assumption that all modes are excited uniformly, we carried out computational analyses to investigate near- and far-field power distribution in W-shaped plastic optical fibers.

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An improved analysis of intermodal delay in few-mode fibers

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Mode-division multiplexed transmission in few-mode fibers has recently attracted considerable attention as a means of increasing the transmission capacity of a single fiber [1,2]. The step-index fiber is applicable for up to two-mode mode-division multiplexing transmissions. The intermodal delay is one of the fundamental issues in mode of transmission which limits the propagation distance of mode division multiplexing. In this paper we numerically investigated effective index and intermodal delay of few-mode fibers with step-index profile. An improved analysis of group delay difference between fundamental mode and four selected modes, including material dispersion, is made. We suggested about reasonable impact of material dispersion that should be included when the intermodal delay is calculated.

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Transport and edge localization in linear Sawtooth photonic lattices

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The propagation of waves in periodic photonics lattices has been extensively studied, and is well understood, for conventional geometries. In the context of the coupled mode theory, there exist some exotic lattice geometries that possess flat bands in the linear spectrum. This is an important area of research where not many experiments have being performed, due to the nontrivial characteristic geometries [1]. However, nowadays, the fabrication of photonic lattices of different dimensions and geometries is possible by the femtosecond laser written technique [2]. In this work, we study theoretically and experimentally a photonic realization of a Sawtooth lattice. This system belongs to a class of quasi-one dimensional lattices possessing, at least, one flat band. A Sawtooth lattice possesses two linear bands, with one of them having a zero width for a special ratio of coupling coefficients. When exciting a bulk lattice site, we observe different transport

regimes, including a strong reduction of transport as a manifestation of the flat band. Depending on the particular lattice edge, linear localized Tamm-Shockley surfaces modes [3, 4] appear at the gap between the two bands of the system.

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A long-period fibre grating sensor for respiratory monitoring

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In the current clinical practice of non-invasive mechanical ventilation (NIV), continuous monitoring of respiratory volumes is based on the measurement of air flow through an oronasal mask or mouthpiece. Errors in respiratory-volumes monitoring and patient-ventilator asynchrony due to the inevitable air leaks from the mask may lead to insufficient ventilation and/or damage of the airway system. Therefore, clinician's observations of the chest wall expansions are required, but they are subjective, time consuming and strongly dependent on clinician's experience [1].

We present and validate a method for the measurement of respiratory volumes by a single long period fibre-grating (LPG) sensor of bending. This method is grounded on the hypothesis that the volume of the inhaled air can be correlated with the change in a local torso curvature in a ribs area with stiff underlying tissues. Here, we explain the working principle of the LPG sensors, a monochromatic interrogation scheme, a two-step calibration-test measurement procedure and present results that establish a linear correlation between the change in the local rib-cage curvature and the change in the lung volume. Results also show good sensor accuracy in measurements of tidal and minute respiratory volumes for all clinically relevant breathing volumes [2].

Additionally, we examine the possibility of using the rib-cage movement signal measured by a single LPG sensor as a new way to provide a trigger to the ventilator. Our preliminary results on healthy volunteers provide the statistical evidence of the 200 ms lag of the pneumotechometer with respect to the fibre-optic signal.

The proposed single-sensor method is non-invasive, simple, low-cost and easy to implement. Moreover this method does not suffer from the flaws of air-flow measurements, it eliminates the need for chest movement observation by clinicians and can be implemented on both male and female patients. The preliminary results are promising and indicate that the method proposed here could be used in NIV.

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Liquid crystal on subwavelength metal gratings

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Recently nanostructured metallic films have become of great interest for many optical applications because of their plasmonic resonances as well as unusual properties characteristic of metamaterials [1, 2]. By changing the geometry and surface patterning of such films one can control their resonance properties influencing their optical performance.

In this work the optical and electrooptical properties of a system consisting of sub-wavelength metal gratings and nematic liquid crystal layer are studied [3]. Aluminium gratings that also play a role of interdigitated electrodes are prepared by focused ion beam lithography. It is found that a liquid crystal layer strongly influences both the resonance and light polarization properties characteristic of the gratings. Enhanced transmittance is observed not only for TM-polarized light in the near infrared spectral range, but also for TE-polarized light in the visible range. Despite nanosized slits separating the electrodes, which results in strong localization of the electric field near the surface, a pronounced electrooptical effect is registered. The effect is explained in terms of local reorientation of liquid crystal molecules at the grating surface and propagation of the orientational deformation from the surface into the bulk of liquid crystal layer.

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Modifications of spheroid plasmonic particle geometry for enhancement of ultrathin semiconductor infrared detectors

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We consider the enhancement of the specific detectivity of semiconductor infrared photodetectors utilizing plasmonic light concentrator consisting of submicrometer doped

transparent conductive oxide (TCO) particles with different shapes embedded within high electric permittivity medium topped with an antireflective layer.

Localized Surface Plasmon Resonance (LSPR) on plasmonic particles ensures high field localization around and directly beneath the particles translating into high density of optical energy within the photodetector active area [1]. We investigate the possibilities to modify the particle shape end size in order to maximize the photodetector optical energy intake i.e. to maximize photodetector external quantum efficiency. We perform ab initio simulation of the optical response of the whole system utilizing the finite element method, starting with spherical particles [2] and then extending our approach to include spheroids and sub-micrometric plates.

As an illustrative example, we analyze a mercury cadmium telluride infrared detector with an ultrathin active epitaxial active layer. An increase in external quantum efficiency can be used to offset a decrease in the optical path/internal quantum efficiency. Plasmonic localization is extremely beneficial for this approach since optical energy density is strongly localized close to the illuminated surface, thus ensuring a large decrease of the total photodetector volume and therefore suppressing the total generation-recombination noise levels that are proportional to the device volume.

Our results show that it is possible to realize an uncooled semiconductor detector for midd-wavelength infrared range with its specific detectivity strongly increased compared to the conventional photodetectors.

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Field localization control in aperture-based plasmonics by Boolean superposition of primitive forms at deep subwavelength scale

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Aperture-based nanoplasmonics deals with an important class of structures using surface plasmons polaritons at subwavelength hole arrays to control propagation and localization of electromagnetic fields [1]. Such structures include extraordinary optical transmission arrays [2], fishnet-based metamaterials [3] as well as different other metasurface with applicability in sensing and detection, waveguiding, etc. [4].

The electromagnetic field localization in aperture-based plasmonic structures can be controled by modifying of the structure geometry at the deep subwavelength scale [5-6]. In this contribution we define subwavelength primitive objects that are combined in Boolean manner by applying logical operations like AND or OR to them to generate complex-shaped apertures and thus modify the subwavelength unit cell geometry. Generally, any arbitrary shape may be presented as superposition of a number of primitive forms (corresponding to a series expansion).

The approach can be used to generate field hotspots in a controled manner and redistribute field within a unit cell. Boolean operations applied to aperture shapes not only ensure “fine tuning” of scattering characteristics, but also the redesign of spectral characteristics of nanohole-based metasurfaces, owing to control over field concentration and the appearance of strong field nonlocalities.

We designed our designer (spoof) plasmon structures [7] with deep subwavelength modifications, simulated their scattering parameters by the finite element method and fabricated the experimental samples for the mid-wavelength infrared range using the conventional silicon-based planar technologies with silver as plasmonic material. The shapes were obtained by overlapping (Boolean OR) square primitive objects.

We show that one can use a set of primitive shapes readily produced by the existing lithographic equipment to generate strong field nonlocalities without increasing the complexity of the system or requiring finer resolutions. Actually the simplest situation would be to simply shift the same photolithographic mask and repeat the already used pattern. Owing to the redistribution of spectral characteristics and their structural tuning, the present approach can be used for multispectral operation of plasmonic chemical or biological sensors.

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Optical spectroscopy of gap plasmon polaritons in a Swiss cross metamaterial

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Nanoscopically thin metallo-dielectric layers formed by noble metals, such as gold or silver, and oxides, SiO_2, MgO or TiO_2 for example, have a range of interesting optical properties arising from hybridized surface plasmon polaritons supported by each metal-dielectric interface [1]. In particular, the metal-dielectric-metal trilayer structure is important for nano-optics and integrated optoelectronics as it supports the propagation of the so-called gap plasmon polaritons. These are highly confined optical modes that can propagate in only few nanometer thick dielectric slabs sandwitched into a noble metal cladding [2].

Here we report on optical spectroscopy of gap plasmon polaritons in a thin Au-MgO-Au trilayer deposited on top of a glass substrate and drilled by an array of cross-like holes [3], which is known as the Swiss cross metamaterial [4]. The perforations form a 400 nm square lattice leading to a diffraction-grating-assisted [5] excitation of gap plasmon polaritons at near infrared frequencies. By investigating the optical response in the two mirror symmetry planes of incidence and at different angles of incidence [6], we reconstruct the gap plasmon polariton bandstructure and infer how the shape of the holes affects their excitation efficiency [7].

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Estimation of the Sensitivity of a Multi-Parameter Fiber Grating Sensor

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In this paper, we use a powerful mathematical concept based on Fisher information (FI) to estimate the cross-sensitivity of multi-parameter sensors. FI has been used in various branches of natural and social sciences [1], in both classical and quantum systems [2]. Lately, it has been used for estimation of interferometer sensitivity in quantum optics [3], as well as in classical optical interferometers [4]. Here, we expand its application to fibre grating sensors that are sensitive to several environmental (temperature, humidity) and mechanical (strain, pressure, curvature) parameters simultaneously [5].

FI is a local probability measure of obtaining an unknown parameter θ from the data measured at the sensor output, X. In the theory of measurement, FI directly enters the relation which determines the lower bound of the measurement uncertainty known as Cramer-Rao bound ($CRB = 1/\sqrt{FI(\theta)}$). The sensor sensitivity is optimized by maximization of the corresponding FI. In the case of a multi-parameter sensor, FI assumes a matrix form defined via the probability distribution function f(X| θ) of the measured variable X conditioned by θ, where both X and θ are vector quantities.

$$FI(\theta)_{i,j} = -E\left[\frac{\partial^2 \ln f(X|\theta)}{\partial\theta_i \partial\theta_j}\right]; i = 1,2,...n;\ j = 1,2,...,n\,.$$

Here, we develop a comprehensive model of the spectral response of fibre gratings to changes in multiple parameters and apply Fisher's formalism to optimize their sensitivity in the realistic parameter space. We start from a 1-parameter model of a long-period grating sensor of curvature and corroborate our approach by comparison with the conventional sensitivity models and the experimental data. We then expand the model to describe a 2-parameter long-period grating sensor of curvature and temperature. Based on this analysis, we recommend the multi-parameter interrogation scheme (estimator) and optimize grating parameters to render the highest sensitivity.

