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Far-field excitation of single graphene plasmon cavities with ultra compressed mode volumes

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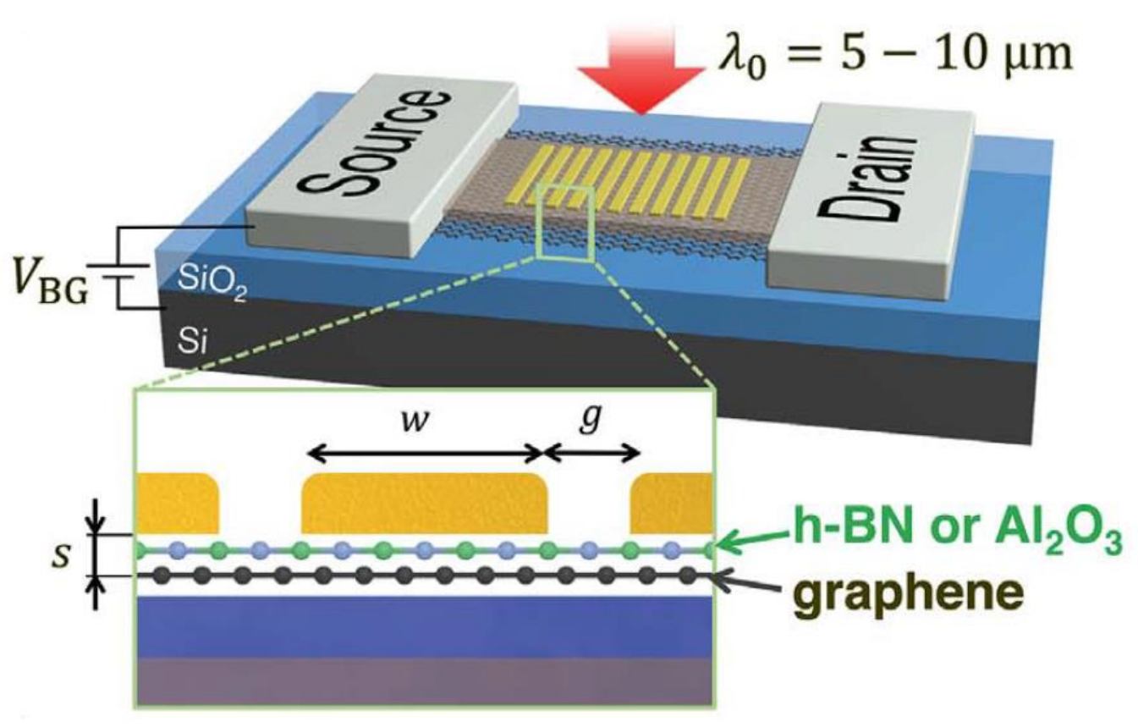
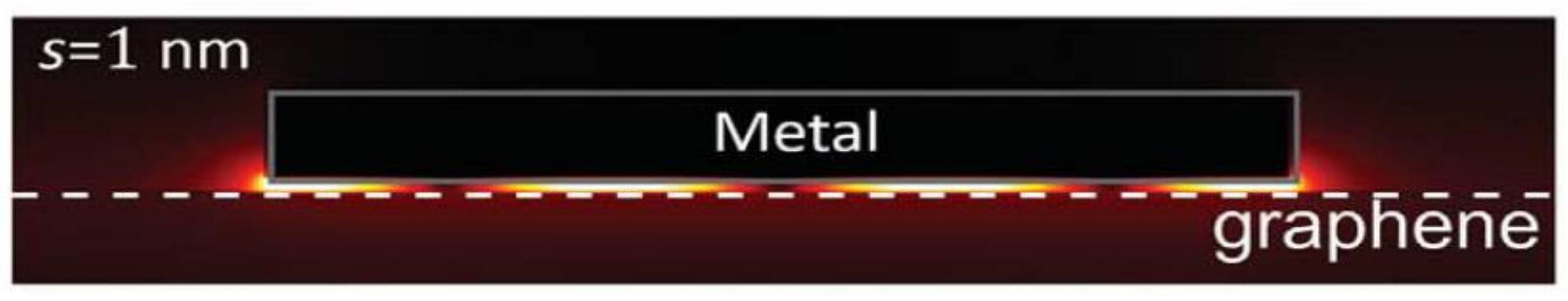
ABSTRACT

Acoustic graphene plasmons are highly confined electromagnetic modes carrying large momentum and low loss in the mid-infrared and terahertz spectra. However, until now they have been restricted mainly to micrometer-scale areas, reducing their confinement potential by several orders of magnitude. Using a graphene-based magnetic resonators, we realized single, nanometer-scale acoustic graphene plasmon cavities, reaching mode volume confinement factors of ~ 5 × 10^{-10}. Such a cavity acts as a mid-infrared nanoantenna, which is efficiently excited from the far field and is electrically tunable over an extremely large broadband spectrum. Our approach provides a platform for studying ultra-strong coupling phenomena, such as chemical manipulation via vibrational strong coupling, as well as a path to efficient detectors and sensors operating in this long-wavelength spectral range.

