Nanometer-scale Cavities for Mid-infrared Light Based on Acoustic-graphene-plasmons

Itai Epstein[1,*]
Itai Epstein[1,2] David Alcaraz[2] Zhiqin Huang[3,4] Jean-Paul Hugonin[5] Varun-Varma Pusapati[2] Avinash Kumar[2] Xander Deputy[3,4] Tymofiy Khodkov[2] Tatiana Rappoport[6] Nuno M. R. Peres[6,7] David R. Smith[3,4] and Frank H. L. Koppens[2,8]
1 Department of Physical Electronics, School of Electrical Engineering, Faculty of Engineering, Tel Aviv University, Tel Aviv 6997801, Israel. 2 ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain, 3 Department of Electrical and Computer Engineering, Duke University, Durham, NC, 27708, USA, 4 Center for Metamaterials and Integrated Plasmonics,Duke University, Durham, NC, 27708, USA, 5 Laboratoire Charles Fabry, Institut d'Optique Graduate Scool, CNRS, Université Paris-Saclay, 91127 Palaiseau, France, 6 Centro de Física and Departamento de Física and QuantaLab, Universidade do Minho, P-4710-057 Braga, Portugal, 7 International Iberian Nanotechnology Laboratory (INL), Av. Mestre José Veiga, 4715-330 Braga, Portugal, 8 ICREA – Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain
*itaieps@tauex.tau.ac.il

Abstract: Acoustic-graphene-plasmons (AGPs) are highly confined electromagnetic modes, which carry extreme momentum and low loss in the Mid-infrared (MIR) to Terahertz (THz) spectra. Here, we demonstrate a new way to excite highly confined AGPs from the far-field, with localized graphene-plasmon-magnetic-resonators (GPMRs). This approach enables the efficient excitation of single AGP resonators, which are able to confine MIR light to ultra-small mode-volumes which are over a billion times smaller than their free-space volume.

In the presented work [1], the GPMRs are formed by depositing specialized metal nanometric cubes on top of graphene capped with monolayer hBN, forming a cavity for AGP's via the generation of magnetic resonances (Fig.1 left pannel). The gate dependent extinction spectra, as measured from a GPMR device in an FTIR spectrometer, is shown in Fig.1 (middle panel). The AGP resonances and their tunable response with the change in the graphene Fermi-level can be clearly seen, together with their well-known hybridization with the surface-optical-phonons of the SiO2 substrate and h-BN layer. The calculated mode-volume normalized to free-space volume, $(\lambda_0)^3$, is shown in Fig.1 (right panel) for different graphene-nanocube distance "d", reaching a huge factor of $\sim 5 \cdot 10^{-10}$ at 1nm spacing. We further show that each nanocube acts as an individual GPMR resonator, compressing the AGPs into the nanometer-scale volume between the graphene and nanocube.
Our approach provides direct access to the extremely small mode-volumes of AGPs, enabling a new platform for strong light-matter interaction and efficient AGP-based devices, such as photodetectors and sensors, in the long wavelength spectrum.

REFERNCES:
[1] I. Epstein et al, Science 368, 1219–1223 (2020), DOI: 10.1126/science.abb1570

Figures:

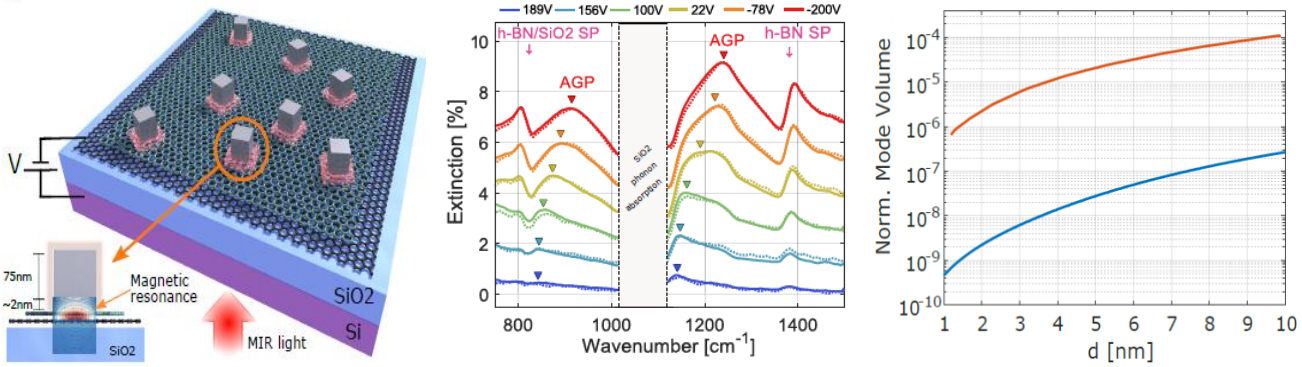

Figure 1: (Left) Configuration of the GPMR device. (Middle) Measured GPMR device extinction spectra for different gate voltages (colors). The triangle marks the AGP peak and the downward arrows mark the location of the h-BN and SiO2 surface-phonons. (Right) Calculated normalized mode volume of the GPMR (blue curve) compared to its equivalent metal-based magnetic resonance in the visible spectrum (red curve), showing several orders of magnitude smaller confinement factor of MIR the GPMR system.