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Near-Field Imaging with Subwavelength Resolution by a Plasmonic Moiré Magnifier

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In 1874 Lord Rayleigh was the first person to describe the aliasing Moiré effect and the resulting interference pattern, which occurs whenever two gratings with slightly different periods are stacked [1]. Such a stack of gratings forms a supergrating with a super-period depending on the ratio of the periods of the individual gratings. If one of the gratings, which will be referred to as imaging grating, is formed by point-like ideal scatterers, the diffraction pattern of the super-grating is a magnified version of the other grating, called structure grating. This can be understood in terms of a spatial frequency mixing picture [2] as the resolution is, in a lowest order approximation, defined by the width of the spatial Fourier transformation of the scatterer.

Investigations on the Moiré effect attracted strong interest in the 1960s and 1970s as methods, e.g., to measure relative displacements and strains, map three dimensional surface contours and align structures very accurately [3, 4]. During the last years, this approach was developed further to investigate sub-wavelength structures and efforts were made to increase the contrast ratio of the Moiré pattern with the help of super- and hyperlenses [5, 6, 7].

While the previous works focused on the magnification and visual inspection of the structure in a non-resonant excitation scheme, Koller et al. went on to image the near-field of resonantly excited plasmonic particles [8]. By using fluorescence particles in the imaging grating they mapped the intensity of the near-field of the plasmonic particles with a sub-wavelength resolution.

Extending the work by Koller et al. we use the Moiré effect to project the sub-wavelength electric fields of plasmonic particles to the far-field by using small scattering particles. With this approach it is possible to image the near field to the far-field at almost arbitrary wavelengths by simple plane wave illumination and standard microscope setup measurements. Because of the absence of fluorescence particles the signal will be stable and reliable and no blinking and bleaching will occur. In return this technique can only be applied to arrays of particles and can’t be used to investigate single particles and, hence, the result will be a collective response of the system.

Our plasmonic structures under investigation are complementary split ring resonators with a period of 1500 nm which are quite large compared to the operational wavelengths of 600 to 900 nm to excite higher order modes with many subwavelength features. The

Moiré effect of this structures was mapped at magnifications of 30 and 100 fold and shows strong resemblance to FDTD and FMM simulations and sub wavelength resolution.

Additionally some super cell simulations where done to compare the experimental data with an equivalent simulation of a complete Moiré magnifier also showing good agreement between simulation and experiment.

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Surface plasmons in heterometallic superlattices

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Surface plasmon polaritons lead to a substantial increase of the photonic density of states (PDOS) in the vicinity of planar metalo-diellectric interfaces, thin multilayers and their superlattices [1]. This is important in various applications where the sensitivity of chemical and bio-sensors relies on surface plasmon excitation [2]. More recently, surface plasmons in multilayers and superlattices have been receiving much attention due to potential applications in hyperbolic metamaterials [3], nano-optics [4] and PDOS engineering in general [1].

Thin films of gold or silver are traditionally used in plasmonic metamaterials [5] because they combine favorable chemical properties with a high plasma frequency ω_p [6], allowing surface plasmon propagation even in the visible spectrum. Recent progress in highly-doped semiconductor growth [7] has resulted in demonstration of thin layers of high-quality Ga-doped ZnO [8] with ω_p falling into near-infrared and up to the visible range, showing potential for applications in near-infrared sensing [9].

Here we report on a theoretical study of surface plasmon properties in heterometallic superlattices formed by combining nanolayers of silver and ZnO with variable Ga

content. We find that the heterometallic content of the superlattice results in the appearance of new plasmonic bands with properties controlled by ZnO doping. Our analysis of the corresponding complex bandstructure [10] also shows the adverse effects of doping as it increases the dissipation and shortens the surface plasmon lifetimes. Finally, we investigate the PDOS and Purcell factor enhancement on a semi-infinite heterometallic superlattice and how it is affected by the layer doping and geometry.

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Quantitative assessment of PET preforms using GPU-accelerated Spectral Domain Optical Coherence Tomography

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Optical coherence tomography (OCT) is a non-destructive and contact-free imaging modality enabling 2D and 3D visualization of examined samples with the axial resolution within few microns. Spectral domain optical coherence tomography (SD-OCT) is a white light interferometry technique and was demonstrated as a good in-line quality control (QC) tool for monitoring polyethylene terephthalate (PET) preforms at a production line [1]. One of challenges at the production line is the QC process rate of the produced samples. The QC process rate should follow the speed of the passing preforms with the speed rate of 7 samples. This study proposed an optimized graphics processing unit (GPU) based data processing and visualization strategy to measure the thickness of the laminated layers of the preforms in real-time. The developed algorithm also increased the QC process speed of the preforms. Live processing and visualization of the preform's

intermediate layers were achieved and demonstrated by using an NVIDIA GTX 680 GPU card. The compute unified device architecture (CUDA) was employed to implement the optimized signal processing scheme. All challenges were discussed in detail and the solutions were given.

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A second-order nonlinear model of monolayer adsorption in refractometric chemical sensors: Case of equilibrium fluctuations

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As a surface phenomenon, adsorption of molecules at an interface between materials in different phases strongly influences optical wave coupling on that interface. As a process, it can be favorable, like in adsorption-based refractometric sensors, their prime example being nanoplasmonic devices, or in nanostructuring of novel optical materials (for instance when inducing a formation of organic crystal nanopillars on inorganic surfaces, e.g. magnetite or metal nanoparticles). On the other hand, it can be undesirable, for instance when causing adsorption-desorption noise. Since a full control of adsorption cannot be achieved, a good insight into signal fluctuations and related adsorption-caused phenomena is crucial for a range of different nanooptical and nanophotonic devices.

Mathematical models of adsorption have been developed for various contexts and applications [1] and they are still being developed, one of the important fields of application being novel ultra-sensitive chemical or biological refractometric sensors based on plasmonic structures [2-4]. Two main groups of mathematical models for monolayer adsorption have been considered so far within the context of plasmonics: models where adsorption can be interpreted as a first or pseudo-first reaction and models where adsorption process is a second-order reaction [5]. Comparative analysis gives the criteria for the applicability of these models [2, 6]. In all situations where the simpler first-order reaction model is applicable, complete deterministic and stochastic analysis of a mixture with an arbitrary number of components is possible both in time and the frequency domain [7]. However, such complete analysis, based on the use of nonlinear model, needed for the research in practical situations (for instance the case of varying analyte concentration like in closed reaction chambers), has yet to be developed.

In this contribution we perform stochastic analysis of equilibrium fluctuations of the number of adsorbed particles at a nanoplasmonic surface in the case when the use of a nonlinear, second-order model is mandatory. We consider the particular case where the

effective medium theory is applicable for the calculation of refractive index (effects of nonlocality are neglected at the metal-dielectric surfaces with subwavelength structuring). We give for the first time an analytical expression for equilibrium spectral density of adsorption-desorption fluctuations of refractive index for the nonlinear case. We determine the power spectral density of adsorption-induced fluctuations and analyze its dependence on the system parameters and experimental conditions (analyte concentration, pressure, temperature, surface density of adsorption centers, etc.). The obtained results give insight in fluctuations of steady-state plasmonic sensor response and ensure the calculation of the basic parameters of these devices. The results can find wider application for other types of affinity-based sensors and nanostructures where the effects of monolayer adsorption cannot be neglected.

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Properties and applications of Long Period Gratings in Chalcogenide Fibers

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Chalcogenide glasses are unique materials with a large transparency window in the mid-infrared and good rheological properties [1, 2]. Recent advances on their manufacturing processes made possible the development of several applications including bio-chemical sensors, infrared-powers delivery, and mid-infrared sources.

Long Period Gratings (LPGs) in Chalcogenide fibers are considered to be a very versatile fibers device, both within the context of nonlinear optics, and sensing applications [3].
This work reported in this paper, concerns infrared optical fibers obtained in AS_2S_3 Chalcogenide glass. We use a single-mode AS_2S_3 Chalcogenide fiber with a core diameter of 6 µm, a core/cladding refractive index of 2.8, and a numerical aperture at 1550 nm of 2.8.

We studied the various modeling aspects of Long Period Fibers Gratings such as the core effective index, cladding effective index, and transmission spectrum [3, 4]. Two models are proposed to calculate the cladding mode effective refractive index. The first and simpler is a two-layered fiber model, in which the effect of the core is neglected, that is,

only the interface cladding air is considered. The second model, a more complex one, is a three-layered fiber model in which the effects of the core are taken into consideration. The refractive index sensitivity of LPG arises from dependence of the phase matching condition upon the effective refractive index of the cladding modes. This paper has discussed the properties of LPG Chalcogenide fibers, techniques for their applications, and their sensitivity to the various measurands [5]. The prospect of the development of multi-parameter sensors capable of simultaneous monitoring a number of these measurands will be discussed [6, 7].

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Manufacture a fiber sensors based in air-silica micro-structured fiber for application in capillary electrophoresis

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Micro-structured optical fibers or photonic crystal fibers (PCF) are one of the most exciting recent developments in fiber optics and sensors. A micro-structured optical fibers consist of a hexagonal arrangement of air holes running down the length of a silica fiber surrounding a central core of solid silica or, in some cases air [1, 2]. PCF can exhibit a number of unique properties, including zero dispersion at visible wavelengths [3] and low or high effective non-linearity [4].

The aim of this communication was the manufacture a fiber sensors air-silica micro-structured fiber for application in capillary electrophoresis by the method Stack & Draw; our role was mainly to fabricate a specific fiber consisting of multiple holes but without an optical core. We briefly present the manufacturing processes of air-silica microstructured fibers that is often difficult. The tools that were available to us allowed us to respond to FMAS manufacturing needs.

Such a multiple capillaries air-silica fiber would be of great interest to improve the performances of capillary electrophoresis (CE). CE is a method of separation of analytes [5] (Biophotonics applications sensors and chemistry) that can be improved by developing such fibers, which will contain a large number of small holes (as regularly as possible) instead of one large hole like in usual capillaries.

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Surface plasmons at a single air - parallel-plate metamaterial interface

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Surface plasmon polaritons (SPPs) are electromagnetic excitations propagating at the interface between a conventional dielectric and an electron plasma [1]. The corresponding electromagnetic surface waves are evanescently confined between the two semi-infinite materials and have several interesting applications in waveguiding, light generation, enhancement of the Purcell factor of emitters near metal nanostructures, sensing and in the development of new photonic devices [1]-[2].