INTRODUCTION

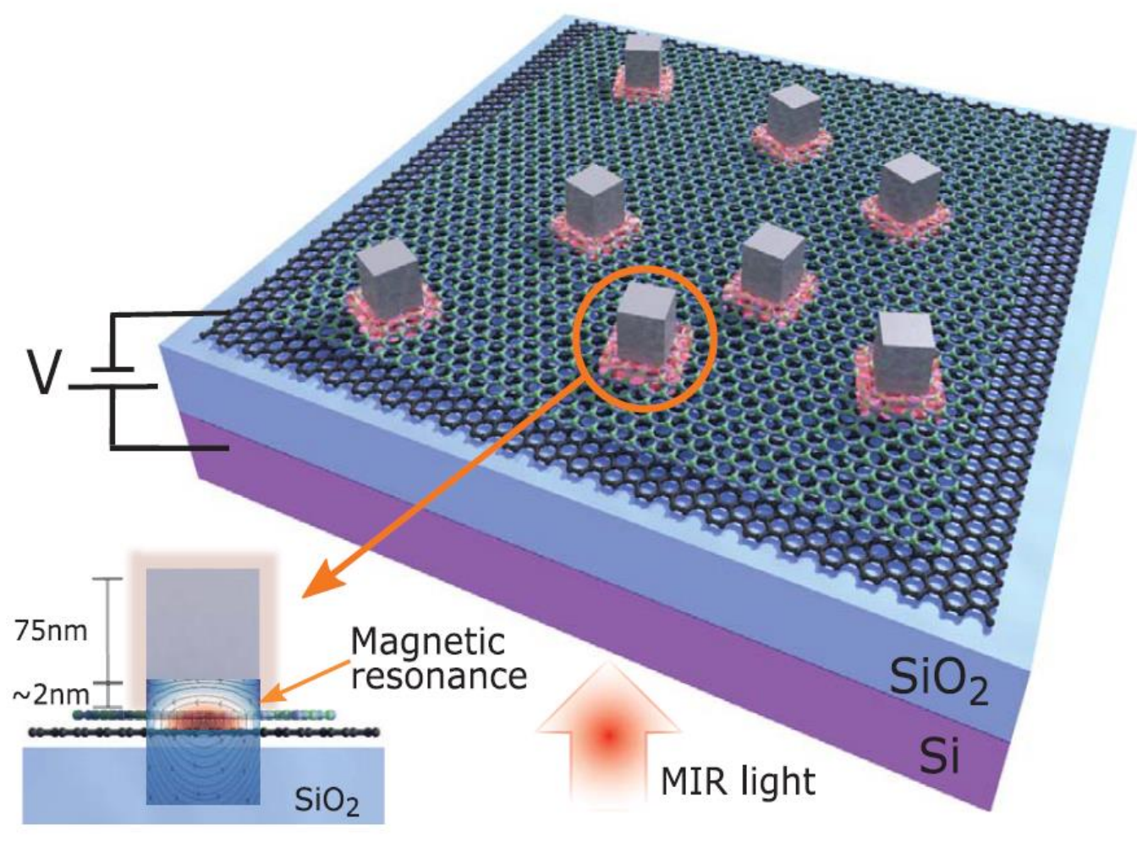
EM waves that couple to electron oscillations in graphene when placed close to a metallic surface support highly confined asymmetric mode referred to as an acoustic graphene plasmon (AGP) [1] .





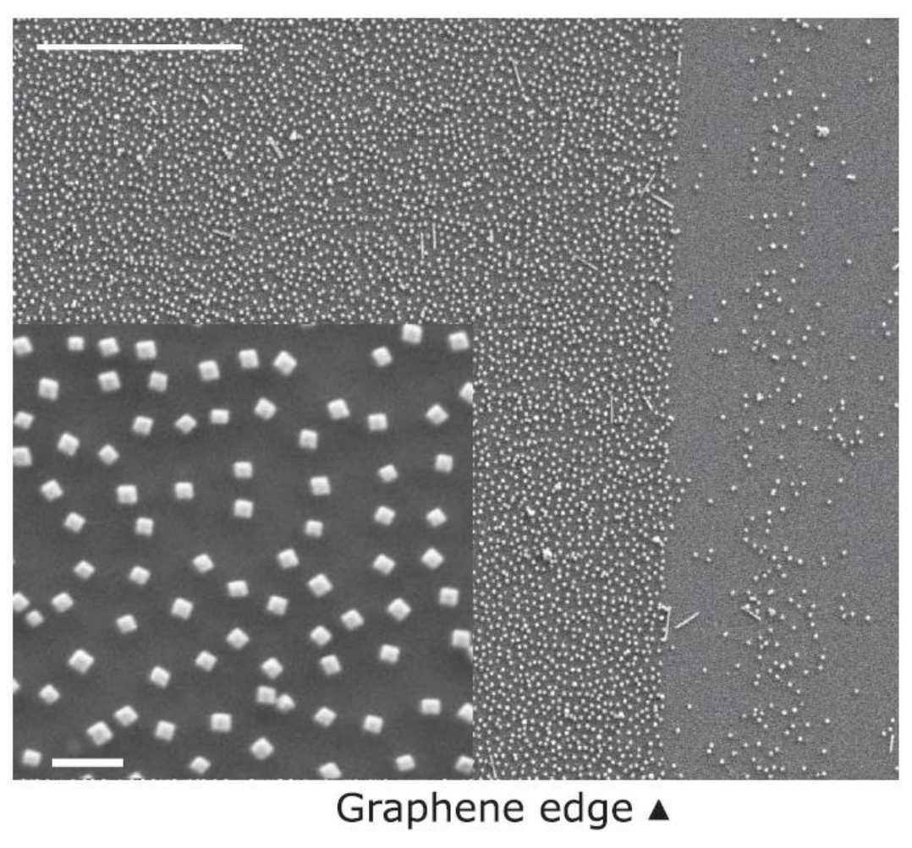
The AGPs exhibit extreme confinement in the mid-IR to THz spectrum with an in-plane confinement of almost 1/300 of λ_0[2] and can be vertically confined to as small as 1 atom thick [3].

