Acoustic terahertz graphene plasmons revealed by photocurrent nanoscopy

Terahertz (THz) fields are widely used for sensing, communication and quality control. In future applications, they could be efficiently confined, enhanced and manipulated well below the classical diffraction limit through the excitation of graphene plasmons (GPs).

These possibilities emerge from the strongly reduced GP wavelength, λp, compared with the photon wavelength, λ0, which can be controlled by modulating the carrier density of graphene via electrical gating. Recently, GPs in a graphene/insulator/metal configuration have been predicted to exhibit a linear dispersion (thus called acoustic plasmons) and a further reduced wavelength, implying an improved field confinement, analogous to plasmons in two dimensional electron gases (2DEGs) near conductive substrates. Although infrared GPs have been visualized by scattering-type scanning near-field optical microscopy (s-SNOM), the realspace imaging of strongly confined THz plasmons in graphene and 2DEGs has been elusive so far—only GPs with nearly freespace wavelengths have been observed. Alonso-González et al., demonstrate real-space imaging of acoustic THz plasmons in a graphene photodetector with split-gate architecture. To that end, they introduce nanoscale-resolved THz photocurrent near-field microscopy, where near-field excited GPs are detected thermoelectrically rather than optically. This on-chip detection simplifies GP imaging as sophisticated s-SNOM detection schemes can be avoided. The photocurrent images reveal strongly reduced GP wavelengths ($\lambda_p \approx \lambda_0/66$), a linear dispersion resulting from the coupling of GPs with the metal gate below the graphene,

and that plasmon damping at positive carrier densities is dominated by Coulomb impurity scattering.