In noble metals the interesting regime of strong SPP confinement occurs at optical frequencies. On the other hand, at the terahertz and infrared regimes metals resemble perfect electric conductors, leading to weakly bounded SPPs. One solution to overcome this limitation is tailoring the metal surface with subwavelength corrugations [3]-[7]. Corrugated structures support "spoof" plasmon excitations that can mimic to some extent SPPs. However, spoof plasmons typically have a narrowband electromagnetic response. Another solution to imitate SPPs is to design a metamaterial that mimics an electron gas [8]. In particular, waveguides at cut-off have an electromagnetic response that resembles that of a plasma [9]-[11]. However, such analogies are imperfect and in practice the response of a metamaterial plasma may deviate considerably from that of an idealized electron gas due spatial dispersion effects. One important step towards the solution of this problem was taken in [11] by recognizing that in a waveguide scenario it is possible to drastically reduce the effects of spatial dispersion by adding metallic wires to the pertinent metamaterial interface.

Building on these ideas, here we develop a new analytical homogenization model to characterize the guided modes supported by a single interface formed by a regular dielectric and a parallel-plate metamaterial (i.e. an array parallel metallic plates embedded in a dielectric host). We highlight the importance of spatial dispersion effects in this

problem and discuss to which extent they can be suppressed. We numerically validated our results using a full wave electromagnetic simulator.

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XDental composite polymerization process: digital holographic interferometry method

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Photosensitive composites are extensively used for dental fillings [1]. It is well known that they contract during photo-polymerization and induce high internal pressures in the dental tissue [2]. We describe a digital holographic interferometry (DHI) technique which was used to obtain information about shrinkage of dental composite and corresponding deformation on the walls of MOD cavity during polymerization. A tooth model is used in order to verify the technique, using a well defined geometry and to avoid ethical issues connected with experiments on human teeth. A biomechanical tooth model with mesio-ocluso-distal (MOD) cavity was used to study the polymerization process. Experimental results were later compared to finite element method (FEM) calculations.

The model was placed in front of the spherical mirror at a distance of two focal lengths. A single laser beam (532 nm) was used to simultaneously illuminate both sides of the subject, the beam directly reflected from the mirror served as a reference. As a result, both sides of the subject were observed at the same time [3]. The holographic image was recorded directly on the CCD of a standard SLR camera: a very high resolution (4752 x 3168 pixels) - Canon EOS 50D, without using the objective. Registered holograms were processed calculating the Fresnel transform on the computer with nVidia (CUDA enabled) card which enables parallel processing [4]. As a result, the processing time of the hologram (2048 x 2048 pixels) is about 5 seconds.

When MOD cavity was filled with dental polymer, the process of polymerization was initiated using the blue lamp; during the polymerization one hologram per second was recorded. The process was finished after approx. 2 minutes. Interferograms were created by comparing the initial state with the current state (e.g. an insight into the deformation in twentieth second was be gained through comparison of hologram recorded in the twentieth second with hologram recorded in the first second), thus allowing for the dynamic monitoring of the entire process.

We investigated the mechanical deformation of tooth structure caused by polymerization of dental fillings. The process of polymerization is accompanied by contraction that is transferred to the tooth structure. Holographic interferometry has enabled us to determine the maximum deformation of tooth structure. A model of the tooth was made using stereolithography techniques, and we were able to use it in a real, holographic experiment, but also to calculate deformations by finite element method. The resulting interferograms were used for calculation of deformation and dynamic monitoring of the entire process.

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Curved fork-shaped hologram for producing optical vortex beams

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In this work we investigate a computer-generated hologram - interferogram between a conical beam (obtained by using an axicon) and a slightly inclined optical vortex beam with integer phase singularity p in azimuthal direction, as a diffractive optical element when being illuminated by a Gaussian laser beam. It is similar to the fork-shaped hologram (FH), which is obtained by interference between a plane wave and a tilted wave carrying topological charge p [1], except, now the fork-shaped dislocation arms are curved. Because of this, we named this hologram the curved fork-shaped hologram (CFH).

The light beam is incident with its waist in the hologram centre (where the fork-shaped singularity exists). The diffracted wave field amplitudes and intensities in the zeroth and higher diffraction orders are calculated and analyzed.

Optical vortex beams carrying phase singularity with charges mp and $-mp$ (m is the diffraction order), are the higher positive and negative diffraction order beams, deviated from the incident beam axis, and described mathematically by Bessel functions of the first kind. Also, they are nondiverging [2] in a defined propagation interval, due to the presence of the axicon phase function in the hologram transmission function. They differ from the vortex higher diffraction order beams generated by the FH, which are diverging and described by the product of mp-th order Gauss-doughnut function and a Kummer function, or by the first order Gauss-doughnut function and a difference of two modified Bessel functions, whose orders do not match the singularity charge value [3].
The amplitude reduced straight-through beam (zeroth diffraction order) is Gaussian beam. The specialization of the results when the hologram charge p=0 is also done.
Some applications of the obtained nondiverging, dark vortex (when $p \neq 0$) and bright (when p=0) cores in the higher diffraction orders, are proposed.

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Comparison of polarization holographic recording characteristics in thin films of pure azopolymer and azopolymer based hybrid materials

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Azopolymers are well known for their unique ability to record the polarization state of light due to the induced anisotropy under illumination with polarized light [1]. A number of studies during the last decade indicate that doping with nanoparticles (NP) optimizes the optical response of various photosensitive media [2-4]. An increase of the photoinduced birefringence in hybrid materials made from azopolymer and zinc oxide or silica NP was also recently reported [5,6].

In this paper we present a study of the parameters of polarization holographic recording in different materials – pure azopolymer PAZO (Poly[1-[4-(3-carboxy-4-hydroxyphenylazo)benzenesulfon amido]-1,2-ethanediyl, sodium salt]) and hybrid organic/inorganic materials based on PAZO and incorporated ZnO nanoparticles with size below 50 nm. For the recording, a laser emitting within the absorption band of the azopolymer is used. Diffraction gratings with different spatial frequencies are recorded by varying the interaction angle. The kinetics of the diffraction efficiency is probed with a diode-pumped solid-state (DPSS) laser at 635 nm. Parameters such the maximal saturated value of the diffraction efficiency, the response time, the time stability etc. of the materials are measured and compared. The results will allow us to optimize the process of recording in these materials aimed at applications such as holographic data storage and formation of diffractive optical elements with specific polarization properties.

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Experimental Study of the Plasmonic Superradiance

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Hybridization of quantum emitters and plasmonic nanostructures has attracted much attention over the last years, due to their interest in the design of novel optoelectronic devices and biosensors [1,2]. Yet, the physical interactions between nanohybrids are complex and still poorly understood. Numerous studies have been developed to uncover their behavior [3,4].

It has been recently theoretically predicted that, for an ensemble of dipoles located at the surface of a plasmonic nanoparticle (NP), the emission of a photon becomes a cooperative process involving all the dipoles and the metal nanoparticle. The cross-talking between emitters through plasmon oscillations leads to the formation of collective states known as superradiant states [5]. It is predicted that at large distance from the plasmonic core (distance larger than 10nm for a 32nm-NP), the energy transfer occurs mainly via optically active dipole surface plasmons. In this cooperative regime governed by the superradiant states, the corresponding decay rate scales with the number of emitters placed in vicinity to the core. Moreover, the authors also point out that the resulting cooperative emission can survive the Förster resonance energy transfer (FRET) that may occur between neighbor emitters. Yet, experimental evidence is still lacking to support the theory of plasmon-mediated superradiance near a metal NP. This is a due to the difficulty to create a system with precise control over the number of emitters and their relative distance to the core.

In this work, we experimentally investigate the plasmonic Dicke effect from the fluorescence characterization of organic or inorganic emitters grafted on plasmonic nanoparticles. The nanohybrids consist in gold nanoparticles coated with a homogeneous silica shell which acts as a spacer between the grafted emitters and the Au core. An ensemble study of RhodamineB-nanohybrids dispersed in ethanol revealed that the average decay rate scales with the number of grafted emitters, in agreement with theoretical predictions. Then for a large number of emitters (few thousands per NP), FRET between dyes was observed and the average decay rate was saturated. To observe homo-FRET-free superradiance, we performed single-particle spectroscopy on Atto532-nanohybrids embedded in a polymer matrix for varying silica shell thicknesses and smaller numbers of emitters (less than 300 per NP). Our results show that, in the cooperative regime, the decay rate scales with the number of emitters and is increased as the dyes get closer to the core, as predicted by Pustovit and Shahbazyan [5].

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Laser-induced microlensing as a power limiting, protective mechanism

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Self-induced microlenses are used to protect an imaging system against high power direct laser radiation. The idea is to utilize a material capable of producing negative (diverging) lens under the influence of the laser beam [1]. Material should bleach during irradiation in order to produce high quality microlens, reduce thermal load and prevent the material from being burnt or punctured. Phenomenological model of a laser-induced microlens formation on a bleachable material is developed. It is shown that the irradiance level is reduced several orders of magnitude due to diverging properties of microlens. The effect is twofold: radiation is diverted away from the input aperture of an imaging system, and the radiation cannot be focused by the imaging system [2].

To experimentally test the idea we used gelatine doped with eosin and tot'hema (trade name of a mixture of Fe-, Ni-, and Cu- gluconates) [3]. The material is soft, transparent everywhere except a region around 532 nm and capable of producing microlenses under the influence of the laser beam. We have shown that the material protects from up to 400 mW of direct laser radiation according to EN 207 and EN 208 standards [4, 5].

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Microstructures and oxides formation on structural steel by nanosecond laser irradiation

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Creation of various surface structures on the laser-irradiated materials and formation of metal oxides play an important role to improve the mechanical, physical and chemical properties of materials used in different fields of industry [1-4]. Therefore, the establishment of main mechanisms and optimal regimes of laser micro and nanostructuring of materials and regularities of oxides formation is an important task.

In the present study the multipulse laser irradiation (λ = 1064 nm, τ = 1 ns, f = 100÷500 Hz, $q = 4.4 \cdot 10^9$ W/cm^2) was used to create micro and nanostructures on the surface of high quality structural carbon steel at different conditions. Steel samples were moving along a computer given trajectory with a velocity of v = 0.2 cm/s. Steel samples were irradiated in ambient air, 3% hydrogen peroxide (H_2O_2) and ethanol (C_2H_5OH). Surface structures and composition analysis were examined by methods of optical and scanning electron microscopy. X-ray diffraction (*XRD*) was used to analyze a phase composition of irradiated steel samples. XRD spectra for various conditions of laser action have had different intensity profiles (peaks value, its position and width). Energy-dispersive X-ray spectroscopy (EDS) was used for elemental analyses.

Surface structures were examined by scanning electron microscope (SEM). The detected surface structures are strongly depends on environment conditions and parameters of laser irradiation. In particular, on the surface of steel samples irradiated in the ambient air, wave structures with a period of 1 μm, irregular structures with a size of 200÷2000 nm, grains with the size of 50÷200 nm, pores and irregular threadlike structures were observed. Quasiregular structures with a size of 100÷200 nm and plurality of pores with a size of 40÷600 nm were discovered on the surface of steel samples irradiated in the ethanol. On the surface of the samples irradiated in the environment of hydrogen peroxide numerous cracks and grain structures with the size of 30÷70 nm were observed. The reasons of these differences are discussed.

