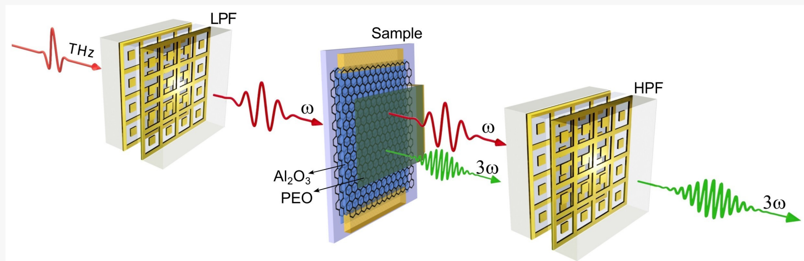
Harnessing device architecture for enhanced terahertz harmonic generation

GA, UNITED STATES, January 13, 2025 /EINPresswire.com/ -- Breakthroughs in terahertz nonlinear optics are essential to the development of high-speed wireless communication and signal processing technologies. Leading this charge, researchers from the University of Ottawa have demonstrated innovative methods to enhance terahertz nonlinearities in graphene-based structures, unlocking new potential for faster, more efficient devices. Graphene, with its remarkable optical nonlinearity and ease of integration, is at the heart of this transformation, offering a promising platform for future all-optical switching and frequency conversion applications.



Schematic of the experimental configuration to generate and detect THz third harmonic generation.

Nonlinear optical processes in the technologically important terahertz (THz) spectral range have gained increasing attention for their potential to revolutionize fields such as wireless communication and signal processing. Among the most extreme phenomena in nonlinear optics is harmonic generation, a process converting optical energy into different frequencies able to establish new communication channels and increase the information transfer rate. Graphene, a hexagonal layer of single carbon atoms, is a promising material for this technology as it offers exceptional nonlinear properties and seamless integration capabilities to compact, scalable devices. However, harmonics generated in single-layer graphene are relatively weak, primarily due to an intrinsically short light-matter interaction length, which poses a major hurdle to real-life applications. To overcome this challenge, researchers are developing innovative approaches to enhance nonlinear effects and fully leverage graphene's unique properties.

In a new paper (doi:https://doi.org/10.1038/s41377-024-01657-1) published in Light: Science & Applications, a team of scientists, led by Professor Jean-Michel Ménard from the University of Ottawa, Canada, in collaboration with researchers from the University of Bayreuth, Germany, and co-workers, have demonstrated novel strategies to significantly enhance THz nonlinearities in graphene-based structures. The researchers employed a multilayered graphene design, in which several decoupled graphene sheets are stacked to increase the interaction length between the nonlinear sample and a driving THz field. This approach led to a remarkable increase in third harmonic generation (THG), with enhancements of above 30 times compared to single-layer graphene. Similar enhancements of harmonic generation at higher frequencies can also be expected. The team identified the optimal number of layers to maximize this frequency conversion process, which required finding the perfect balance between nonlinear interactions and linear absorption.

In addition to exploring multilayered designs, the team integrated electrodes into these structures to fine-tune the doping concentration of graphene and, thus, its nonlinear response. By applying a gate voltage, free carrier density could be controlled, leading to further optimization of the THG process, up to a factor of 3. These experiments demonstrate a potential for dynamic control of frequency conversion in practical multilayered samples.

In a third series of experiments, the team used plasmonic metasurface substrates to locally enhance the THz field within the graphene-based devices. These metasurfaces acted as resonators, amplifying the intensity of the THz driving field and further boosting the harmonic generation efficiency. Among the different types of plasmonic metasurfaces, a bandpass resonator design was demonstrated to be the most effective.

Interestingly, innovative experimental strategies were used by the researchers to explore these nonlinear effects with a table-top THz system. They notably relied on custom lowpass and highpass filters to control the spectrum of the THz driving field, allowing them to optimize detection sensitivity at the third harmonic frequency.

These experiments demonstrate that a device architecture combining a multilayered design, electrical gating, and metasurface substrates can enhance harmonic generation efficiency by more than two orders of magnitude. The researchers explain that: “This platform offers the possibility to explore a vast range of materials and potentially identify new nonlinear mechanisms”. Such research and development are crucial for refining THz frequency conversion techniques and eventually integrating this technology into applications, particularly to enable efficient, chip-integrated nonlinear THz signal converters that will drive future communication systems.

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Lucy Wang
BioDesign Research
email us here
