Graphene antidot lattice waveguides

Jesper Goor Pedersen, Tue Gunst, Troels Markussen and Thomas Garm Pedersen

DTU Nanotech - Department of Micro- and Nanotechnology, Technical University of Denmark, DTU Building 345 East, DK-2800 Kongens Lyngby, Denmark
jeped@nanotech.dtu.dk

Abstract

In recent years, the concept of graphene antidot lattices (GALs) – periodic perforations of graphene – has proven an efficient way of tuning the properties of graphene [1]. In particular, experimental indications of a transport gap in graphene have recently been demonstrated [2]. While bulk GALs are interesting in their own right, there is a rich opportunity for developing graphene-based devices based on combinations of GALs and pristine graphene. We have recently theoretically proposed one such device, namely GAL waveguides [3]. Here, a region of pristine graphene is sandwiched between regions of GALs, as illustrated in Fig. 1. As the low-energy properties of GALs are quite well-described by the addition of a mass term to the Dirac equation of graphene, the surrounding GALs allow tight confinement of carriers within the central, pristine graphene region. This is in contrast to the case of electrostatic confinement, which in graphene is hindered by Klein tunneling. By including the effect of the GALs via a position-dependent mass term in the Dirac equation we arrive at analytical expressions for the dispersion relation and eigenstate spinors of the localized states. We find excellent agreement between the analytical results and more exact tight-binding simulations, as shown in Fig. 2. The results reveal tightly confined states, with eigenstates resembling those of graphene nanoribbons. Contrary to nanoribbons, however, GAL waveguides do not have sharply defined edges. We find that overall GAL waveguides resemble graphene nanoribbons but without the intricacies related to edges. In particular, GAL waveguides are always semiconducting.

Using recursive Green's functions techniques we calculate the transmission through a GAL waveguide attached to semi-infinite graphene leads and compare to the transmission through a graphene nanoribbon of comparable dimensions. We find that generally transmission is higher through the GAL waveguides. Including disorder in the shape of carbon atoms randomly removed at the edges of the antidots, we find that the waveguides are quite robust to disorder.

Relying on the close analogies with photonic crystal waveguides we expect negligible backscattering through bends in the waveguide. We find that the transmission through a kink in the waveguide, shown in Fig. 3, is nearly identical to the transmission through a straight waveguide of similar length, despite the fact that the waveguide in Fig. 3 switched between zigzag and armchair orientations.

With the benefit of the surrounding GAL in terms of mechanical stability and the possibility of carrying away Joule heating from the device, we believe that GAL waveguides may offer an attractive way of realizing electronic wires in graphene-based electronics.

References

[1] T. G. Pedersen, C. Flindt, J. Pedersen, N. A. Mortensen, A.-P. Jauho, and K. Pedersen, Physical Review Letters, **100** (2008), 136804.
[2] A. J. M. Giesbers, E. C. Peters, M. Burghard, and K. Kern, Physical Review B, **86** (2012), 045445
[3] J. G. Pedersen, T. Gunst, T. Markussen and T. G. Pedersen, Physical Review B, **86** (2012) 245410.

Figures

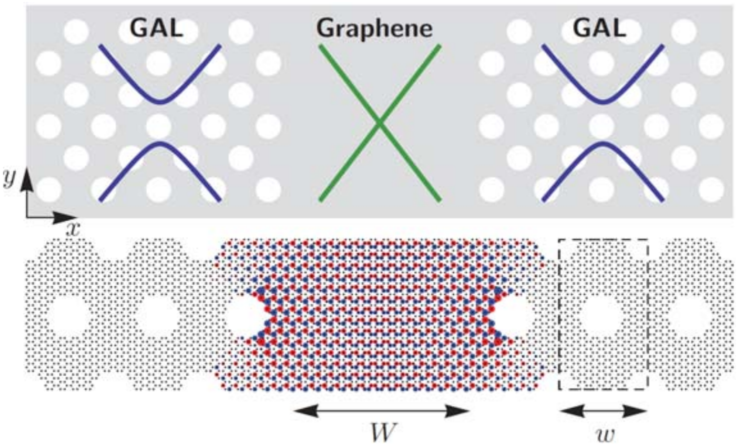

Fig. 1. (upper panel) Schematic illustration of GAL waveguides; the band gap of the surrounding GAL regions confine carriers to the central waveguiding region of pristine graphene. (lower panel) One example of a GAL waveguide. Black dots indicate carbon atoms, while the red (blue) circles illustrate the probability distribution of the lowest eigenstate at the G point of the waveguide. The size of the circle shows the absolute square of the probability density while color indicates sign. Note the strong confinement.

