Edge-dependent reflection and inherited fine structure of higher-order plasmons in graphene nanoribbons

We investigate higher-order plasmons in graphene nanoribbons, and we present how electronic edge states and wave-function fine structure influence the graphene plasmons. Based on nearest-neighbor tight-binding calculations, we find that a standing-wave model based on nonlocal bulk plasmon dispersion is surprisingly accurate for armchair ribbons of widths even down to a few nanometers, and we determine the corresponding phase shift upon edge reflection and an effective ribbon width. Wider zigzag ribbons exhibit a similar phase shift, whereas the standing-wave model describes few-nanometer zigzag ribbons less satisfactorily, to a large extent because of their edge states. We directly confirm that also the larger broadening of plasmons for zigzag ribbons is due to their edge states. Furthermore, we report a prominent fine structure in the induced charges of the ribbon plasmons, which for armchair ribbons follows the electronic wave-function oscillations induced by intervalley coupling. Interestingly, the wave-function fine structure is also found in our analogous density-functional theory calculations, and both these and tight-binding numerical calculations are explained quite well with analytical Dirac theory for graphene ribbons.

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