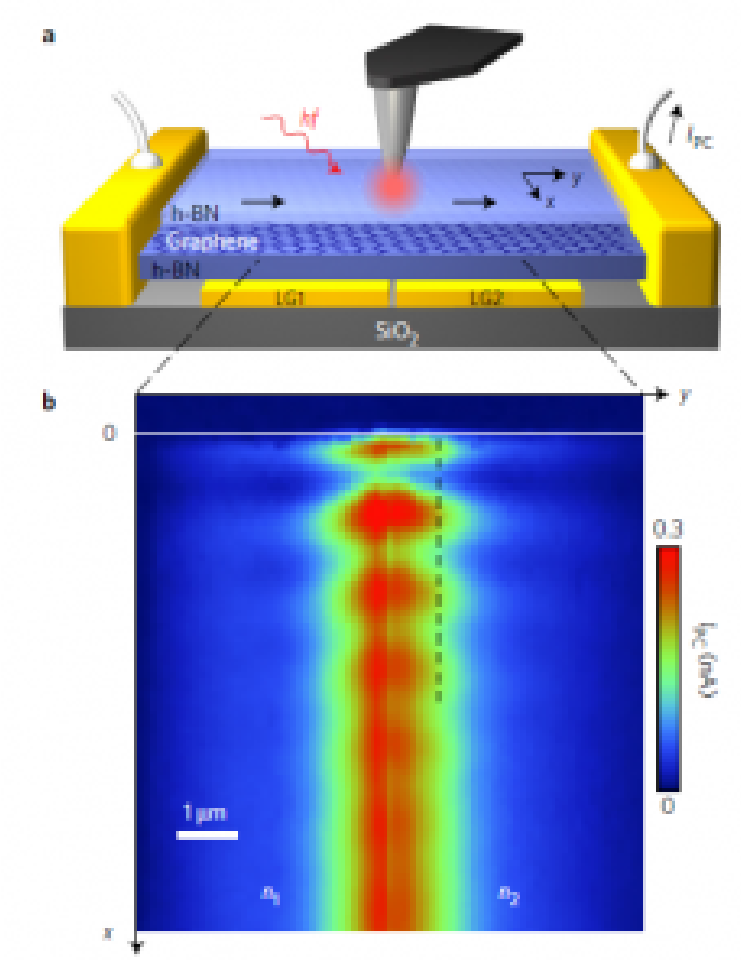

Figure 1 | THz photocurrent nanoscopy of graphene plasmons in a split-gate photodetector. a, Schematics of the experimental set-up. The laser-illuminated metal tip of an atomic force microscope (AFM) serves as a nanoscale near-field light source. The near-field induced photocurrent in the graphene (encapsulated by h-BN layers) is measured through the two metal contacts to the left and right. LG1 and LG2 represent the split gate (gold) used to control the carrier concentration in the graphene to the left and the right of the gap between them. b, Image of the experimental near-field photocurrent, IPC, recorded at f=2.52 THz. The carrier densities were chosen to be n1 = 0.77 × 1012 cm−2 and n2 = −0.71 × 1012 cm−2. The horizontal white solid line marks the edge of the graphene sheet.

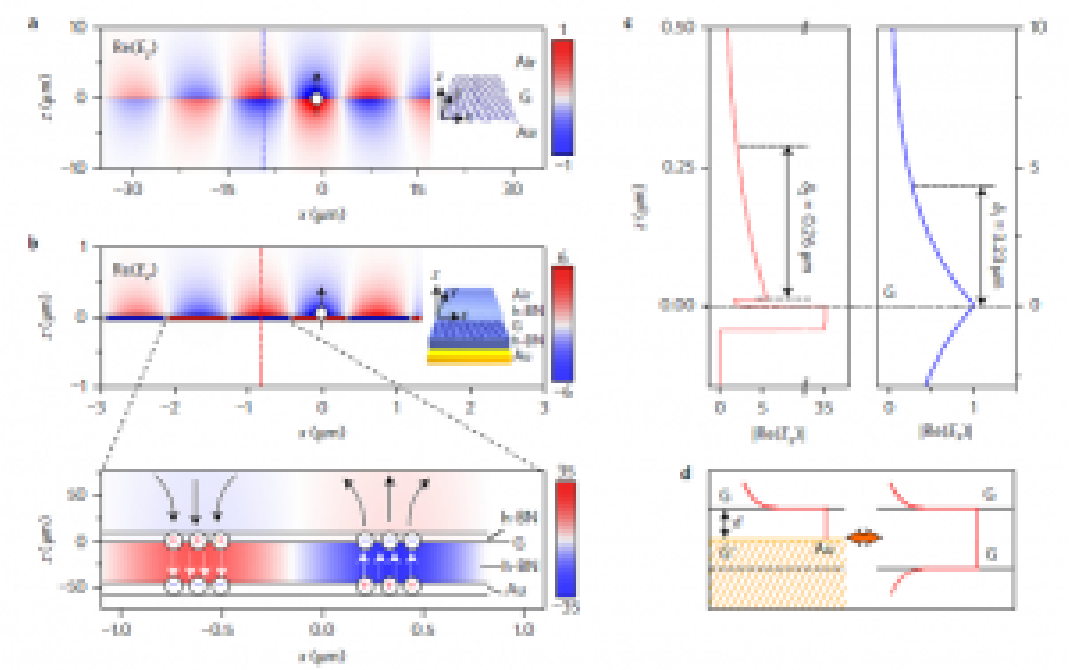

Figure 2 | Near-field distribution of THz graphene plasmons. a,b, Numerical simulations of the near-field distribution of THz graphene plasmons excited by a point dipole source located above a free-standing graphene sheet (air/G/air) (a) and an air/BN/G/BN/AuPd/SiO2 heterostructure (b) assuming the experimental layer thicknesses. The real part of the vertical field component, Re(Ez(x,z)), at a frequency of 2.52 THz is shown for both cases. The + and – symbols in the zoomed-in image in b sketch the charge distribution in graphene and AuPd. c, Near-field profiles |Re(Ez)| perpendicular to the grapheme surface. Left, profile along the dashed red line in b. Right, profile along the dashed blue line in a. Both profiles were normalized to the maximum of |Re(Ez)| on top of a free-standing graphene sheet. d, Schematics of the plasmonic near-field profile for a graphene sheet above a gold surface (left) and for two parallel graphene sheets (right). The distance between the two graphene sheets is twice the distance between the graphene and the gold surface.

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