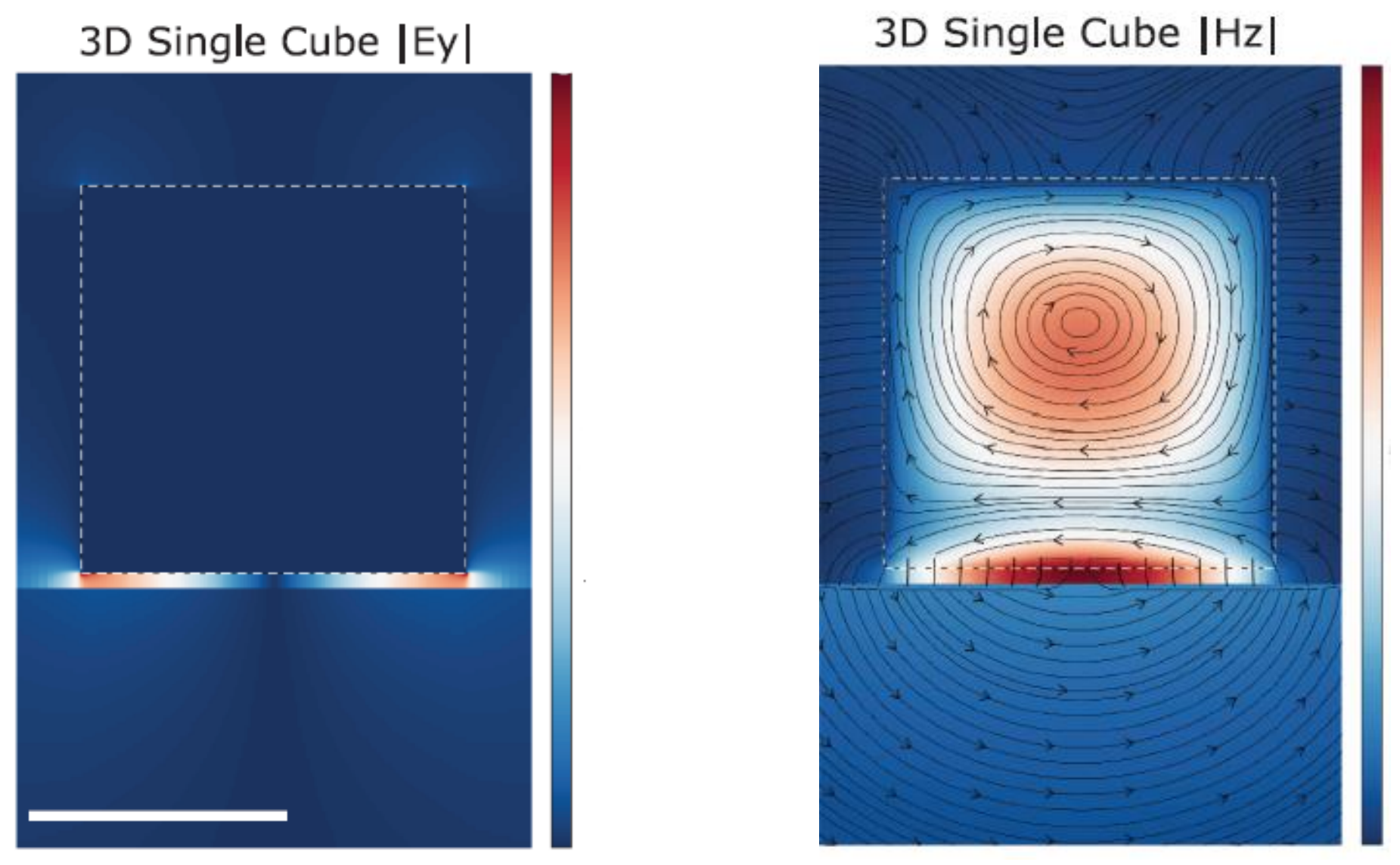
We realized single, nanometer-scale AGP cavities by the generation of a graphene plasmon magnetic resonance (GPMR), which enables the far-field excitation of AGP cavities [4].



