Electron optics in graphene and phosphorene heterojunctions

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The current flow in graphene and phosphorene *np*-heterojunctions is studied theoretically. The propagation of narrow electron beams is calculated by means of a tight-binding model and the NEGF method. The heterojunctions are modelled by an atomically sharp potential.

In general, the calculated current flow paths (for electrons with energy *E*) agree with trajectories that are obtained in the continuum and geometric optics approximations, see Fig. 1. Moreover, the current paths show additional effects due to the wave nature of the electrons. The interference of the incoming and reflected electron beams generate a ripple pattern, and the dispersion of the electron beams causes transmission beyond the critical angle obtained from geometric optics.

In phosphorene, see Fig. 2, the current flow through the junction depends strongly on the lattice orientation due to the anisotropy of the electronic structure. In the x-direction the electrons behave as pseudo-relativistic particles similar to graphene with a gap Δ. In the *y*-direction the propagation is due to a gapped quadratic dispersion which resembles bilayer graphene. Hence, in the x-direction the electrons impinging perpendicular to the junction are transferred, whereas in the *y*-direction they are reflected. For incidence angles different to 0°, partial transmission is observed up to a critical angle.

Our studies may pave the way to the next generation of electron optics experiments in graphene and the first generation of such experiments in phosphorene.

Figures

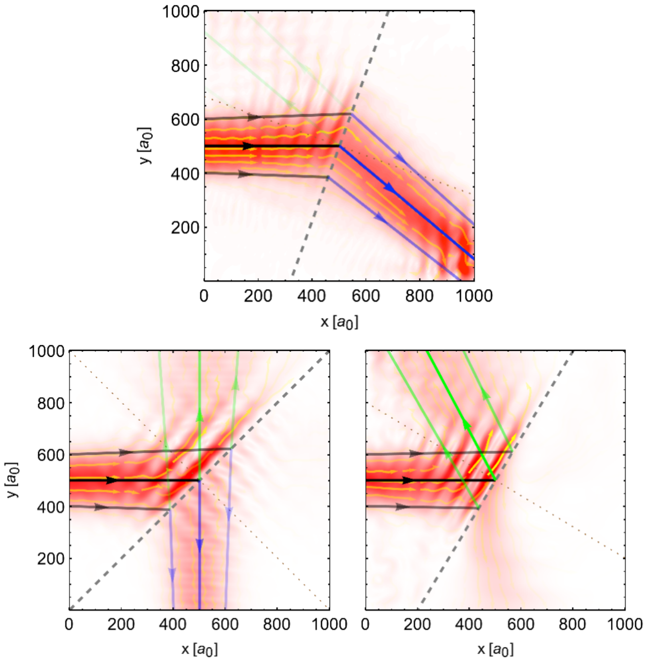

Figure 1: Current flow (red color density, yellow arrows) in a symmetric graphene heterojunction (*n*=0, *p*=2*E*). Semi-classical trajectories are shown by solid lines. Left: the junction (dashed line) is tilted by 45° and acts as a beam splitter. Right: transmission beyond the critical angle.

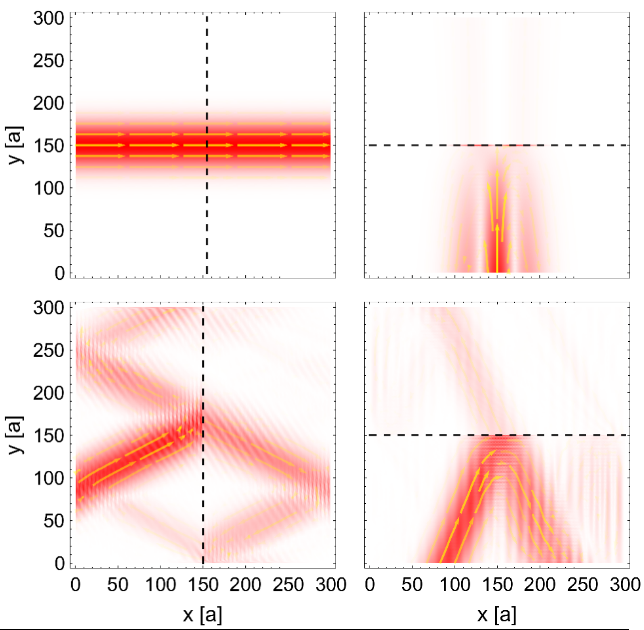

Figure 2: Current flow in a symmetric phosphorene heterojunction (*n*=0, *p*=2(Δ+*E*)). The transmission through the junction depends strongly on the orientation of the lattice.