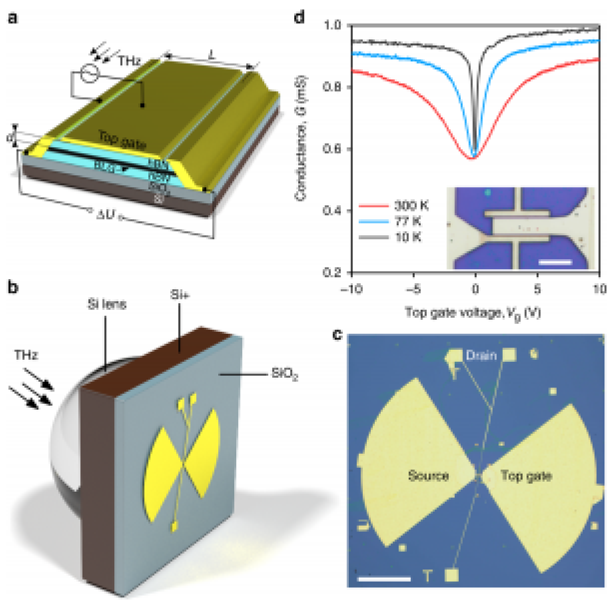
Resonant terahertz detection using graphene plasmons

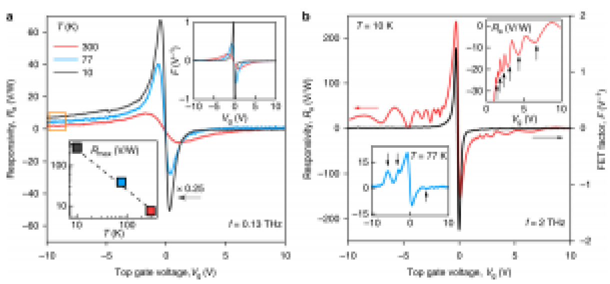
Plasmons, collective oscillations of electron systems, can efficiently couple light and electric current, and thus can be used to create sub-wavelength photodetectors, radiation mixers, and on-chip spectrometers. Despite considerable effort, it has proven challenging to implement plasmonic devices operating at terahertz frequencies. The material capable to meet this challenge is graphene as it supports long-lived electrically tunable plasmons. Here we demonstrate plasmon-assisted resonant detection of terahertz radiation by antenna-coupled graphene transistors that act as both plasmonic Fabry-Perot cavities and rectifying elements. By varying the plasmon velocity using gate voltage, we tune our detectors between multiple resonant modes and exploit this functionality to measure plasmon wavelength and lifetime in bilayer graphene as well as to probe collective modes in its moiré minibands. Our devices offer a convenient tool for further plasmonic research that is often exceedingly difficult under non-ambient conditions (e.g. cryogenic temperatures) and promise a viable route for various photonic applications.



Graphene-based THz detectors. **a** Schematics of the encapsulated BLG FET used in this work. **b** 3D rendering of our resonant photodetector. THz radiation is focused to a broadband bow-tie antenna by a hemispherical silicon lens yielding modulation of the gate-to-source voltage, as indicated in **a**. **c** Optical photograph of one of our photodetectors. Scale bar is 200 µm. **d** Conductance of one of our BLG FETs as a function of the gate voltage V_g, measured at a few selected temperatures. Inset: zoomed-in photograph of **c** showing a two-terminal FET with gate and source terminals connected to the antenna. Scale bar is 10 µm.

Broadband operation

We intentionally start the photoresponse measurements at the low end of the sub-THz domain, where the plasma oscillations are overdamped (see below). This allows us to compare the performance of our detectors with previous reports.



Plasmon-assisted THz photodetection. **a** Responsivity measured at f = 130 GHz and three representative temperatures. Orange rectangle highlights an offset stemming from the rectification of incident radiation at the p-n junction between the p-doped graphene channel and the n-doped area near the contact. Upper inset: FET-factor F as a function of V_g at the same T. Lower inset: maximum R_a as a function of T. **b** Gate dependence of responsivity recorded under 2 THz radiation. The upper inset shows a zoomed-in region of the photovoltage for electron doping. Resonances are indicated by black arrows. Lower inset: resonant responsivity at liquid-nitrogen temperature.

Resonant responsivity is a universal phenomenon in ultra-clean graphene devices and is expected to be independent of the physical mechanisms behind the rectification of the ac field into a dc photovoltage. Nevertheless, it is important to establish possible nonlinearities responsible for the rectification, for example, in order to be able to increase the magnitude of responsivity. We first note that the aforementioned asymmetry in R_a (V_g) between electron and hole doping indicates rectification at the *p*–*n* junction formed in vicinity of the contacts. This rectification usually appears due to the thermoelectric effect arising as a result of non-uniform sample heating and the difference between the Seebeck coefficients in the graphene channel and contact regions.

For more information: https://www.nature.com/articles/s41467-018-07848-w