GRAPHENE PLASMON MAGNETIC RESONANCE CAVITIES (GPMRs)

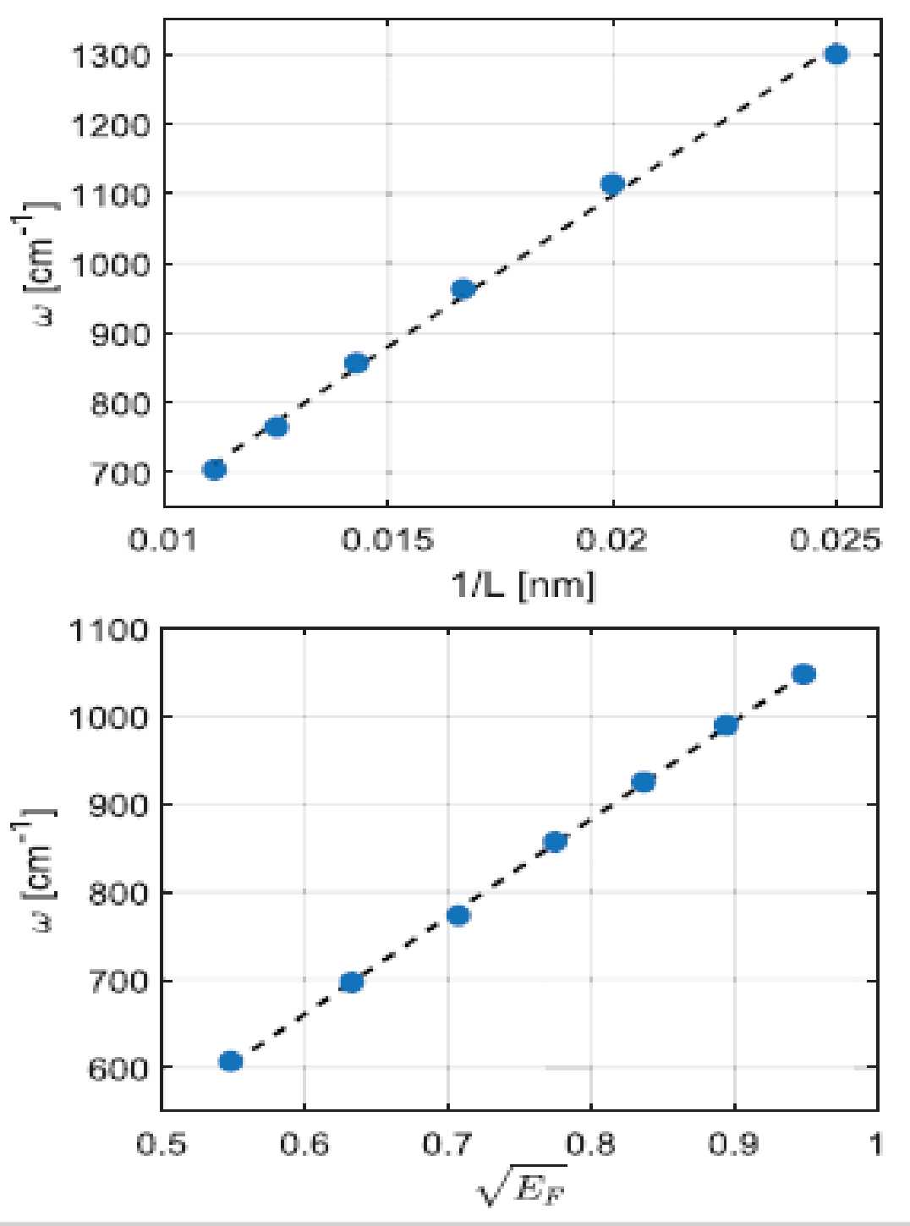
The GPMRs are formed by dispersing metallic nanocubes, with random locations and orientations, over a hexagonal boron nitride (hBN)/graphene van der Waals heterostructure.



