Broadband electrical detection of propagating graphene plasmons

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Abstract

Controlling, detecting and generating propagating plasmons by all-electrical means is essential for on-chip nano-optical circuits. Graphene can carry long-lived plasmons that are highly confined and controllable in-situ.[1,2,3] However, electrical detection of propagating graphene plasmons has thus far not been realized.

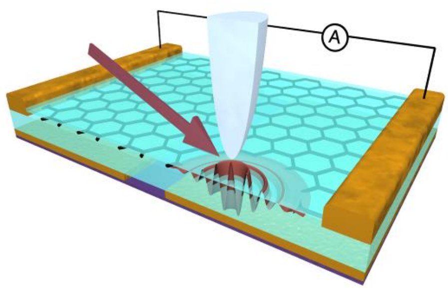
Here, we show how high-resolution photocurrent nanoscopy can be not only applied to directly measure the charge neutrality point as well as the carrier density profile of encapsulated graphene devices in real space[4] but also to measure propagating graphene plasmons.

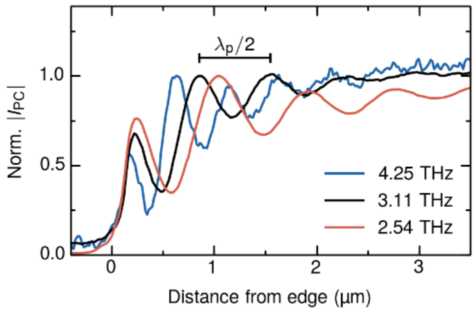
We present an all-graphene broadband plasmon detector. Instead of achieving detection via added optoelectronic materials, as is typically done in other plasmonic systems,[5] our device harvests the natural decay product of the plasmon - electronic heat - and converts it directly into a voltage through the thermoelectric effect.[6,7]

We use high quality graphene encapsulated between two layers of hexagonal boron nitride[8] and employ two local metal gates to fully tune the thermoelectric and plasmonic behavior. We investigate the plasmon propagation, frequency dispersion, and thermoelectric generation.

We electrically measure propagating graphene plasmons both for mid-infrared[9] and THz[10] frequencies. In the case of the THz frequency range we find that the graphene plasmon couples with the underlying metal gate. This so called graphene-insulator-metal plasmons exhibit a linear, acoustic, dispersion instead of the common square root dispersion and are strongly confined.

This work paves the way for efficient ultra-compact detectors in both the mid-infrared and THz frequency range based on graphene plasmons as well as fully integrated graphene plasmonic circuits and THz sensors.





References

[1] Z. Fei, et al., Nature **487** (2012) 82-85
[2] J. Chen, et al., Nature **487** (2012) 77-81
[3] A. Woessner, M.B. Lundeberg, Y. Gao, et al., Nature Materials **14** (2015) 421-425
[4] A. Woessner, et al., accepted in Nature Communications (2016) arXiv:1508.07864
[5] M. L. Brongersma, et al., Nature Nanotechnology **10** (2015) 25-34
[6] F.H.L. Koppens, et al., Nature Nanotechnology **9** (2014) 780-793
[7] M. Badioli, A. Woessner, et al., Nano Letters **14** (11) (2014) 6374-6381
[8] L. Wang, et al., Science **342** (2013) 614-617
[9] M.B. Lundeberg, Y. Gao, A. Woessner, et al., arXiv (2016) arXiv:1601.01977
[10] P. Alonso-González, A.Y. Nikitin, Y. Gao, A. Woessner et al., arXiv (2016) arXiv:1601.05753