Damping mechanisms and phonon interactions of graphene plasmons

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Abstract

We present the effect of (substrate and intrinsic) phonons on graphene plasmons, revealed by infrared transmission measurements on nanoholes and nanoribbons. The plasmon losses and dispersion were extracted and quantitative comparison to theory was provided by independently measuring electron and hole densities. Coupling, damping and hybridization effects of the intrinsic optical phonon and edges have been studied in combination with the coupling of plasmons to the substrate (polar) surface phonons. These results are complemented with near-field (SNOM) measurements of the plasmon dispersion. Finally, we propose to take advantage of plasmonic resonances to increase the photoresponse of graphene p-n junction devices which we recently measured in the 6-10 µm range..

In addition to its well-known electronic properties and the absence of a band gap, graphene exhibits optical properties which are tunable by varying the charge carrier concentration. Typically from ultraviolet to the near-infrared range, absorption is dominated by interband transitions; while in the terahertz range, intraband transitions take place. As a consequence, graphene absorption is the lowest in the mid-infrared range. Nevertheless, it has been predicted [1,2] and recently demonstrated [3-5] that the absorption can be enhanced through nanostructuration of ribbons or discs. Wavevector-matching allows to resonantly excite plasmons, with their resonance defined by $\omega_p^2 \propto E_F / \varepsilon_{env} \cdot W$. Graphene plasmons have the advantage to be easily tuned by electrostatic doping and provide an extremely strong confinement of the electromagnetic energy[6,7] ($\lambda_p \square \lambda_0 / 100$).

We designed nanoribbons and nanoholes arrays by e-beam lithography on SiO_2/Si substrates with their widths (resp. diameters) ranging from 80 to 300 nm (50 to 200 nm). Their doping is electrostatically modulated either by a standard backgate or an electrolyte polymer topgate. We initially made an exact characterization of the carrier density by Hall measurements of a device fabricated during the same process. This allows us to quantitatively compare theory and experiments. The unpatterned and patterned graphene optical properties were measured by FTIR transmission or reflection at various gate voltages in the 700-7000 cm^{-1} range (Figure 1). Typical spectra exhibit between one and three peaks corresponding to coupled mode between graphene plasmonic resonances and SiO_2 surface phonons.

These results allowed us to determine the plasmonic dispersion either as a function of wavevector (given by the nanostructure dimension) for a fixed carrier density, or reversely, as a function of carrier density for both electron and hole doping. We used the width and doping dependence of the resonance to determine the coupling strength of the surface phonon with plasmon modes. Moreover, a broadening of the resonant peak can be observed for larger wavevector (smaller width or diameter), when the resonant energy approaches 1580 cm^{-1} corresponding to the optical phonon energy. The combination of these sets of data allows us to determine the respective contribution of carrier mobility, nanostructure edges and intrinsic phonon to the plasmon damping.

We compare these results with wavelength dependent near-field measurements in order to identify the origin of edge and phonon effects. Finally, we will report on recently observed p-n junction photocurrent in the mid-infrared range and propose to combine it with plasmon enhanced absorption to increase the hot electron population and, as a result, the photocurrent in this typically unused wavelength range for graphene photodetectors.

References

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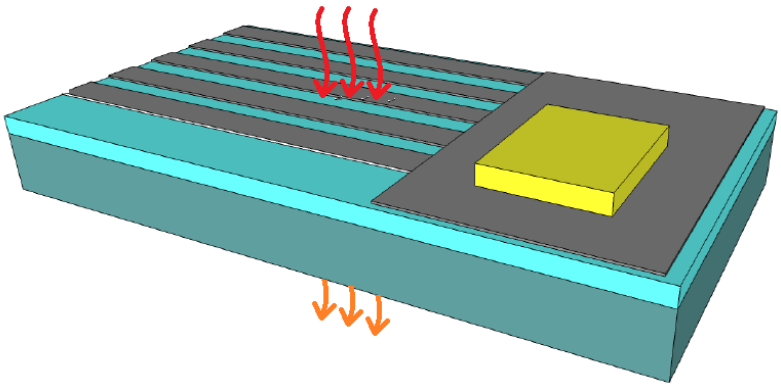

Figure 1: Sketch of a graphene nanoribbons structure on Si/SiO2 substrate, used for FTIR measurements as a function of a backgate voltage applied through a gold electrode connecting the unpatterned graphene region.