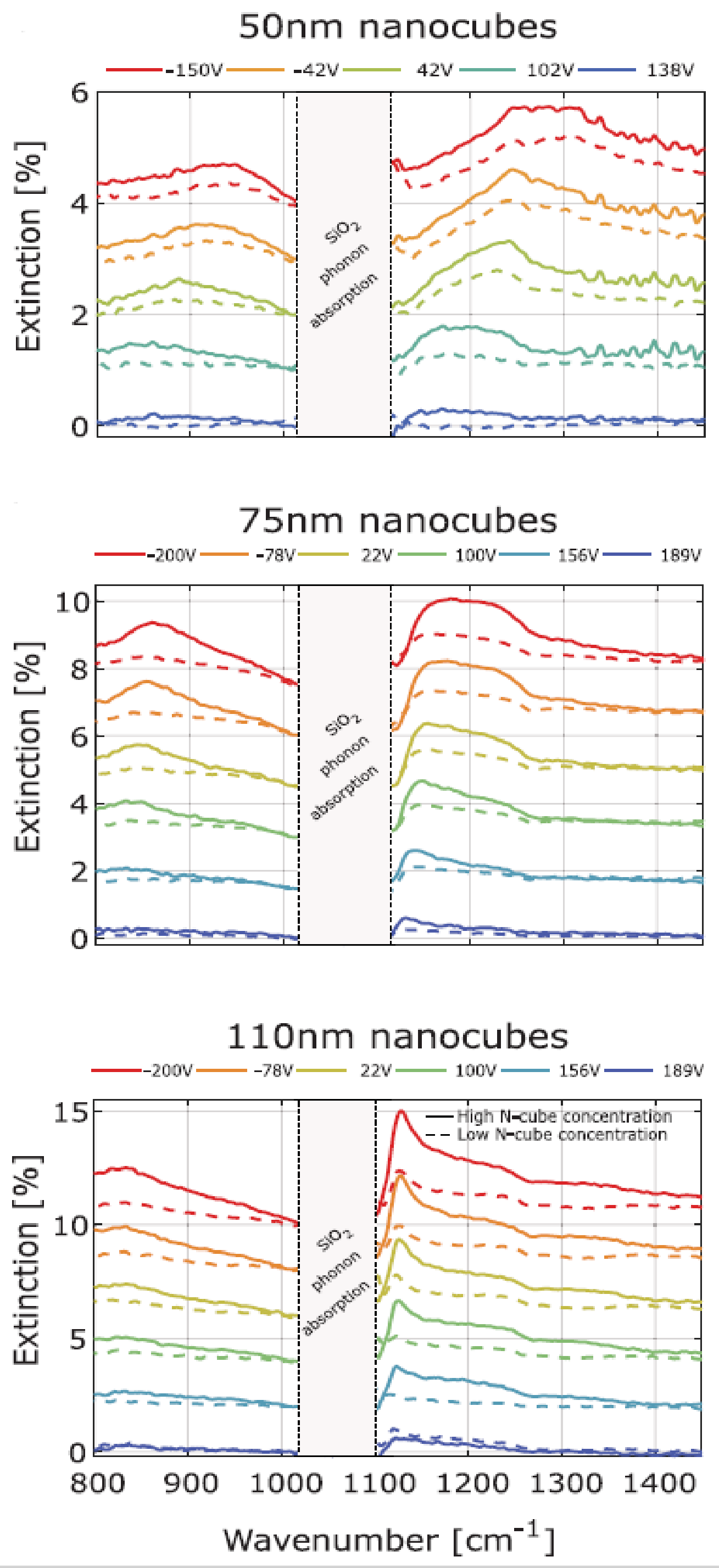


The electric field lines around the graphene-nanocube interface when imposed on the magnetic field lines form a loop that is correlated with a strong magnetic field in its center and has the shape of a magnetic dipole resonance.

Farfield illumination excites the GPMR patch antenna mode that is associated with excitation of AGP and shows linear dispersion.

