**Graphene Based Plasmon-Induced Terahertz Metamaterial for High-Performance Multispectral Detecting**

Y. Demirhan1,2, N. A. Tertemiz4, S. Balcı4, H. Altan5, G. Aygün1, L. Özyüzer1,3

1*Department of Physics, İzmir Institute of Technology, İzmir, Turkey*

2*Center for Materıals Research, Integrated Research Centers, İzmir Institute of Technology, İzmir, Turkey*

3*Teknoma Technologıcal Materials Industrial and Tradıng ınc, İzmir, Turkey.*

4*Department of Photonıcs, İzmir Instıtute of Technology, İzmir, Turkey*

5*Department of Physics, Mıddle East Technical Uniıversiıty, Ankara, Turkey*

e-mail: [yasemindemirhan@iyte.edu.tr](mailto:yasemindemirhan@iyte.edu.tr)

The invention of metamaterials has attracted significant academic and technological interest due to their extraordinary electromagnetic (EM) properties, which are not readily achievable with conventional photonic and optical materials [1-3]. Among the various types of metamaterials, plasmonic metamaterials stand out by harnessing surface plasmons (SPs), which exhibit some of the most compelling EM characteristics [4]. Graphene and other two-dimensional (2D) materials have opened new possibilities for next-generation optoelectronic devices, including ultrafast photodetectors. Graphene supports tightly confined surface waves with low losses and tunable properties, making it a strong candidate for terahertz (THz) detection. Plasmonic metamaterials with multiband and broadband responses provide a promising approach for detector design. Using graphene-coated mesa structures can enhance light–matter interaction through plasmonic effects in the THz range. Additionally, three-dimensional graphene-based structures enable the excitation of higher-order plasmonic modes and multiple resonance frequencies. In this study, a high-performance terahertz metamaterial structure based on graphene and induced by surface plasmon resonance is proposed, featuring tunable resonance frequencies. Graphene-coated mesa metamaterial structures were designed and fabricated as integrated photodetector arrays on a single chip. These structures inherently enable plasmonic enhancement without the need for separate metamaterial integration. THz lenses were incorporated into the multispectral photodetector chips to improve performance. Metamaterial unit cells with varying mesa dimensions (70 x 70 um2 – 90 x 90 um2), (85 x 85 um2 – 100 x 100 um2), (115 x 115 um2 – 135 x 135 um2), were optimized through CST Microwave Studio simulations for operation at 1.1, 0.9, and 0.6 THz. Fabrication was carried out on high-resistivity silicon substrates using UV lithography and reactive ion beam etching, followed by graphene deposition via Plasma-Enhanced Chemical Vapor Deposition (PECVD). The electromagnetic response of the devices was characterized using both THz Time-Domain Spectroscopy and continuous-wave THz imaging systems. The effects of graphene thickness and Fermi level on the reflection spectrum have been determined. Furthermore, the characteristics of the plasmonic resonance modes were qualitatively analyzed and compared with experimental results.

*Acknowledgement: This research is partially supported by TUBITAK (Scientific and Technical Research Council of Turkey) project number 221M087. We would like to thank the Research and Application Center for Quantum Technologies (RACQUT) of IZTECH for the experimental facilities.*

REFERENCES:

1. M.Tonouchi, Cutting edge THz technology, Nat. Photonics 97, 1 (2007).
2. L. Ozyuzer et al., Emission of THz waves from superconductors, Science 318, 1291 (2007).
3. Y. Demirhan et al., Fourcross shaped metamaterial filters fabricated from high temperature

superconducting YBCO and Au thin films for terahertz waves” Supercond. Sci. Technol. 30 074006 (9pp) (2017).

[4] B. Akyurek, A. Noori, Y. Demirhan, L. Ozyuzer, K. Guven, H. Altan, & G. Aygun, VO2-Based Dynamic Coding Metamaterials for Terahertz Wavefront Engineering. Journal of Infrared, Millimeter, and Terahertz Waves, 46(1), 1-19, (2025).