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Assessment of structural and optical properties of self-assembled photonic structures

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The great potential of self-assembled colloidal structures in several technological areas of modern photonics derives from the low cost and relative simplicity with which they are fabricated. The optical properties of this kind of medium are not only determined by the response of its isolated constituents but also by their spatial arrangement. When polystyrene spheres self-assemble in a periodic fashion, the spatially ordered variation of the dielectric function gives rise to photonic bands and thus the colloidal structure becomes a photonic crystal [1,2].

In this study, colloidal thin films were prepared by the spin-coating [3] and vertical deposition method [4]. By varying the spinning velocity, acceleration and duration of rotation, we obtained different number of colloidal crystal layers. Also, we have prepared opals (multilayer films) with the vertical deposition technique and compared the obtained structures with those obtained by the spin-coating method. In both cases, the thin films were fabricated by depositing colloidal dispersions of 300 nm polystyrene spheres onto microscope glass slide substrates.

The morphology of samples was studied by atomic force microscopy, while their optical properties were investigated by spectroscopic ellipsometry and UV-VIS-IR spectrophotometry. An appropriate model has been developed for the determination of the optical properties of the colloidal films by ellipsometry. In order to validate the model applied, the parameters obtained have been compared with those determined by means of transmittance measurements. From transmittance measurements, in the case of monolayer films, diffraction peak in the visible range was observed. On the other side, in the case of opal has been verified the presence of a photonic band gap which should be attributed to Bragg diffraction [5].

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Localization of light in a polysaccharide-based complex nanostructure

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Complex nanostructures are interesting research topic, due to remarkable properties for photonic applications [1]. Photonic structures are generated by many methods. Holographic method [2] has several advantages: it is simple and fast, capable of producing one-, two- and three- dimensional periodic nanostructures over a large area. We combine the holographic method with non-solvent induced phase separation to generate complex photonic structures.

Polysaccharide sensitized with ammonium dichromate was used as recording material. Photonic structures were fabricated as a volume Bragg reflection grating recorded with the single-frequency, diode pumped Nd-YAG laser, at 532 nm. After exposure, grating was chemically processed in a developer. The resulting Bragg layers, upon phase separation, is filled with polydisperse, almost spherical nanoparticles arranged in a random way.

We investigated optical bandgap properties in the complex nanostructure, as a measure of the photon confinement in the layer, and we have measured the backscattered light cone and determined the mean free path of light in structure. The width of backscattering cone indicates a weak localization regime.

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Transparent and conductive films from liquid phase exfoliated graphene

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Liquid phase exfoliation of graphite presents a promising route for large-scale graphene production [1]. We describe basic advantages and disadvantages of the controlled deposition of few-layer graphene using the Langmuir-Blodgett (LB) method, which is compatible with usage in transparent conductors [2,3]. The graphene sheets (GS) were exfoliated from graphite by ultrasonic treatment in N-Methyl-2-pyrrolidone (NMP) and dimethylacetamide (DMA) solvents. For comparison, graphene sheets were also exfoliated in a water solution of surfactants. We confirm a higher exfoliation rate for surfactant-based processing compared to NMP and DMA. Furthermore, we demonstrate that our films exfoliated in NMP and DMA and deposited with LB have a higher optical transmittance compared to films obtained with vacuum filtration, which is a necessary step for GS exfoliated in water solutions [4]. The structural, optical and electrical properties of graphene layers were characterized with scanning electron microscopy, atomic force microscopy, ellipsometry, UV/VIS spectrophotometry and sheet resistance measurements. Our facile and reproducible method results in high-quality transparent conductive films with potential applications in flexible and printed electronics and coating technology.

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Band structure of gap plasmon polaritons in stacked fishnet structures

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Metal-dielectric-metal fishnet structures in general consist of a single functional layer along the direction of propagation. They support different kinds of electromagnetic modes and highly confined gap plasmon polaritons (GPPs) in the thin dielectric layer are particularly interesting [1-4]. GPPs represent a promising platform for nanooptics and integrated optoelectronics due to their deeply subwavelength optical confinement [3]. There are many different designs that are exploiting fishnet structures and stacking single functional layers is one of the possibilities [5-6].

Here we are investigating the GPP modes arising in multilayer fishnet structures, consisting of different numbers of functional layers separated by dielectric spacers. Single fishnet structures considered here consist of Ag(40 nm)/SiO_2(20 nm)/Ag(40 nm) films perforated by 100 nm sized holes arranged in a 200 x 200 nm^2 periodic lattice, which leads to GPPs excitation at optical frequencies. Because misalignment of stacked layers is a common issue in real structures, leading to the formation of Moire patterns [7], we also investigate how much it affects the optical response of the stacks.

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Optical activity theory for the oxygen tetrahedra in doped $Bi_{12}TiO_{20}$

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In this work, Co, Cu and Ag doped sillenites ($Bi_{12}TiO_{20}$) are investigated in the spectral region 450-800 nm. The components n_x, n_y and n_z of refractive index n and components $\varepsilon_\perp$ and $\varepsilon_\parallel$ of dielectric constant ε are determined [1]. The relation between factor g and the indices of refraction for circularly polarized light is presented. The atomic static polarizability of doped gyrotropic crystals is also calculated [2].

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Ab-initio study of optical properties of alkali metal-intercalated graphene and MoS_2

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In nanoscience and nanotechnologies research and characterization of materials is available due to the large set of spectroscopic techniques. However, complete understanding of the results obtained this way requires accurate modeling, especially when it comes to novel materials. With the use of the high-end modeling codes, it is possible to simulate from the first principle more than few spectroscopic techniques. Using approaches based on density functional theory (DFT), including density functional perturbation theory, time-dependent DFT and many-body perturbation theory, implemented in Quantum Espresso software package [1], we study optical properties of graphene, graphene-related and other 2D materials based on first principle modeling techniques. The final goal of theoretical spectroscopy is a comparison between corresponding experimental data and theory as well as a tool to provide guidelines for new experiments.

In the past ten years the discovery of graphene and other 2D materials had started a completely new chapter in material science. Graphene, a single atomic layer of carbon atoms arranged in a honeycomb lattice, has been attracting remarkable attention for its unique properties ever since it was successfully isolated in 2004 [2]. After graphene,

other 2D materials appeared, among which MoS2 is. MoS_2 monolayer is a member of transitional metal dichalcogenides 2D materials family, it has a hexagonal structure, like graphene, with the monoatomic Mo plane placed between two monoatomic S planes, and it displays some interesting electronic and photocatalytic properties [3, 4].
Intercalation of atoms into layered materials is a well known method for providing new properties that are usually distinctly different from those of pristine materials. Intercalated graphene shows various fascinating physical properties lacking in pristine one [5, 6] that offers new possibilities for both applications and fundamental research. The monolayer MoS_2 doped with alkali adatoms has been suggested as possible answer to hydrogen storage problems and various energetic applications [7, 8].

We present results of performed ab-initio calculation within density functional theory formalism where we investigate optical properties of those structures.

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Boundary Influences to Changes of Molecular Nanofilms Optics

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The precise structuring of materials to the dimensions of the order of nanometer is of great importance in electronics, optoelectronics, high temperature superconductivity, biology, medicine, environmental protection and many other scientific and technological disciplines. Application of nanostructures requires knowledge of their fundamental physical (mechanical, electromagnetic, optical, etc.) characteristics [1]. Theoretical investigations of low-dimensional crystalline systems (nanostructures: ultrathin films, quantum wires, points etc.) have been intensified recently in order to obtain fundamental information relating to extremely different physical and chemical properties of material,

and also due to their wide practical application (technical and technological) in nano-, opto- and bio-electronics [2]. Specificity of these "tiny" structures is that presence of near boundary planes causes highly changed general properties of these materials and occurrence of nonspecific phenomena (as a consequence of quantum size and confinement effects [3]) in comparison to the properties of corresponding "large" samples.

Nevertheless, the uncharted part of low-dimensional samples properties is the one due to presence of physically different structure boundaries and changed fundamental energy parameters of elementary excitation systems at those boundaries, i.e. in the boundary layers. Changing values of these parameters that correspond to levels of intermolecular interactions in boundary regions has the important role in creating differences in physical properties of nanoscopic structures in comparison to corresponding bulk structures [4]. This was investigated in molecular crystalline nano-films, which are typical examples of optically active materials. Their properties are described using quasi-particle model of Frenkel's excitons and most essential results will be presented here.

This paper analyzes the influence of presence of boundary planes and boundary layers of crystalline ultrathin molecular film on energy spectrum and states of excitons. In addition, dielectric properties were investigated (their permittivity was determined). Analyzes were done using the innovated method of Green's functions, adapted for investigation of quantum structures [5]. In further investigation, the basic optical characteristics of the observed film are established, namely the reflection, refraction, transparence and absorption indices. Due to impossibility of analytical analysis of the impact of the boundary parameters on the changes of dielectric and optical properties of nanofilm as compared to the same properties of bulk, the software package has been created and developed and consequently applied on numerical analysis and graphic displays of the relation between microscopic (exciton) and macroscopic (dielectric and optical) properties in the function of the frequency of external electromagnetic field and for the specified set of values of the boundary parameters. Hence, it has been proven that outer environment of the film affects the given fundamental properties of a nano film, i.e. that their choice/change directly controls optical properties of the film.

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Photoluminescence of graphene quantum dots: approaches to tune their luminescence, size and structure

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Graphene quantum dots (GQDs) are a star member of graphene family and new type of quantum dots. They attracted a large attention from scientific community because of their tunable luminescence, high photostability against photobleaching, low toxicity and chemical reactivity as well as good biocompatibility [1, 2]. This new fluorescent nanomaterial is consisted of graphene sheets with diameter below 100 nm. Large number of hydrophilic functional groups in structure of GQDs makes them highly soluble in water.

GQDs can be synthesized with two different approaches: *bottom-up* and *top-down* route [3-5]. Bottom-up approach is based on condensation reactions between small carbon precursors. In contrast, top-down route includes graphene based materials as a starting material and their cutting into small round sheet-quantum dots. The economically favored procedure is *top-down* electrochemical oxidation of graphite electrode. Although GQDs show a great potential for bioimaging, the problem with their application in this field is low intensity of photoluminescence.