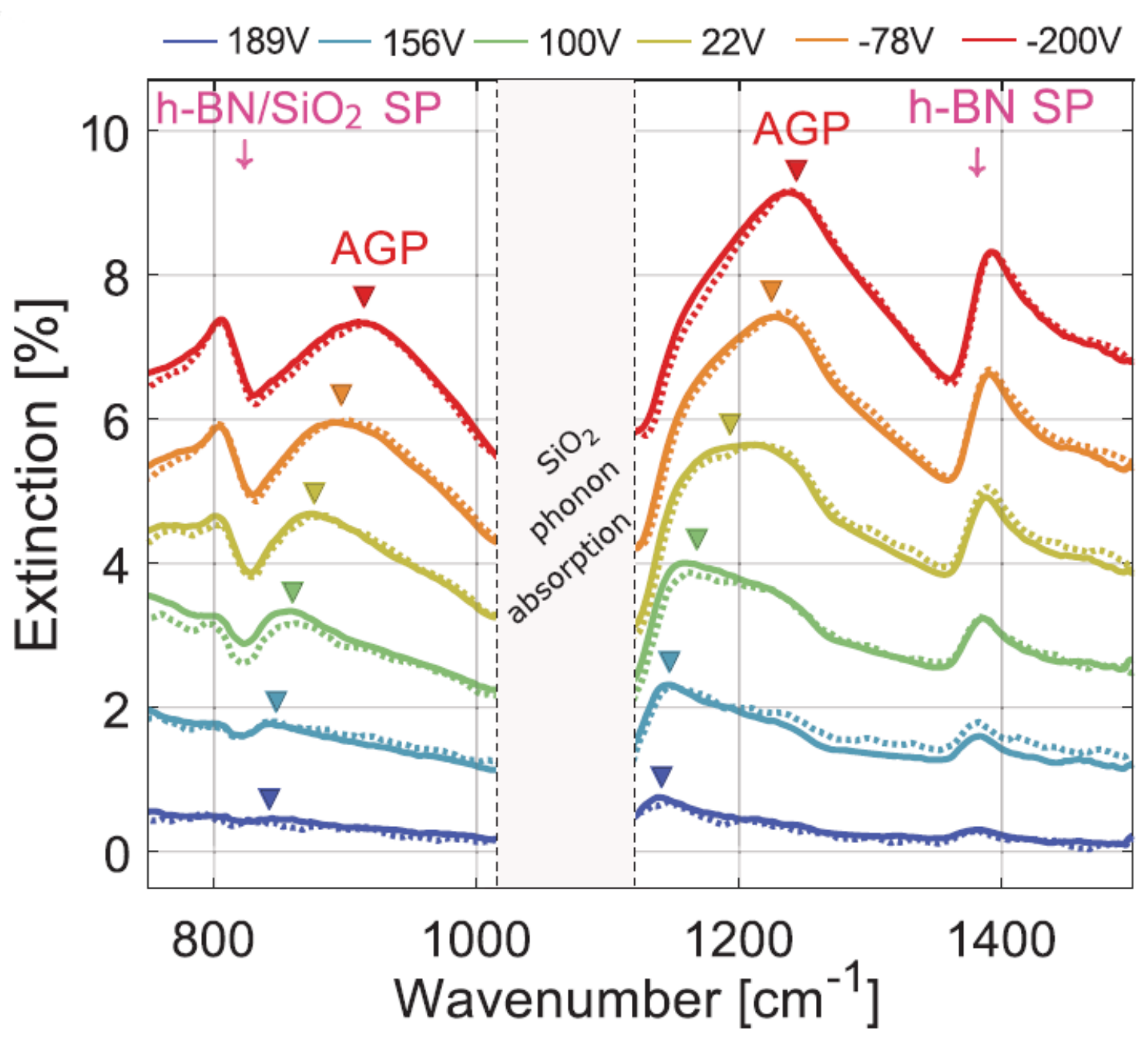


FARFIELD EXCITATION REVEALED BY FTIR EXTINCTION SPECTRA



The Fourier-transform infrared spectroscopy (FTIR) extinction spectra measured from the device for different back-gate voltages tunes the plasmon resonance.

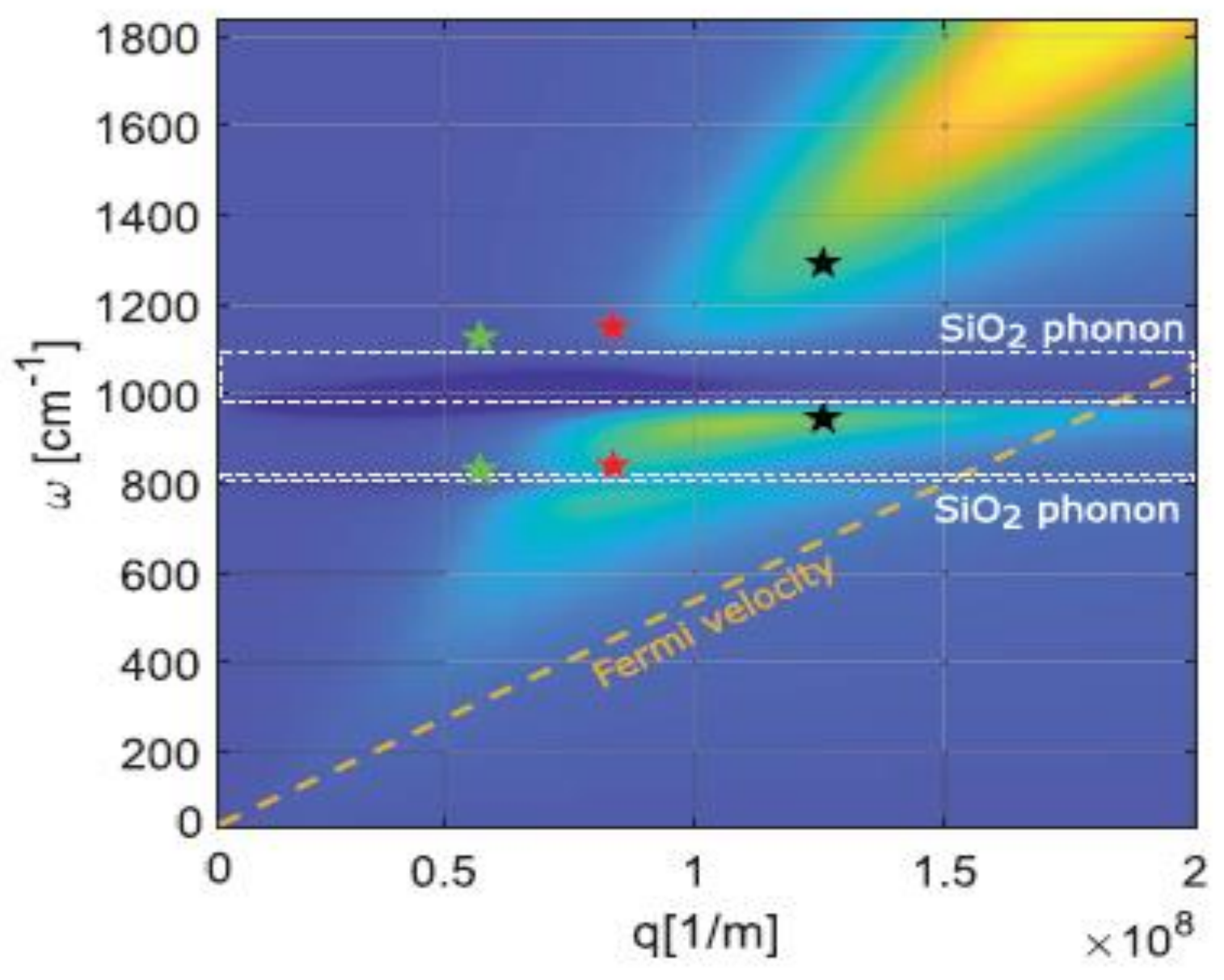
The scalable nature of the patch antenna can be observed in for different nanocube sizes, where a larger nanocube size corresponds to a larger effective wavelength of the mode.



