Numerical Simulation Of Transport And Noise In Mesoscopic Cavities

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Mesoscopic cavities are relatively large (a few microns across) regions in a 2-dimensional electron gas (2DEG) delimited by constrictions a few tens of nanometers wide. They have received significant attention in the last few years, because of their peculiar transport and noise properties.
Here we will analyze their tunneling enhancement property and their noise behavior in the presence of a magnetic field. Our numerical approach is based mainly on two techniques: the recursive Green's function method and the recursive scattering matrix technique. In both cases we use a representation on the transverse mode space along the direction orthogonal to carrier propagation; this enables us to reduce the computational size of the problem, including only the modes that give a nonnegligible contribution to the solution.

As far as the tunneling enhancement phenomenon is concerned, we consider a mesoscopic cavity containing a potential harrier orthogonal to the direction of current flow (Fig. 1). We have observed that the overall conductance of the cavity, from the entrance to the output constriction, is strongly influenced by the longitudinal position of the barrier, and that it is maximum when the barrier is exactly in the middle. The most striking feature is that in such a symmetric configuration the resulting total transmission can be much larger than that which would be expected from the transparency of the isolated barrier.

We study cavities that are 5 μm long and in Fig. 2 we report the transmission as a function of the longitudinal position of the barrier, for a cavity that is 500 nm wide and delimited by 50 nm constrictions. The barrier is 50 meV high, 11 nm thick and, inserted in a channel 500 nm wide, it has a total transmission of 0.195 for the Fermi energy we are considering of 9 meV, typical for the 2DEG in a GaAs/AIGaAs heterostructure. When the barrier is exactly in the middle, the transmission is about 0.6 which is much greater than that of the *barrier* alone. Some enhanced tunneling effect can be observed also for positions of the barrier corresponding to 1/4 and 3/4 of the cavity length.
Tunneling enhancement is even more apparent as the width of the cavity is increased, as shown in Fig. 3, where the transmission dependence is reported for a cavity 4 μm wide and a 15 nm barrier with a transmission of 0.244.
The observed effect cannot be attributed to a resonance because it survives also if the symmetry properties of the cavity break down, as in the case of an output constriction with a width different from that of the input constriction. Our preliminary explanation is based on the observation that odd longitudinal modes are not affected significantly by the presence of a barrier in the middle and they can provide good coupling *between the* two ends of the cavity.

Another important characteristic of mesoscopic cavities consists in the peculiar properties they have in terms of shot noise suppression. It is well known that a symmetric cavity with narrow enough constrictions is characterized by a Fano factor (ratio of the shot noise power spectral density to that predicted by Schottky's theorem) of 1/4; it has however been experimentally shown that in the presence of an orthogonal magnetic field the Fano factor for a symmetric cavity drops below 1/4 and, as the magnetic field is increased, goes down to zero. Based on our numerical simulations, whose results are shown in Figs. 4 and 5 for the case, of a cavity 5 μm long and 8 μn wide, we have elaborated an intuitive explanation for this effect, which we believe is due simply to the reduced diffraction at the constrictions, as the cyclotron diameter for semiclassical electrons becomes comparable and then smaller than the constriction width. This implies also that, in the presence of a large enough magnetic field. There is no significant dependence of the Fano factor on the length and width of the cavity, as shown in Fig. 6.

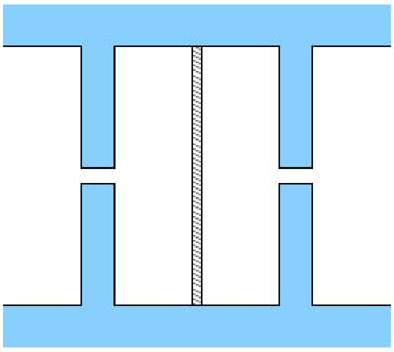

Fig. 1: Sketch of the cavity with the potential barrier in the middle.

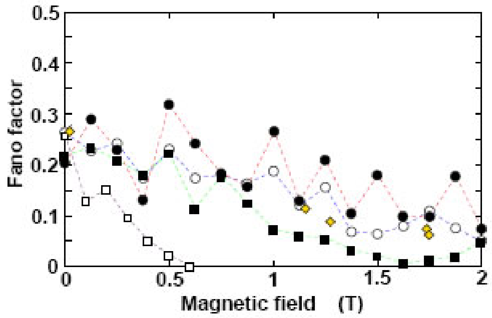

Fig. 4: Fano factor vs. magnetic field for a constriction width of 40 nm (solid dots), 60 nm (empty dots), 100nm (solid squares), 300 nm (empty squares).

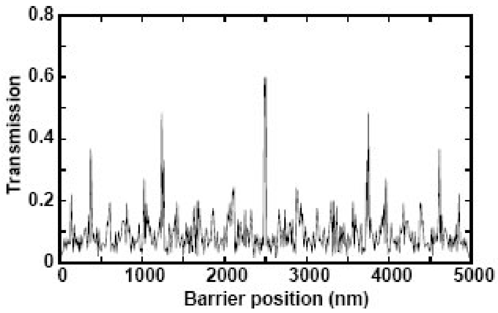

Fig. 2: Transmission vs. barrier position for a symmetric 500 nm wide cavity

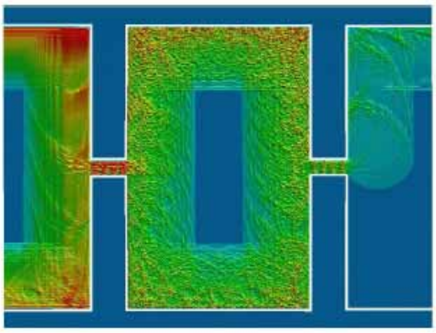

Fig. 5: Electron density in a cavity with 400 nm constrictions for B=0.09T.

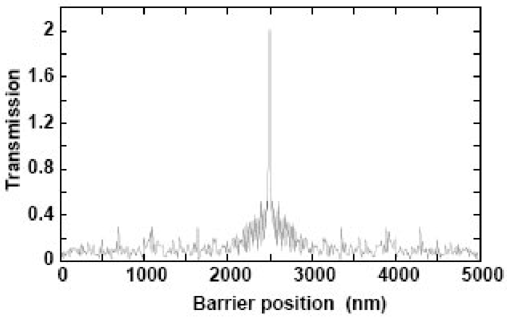

Fig. 3: Transmission vs. barrier position for a symmetric 4000 nm wide cavity.

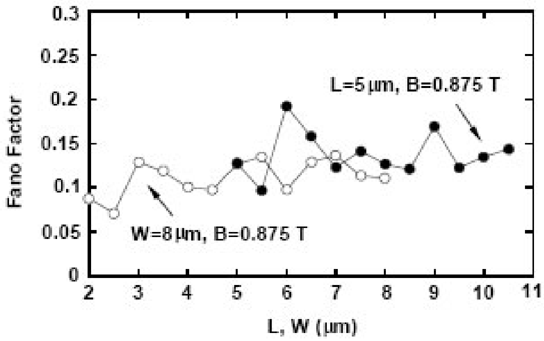

Fig. 6: Fano factor as a function of the cavity width W (solid dots) and length L (emtpy dots) for 100 nm constrictions