IMAGING IN QUANTUM POINT CONTACTS

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Electron transport through two-dimensional mesoscopic devices, built in a two-dimensional electron gas at the interface of heterostructures, has the advantage of high mobility of the carriers and typical wave-length and means free path much larger than in metals. One of the most interesting devices is the quantum point contact (QPC), which has played an important role in the discovery of conductance quantization in mesoscopic systems [1]. Many progresses in technology have made it possible to obtain geometrically very defined QPCs, and to vary their shape by means of proper energized gates; moreover, in the last years, much effort has been devoted to the experimental imaging of current flowing through QPCs [2]. The technique used for current imaging consists, substantially, in measuring the differences between the total conductance of the device in the absence and in the presence of a capacitively coupled scanning microscope tip at different positions, see Fig.1; we refer to this technique as 'tip method'. The effect of the tip is to deplete the zone under it; varying its position all above the device, a detailed map is obtained.

Our work is intended to simulate these experimental results and to compare them with the theoretical maps of the currents obtained in the absence of the scanning microscope tip. We do it by means of the Keldysh Green's functions theory in a tight-binding framework [3], that allows a detailed description of the device geometry and an efficient calculation thanks to the decimation-renormalization method [4].

The QPC potential is modelled by a specific Ando potential [5], which leads to conductance quantization at step integer multiples of $2e^2/h$, see Fig.2. In the following we concentrate on the third step in the conductance plot, corresponding to the activation of three conduction modes in the QPC.

The results show that the typical $\lambda_F/2$ interference fringes (Fig.3 and Fig.4) are visible only in the tip method images and they are due to the presence of the tip that acts as scatterer, while the images obtained calculating directly the currents (Fig.5) show the fringes caused by the interferences between the propagating wave and the wave reflected by the boundaries of the wire.

The main features of the currents distribution are common in the two kinds of imaging, especially the number of electron jets corresponding to the number of active modes in the QPC (three in the figures here reported, i.e. the conductance is approximately $3x2e^2/h$); moreover we confirm that the interference effects of the tip are responsible of the $\lambda_F/2$ interference fringes and thus evidence the coherence of the electrons.

References:

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Figures:

Figure 1: Schematic of the experimental setup to obtain currents distribution. A STM tip scans the surface of the device, depleting the zone beneath. The difference between the total conductance in the presence and in the absence of the tip is reported on the map.

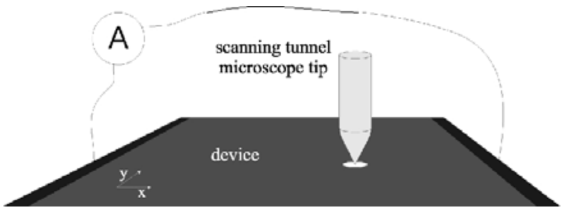

Figure 2: Step-like conductance of the QPC at fixed Fermi energy (20 meV) and varying the gate potential.

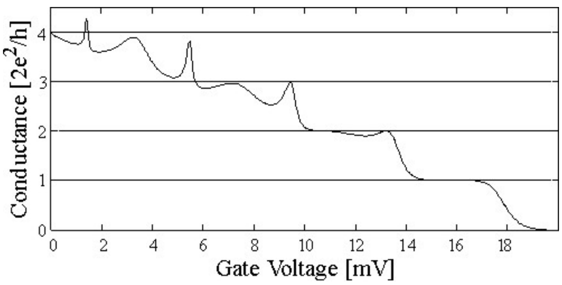

Figure 3: Theoretical imaging of the currents obtained simulating the experimental method, when the total conductance is around $3x2e^2/h$. Notice the interference fringes.

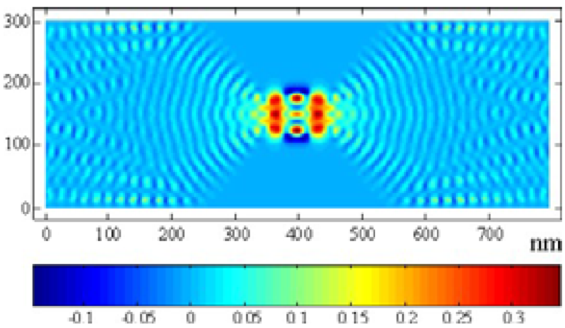

Figure 4: Section of Fig.3 in the zones where the fringes are more regular for E_F=20 meV and E_F=50 meV; the corresponding cosine-transforms are shown. The spatial separation between two consecutive fringes is about $\lambda_F/2$.

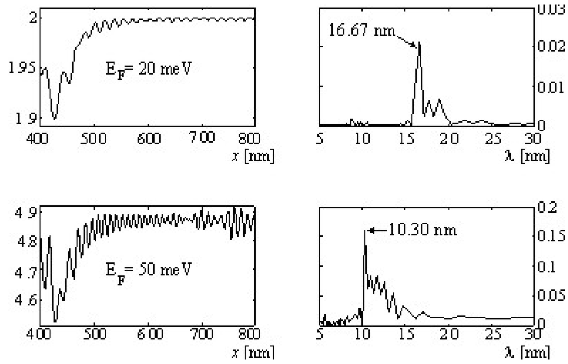

Figure 5: Theoretical imaging of the currents through the quantum device obtained by means of the Keldysh Green's function formalism and without the aid of the tip. The fringes observed in Fig.3 disappear, but some interference effects due to the reflection of the wave on the wall of the wire, are still visible.