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Plasmonic response of graphene nanoribbons

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Plasmonics, as a promising way for shrinking the size of photonic and electronic circuits, has attracted a great interest [1], [2]. Plasmons are collective exci- tations of surface electrons in a good conductor and can confine the electromagnetic energy beyond the diffraction limit. Conventionally, metals like gold have been used as plasmonic materials; however, because of high dissipation in these materials, plas- mons cannot propagate long distances. Graphene [3], [4], a two dimensional semimetallic allotrope of carbon, has high electron mobility and has been of a great interest as a novel plasmonic material [5], [6], [7], [8].

Graphene has a gapless electron band structure with Dirac cones; so, its plasmon dispersion is different from the plasmon dispersion in quasi- two-dimensional (quasi-2D) electron systems with a parabolic band structure. The plasmon resonances in graphene typically fall into the terahertz and mid-infrared range. Unlike in metals, the carrier density in graphene can be controlled by applying a gate voltage, which provides plasmon-resonance tunability. However, it has been shown that gaining tunability by putting graphene on substrate reduces the plasmon propagation length [7]. However, by lowering the system dimension and moving from graphene to graphene nanoribbons, one can de- crease the electron scattering rates. Thus, supported graphene nanoribbons (GNRs) have higher electron mobility and offer the tunability feature, as well.

Here, we calculate the plasmon dispersion and plasmon propagation length in armchair graphene nanoribbons (aGNRs) and zigzag graphene nanorib- bons (zGNRs) via self-consistent field and Marko- vian Master equation (SCF-MMEF) [7]. Electrons in supported GNRs, as in every open system, in- teract with a dissipative environment. SCF-MMEF is able to capture all the concurrent dissipative mechanisms, such as phonons, ionized impurities, surface optical (SO) phonons, the line-edge rough- ness. We derive the interaction Hamiltonian for electrons and SO phonons in GNRs, and quasi- one-dimensional (quasi-1D) systems in general. The SO phonon and electron interaction only requires the momentum conservation along the length of the ribbon. This means that a single electron transition can be mediated by a number of SO-phonon modes, unlike in the quasi-2D systems. As a result, in narrow GNRs, SO-phonon scattering is as important as ionized impurity scattering for electron transport.

By calculating the dielectric function via the SCF-MMEF, we calculate the loss function for GNRs on the SiO_2 substrate. The loss function peaks at the plasmon resonances. The higher the peak, the farther the plasmons propagate. In zGNRs, because of heavy carriers (flat energy dispersions) and high scattering rates, plasmons are highly damped and the plasmon propagation length barely exceeds 100 nm. The same behavior happens in $(3N)$-aGNRs and $(3N+1)$-aGNRs, where N is an integer and $3N$ and $3N+1$ are the number of dimer lines. However, in $(3N+2)$-aGNRs, plasmons can propagate up to a micron. In Fig. 1, the loss function of three different $(3N+2)$-aGNRs on SiO_2 is shown. The sheet electron density is $ns = 7 \times 10^{12}$ cm^{-2}, and the impurity density is $N_i = 4 \times 10^{11}$ cm^{-2}. By increasing the width of the $(3N+2)$-

aGNRs, for the same sheet carrier density, the Fermi level increases; as a result, the loss-function peaks get higher and narrower (which equals longer plas- mon propagation length). But, this trend stops when the Fermi level approaches the second conduction subband. This trend can be seen in Fig. 1. Also, in aGNRs, unlike in graphene, plasmons are not totally damped below the highest SO phonon mode.

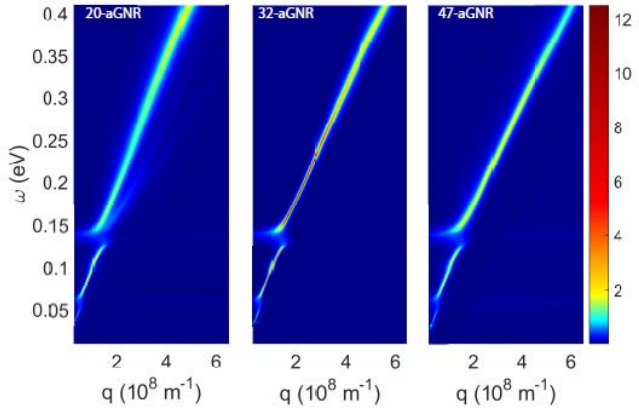

Fig. 1: The loss function of (left) 20-aGNR, (middle) 32-aGNR, (right) 47-aGNR as a function of the wave vector, q, and frequency, ω. The sheet electron density is n_s = 7 x 10^{12} cm^{-2}, and the impurity density is N_i= 4x10^{11} cm^{-2}. All color bars have the same scale. The loss-function peaks are highest and narrowest in 32-aGNR (middle), which implies a long propagation length.

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