Scientific achievement for Prof. Asgari

A paper by Prof. Reza Asgari and his collaborators on “ *Tuning quantum non-local effects in grapheme plasmonics*” has been accepted for publication in Science Magazine.

Plasmon modes represent a second kind of possible elementary excitation for the Fermi liquid. Basically, plasmon modes involve a cooperative motion of the system, governed by the global interaction between the electrons. Plasmon modes in two-dimensional electron liquids illustrate a long-wavelength dispersion that can be captured by classical equations of motion. The dispersion, however, departs from its classical value, becoming sensitive to quantum effects, by increasing the plasmon momentum.

Surface plasmons polarities (SPPs) are electromagnetic surface waves coupled to collective excitations of the conduction electrons in metal or semiconductor, propagating along the surface. SPPs in doped graphene show very peculiar behaviors. Doped grapheme is capable of sustaining SPPs which can be actively controlled and tuned through doping, the SPP enable higher level of confinement with having large lifetimes and propagation lengths, it emerges in the terahertz and mid-infrared region and it illustrates spectacular behaviors in graphene quantum dots as a quantum emitter.

The response of an electron system to electromagnetic fields with sharp spatial variations is strongly dependent on quantum electronic properties, even in ambient conditions, but difficult to access experimentally. Asgari and his collaborators have used high-quality graphene sheets encapsulated in hexagonal boron nitride and in the presence of nearby metal gates to tune the degree of quantum non-locality in the dispersion relation of graphene plasmons [1]. For illumination frequencies in the Terahertz range, acoustic plasmons in the system have a group velocity that can be made arbitrarily close to the graphene Fermi velocity by decreasing the graphene-metal distance. To tune, this causes the emergence of large plasmon momenta and therefore a high degree of non-locality. Their near-field imaging experiments reveal a parameter-free match with the full theoretical quantum description of the massless Dirac electron gas, in which they have identified three types of quantum effects as keys to understanding the experimental response of graphene to short-ranged terahertz electric fields. The first type is of single-particle nature captured by the random-phase-approximation and is related to shape deformations of the Fermi surface during a plasmon oscillation. The second and third types, which are well beyond the random-phase-approximation, are carrier-density-dependent many-body effects controlled by the inertia and compressibility of the interacting electron liquid in graphene.

The recipe set forth in this work can be transferred to probe other electron systems with exotic physical properties. Not only does this technique reveal the collective excitation, but they have also shown how one may isolate the electronic response from its environment, quantitatively mapping out the underlying response function (non-local conductivity) as a function of wavelength. This kind of spatial spectroscopy forms a valuable counterpart to the traditional temporal (frequency) spectroscopy, and the marriage of these two approaches into a precision spatiotemporal spectroscopy—a full determination of $\sigma(\omega, q)$—would provide an unprecedented window into electron physics. This may allow a greatly enriched understanding of electron correlation physics such as those underlying fractional quantum hall effects and the binding mechanism in superconductors, as well as probing the non-locality of Fermi surface deformations in unusual band structures, e.g. Weyl fermions.

[1] M. B. Lundeberg, Y. Gao, R. Asgari, C. Tan, B. V. Duppen, M. Autore, P. Alonso-González, A. Woessner, K. Watanabe, T. Taniguchi, R. Hillenbrand, J. Hone, M. Polini and F. H. L. Koppens, To appear in Science (2017)