AGPs being TM modes, lack preference of polarization on the response.

BROAD BAND TUNABILITY AND ULTRA SMALL MODE VOLUMES

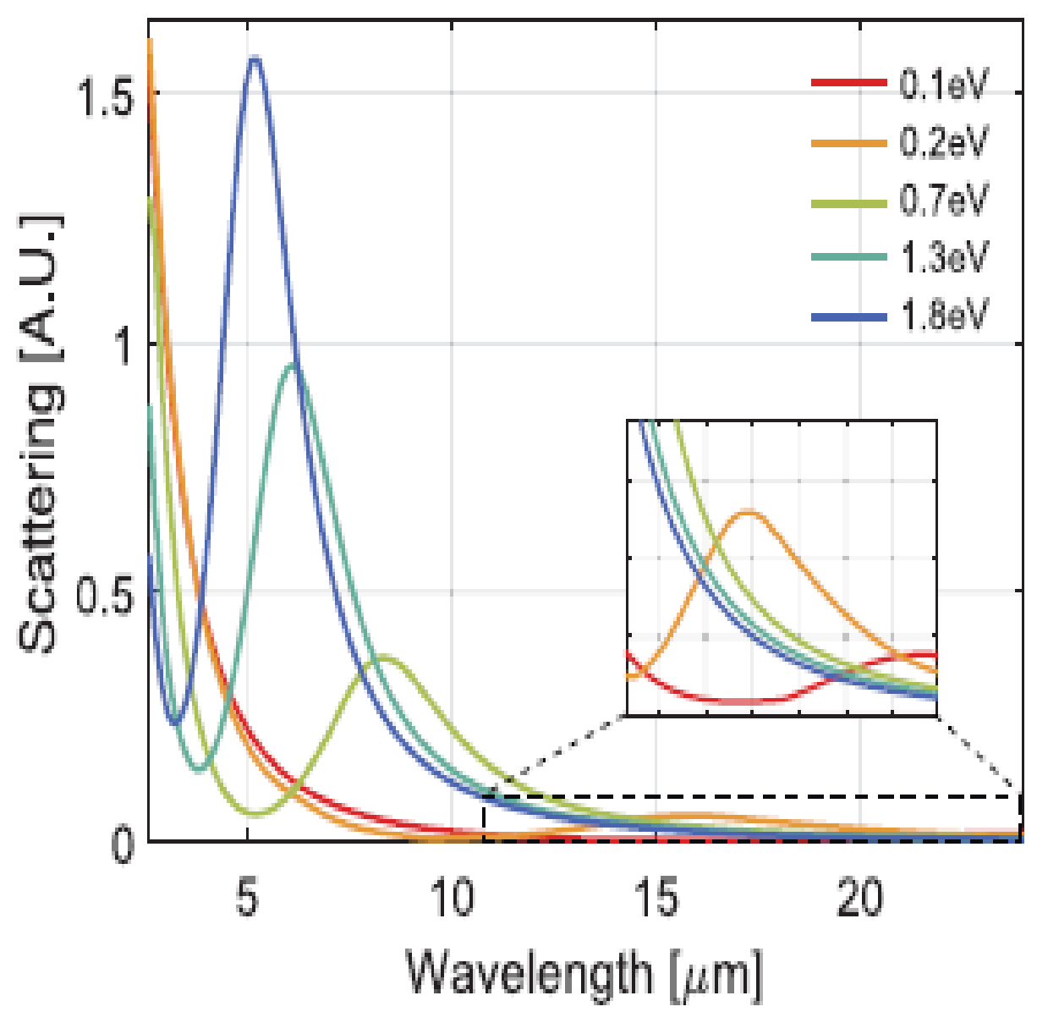
For 50nm cubes, the velocity of AGPs approaches the Fermi velocity and has a value of ~$1.42 * 10^6\ ^{m}/_{s}$

