Quantum transport in mesoscopic systems

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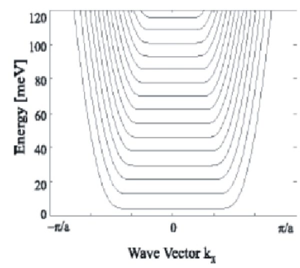
In the last year we have developed analytic and numerical methods to improve the codes which had been recently elaborated in our group for the study of electronic transport in nanodevices. The method we use is based on the non-equilibrium Keldysh Green's function formalism implemented with the real space recursive technique in the tight-binding framework. Our numerical codes are now able to simulate realistic quantum wire devices of width of the order of few microns also in the presence of magnetic fields of arbitrary strength and different kinds of disorder.

The formalism we have settled, allows to gain a very detailed description of the microscopic currents in the device, discerning between equilibrium and non-equilibrium components of conductances and of total currents, and corresponding population analysis [1-3]. We have addressed the subtle problem of interplay between conductance quantization and chirality of currents in Hall-bar devices [4] considering effects of disorder and the presence of quantum point contacts [5].We have considered a lead-device-lead impurity free system case in the form of a Hall bar composed by N_y chains infinitely extended along the x-direction, threaded by a z-directed magnetic field with vector potential **A**= (-By,0,0). Landau levels and edge states produced by confinement are reported in Figure 1.

The conductance for the perfect wire in the presence of a magnetic field shows the typical quantization steps in multiples of $2e^2/h$. To analyze the effect of disorder on currents and conductance quantization, we have then introduced a 100 sites wide region of Anderson disorder with strength $|t|/3$, where t is the nearest neighbor interaction in the system Hamiltonian. The total conductance is reported in Figure 2(a). In figure 2(b) a map of the total persistent currents when E_F=17 meV (plateau region) is reported.

It is evident that these currents spread all over the device and not only at the edges. The corruption of the sharp steps of the conductance due to disorder is evident even if the central part of the lower plateaus is preserved flat. This suggests that in the plateau regions chirality of currents holds as shown by the spatial distribution of persistent and transport currents reported in figures 2(c) and 2(d). When chirality of charge flow is not present (as in Figures 2(e) and 2(f) for E_F=21 meV) currents invade all the device and quantization is absent.

Fig. 1
Dispersion curve of an ideal wire with site energies $E_0=4|t|$, $m^*=0.067$ m, T=-0.125 eV and B=5T



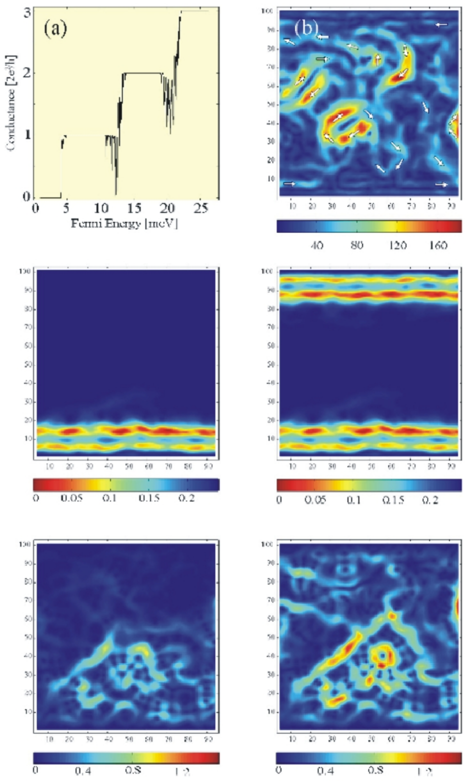


Fig. 2
(a)Total conductance versus Fermi energy in the presence of disorder.
(b)Persistent current distribution up to E_F=17 meV, the unit on the color scale is nA. The arrows are a guide to the eye and indicate schematically the local direction of the currents.
(c)Transport differential conductance distributions at E_F=17meV
(d)Persistent differential conductance distributions at E_F=17meV;
(e)Transport conductance distributions at E_F=21 meV.
(F)Persistent conductance distributions at E_F=21 meV.
For conductances, the unit on the color scale is $2e^2/h$

We have studied conductive channels and currents distribution through a narrow quantum point contact in a 2DEG in magnetic field (Fig. 3). We have shown that when the conditions of chiral transport regime are met in the two regions separated by the QPC, exact quantization in integer multiples of $2e^2/h$ is maintained both for the conductance of the incident current and the backscattered plus transmitted currents.

