Ultrafast Opto-Electronic tuning of Third-Harmonic Generation in a Graphene Field Effect Transistor

Omid Ghaebi[1], Sebastian Klimmer[1,2], Nele Tornow[1], Andrea Tomadin[3], Habib Rostami[4] and Giancarlo Soavi[1,5]

[1] *Institute of Solid State Physics, Friedrich Schiller University Jena, Jena, Germany*

[2] *ARC Centre of Excellence for Transformative Meta-Optical Systems, Department of Electronic Materials Engineering, Research School of Physics, The Australian National University, Canberra, Australia*

[3] *Dipartimento di Fisica, Università di Pisa, Largo Bruno Pontecorvo 3, 56127 Pisa, Italy*

[4] *Department of Physics, University of Bath, Claverton Down, Bath BA2 7AY, United Kingdom*

[5] *Abbe Center of Photonics, Friedrich Schiller University Jena, Jena, Germany*

omid.ghaebi@uni-jena.de

Graphene is a unique platform for non-linear optics thanks to its linear band dispersion that allows gate-tunable resonant light-matter interactions [1]. Due to its inversion symmetry, the third-order nonlinear optical susceptibility is the only viable means for frequency conversion in graphene. Although there have been studies on the electrical-tunability of linear absorption [2] and third harmonic generation (THG) in graphene [1] in recent years, there is still limited knowledge on the possibility of realizing all-optical nonlinear modulation, which could provide higher speed compared to electrical tuning for the realization of nanoscale nonlinear switches and frequency converters [3]. In this work [4], we provide a detailed study of the TH (third harmonic) all-optical modulation in a high-quality graphene FET (field effect transistor) (Fig.1.a). First, we show for the first time to our knowledge the impact of lattice temperature on the electrical modulation of TH in graphene for both electrons and holes and observe up to 300% modulation of the TH signal by tuning the lattice temperature from 295 to 33 K. Second, we show that by electro-static tuning one can actively control the recombination dynamics of the modulated THG signal via phase-space quenching of the scattering between hot electrons and optical phonons (Fig.1.b) [2]. Third, we shed light on the origin of the TH modulation and highlight the impact of transient electronic temperature and Pauli-blocking in our all-optical modulation scheme. With our ultrafast opto-electronic control of THG in graphene we achieve close to 90% modulation depth at Fermi energy of $E_\mathrm{F} = 300\,\mathrm{meV}$ and peak fluence of $200\,\mu\mathrm{J\,cm^{-2}}$. This work offers new insights for the understanding of THG all-optical modulation and thus for the realization of ultrafast frequency converters and nonlinear modulators.

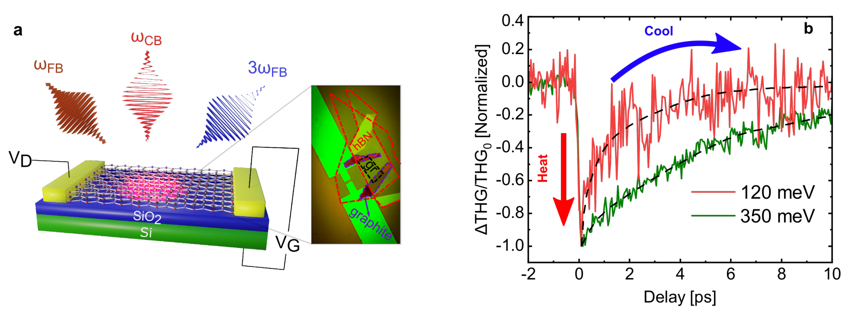

Fig. 1. **Ultrafast opto-electronic modulation of THG in a graphene FET. a)** Schematic and microscope optical image of the device. Monolayer graphene is encapsulated between two hBN flakes. V_G, V_D, ω_FB and ω_CB represent the gate voltage, source-drain voltage, fundamental beam, and control beam, respectively. **b)** Normalized relative changes of THG ($\frac{\Delta THG}{THG_0}$) for $E_\mathrm{F} = 120\,\mathrm{meV}$ and $E_\mathrm{F} = 350\,\mathrm{meV}$.

References

[1] G. Soavi *et al., Nat. Nanotechnol.* **13**, 583–588 (2018).
[2] E. A. Pogna *et al., ACS nano* **16**, 3613–3624 (2022).
[3] Y. Cheng *et al., Nano Lett.* **20**, 8053–8058 (2020).
[4] O. Ghaebi *et al., arXiv:2311.17208* (2023).