In this study, we prepared GQDs using electrochemical approach [5]. We investigated luminescent properties of GQDs at various excitation wavelengths. In order to examine possibility to improve these properties, we applied a low dose of gamma irradiation (20 kGy) on GQDs dissolved in two media: water and 3 % isopropyl alcohol solution. Upon gamma irradiation of water, various free radical species are formed that usually cause oxidation, while in the present of isopropyl alcohol oxygen contained radicals are quenched and only hydrogen radicals can survive and reduce material exposed to irradiation. Morphology of GQDs before and after gamma irradiation is examined with atomic force microscopy and transmission electron microscopy. After gamma irradiation the increase of photoluminescence was noticed for GQD samples. A higher intensity of photoluminescence is detected for GQDs irradiated in 3 % isopropyl alcohol solution. This result shows that further increase of gamma irradiation dose has a great potential for improvement of luminescence properties of GQDs.

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Semi-Analytical Treatment of Stacked Metasurfaces by a 4x4 S-Matrix Formalism

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The concept of metamaterials (MMs) was brought to life for nothing minor than revolutionizing optics. A three-dimensional MM ought to be a medium described by effective parameters enabling characterization even after stacking of similar or different MM. However, due to near-field coupling between sub-wavelength structured MM layers [1,2] or their environment, meaningful applications are limited to specific implementations of the MM and are useless whenever additional layers are added. Hence, a MM layer, which is to be treated as a material, necessarily has to be embedded into a homogeneous medium such that all higher diffraction orders decayed at its boundary. This decay manifests in the validity of the Fundamental Bloch Mode Approximation [3].
Although effective parameters seem very intuitive in their description, their retrieval becomes fundamentally more difficult when dealing with low-symmetry MM because they turn from scalars to tensors. Changing the paradigm from describing materials to designing functionalities puts the focus on transmission and reflection rather than effective parameters. To manipulate light comprehensively, as is desired for integrated optical devices, polarization control is of great importance and needs to be included in any theoretical formulation. The Jones matrix formalism comes to mind when thinking of stacking different layers to affect polarization. There however, reflection is neglected which is needed for a stacking of resonant of the MM layers. In our approach we choose a reduced 4x4 scattering matrix, short S-matrix, formalism [4] for the description of the MM's properties. Besides the design of functionality our focus lies on the creation of compact materials for use in integrated optics. Thus we restrict ourselves to the design and stacking of periodic metasurfaces (MS).

Such stacked systems can be reduced to a series of two-layer interactions. The basic problem is that of linking waves between layers that can either be adjacent or separated by other layers to understand the properties of the entire stacked MS. For the system to be completely characterized this has to be done for waves coming from both sides of the interface. Each layer can be fully described by a 4x4 S-matrix constructed by four 2x2 block matrices that give front and back transmission as well as reflection. The block matrices themselves contain the respective polarization state. Using the starproduct introduced by Li [4] multiple S-matrices can be intuitively connected. However, this entire approach solely works in the FMA regime since the S-matrix only allows for one incoming and one outgoing wave on each side.

The combinatory character of the starproduct implies an easy way to design functionalities from stacks of complex MS. It is possible to combine any number of layers or even stacked layers in arbitrary order. However, to ensure the validity of the FMA

separations between complex, periodic (metallic) layers have to be large enough. That calls for the introduction of homogeneous (dielectric) spacer layers. These can be calculated analytically from Fresnel and are easily implemented for varying distance into simulations. Given a certain set of single periodic layers, we then try to identify interesting features in their spectra and use them as building blocks for a combined target spectrum that is motivated by a desired functionality.

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Modification of optical and electronic properties of DC sputtered TiO_2 thin films by nitrogen ions doping

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TiO_2 thin films are of the great interest in modern material science because of many application possibilities of this material. One of the most significant is as a photocatalytic material in environmental physics. Hereof, achieving cheap and easy to apply method for depositing of photocatalytically active TiO_2 films is an important goal. Reactive DC sputtering could be one of those methods, which can be easily applied for producing large area TiO_2 covered materials. Main problem with TiO_2 thin films is that they exhibit photocatalytic properties just in UV region of light [1]. For visible light photocatalysis it is necessary to alter its optical and electrical properties.

In this work TiO_2 thin films were produced by reactive DC sputtering of Ti target in O_2 and N_2 atmospheres for different nitrogen partial pressures. After-deposition annealing was conduct in air or in nitrogen atmosphere, under different conditions. Compositional analysis of such material were done by XRD and RBS methods, optical properties were evaluated by UV/VIS spectroscopy and ellipsometry, while changes in electronic structure were detected by XPS analysis.

Anatase and anatase-rutile mixture TiO_2 thin films were obtained. We found that sputtering with added nitrogen atmosphere and different annealing conditions had an important impact on optical and electronic properties of TiO_2 films. In some cases, energy gap values were shifted towards visible region in comparison with TiO_2 thin film deposited without nitrogen atmosphere. Refractive index also showed important dependence of N ion concentration in material and annealing conditions. This work could

be of importance towards achieving TiO_2 thin film materials with defined optical and structural properties.

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Exact Analytical Solution for Fields in a Lossy Cylindrical Structure with Hyperbolic Tangent Gradient Index Metamaterials

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In the present paper, we study the electromagnetic wave propagation across a finite inhomogeneous and anisotropic cylindrical metamaterial composite containing both positive and negative effective refractive index parts with a spatial gradient described by a hyperbolic tangent function. Exact analytical solutions for the electric and magnetic field distributions are obtained for a hyperbolic tangent variation of effective refractive index across the structure. The proposed model allows for general temporal dispersion and uniform losses within the composite.

Most of the studies of anisotropic metamaterial composites usually consider structures with constant effective permittivity and permeability within the LHM part and abrupt transitions to the surrounding "right-handed media" (RHM). However, there is a growing theoretical and practical interest in composites with gradual spatially varying effective permittivity and permeability between LHM and RHM as well as within the LHM structure.

The LHM structures with gradient index are of importance for transformation optics [1, 2]. For instance, optical carpet cloaks [3] were reported with effective index gradient obtained by drilling hole arrays with varying geometry [4]. Other important applications include optical and generally electromagnetic concentrators based on metamaterials, beam shapers and beam steering devices, as well as different kinds of GRIN lenses. Finally, an important application is gradient index circuitry utilizing metamaterial waveguides [5].

The present study is a generalization of our previous work [6-9] to coaxial cylindrical structures with radial propagation of the electromagnetic wave. We present exact analytical solutions of Helmholtz equations for the radial propagation of electromagnetic waves through lossy hyperbolic tangent-index RHM-LHM composites.

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Time resolved luminescence spectra of YVO_4:Eu powder samples

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Rare earth doped yttrium vanadate (YVO_4) phosphors have found many applications [1]. In this study we investigate the time resolved luminescence spectra of nano powder samples of europium-doped yttrium vanadate, YVO_4:Eu. Europium is a phosphor suitable as red-emitting material that can be pumped with near-UV light emitting diodes. YVO_4:Eu nano powder samples were prepared using combustion synthesis, as described in [2].

The basic setup of our time resolved laser induced fluorescence experiment consists of Nd-YAG Vibrant OPO (Optical Parametric Oscillator) laser system and Hamamatsu streak camera. The output of the OPO can be continuously tuned from 320 nm to 475 nm. Our experimental setup is described in detail in [3]. For measurements presented in this study we used excitation in the range from 330 nm to 370 nm and obtained similar spectral characteristics of the YVO4:Eu samples as presented in [1,4-6]. However, our data, obtained by a streak camera, provide possibility of time resolved analysis. Several recognizable fluorescence bands were identified in emission spectra acquired on streak images, in visible region from 580 nm to 720 nm wavelength range. A pronounced peak at about 611 nm on the spectrum is in accordance with expectation based on the existence of f-f transitions that are responsible for luminescence in trivalent rare earth ions (Eu^{3+}) [3]. The most intense peaks are resolved between 610 and 635 nm, which are caused by forced electronic dipole transitions between $^5D_0 - {}^7F_2$ states.

The fluorescence emission is collected, by using the beam splitter, at the same optical axis as the excitation and dispersed by a 0.3 m focal length triple grating imaging spectrograph (SpectraPro-2300i). For measurements presented here the grating of 50 g/mm was used covering a 300 nm spectral range. The streak camera (HPD-TA) software was applied to determine fluorescence lifetimes of YVO4:Eu samples at various excitations, obtaining the values of about 0.5 ms.

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Thermal annealing for tailoring and stabilization of mechanical properties of polymer optical fibers

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In recent years, fiber Bragg gratings (FBGs) inscribed in polymer optical fibers (POFs) have attracted attention among fiber sensor community [1]. This notion is based on well-established silica FBG sensor technology [2, 3] and trying to exploit some of the advantageous properties of polymer materials to improve performance of the sensors. One of the key advantages of POFs is increased ductility which can yield sensors with much higher stress sensitivity and wider strain operation range than silica-based fibers. However, mechanical properties of polymer fibers can vary relatively widely depending on molecular alignment along the fiber, which is in turn strongly dependent on drawing conditions [4, 5]. This opens space for tailoring of fiber mechanical properties for particular application but at the same time complicates manufacturing process and characterization of POFs, as relatively small changes in drawing conditions can lead to dramatic changes of fiber performance. Thermal annealing, as an entropy driven process, leads to relaxation of molecular alignment accompanied by fiber shrinkage and change of its mechanical characteristics. In this work, we present systematic study of thermal annealing of polymer fibers as a potential mechanism for post-fabrication tailoring of its main mechanical parameters.

In the first step, annealing dynamics of homogeneous polymethyl methacrylate (PMMA) fibers with different level of molecular alignment were studied. Measurements based on fiber length monitoring indicate that fiber shrinkage follows stretched exponential decay function, suggesting heterogeneous dynamics of the process [6]. Relation between annealing dynamics and fiber molecular alignment is examined and underlying mechanisms are discussed. In the next step, influence of different level of annealing on fiber straining behavior was investigated. We demonstrate that molecular alignment and thus mechanical characteristics of the fiber can be effectively tailored by thermal annealing. Broad range of straining behavior can be achieved for fibers with high initial level of molecular alignment by controlling the annealing temperature. Further fine-tuning of mechanical parameters is possible by varying the annealing time. General

trends obtained for fiber ultimate stress and strain measurements are in agreement with previously published results studying relation between molecular alignment and fiber strength [4, 5]. Additional focus is paid to elastic region of fiber stress/strain curve. Moreover, annealing process is shown to decrease relative diameter fluctuations as well as mechanical behavior variation between fibers with initially different properties. Obtained results indicate that thermal annealing can be used for fiber post-fabrication processing in order to optimize and stabilize its mechanical behaviour.

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Simple analytical relation between vibration frequencies of linear XY_2 –type molecules

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Usual methods for calculation of vibration frequencies of molecules and single crystals are either numerical or based on empirical potentials. In this contribution we present simple relation between all three vibration frequencies of XY_2 – type molecules of symmetry $D_{\infty h}$ (e.g. the molecule CO_2) from one side, with masses and charges of nuclei in the molecule, from the other. The derivation relies on the symmetry adapted [1] Taylor expansion of the electronic energy of a molecule around the united atom configuration. In spite of simplicity and crudeness of this approximation, the formula is in reasonable agreement with the values based on experimental [2] vibration frequencies. Therefore, the formula might be useful for the interpretation of optical spectra of such molecules.

