Nano Imaging Of Surface Plasmon Polariton And Phonon Coupling In Graphene Nanostructures

Samaneh Pakniyat, Damia Casas, Sebastian Gomez-Dia[1]

[1]University of California, Davis, Davis, California, USA

Abstract

Graphene surface plasmon polaritons (SPPs) hold tremendous potential for advancing a wide range of technologies. Their unique properties, such as strong light-matter interaction, tunability, high-speed propagation, and compatibility with miniaturized devices, make them ideal for innovative solutions in sensing, communication, energy, and healthcare. However, the experimental study of graphene SPPs and their interaction with phonons is still limited. High-resolution nanoscale real-space imaging of surface plasmon polaritons by scattering-type scanning near-field optical microscopy (s-SNOM) plays a pivotal role in this endeavor.
In our project, we aim to image the SPPs of graphene tapered ribbon using s-SNOM and evaluate the near-field interaction of the SPPs with the phonon modes of a silicon carbide (SiC) substrate. We utilize COMSOL simulation results for interpretation, and validation of our measured data as well as parameter optimization. We numerically obtain the near-field scattering of the metallic nanotip of the s-SNOM due to interaction with the sample. In COMSOL, we model a metallic tip under a background plane wave to excite SPPs on the graphene/SiC structure. The SiC is modeled as a dispersive material using a Lorentz-Drude model, and graphene is modeled by a surface current density boundary condition using the intra-band Kubo conductivity.
We calculate the local density of states (LDOS) using the scattered field data at the tip position for different wavelengths, specifically at the epsilon-near-zero and transverse phonon resonance frequencies. The SPP wavelength is obtained from the fringes revealed in the LDOS map due to the reflected field from the graphene sample edges. Eventually, we model the surface roughness of our sample obtained from atomic force microscopy topography data to determine the roughness impact on the quality of SPPs at nanoscale. We employ the Wave Optics module, Electromagnetic Waves, Frequency Domain physics, Eigenfrequency, and Frequency Domain studies, gaining insights from models related to graphene in the Application Libraries.

Reference

j. Chen et al., Optical nano-imaging of gate-tunable graphene plasmons, Nature, 487, 7405 (2012).
W. Zhao et al., Efficient Fizeau drag from Dirac electrons in monolayer graphene, Nature, 594, 7864 (2021).
D. Navajas et al. Addressing the Impact of Surface Roughness on Epsilon-Near-Zero Silicon Carbide Substrates, ACS photonics, 10, 9 (2023).

Figures used in the abstract

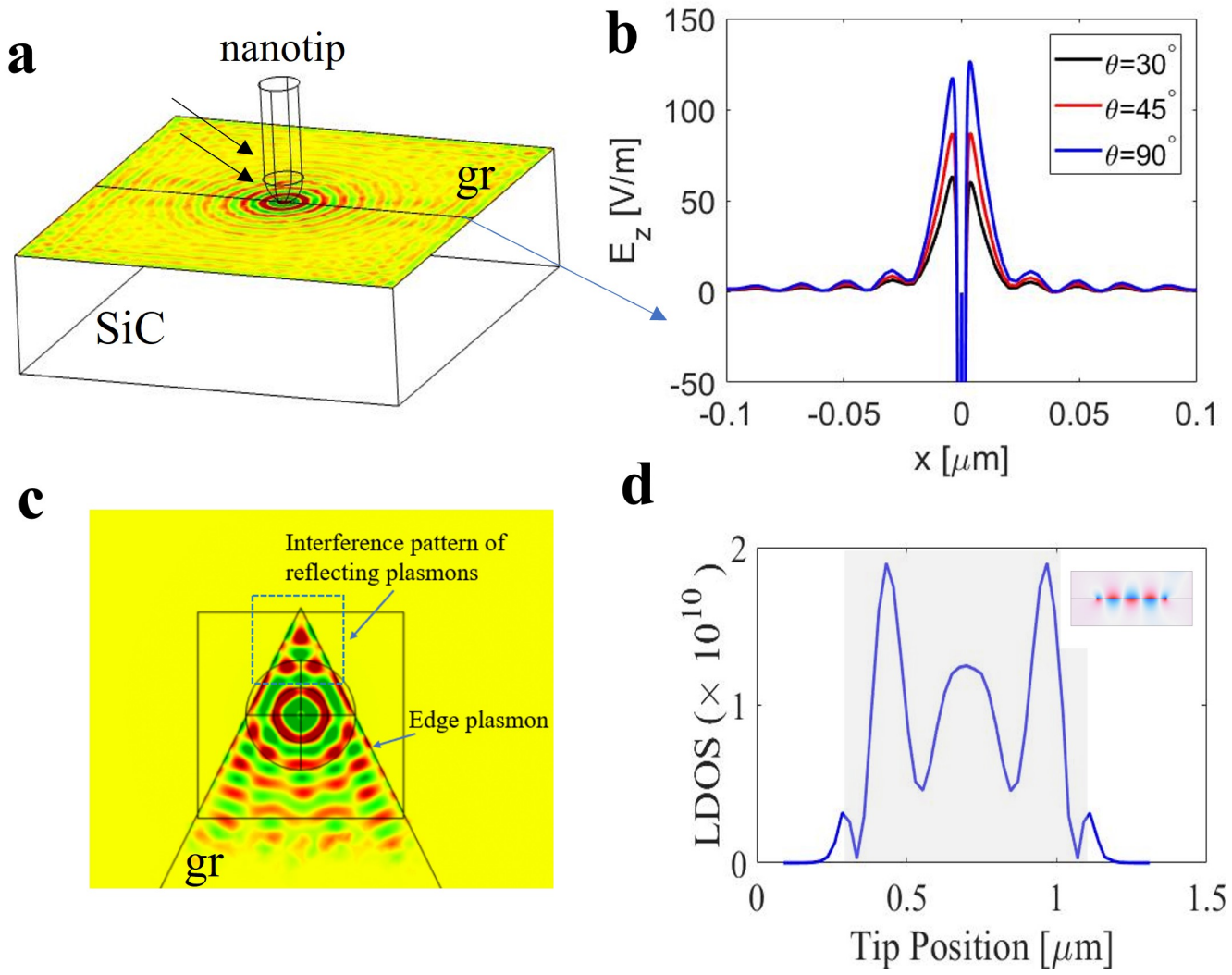

Figure 1 : (a) Surface plasmon polaritons (SPPs) excited by a metallic tip under plane wave illumination on graphene. (b) SPP oscillations along the central line indicated in panel (a) for different incident angles of the plane wave. (c) Plasmon interference pattern