For this system we have also evaluated the non-equilibrium electron distribution function at different positions inside the bar when a finite chemical potential difference is applied to the electrodes (see Fig. 4 and Fig. 5)

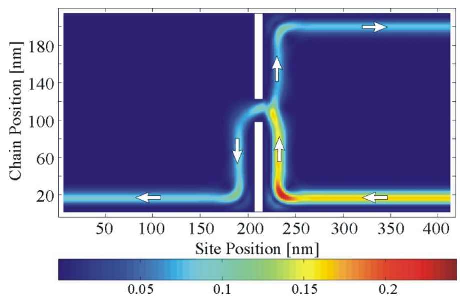


Fig. 3
Differential conductance profile for transport current for a two-dimensional bar of width 200 nm (and infinite length) with a narrow constriction of width 8 nm and a central opening of 20 nm. The Fermi energy is E=9.5 meV (we take $\mu_L<E<\mu_R$ so that the electron beam is injected from the right lead in the lower edge of the device). The unit on the color scale is $2e^2/h$. The unit of length is nm.

Fig. 4
Density-of-states D (states/eV), density-of-occupied-states r (states/eV) and non-equilibrium distribution f at various sections of the device (indicated in the inset) at the energy E=9.5 meV. (a) section at x=350 nm in the injecting region; (b) section at x=222 nm slightly at the right of the quantum point contact zone; (c) section at x=201 nm slightly at the left of the quantum point contact; (d) section at x=50 nm in the collector region.

Fig. 5
(A) Density-of-states D far from the constriction (states/eV); (b) density-of-occupied-states r in the collector region (states/eV); (c) density-of-occupied-states r in the injection region (states/eV)

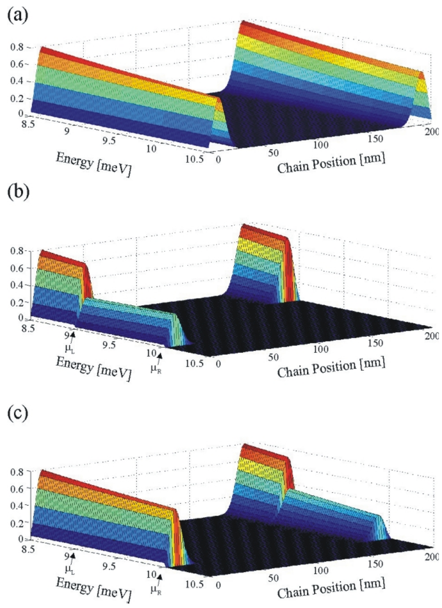


Fig. 5

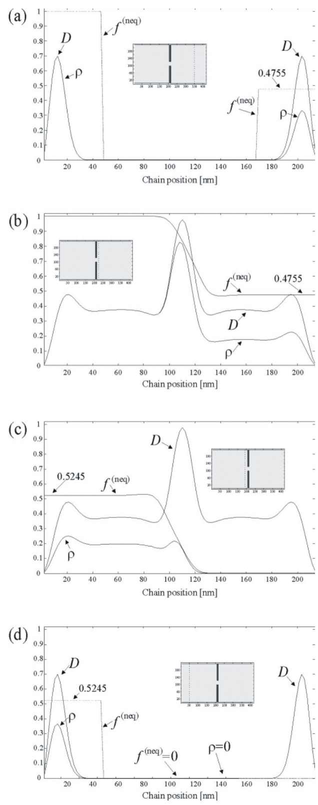


Fig. 4

References

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