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Time Domain Modeling of Pulsed Flash Thermography by Finite Element Method

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The purpose of this work is to model pulsed flash thermography method in structures with defects of cylindrical shape by Finite Element Method (FEM) in time domain. Due to it is simplicity, usual way to model such structures is Finite Difference Time Domain (FDTD) method, but structural mesh of FDTD method is not optimal choice for modeling defects of cylindrical shape. Analysis of results obtained by pulse thermography performing experiments on a complex structure sample containing defects of different types and sizes located at different depths is presented in [1]. FDTD modeling of defects with square shapes is presented in [2]. Numerical modeling is used to interpolate surface temperatures for periods between two frames recorded by thermal camera. Due to pulsed nature of the flash source, finer mesh was required at incident area, while coarse mesh can be used through the sample, so uniform mesh of the FDTD method was not good choice.

In order to validate numerical model, experiments were provided with the test samples (TS), made of three different types of material panel with inserted defects of specified size, position and type. The sequence of thermograms obtained by experiment was used to extract the surface temperature evolution curves above the defective and non-defective sample areas [3]. These evolution curves were used for comparison of the experimental results and results obtained by numerical modeling. Furthermore, thermal contrast evolution curves were used to analyze the differences in results obtained experimentally and through modeling [4].

Extraction of meaningful data from experimental results obtained by IR pulsed flash thermography used for defects detection on aluminum, iron and brass TS with cylindrical holes was presented in [5]. Two photographic flashes (BOWENS BW-3955 Gemini R and Pro) were used to heat the test surface. The non-stationary propagation of heat, leading to a temperature distribution on TS surface, was monitored by means of a thermal camera (SC620 FLIR).

The change in temperature distribution on the TS surface, between two frames, was determined by a three-dimensional numerical model of the TS, specially developed for this study, based on the finite element method (3D FEM). The numerical model was validated by comparing with recorded thermal images.

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Calculations of changes of optical properties of pernigraniline base polyaniline upon exposure to oxygen and humidity

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Due to its unique properties [1, 2], and extensive applications [3, 4], polyaniline (PANI) is one of the most investigated organic materials. The one of the still unresolved issues concerning this material is its peculiar behaviour on exposure to oxygen and humidity [5]. From that reason we have investigated the changes of optical properties of the pernigraniline base (PB) PANI upon exposure to oxygen and humidity by semi-empirical quantum mechanics, and ab-initio Hartree-Fock calculations using the HyperChem software package [6]. The equilibrium conformations, infrared (IR), and electronic (UV/VIS) spectra of the pristine PB oligomers of various lengths, and after attachment of oxygen and OH groups at various positions of PB molecules are determined. The vibrational modes and electronic transitions that change the most upon oxygen and OH group attachment are identified, providing the orientation point for their spectroscopic detection. The results are compared to existing experimental data and to results of similar calculations, and the possible implications for the applications of different forms of PANI have been discussed.

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Laser processing of Al/Ti multilayer system

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Due to low specific weight and high brittleness and hardness, titanium aluminides may become interesting for applications as medical implants. The biocompatibility of titanium implants is associated with the surface titanium oxide (2 – 7 nm thick) and not with the bulk titanium [1]. It is generally accepted that creating an appropriate porous structure on the Ti-based implant surface is very important when biocompatibility is a great concern. Chemical and thermal roughening procedures induce contamination, while laser enables surface treatment without direct contact and an easy control of the surface roughness [2].

Multilayer structures, consisting of 5 alternate Ti and Al films, and covered with thicker Ti layer, were deposited on a Si substrate to a total thickness of 200 nm. Laser treatment was performed in air by defocused Nd:YAG laser pulses (150 ps) with two different energies, covering an area of 3 mm in diameter, (corresponding fluences were 0.06 and 0.1 J cm^{-2}). Laser beam was scanned over the 5x5 mm^2 surface area. Scanning speed was chosen on that way to provide different overlapping of laser spots. Characterizations were done by X-ray diffraction, Auger electron spectroscopy, X-ray photoelectron spectroscopy, atomic force microscopy and transmission electron microscopy.

Obtained results show that irradiation with picoseconds laser pulses leads to the mixing between titanium and aluminum layers and to the formation of Al-Ti intermetallic compounds. Titanium aluminides have been found to exist in three different phases, but only Ti_3Al and TiAl phases can be of engineering significance [3]. In this experiment was registered the formation of just these two phases. Processes of intermixing were more pronounced for higher value of totally transferred energy to multilayer system. Higher value of laser energy induces undesired ablation of surface material.

Laser processing induces surface melting and transformation of relatively flat surface into mosaic shaped one consisting of interconnected micro-cracks. These micro-cracks are overlaid by thin TiO_2 layer (about 5 nm thick) and represent ideal places for cell adherence, migration and proliferation.

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Surface nanostructures on surface of multilayered thin films induced by femtosecond laser beam

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The area of apllication of thin films is wide, from optics to semiconductor technology, from chemistry to mechanics. Some of the applications, like filtering, coatings (reflection/antireflection), diffusion barriers, waveguiding, sensing, protection and decorative purposes could be mentioned. The structuring of thin films can enhance their characteristics. The interaction of ultrafast laser beams with thin films in order to modify their surfaces gains more and more interest. Such interaction yields the generation of nanoparticles which tend to regroup on the surface and form the structures. Nanoparticles are of great interest due to their position between bulk materials and atomic/molecular structures. Graphene is a material of outstanding electronic, optical, magnetic, thermal and mechanical properties, and Al/Ti films have an important mechanical applications due to their extraordinary wearing behavior and corrosion resistance.

For exposition of the samples, we have used low-fluence fundamental and frequency-doubled femtosecond beam of 76 MHz of repetition and different wavelengths. The beam was generated by Coherent Mira 900 system accompanied by Inrad 5-050 SHG. Exposed thin-film samples were: Al on Si, Al/Ti multilayer on Si and multilayer graphene on SiO_2. The exposition yielded the generation of nanoparticles and the formation of subwavelength laser-induced periodic surface structures (LIPSS). In Al and Al/Ti samples, spatial period and width of LIPSS were ~320 nm and ~200–220 nm, respectively [1]. In graphene, preferential radius of nanoparticles was ~18 nm; spatial period and width of LIPSS were ~70–100 and ~35 nm, respectively [2]. The processes of liquid or solid-state dewetting could be responsible for regrouping of generated nanoparticles and nanoparticle clusters on the surface. Regrouping in the form of LIPSS is most probably governed by the occurrence of the surface plasmon polariton. The presence of the sublayer, depending on its optical characteristics, strongly influences both the shape and the quality of the LIPSS.

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Wavelength dependence of laser shock peening on Ni – based superalloy surface

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Microstructure modifications of the nickel based superalloy Nimonic 263 surface, irradiated by the infrared and visible picosecond Nd:YAG laser pulses to induce a laser shock peening (LSP) process on the surface were studied and compared.

Absorbent material, as the overlay (black paint), was applied onto the surface and subsequently, the samples were submerged into the transparent liquid – water. Laser beam parameters were: maximum output pulse energy of 60 mJ; pulse duration of 150 ps; wavelengths of 1064 and 532 nm and 10 Hz repetition rate. Modified surface areas obtained by the laser/material interaction were observed by scanning electron microscopy. Elemental composition of the modified surface was evaluated by energy dispersive spectroscopy. Vickers microhardness tests were also performed.

LSP processing at both 1064 nm and 532 nm wavelengths produced the favorable phases, improved the structure and microhardness of target material. However, the LSP at 1064 nm produced the finer structure, but on the other hand some unfavorable phases were also recorded. Surface morphology changes of the irradiated samples were determined and surface roughness was calculated. The average surface roughness parameter after the LSP has decreased comparing to original surface in both cases, but overall, better results are obtained by using 1064 nm wavelength LSP processing. The microstructures arisen by different processing parameters were analyzed and discussed. These investigations contribute to the understanding of the microstructure and mechanical properties improvements due to LSP processing of the superalloys.

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Laser irradiation of 5(Ni/Ti)/Si multilayers at different wavelengths

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Studies of the specific and complex systems, such as multilayered thin films deposited on a substrate, are highly desirable, primarily due to the existence of new, improved properties of the system, different from the uniform, bulk material properties [1]. The nickel-based multilayer and alloy, the subject of this investigation, possesses extraordinary physico-chemical and mechanical characteristics [2]: high corrosion resistance, electrical conductivity, super-elasticity, high strength and ductility, etc. Laser-induced modifications of solid materials, particularly those limited on the sub-surface region, is used for material processing in many ways: micro- and nano-scale machining in microelectronics, forming stable metal nanoparticles, creating desired surface micro- and nano-patterns and modifying the composition and chemical state of the irradiated surface.

A study of the effects of laser irradiation on the morphology and composition of Ni/Ti multilayers induced by nanosecond laser pulses at different wavelengths is reported. Multilayers of 5(Ni/Ti)/Si were deposited by dc ion sputtering on Si(100) substrates in a single vacuum run to the total thickness of 210 nm. Irradiation of complex target was done by a Nd:YAG laser which operate at a 1064 nm wavelength, frequency doubled wavelength (532 nm) and dual-wavelength (1064 nm and 532 nm). Pulse duration is 100 ns and the intensities were in the range 2.5×10^{8} - 4.2×10^{9} W/cm^2. The energy absorbed from the laser beam is partially converted to thermal energy, which generates a series of effects, such as melting, vaporization of the molten material, shock waves, etc. The following surface morphological changes were observed: (i) ablation of the thin film during the first laser pulse. The boundary of damage area was relatively sharp after action of one pulse whereas it was diffuse after irradiation with higher energy per pulse; (ii) appearance of some nanostructures (mosaic structure) in the irradiated region; (iii) appearance of the microcracking. The results obtained show that laser irradiation induced mixing between Ni and Ti layers which creates conditions for the formation of intermetallic compounds. A numerical model was used to predict ablation depths and temperatures inside the material during the time. The model prediction shows a close agreement with experimental data.

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Optical properties of zinc oxide nanostructures prepared by laser assisted technique

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Due to the physical and chemical stability, low toxicity in combination with direct wide band gap (3.37 eV) and large exciton binding energy (60 meV) zinc oxide based nanomaterials are considered as promising candidates for applications in blue/UV light emitting diodes, piezoelectric transducers, gas sensors, photocatalysts, optical coatings, varistors, etc. Usually, as-grown ZnO exhibits n-type conductivity due to native defects such as zinc interstitials and oxygen vacancies. The reliable p-type doping is still a major problem, although there have been some reports on the realization of p-type ZnO using a dual-acceptor doping method, where two acceptors such as Li–N, N–As and N–Ag could be simultaneously introduced.

