# Magnetoplasmons in Quasi-Neutral Epitaxial Graphene Nanoribbons

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## Introduction

Graphene plasmons, the collective oscillations of Dirac fermions, have recently attracted a great deal of attention. It has been theoretically suggested that graphene may be able to replace noble metals in future plasmonic devices, as it can host surface plasmons with longer lifetime and higher degree of optical-field confinement, owing to its extraordinary material properties. Moreover, recent advances in graphene synthesis and fabrication have made it possible to pattern large-scale micrometer-sized structures with increasing carrier mobility and tunable carrier density. These advances enable broadband graphene plasmonics operating at terahertz (THz) frequencies and make graphene promising candidate material for next generation optoelectronics.

## Experimental

We have fabricated large-area arrays of graphene nanoribbons (as shown in Fig.1a) from multilayer epitaxial graphene grown on the C face of SiC, using e-beam lithography and oxygen plasma etching. The ribbons are 50 nm, 100 nm, or 200 nm in width, and the length is as long as 2 mm. Using the 17.5 T superconducting magnet in SCM-3 and the Fourier transform infrared spectrometer, we have studied the dispersion of graphene magneto-plasmons, as a function of the magnetic field and the ribbon width.

## Results and Discussion

We have studied the plasmon-type collective excitations in quasi-neutral epitaxial graphene nanoribbon (GNR) arrays exposed to a perpendicular magnetic field [1]. Most saliently, we reveal a peculiar scaling behavior which allows us to identify this mode with the upper-hybrid mode (UHM) between the plasmon resonance and the $L_{0(-1)} \rightarrow L_{1(0)}$ Landau level transition. This scaling is different from that of the UHM in conventional two-dimensional electron gases (2DEGs) with parabolic bands or in highly doped graphene as well as from that of magnetoexcitons. Furthermore, we show that the possibility to confine plasmons in narrow GNRs allows to probe the dispersion relation of the UHM in a large parameter range (as shown in Fig.1b). For the 100nm-wide GNR arrays, we observe a wavelength shrinkage of ~165, a value difficult to achieve in common plasmonic materials, but in agreement with that predicted for graphene.

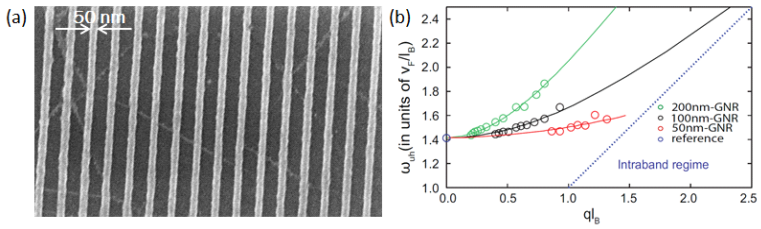


Figure 1: (a) Scanning electron microscopy image of a 50nm-wide GNR array sample. (b) Dispersion relation of the UHM, $\omega_{uh}(ql_B)$, in units of $v_F/l_B$, where $\omega_{uh}$ is the UHM frequency, $q$ is the in-plane wave vector, $v_F$ is the Fermi velocity, and $l_B$ is the magnetic length.

## Conclusions

In conclusion, we fabricated large-scale epitaxial GNR arrays with various widths and studied their plasmon properties in a magnetic field. We show that large-$q$ graphene plasmons can couple with the cyclotron resonance, forming an UHM and resulting in a blueshift in the energy of inter-LL transition. The observed energy shift exhibits a peculiar scaling behavior, which distinguishes it from the UHM in conventional 2DEGs and in highly doped graphene.

## Acknowledgements

The infrared measurement of this work was supported by the DOE (DE-FG02-07ER46451), and the GNR array fabrication was supported by the NSF (DMR-0820382) and the DOE BES through a contract with SNL. The work at SNL was supported by the DOE BES, Division of Materials Science and Engineering, and by Sandia LDRD.

## References

[1] Poumirol, J.M., *et al*., Phys. Rev. Lett. **110**, 246803 (2013).