High-speed bolometry from Johnson noise detection of hot electrons in cavity-coupled graphene

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High sensitivity and fast response are the most important metrics for infrared sensing and imaging and together form the primary tradeoff space in bolometry. To simultaneously improve both characteristics requires a paradigm shift on the thermal properties of bolometric materials. Due to a vanishingly small density of states at the charge neutrality point, graphene has a record-low electronic heat capacity which can reach values approaching one Boltzmann constant Ce ~ kb. In addition, its small Fermi surface and the high energy of its phonons result in an extremely weak electron-phonon heat exchange. The combination will allow a strong thermal isolation of the electrons in graphene for higher sensitivity without sacrificing the detector response time. These unique thermal properties and its broadband photon absorption, make graphene a promising platform for ultrasensitive and ultra-fast hot electron bolometers, calorimeters and single photon detectors for low energy light.

Here, we introduce a hot-electron bolometer based on a novel Johnson noise readout of the electron gas in graphene [1,2,3], which is critically coupled to incident radiation through a photonic nanocavity. This proof-of-concept operates in the telecom spectrum, achieves an enhanced bolometric response at charge neutrality with a noise equivalent power NEP < 5pW/√Hz, a thermal relaxation time of τ < 34ps, an improved light absorption by a factor ~3, and an operation temperature up to T=300K [3]. Altogether this shows that our proof-of-concept device can be a promising bolometer with efficient light absorption and a superior sensitivity-bandwidth product. Since the detector also has no limitations on its operation temperature, it provides engineering flexibility, which overall opens a new route for practical applications in the fields of thermal imaging, observational astronomy, quantum information and quantum sensing. In particular, since it is more than 5 times faster than the bandwidth of the intermediate frequency in the hot electron bolometer mixer, it can be employed as a cutting edge bolometric mixer material.

References

[1] K. C. Fong, PRX, 2 (2012);
[2] J. Crossno et.al., Science, 351 (2016);
[3] D. K. Efetov et. al., (accepted to Nature Nano. (2018));

Figures

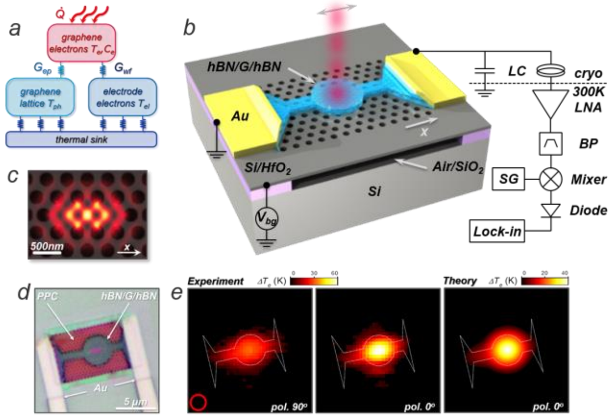

Figure 1: Figure 1: Device schematics and operation principle. (a) Schematics of heat dissipation channels of irradiated hot electrons in graphene. (b) Schematic of the device, which consists of a side contacted hBN/G/hBN heterostructure on top of a suspended silicon L3 PPC. The device is impedance matched to a LC network at cryogenic temperatures and is read out by a heterodyne JNR thermometry scheme at room temperature. (c) Resonant modes form in the L3 PPC. (d) Optical microscope image of the device. (e) Map of the bolometric response of the device as a function of laser position (red circle – laser spot size). Overall the bolometric response occurs only when the laser beam is injected on the graphene covered area, which is strongly enhanced when the PPC mode is on resonance.