In the present paper to prepare doped ZnO NPs we used laser irradiation processes in two different ways. First, ZnO NPs were synthesized by two step process which involved a sequential laser ablation of Zn (N1) and Ag (N2) targets in the 0.01 M ammonium nitrate solution followed by the additional laser irradiation of the formed colloid with the second harmonic of the Nd:YAG laser (532 nm, 90 mJ). Second, laser ablation of Zn target in the mixture of Ag colloid in ethanol and NH_4NO_3 (N3) was used. The laser ablation experiments were carried out by focusing of radiation of the Nd:YAG laser (LOTIS TII, LS2134D), operating in a double-pulse mode at 1064 nm, on the surface of a target placed in the cell filled with a solvent (repetition rate 10 Hz, pulse duration 10 ns, pulse energy 50 – 80 mJ). The resulting NPs were characterized by TEM, XRD, SAED and UV-vis optical absorption, Raman and FTIR spectroscopy.

It was shown that laser ablation of Zn target in 0.01 M NH_4NO_3 solution (N1) resulted in the formation of two types of particles: rod-like and spherical with a size of 30-50 nm. However, the phase composition of both types of particles is analogous. The major phase was polycrystalline ZnO with the hexagonal zincite structure. The ablation of Ag target in the solution N1 resulted in the transformation of rod-like particles into spherical ones (N2). The analysis of SAED patterns of the N3 sample showed that the NPs are composed of ZnO in zincite structure and of cubic Ag. Laser irradiation of NPs in the third sample resulted in the distortion of the lattice and disappearing of Ag reflections that may be the consequence of doping of ZnO or alloying of Ag and Zn NPs.

Raman and FTIR spectra of the formed NPs confirmed the formation of ZnO in zincite structure after laser ablation. The FT-IR spectrum of the prepared ZnO NPs showed the broad peak at 435 – 544 cm^{-1}, that is characteristic to zinc oxide and is related to the stretching vibrations in Zn–O. Raman analysis of the samples showed that for the sample N3 the fundamental optical modes A1 (TO) and A1 (LO) were observed at 381 and 553 cm^{-1}, respectively. The A1 (LO) mode is known to be related to the defects such as

oxygen vacancy, interstitial Zn in ZnO. Moreover the line at 493 cm^{-1} is observed that can be used to confirm the incorporation of Ag in the ZnO lattice [1].

The absorption spectra of the as-synthesized nanocrystals revealed two prominent absorption bands in the UV-visible region. The peak at 360 nm can be attributed to the excitonic absorption of ZnO while the peak around 415 nm corresponds to the plasmon absorption band of Ag NPs. The appearance of two kinds of characteristic absorption bands also confirms that the as-synthesized samples are composed of zerovalent Ag and ZnO. Additional laser irradiation of the N3 colloidal solution resulted in the merging of the bands resulting in a weak excitonic peak and a broad absorption in the range of 400–600 nm. This can be indicative of the formation of the ZnO/Ag nanocomposite.

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Influence of the chirality magnitude on the reflection and transmission group delays in terahertz chiral metamaterials

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As the terahertz (THz) technology is a very attractive research field with a wide area of applications [1], it provides a continuous motivation for the search of novel materials which can be used in the THz spectral range. The resonant response of THz metamaterials is typically fixed by their structural geometry and dimensions which limits their capability for manipulation of electromagnetic waves. On the other side, THz chiral metamaterials have been established as very efficient in controlling the state of polarization and enabling full exploitation of the attractive applications of THz radiation [2]. One of the main characteristics of chiral metamaterials is the optical activity which in chiral media can result in negative refraction and negative reflection [3].

Recently, the group delay has been proven very convenient for control of the THz electromagnetic signal used for filters, waveguides and polarization components [4]. Here, we investigate the change in propagation of a THz pulse via group delay in a chiral metamaterial. When varying the magnitude of the chirality parameter, a significant modification of electromagnetic fields across the slab is observed. This influences the reflection and transmission coefficients of left-circularly (LCP) and right-circularly (RCP) polarized waves, as well as the corresponding group delays. In this kind of medium, there are bireflections which appear due to different refraction indices of RCP and LCP waves [5]. The interesting result was that the group delays of reflection were the same for RCP and LCP waves and the chirality parameter did not have an influence on it.

In the case of transmission, coefficients of RCP and LCP waves were different and the influence of chirality was high, which opens up a possibility for potential applications. After the calculations were performed for the case of normal incidence, we extended our study to the case of different angles of incidence.

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Raman spectroscopy study of graphene thin films synthesized from solid precursor

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Raman spectroscopy is very important tool for the study of different allotropes of carbon, since it is very sensitive to geometric structure and bonding within molecules [1]. In this work we present Raman spectroscopy study of graphene thin films obtained by rapid thermal annealing (RTA) in vacuum. As a carbon source, we used spectroscopic graphite electrodes cut into small pieces and polished with diamond pastes. After that, we deposited copper/nickel (Cu/Ni) thin films on the sample surface and the samples were annealed at different annealing temperatures (600 ºC, 700 ºC, 800 ºC and 900 ºC) for 30 min.
Raman spectroscopy study showed that annealing at lower annealing temperatures (600 ºC and 700 ºC) leads to formation of single layer graphene thin films with relatively high level of defects. Annealing at higher annealing temperatures (800 ºC and 900 ºC), on the other hand, resulted in formation of homogenous multilayer graphene thin films. From Raman spectra, we also concluded that samples annealed at higher annealing temperatures have lower level of defects comparing to the samples annealed at lower annealing temperatures.

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Photoluminescence Study of CuSe Thin Films

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This paper describes photoluminescence study along with XRD and reflectance R(λ) measurements of CuSe thin films. The films of tree different thicknesses (56.75, 79.74 and 172.70 nm) were grown by thermal evaporation on glass substrate, at room temperature and pressure better than 1 mPa. X-ray diffraction pattern indicates that CuSe thin films have a preferentially oriented crystal structure, with no random distribution of crystallites. Reflectance measurements were used to estimate optical bandgap (both direct and indirect). Photoluminescence measurements are performed in the temperature range from 20 K to room temperature. At room temperature they reveal two main peaks: one in low – frequency region (≈760 nm), and the other one in high – frequency region (≈530 nm). At low temperatures, one more peak can be distinguished beside the two ones mentioned, in the middle – frequency region (≈700 nm). Comparing with the spectra of glass substrate, we concluded that high – frequency and middle – frequency peaks belong to substrate, but the low – frequency peak originates from our material – CuSe. We dedicated this peak to indirect transitions in CuSe. That is in consistence with results of reflectance measurements, but a bit bigger than in literature [1,2].

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Efficient electron injecting layer for OLEDs based on $(PLAGH)_2[ZnCl_4]$

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Herein the new organic light emitting diode is introduced using $(PLAGH)_2[ZnCl_4]$ ($PLAGH^+$ = pyridoxalaminuguanidiniumcation) as an electron injecting layer in poly[(9,9-dioctylfluorenyl-2,7-diyl)-co-(1,4-benzo-2,1′,3-thiadiazole)] (F8BT) based OLEDs. The device structure that is created is

glass/ITO/PEDOT:PSS/F8BT/$(PLAGH)_2[ZnCl_4]$/Al, and the reference device for comparison is the same one, but without $(PLAGH)_2[ZnCl_4]$ layer. $(PLAGH)_2[ZnCl_4]$ was deposited from its water/methanol solution via spin-coating. In particular, this research shows that the incorporation of $(PLAGH)_2[ZnCl_4]$ at the polymer/Al interface improved the luminous efficiency of the device (from 2.6 to 3.32 cd/A) and reduced the turn-on voltage, whereas an up to 3-fold increase in brightness (~14106 cd/m2 for $(PLAGH)_2[ZnCl_4]$ compared to ~5850 cd/m2 for the reference device) was observed.

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Fabrication and optical characterization of nano scale zinc oxide layers on porous silicon substrates

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Zinc oxide nano and microstructure on porous silicon substrates are characterized by optical methods. In this work we produce thin films of zinc oxide on porous silicon substrates ranging from a bulk film with 100% coverage to layers consisting of micro and nanoscale structures with lower degrees of coverage. Sample configurations are fabricated by varying synthesis parameters of the hydrothermal method [1]. Zinc oxide layers are characterized using scanning electron microscope and UV-visible-near-IR spectroscopy. In the last the zinc oxide nanorods on porous silicon structure is used to make a guided medium for light. The refractive index of porous silicon substrate was made less that the zinc oxide nanorods so that due to total internal reflection the light remains inside the nanorods.

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Optimization of molecular beam epitaxy growth conditions for InSb based mid-wavelength infrared detectors

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Mid-wavelength infrared (MWIR) detectors are devices of interest mainly due to their possible application in gas detection, human body radiation detection or thermal imaging. InSb, due to its small band gap, is a perfect candidate for detection of MWIR radiation in the wavelength range from 3 to 7 μm. Although InSb based MWIR detectors have already been reported [1], the growth of InSb in molecular beam epitaxy (MBE) process still remains a challenge. The main reasons causing problems are the low melting point of InSb (527 °C), the low substrate temperature during growth, and the big lattice constant, which complicates the growth of heterostructures.

To optimize the growth conditions of InSb on semi-insulating GaAs substrate a series of samples was grown and characterized. Each of the samples consists of a 500 nm thick InSb layer grown on a semi-insulating GaAs substrate. During the optimization the following growth parameters were changed: duration of the oxide desorption, the substrate temperature during growth and Sb/In flux ratio. The smoothest sample has a root mean square (RMS) roughness of 4.6 Å measured by atomic force microscopy (AFM). It is only about 2.2 times bigger value than the RMS roughness of the surface of a commercially available epi-ready InSb wafer. High resolution X-ray diffraction (HRXRD) measurements indicate that the InSb layers are almost fully relaxed in our samples. The calculated relaxation level is 99.3%.

Based on the growth optimization we were able to grow an InSb p+-p$^-$-n+ MWIR detector structure on a GaAs substrate. To suppress the diffusion current of the p-i-n photodiode a 20 nm thick $Al_{0.18}In_{0.82}Sb$ barrier layer was implemented into the structure [2]. Under zero bias condition processed devices work up to temperature of 48 °C. Although some more efficient designs for infrared detectors have already been proposed (e.g. cascade infrared detectors [3]), InSb-detectors based on a p-i-n junction are interesting for several reasons. The efficiency offered by those detectors is sufficient for some applications, the design is much more simple and the manufacturing costs are lower compared to more complex structures.