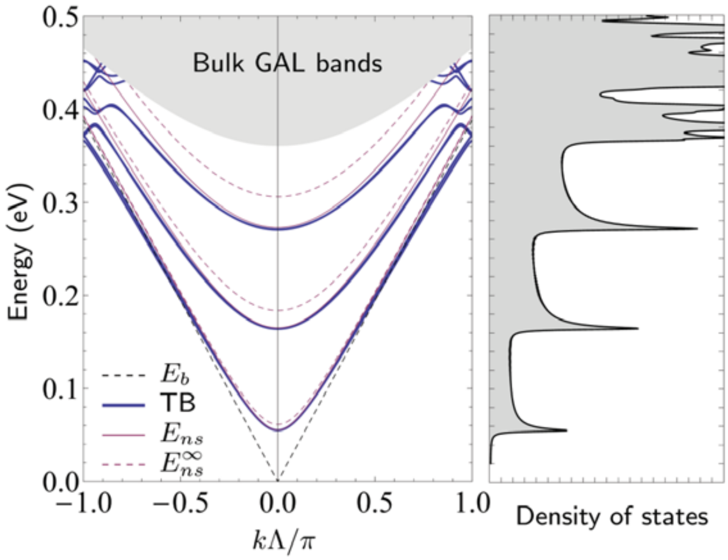

Fig. 2. (left) Dispersion relation of a GAL waveguide. Thick blue lines indicate results from the TB calculation. The solid red lines are results from a Dirac equation, where the GALs are included via a position-dependent mass term. The dashed, red line shows the analytic result obtained in the infinite mass limit. For comparison, the bulk graphene dispersion relation is shown with black, dashed lines. The shaded grey region indicates the projected bands of the surrounding GAL, which define the range below which localized states are expected. (right) Corresponding DOS of the TB model. Note the clear van Hove singularities characteristic of one-dimensionality.

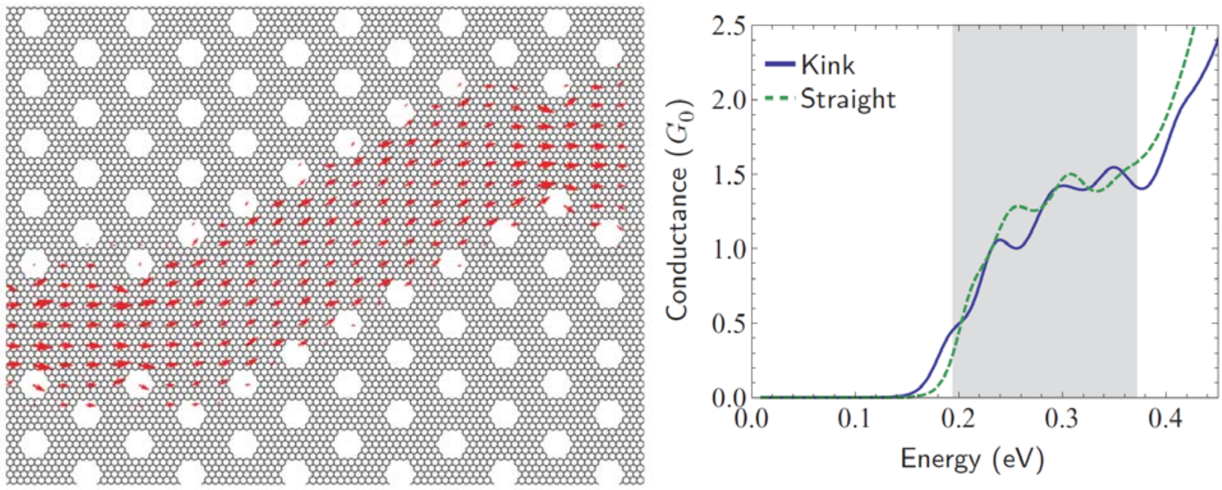

Fig. 3. (left) Waveguide bend, with a transition between zigzag and armchair directions. The arrows show the bond current, illustrating the tight confinement to the waveguide and negligible backscattering through the bend. (right) Conductance of the waveguide 'kink' shown to the left, compared to a structure where the waveguide runs straight through.