Ultrafast dynamics of terahertz plasmons in in-plane periodic nanostructures of epitaxial graphene

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In this paper we investigate THz plasmons in lithographically prepared nanoribbons and nanodots of epitaxial graphene and we demonstrate their ultrafast control by optical pulses using combined near-field and far-field THz spectroscopies.

We grew epitaxial graphene in Ar atmosphere by graphitization of 6H-SiC substrate both on its Si and C side. The layer on Si-face was submitted to the hydrogen intercalation process [1] leading quasi-free-standing single layer graphene (QFSLG) which is p-doped. The C-face of SiC hosts multilayer epitaxial graphene (MEG), where each layer exhibits electronic properties similar to isolated monolayer graphene as a result of twisted, non-Bernal stacking. The inner layers (close to the substrate) are usually significantly n-doped while outer layers are usually quasi-neutral (QN). After the growth we employed e-beam lithography followed by oxygen plasma etching to create graphene nanoribbon and nanodot plasmonic structures (see examples in Fig. 1a,b).

We determined the THz sheet conductivity spectra of the samples in the ground state as a function of temperature. Further we used optical pump – THz probe approach to assess picosecond dynamics of the THz plasmonic behavior after optical excitation. To these aims we used a combination of standard time-domain THz spectroscopy setup (0.15 – 3THz), THz air-based photonics setup (1 – 20 THz) and a THz local probe imaging device (THz-SNOM, Neaspec).

The studied structures feature a plasmonic resonance typically in the 1–4 THz spectral range depending on the lithographically fabricated pattern and its characteristic aspect ratios. The ultrafast dynamics of plasmons in optically excited graphene are entirely controlled by the Fermi level of laser-excited hot carriers through their temperature. The laser pulse heats the carriers up to about 5000 K and the carrier cooling occurs back to the lattice temperature occurs within a few picoseconds. The heating of carriers is accompanied by a weak plasmon redshift in (doped) QFSLG; the carrier mobility is $\sim 1700\ \mathrm{cm^2V^{-1}s^{-1}}$ and does not change significantly upon photoexcitation. In MEG, the doped and QN layers contribute approximately equally to the sheet conductivity in the ground state while the large amount of pexcited hot carriers occurring in QN layers upon the photoexcitation dominates the transient response and lead to a significant blueshift and broadening of the plasmon resonance (Fig. 1c,d). The carrier mobility of the doped layers is $\sim 2300\ \mathrm{cm^2V^{-1}s^{-1}}$, while in QN layers it reaches a value of $7.5 \times 10^5\ \mathrm{cm^2V^{-1}s^{-1}}$ at room temperature and shows a strong temperature dependence due to the variation of the chemical potential and carrier scattering time [2,3]. Peculiarities of the plasmon and electron dynamics will be discussed in the conference contribution.

References:
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[3] A. Singh et al., *Phys. Rev. B* **113**, 115417 (2026).

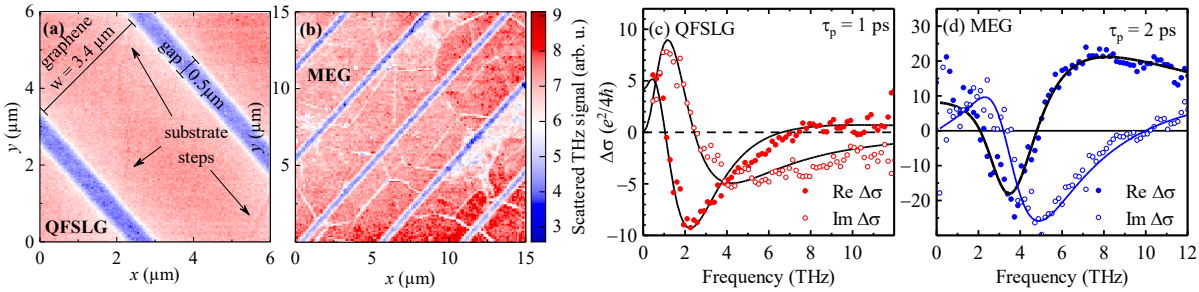

Fig. 1: Near-field THz conductivity image using THz-SNOM for graphene ribbons in (a) QFSLG and (b) MEG samples. Transient sheet photoconductivity spectra of (c) QFSLG and (d) MEG featuring plasmon resonance.