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Can negative-index all-dielectric metamaterials be ever made?

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The square array of cylindrical dielectric rods, aligned parallel to the electric field, is one of the simplest periodic structures that was studied as a photonic crystal (PhC), and, independently later, as a metamaterial (MM) with a possibly negative index of refraction [1]. Using finite-difference time-domain simulations and a robust algorithm for unambiguous refractive index retrieval, we illustrate [2] how a continuous variation of structure parameters causes a qualitative transition between the PhC and MM regimes.

- If the dielectric permittivity is high, e.g. $\varepsilon_r = 100$, an allowed band of negative effective refractive index can be formed in an overlap of the regions of negative permittivity (caused by the electric Mie resonance) with that of negative permeability (caused by the magnetic Mie resonance). Both resonance frequencies obviously depend on the rod radius r, but also on the unit-cell size a. For an array too sparse ($a > 12\ r$), the regions of negative permittivity and permeability do not overlap.

- In the opposite case, for a denser array ($a < 8\ r$), a different mechanism prevents achieving negative values of the effective refractive index: The circular nodal planes that were characteristic for individual Mie resonances join with those of neighbouring cells, changing their topology to a continuous one, typical e. g. of dielectric mirrors or other one-dimensional PhC. In the spectrum, both individual Mie resonances abruptly merge, their resonance peaks disappear and an ordinary (Bragg) forbidden band is formed.

We have shown that an array of dielectric rods or similar structures can exhibit a negative index of refraction in a narrow range of frequencies, however with much stricter requirements for the filling fraction than previously thought [1]. For this to happen, the dielectric permittivity contrast must be higher than ca. 50, which is possible in the terahertz range, used for the simulations, if the rods are made of e.g. titanium dioxide or ferroelectrics. However, to our knowledge, there is no dielectric material exhibiting such a high permittivity at the near-infrared or optical frequencies.

We conclude that, with the current state of the art, no metamaterial seems to capable of having negative index of refraction in the optical range if it consists of dielectrics only.

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All-optical surface micro-patterning by electric field intensity gradient

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All-optical or direct writing technique is a comparatively new solution for lithography and provides new experimental techniques for better understanding of the interaction between the light and matter. The demand of lower cost surface-relief based optical instruments such as grating-based resonators or filters for waveguides, diffractometers, spectrometers, etc. is one of the main driving forces for the investigation of direct light-induced relief formation. The most common techniques for fabricating and investigating these surface-relief gratings involve an interferometric or holographic recording setup. We have investigated that the light-induced mass transfer process strongly depends on the material itself and polarization of the light. The behavior of mass transfer and thus the resulting recording could be related to interaction between the polar photo-induced defects and the polarized electric field of recording beam. It has been shown that the mass transfer can be directed both ways – towards or away from the electric field intensity gradient. The evolution of surface relief in dependence from the recording time and polarization has been investigated in detail. The mechanism of the direct recording of surface relief on amorphous organic and inorganic films based on the photo-induced plasticity has been discussed.

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Adhesion and friction studies of metal nanoparticle arrays for optoelectronic devices

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Characterization of surface processes such as friction and adhesion at nanoscale level are important design factors for nano, optoelectronic and sensor devices. Metal nanoparticle(NP) arrays deposited through ultrathin anodized aluminium membranes are one of the nanosize particle production technique.

In the present work, we have manipulated metal nanoparticles with atomic force microscope (AFM) in order to quantify the adhesion and friction force between the nanoparticles and the substrate. Under ambient conditions, the nanoparticles with diameters of 20-80nm adhere to a substrate until a critical applied force is reached by the probing tip [1].

The influence of critical parameters such as NP size, shape and contact area to the substrate during the manipulation was investigated and discussed. The operating conditions (temperature, humidity, scan velocity of the tip [2]) and substrate structure are shown to have a strong effect on the mobility of the particles.

This study is expected to provide information and approaches useful in the design of optoelectronic devices based on metallic nanoparticles for nanoengineering and nanosystems.

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Nonlinear Absorption of $InAs_{1-X}N_x/InP_{1-Y}N_y$ Superlattices

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The study of new semiconductor materials is important from a fundamental point of view and for the ever increasing number of applications in optoelectronics and understanding the properties of new bulk semiconductors has attracted renewed interest in the solar cell material arena to avoid environmentally unfriendly materials such as Cd [1]. Concrete progress requires accurate and simple modelling that can predict optical properties and become a tool for numerical characterization and massive scale device design from the ultra-violet to the THz range [2,3]. The importance of the Coulomb interaction, many body and correlation effects for realistic semiconductor simulations is now a well-established fact from bulk to quantum dots and the associated nonlinear effects become significantly pronounced when a semiconductor is highly excited with light fields or electrically injected carriers [4]. Strong light fields create electron-hole pairs, which in turn constitute quantum mechanical many body systems that interact in various ways, e.g. band gap renormalization, band filling and Coulomb enhancement, screening and dephasing arising from the attractive and repulsive scattering processes from electrons, holes, phonons and impurity defects. At low temperatures and small carrier densities, excitonic effects dominate the optical absorption of bulk semiconductors and the excitons are bleached as the temperature increases and excitation densities increased due to a

combination of screening, band filling and dephasing effects, which are also crucial at higher temperatures and densities [4]. This paper delivers very simple and accurate formulas for both the nonlinear absorption and luminescence of both anisotropic and isotropic cases. $InAs_{1-x}Nx/InP_{1-y}Ny$ dilute semiconductor superlattices, see Fig.1, described by an anisotropic medium approach [5,6] are used as a concrete example where the anisotropy can be designed and controlled to highlight completely general conclusions: the absorption and nonlinearities increase with anisotropy. This can potentially bring together the research of teams working in different fields, since new bulk materials for solar cells are typically strongly anisotropic and would thus also be useful for nonlinear optics.

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Vibrational properties of eulytite crystals $Bi_4M_3O_{12}$(M=Ge, Si):Ab initio study

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The eulytite crystals $Bi_4Ge_3O_{12}$ and $Bi_4Si_3O_{12}$ have many applications as scintillators, optical devices and laser materials after doping with rare earth ions. In this paper we give the results of a DFT calculation of vibrational properties of these crystals, in the center of the first Brillouin zone. First, the geometry optimization was performed using the analytical energy gradients, with respect to atomic coordinates and unit cell parameters. Vibrational wave number and normal modes were calculated within the harmonic approximation by diagonalizing the mass-weighted Hessian matrix.

The IR and Raman spectra of both crystals were simulated with the periodic ab initio CRYSTAL 09 cod [1], by adopting an all-electron Gaussian-type basis set and the B3LYP HF-DFT hybrid functional. The two sets of Transverse-Optical and Longitudinal–Optical frequencies are generated, together with their intensities. The obtained results are discussed and the agreement between the computed spectra and experimental data [2,3] are quite satisfactory, which justify the model and simulation scheme used for the title system.

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Electromagnetic properties of surface electromagnetic waves supported by anisotropic hyperbolic metasurface

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The latest developments of optical metasurfaces can exhibit extraordinary abilities for controlling the flow of light. Metasurfaces bring a lot of features in the imaging, sensing, data storage, modern planar fabrication technology and other applications [1].

In this work, we study a special class of metasurfaces characterized by a local diagonal anisotropic conductivity tensor. We have presented a comprehensive analysis of surface waves propagating along hyperbolic metasurface. We have shown that the spectrum of waves supported by hyperbolic metasurfaces consists of two branches of hybrid TE-TM polarized modes, that can be classified as quasi-TE and quasi-TM plasmons. Dispersion properties of these waves are strongly anisotropic, and they have some similar features with magnetoplasmons [2] and two-dimensional TE and TM plasmons. We have shown that hyperbolic metasurfaces support simultaneous propagation of both quasi-TE and quasi-TM plasmon surface modes at the same frequency in the certain range of propagation angles like Dyakonov surface states [3].

The contours of equal frequency for surface plasmons were investigated. The polarization varies from linear to elliptic or circular depending on the wave frequency and propagation direction. Also we analyze the losses and derive the corresponding analytical asymptotic expressions. Unique electromagnetic properties of hyperbolic metasurfaces make them quite promising for applications in many areas such as resonance sensing and detection, superlensing and near-field imaging, enhanced Raman spectroscopy, optical antennas, on-chip optical networks, etc. Taking into account their fabrication simplicity, rich functionality, and planar geometry it is possible to assert that hyperbolic metasurfaces can be a basis of many optical and optoelectronic devices.

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Large and flat graphene flakes produced by exfoliation of highly oriented pyrolytic graphite: Raman spectroscopy study

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In this study, we present a simple, green and cost-effective electrochemical exfoliation approach to high quality graphene flakes by using highly oriented pyrolytic graphite (HOPG). The highly oriented pyrolytic graphite (anode) and platinum (cathode) were placed vertically from bottom and top of the electrochemical cell with ammonium persulfate $(NH4)_2S_2O_8$ aqueous solution as electrolyte. Exfoliated HOPG was dispersed in dimethyl formamide (DMF). Obtained suspension was deposited by vacuum filtration on ano-discs with pore size of 200 nm. Deposited graphene thin films were transferred to glass substrates. Transferred thin films were characterized by atomic force microscopy, Raman spectroscopy, UV/ VIS spectrometry and four point method. Sheet resistivity of thin films was in the range from 100 to 1500 ohms per square.

Extraction of Dielectric and Magnetic Material Properties for a Periodic Hole Array THz Filter

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With the increase in optical applications in the terahertz frequency range there is a greater need for devices that work at these frequencies. One such device which has applications which range from spectroscopy to imaging is the band pass filter. The frequency selective nature of this component can be used for filtering noise during signal processing or can be even used for reducing radiation background levels for imaging purposes [1, 2]. The simplest form of this filter structure has been shown to be that of a free-standing metal sheet with a hole array. The frequency selective nature of the filter is realized by changing the structural parameters of the hole array with respect to the propagating input THz wave. Due to the sub-millimeter wave nature of the radiation the patterns are easier to fabricate for low frequency terahertz radiation applications (<1THz). Here, by using a high power Yb:doped pulsed nanosecond fiber laser system with exceptional beam quality, aluminum metal surfaces were machined with high precision leading to a high quality band pass filter that was shown to work in the terahertz frequency range [3]. We modeled the THz transmission through the the structure that was produced using FDTD simulation tools and also characterized them using the existing home-built time-domain terahertz spectrometers in our laboratories. Results of FDTD simulations are found to be consistent with transmission coefficient which is obtained from the experiment. In order to understand the efficiency of the composite structure which can be described as a frequency selective surface, the electrical permittivity (ε) and magnetic permeability (μ) is extracted from the transmission and reflection simulations [4]. The significance of these values is discussed with respect to the width and transmission observed for the fabricated and measured filter.

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