Gate-tuning of graphene plasmons revealed by infrared nano-imaging
Authors: Z. Fei, A. S. Rodin, G. O. Andreev, W. Bao, A. S. McLeod, M. Wagner, L. M. Zhang, Z. Zhao, G. Dominguez, M. Thiemens, M. M. Fogler, A. H. Castro-Neto, C. N. Lau, F. Keilmann, D. N. Basov
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Optical nano-imaging of gate-tuneable graphene plasmons
Authors: Jianing Chen, Michela Badioli, Pablo Alonso-González, Suko Thongrattanasiri, Florian Huth, Johann Osmond, Marko Spasenovic, Alba Centeno, Amaia Pesquera, Philippe Godignon, Amaia Zurutuza, Nicolas Camara, Javier Garcia de Abajo, Rainer Hillenbrand, Frank Koppens
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Recommended and a Commentary by Francisco Guinea,
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Plasmons are ubiquitous excitations of metals, and a clear manifestation of the electron-electron interactions between charge carriers. They are the oscillations of the electric charge density, which induces electric fields and can couple to external electromagnetic fields. The possibility of coupling plasmons to light, and also to electric currents, has lead to the growing field of plasmonics. The fast transfer of information between photons and electric currents can be modulated in metallic structures where plasmons are tailored to have the right properties. The interaction of plasmons with light requires carefully tailored devices, as plasmons have much shorter wavelengths than photons.

Metals have a high carrier density, leading to plasmons with frequencies in the visible range. The number of carriers in a metal cannot be easily altered, and modifications in the plasmon properties are achieved by modifying the device geometry.

Plasmonics has undergone a substantial change with the advent of graphene. The carrier density of graphene can be tuned by an external gate and typical frequencies fall in the interesting Teraherz range. While plasmons in graphene show the same $\omega_{pl} \propto \sqrt{q}$ relation as in the surface of any two-dimensional metallic surface, the dependence of the plasmon frequency on carrier density is unsual, and plasmons can exist even in neutral graphene, due to thermally excited carriers. Moreover, the carrier mobility in graphene at room temperature can be significantly larger than in conventional metals, leading to long lived plasmons. A number of papers have discussed these features, sparkling a lively debate about the adequacy of graphene for opto-electronics applications.

The articles mentioned above give a detailed experimental verification of the tunability of graphene plasmons. Both groups employ the same sophisticated technique to excite plasmons in graphene and to probe the resulting electric fields on a nanometer scale. Light is focused onto a graphene layer deposited on a SiO_2 substrate by means of an oscillating atomic force microscope tip which serves as an antenna, and the resulting scattered radiation is measured. This technique concentrates the incoming radiation into a region much smaller than the wavelength of the electromagnetic wave, so that the region size can match typical graphene plasmon wavelengths (note that in the present experiments the ratio between the radiation and the plasmon wavelengths is 40-100). The tip can be displaced over the graphene layer, allowing the experimentalists to probe the electromagnetic fields on a scale of a few nanometers, the radius of the antenna. The existence of plasmons is manifested by the observation of interference fringes induced by the propagation of the plasmons from the tip to the edges of the sample and back. The plasmon wavelength depends on the frequency of the incoming light and on the carrier density, both of which can be independently varied.

The findings of the two teams are in very good agreement. The observations can be interpreted using theoretical models based on the known properties of graphene and the electromagnetic fields near a sharp metallic object. An intriguing feature is the relatively short plasmon lifetime, which implies a low conductivity of the graphene layer at the frequencies probed by the experiments. Recent, unpublished results by the two groups show that the technique can be used to visualize features in the graphene layers which are very difficult to observe otherwise, like grain boundaries in graphene samples grown by Carbon Vapor Deposition.