Dmitri K. Efetov, Yuanda Gao, Gabriele Grosso, Cheng Peng, Ren-Jye Shiue, Evan Walsh, Jim Hone, Kin Chung Fong and Dirk Englund

Graphene has remarkable opto-electronic and thermo-electric properties that make it an exciting functional material for various photo-detection applications. Its ultra broadband light absorption from the UV to the THz and a strong and ultra-fast photo-thermal-response allow to realize highly responsive photo-detectors with competitive sensitivities to state of the art detectors in the mid-IR and THz wavelengths. In particular, owed to graphenes unique combination of an exceedingly low electronic heat capacity $C_e$ and a strongly suppressed electron-phonon thermal conductivity $G_{th}$, the electronic and phononic temperatures are highly decoupled. These properties enable the use of graphene devices as ultra-sensitive hot electron bolometers (HEB) with predicted photo-detection sensitivities down to single terahertz photons.

Here we demonstrate highly sensitive HEBs made of high quality hexagonal boron nitride/graphene stacks (hBN/G/hBN) and employing a direct electronic temperature read out scheme via Johnson noise thermometry (JNT). The almost two orders of magnitude lower impurity concentrations of $\sigma_i \sim 10^9$ cm$^{-2}$ in the hBN/G/hBN stacks, as compared to typical graphene devices on SiO$_2$, translate into extremely low potential fluctuation of the Fermi energy $\varepsilon_F \sim 5$meV around the charge neutrality point. We perform combined mid-IR pump-probe and JNT measurements to demonstrate the strongly damped $C_e$ and $G_{th}$ in this regime, which results in unprecedented photo-detection sensitivity and noise equivalent power for graphene HEBs. We can increase the sensitivity further, we demonstrate that we can integrate the hBN/G/hBN HEBs into photonic crystal cavities and silicon wave-guides, which enable an almost 20-fold enhancement of the light absorption. The ease and CMOS compatibility of the integration process of the HEBs onto silicon photonic circuits paves the way towards high-speed graphene-based photonic integrated circuitry.