Surface Modification of Wide Bandgap Semiconductor GaN Using Femtosecond Laser Induced Periodic Surface Structuring (LIPSS)

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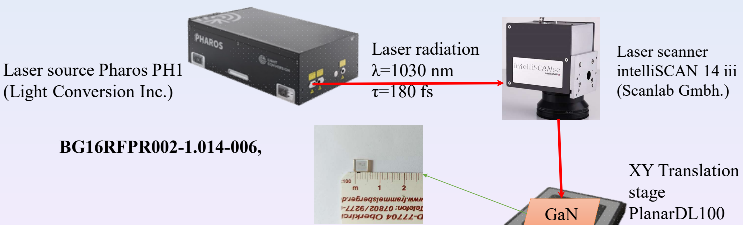
Introduction: Femtosecond laser induced periodic surface structures (LIPSS) is a no contact, low-cost technique used for structural surface modifications of wide range of the materials (metals, semiconductors and isolators), with the aim of surface functionalization of said materials to be used in wide arrange of applications. Technically, LIPSS occur when the surface of a material is irradiated with polarized laser radiation of fluence close to its ablation threshold, resulting in periodic and highly reproducible micro- or nano-structures of periods equal or shorter than the laser beam wavelength [1]. This technique was proved to be highly affective for machining transparent crystalline materials with high hardness and chemical inertness [2], such as the wide bandgap semiconductors Gallium nitride GaN, Silicon Carbide SiC and quartz.

Motivation and application: In our study, we observe femtosecond laser radiation (λ=1030 nm, τ=180 fs) interaction with surface of transparent crystal GaN using different experimental parameters, as shown in table 1., to obtain a database of optimal experimental parameters that allow us to control the characteristics of formed LIPSS (ripples), in order to achieve highly reproducible surface ripples on larger surface areas. The results are discussed regarding the potential applications for the formed LIPSS on GaN, such as: surface characteristic control (wettability), fabrication of quantum dots and quantum-wires (LEDs, solar cells), and enhancement of optical properties (photoluminescence, absorption) [3].

The experimental setup used:



LaserDESK was used to synchronize the laser radiation with the scanning process to control the parameters of the machining process (number of pulses, scanning speed and direction)

Fig.1: Experimental setup

The investigated parameters and their optimal values as determined by experiments shown below:

Experimental parameters	Optimal values
Frequency F	100 Hz
Energy E	10 µJ
Laser spot D	>10 µm
Number of pulses	100
Scanning direction	Perpendicular to direction of LIPSS formation
Position of laser focus relative to GaN surface	100 µm

Table.1:The data base obtained

Determining the laser induced damage threshold LIDT of GaN:

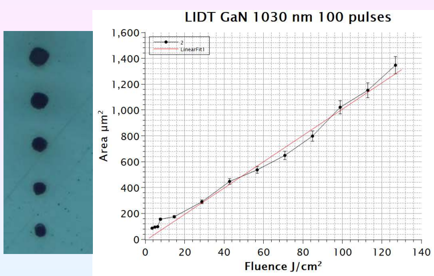


Fig.2: Figure and graph shows the area of laser spot on GaN surface in correspondence to the laser fluence used to determine the LIDT for GaN to achieve LIPSS

LIDT fluence of GaN at 1030 nm is F_{th} = 1.04 J/cm²

Determining the ideal focus position:

The criteria to choose the working position of laser focus relative to GaN surface is:

- Having better control of laser fluence
- Preserving the circularity of the laser spot

Ideal working position is at 100 µm below laser focus

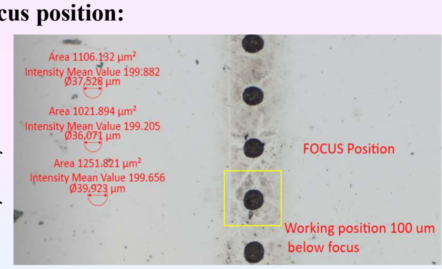


Fig 3. Laser spot sizes at different focus position relative to GaN surface

Determining the energy fluence required:

By definition LIPSS occurs at energies lower than the ablation threshold.

After experimenting with different variable parameters of laser radiation and scanning process, we reach the optimal parameters for LIPSS formation (fig.4), shown in table 1 above.

Experiments show LIPSS can be achieved in depth at higher energy fluence, as shown in fig. 5.

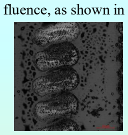


Fig 4. Formation of LIPSS on surface with no depth

Fig 5. Formation of LIPSS on layers in depth (at E=20µJ, 100 pulses)

Determining the scanning speed and overlapping needed:

To get a homogenous LIPSS channel with smooth edges, the position between consecutive laser pulses should be smaller or equal to radius of laser spot.

Experimentally the formula for scanning speed is derived by:

$V \leq \frac{D}{2} F$

V- Scanning speed

D- laser spot diameter

F- Laser frequency

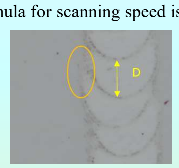


Fig. 6 shows consecutive overlapped laser spots

Determining the best scanning direction:

For longer, parallel, smoother edges and better organized LIPSS, the scanning direction should be perpendicular to the direction of LIPSS formation.

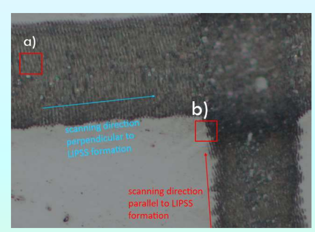


Fig. 7 shows the difference of LIPSS formation at different scanning directions

Conclusion:

- This experiment allowed us to establish a database for the optimal experimental parameters to achieve high reproducible LIPSS on WBG GaN, results presented in table 1.
- We investigated the formation of LIPSS on GaN in consecutively irradiated surfaces (channels), which is essential for embedding LIPSS as a technique for large area treatments
- LIPSS proved to be a simple, fast and eco-friendly surface treatment for WBG in comparison with other machining methods

References:

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