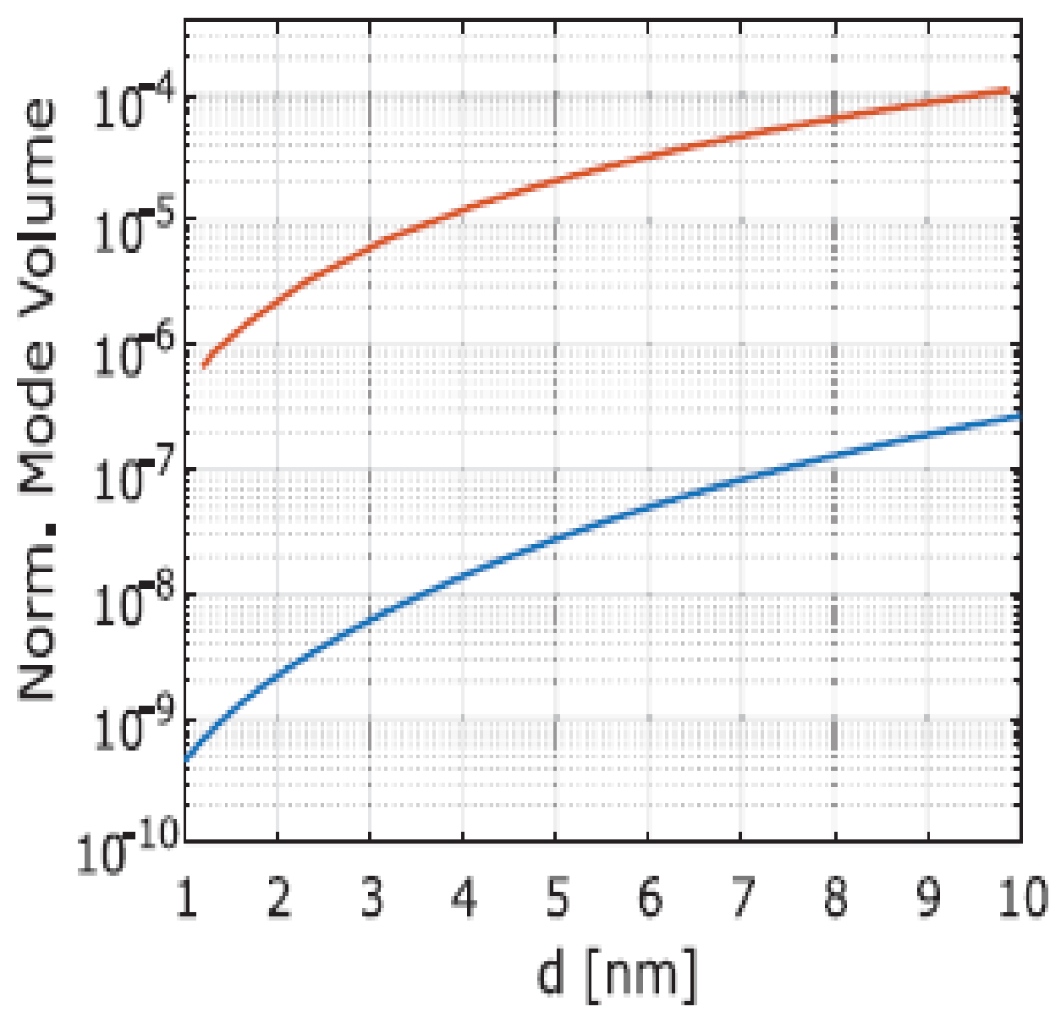


Scattering resonances for a 2D simulated single GPMR structure for various Fermi energy levels correlate to the AGP resonances and they can be tuned just by carrier doping.

The green, red and black stars correspond to 110nm, 75nm and 50nm nanocubes respectively

The normalized mode volume given by $^{V_{GPMR}}/_{\lambda_0{}^3}$ of a single GPMR cavity can reach ~$4.7 * 10^{-10}$





The red and the blue curve correspond to the nanocube on metal and nanocube on Graphene system for the visible and mid-IR spectrum respectively.

CONCLUSIONS

A single GPMR nano-patch antenna acts as a resonator and excites AGPs on illumination with farfield light. This also eliminates the need for lithographic patterning of either the surrounding or the graphene and are polarization insensitive.

In addition to an AGP velocity that is very close to the Graphene Fermi velocity of $1 * 10^6\ ^{m}/_{s}$ that can be achieved, broadband tunability of the optical response from the far-IR to the near-IR is made possible by the GPMR resonators and a normalized mode volume of single cavity can reach ~$4.7 * 10^{-10}$ for very less nanocube, graphene separation.

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