Unbiased plasmonic-assisted graphene photodetectors in near and mid-wave infrared

Ioannis Vangelidis[1]
Sebastián Castilla[2], Tatiana Slipchenko[3], Luis Martín-Moreno[3], Frank H. L. Koppens[2], Andrea C. Ferrari[4], Nikos Pleros[5], Elefterios Lidorikis[1]
1 University of Ioannina, 45110, Ioannina, Greece
2 ICFO, 08860, Castelldefels (Barcelona), Spain
3 CSIC-Universidad de Zaragoza, 50009, Zaragoza, Spain
4 University of Cambridge, CB3 0FA, Cambridge, UK
5 Aristotle University of Thessaloniki, 57001, Thessaloniki, Greece
i.vangelidis@uoi.gr

Current photodetection technology aims for layouts with high optoelectronic bandwidth, improved efficiency, dynamic tunability, low energy operation and improved noise characteristics. Single layer graphene (SLG) can meet these requirements as it exhibits ultrafast interactions, high room temperature mobility, field-effect tunability and broadband detection. Furthermore, low noise graphene photodetectors (GPDs) can operate without bias exploiting the photo-thermoelectric (PTE) effect whereby an electronic temperature gradient gives rise to a photovoltage due to the Seebeck effect. To get a net photoresponse from such devices, the symmetry between source and drain contacts must be broken, which can be achieved by either an architecture supporting asymmetric light absorption [1] or by an asymmetric gate creating a lateral pn-junction configuration [2]. Here we present a self-consistent multi-physics modelling framework including optical, thermal, and electrostatic simulations, that can accurately predict the response of PTE driven GPDs operating in either free-space or integrated platforms and put the model to the test by direct comparison to experiments. We model two different devices. In the free-space device, we concentrate mid-infrared light onto a graphene pn junction by efficiently exciting hyperbolic phonon-polaritons (HPPs) in the hBN encapsulation through their resonant coupling with a metallic bowtie antenna and H-shape gates. This detector exhibited ultrafast response (response time < 15 ns (setup limited)) and excellent sensitivity with noise-equivalent power (NEP) down to 82 pw/√Hz at 6 μm [3]. Comparison to experiment is excellent. The integrated device, on the other hand, is a simple architecture of hBN/SLG/hBN on top of a Si waveguide with asymmetric Au contacts. Here, the optical mode excites and hybridizes with, surface plasmon polaritons (SPPs) on the Au contact edge increasing the local SLG absorption and resulting in strong temperature gradient across the SLG channel. We show that such device can reach for both transverse-electric and transverse-magnetic modes (at $\lambda = 1550$ nm) ~A/W responsivity and ~100 GHz operation speed at zero power consumption [4]. Comparison to experiments is again excellent. Our approach, fully validated by experiments, sets up a new standard for future simulation works and can be applied for modelling a range of different unbiased GPDs architectures.

References

[1] R. J. Shiue et al. Nano Letters, 15, (2015) 7288–7293
[2] S. Castilla et al., Nano Letters, 19 (5), (2019) 2765–2773
[3] S. Castilla, et al. Nature Communications, 11, (2020) 4872
[4] I. Vangelidis et al. ACS Photonics, under revision

Acknowledgement

The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 881603 Graphene Flagship for Core3 and Grant Agreement No. 871391 Plasmoniac.