Quantum fluctuations in the transmission of a ballistic metallic constriction

QUANTUM FLUCTUATIONS IN THE TRANSMISSION OF A BALLISTIC METALLIC CONSTRICTION

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Abstract. We have studied fluctuations in the magnetoresistance of a small ballistic constriction as a function of the well defined excess energy of the electrons. A model based on quantum interference on a length scale given by the elastic mean free path is presented to explain the data.

The magnetoresistance of various mesoscopic systems with *diffusive* electronic transport exhibits reproducible fluctuations[1]. These universal conductance fluctuations (UCF) result from quantum interference between elastically scattered electrons and have the property that their rms amplitude (of order e^2/h) is independent of sample size or degree of disorder. The phases of the electronic waves are shifted by an applied magnetic field resulting in a typical field scale $B_c \simeq \Phi_0/A$, a flux quantum $\Phi_0=h/e$ through a phase coherent area A.

Here we report on reproducible fluctuations, similar in appearance as UCF, but observed in a *ballistic* point contact, a system with an elastic mean free path ℓ_e larger than the constriction radius a. The effective sample size of a point contact is about $2a$, since an applied voltage V drops almost completely across the contact region[2]. The transmission of such a point contact depends on the probability for an injected electron (energy eV) to return through the contact. Elastic (impurity, defects) or inelastic (electron-phonon) scattering events are responsible for this backscattering. The latter gives the possibility to study the energy dependence of the transmission what is known as *point-contact spectroscopy*[2]. At low bias the scattering is completely elastic (phase coherent) allowing quantum-interference effects to be observable. The point contacts were fabricated using nanofabrication techniques and consist of two evaporated *200nm Ag* layers seperated by a *20nm* silicon nitride membrane in which a single hole (radius $a \simeq 5nm$) was patterned. In Fig. 1 we plotted magnetoresistance traces of an 11Ω Ag point contact for different voltages, measured at $T=400mK$. A reproducible fluctuation pattern (magnetofingerprint) superimposed on a slowly varying background is observed. A change in bias changes the fingerprint completely (after $\Delta V \simeq 2mV$), the typical field scale B_c increases whereas the amplitude δG of the fluctuations decreases. At zero bias we find an amplitude $\delta G=1.8\times10^{-2}e^2/h$, decreasing for temperatures above $T=5K$. In Fig. 2 we plotted the rms amplitude of the fluctuations as a function of the applied voltage together with the point-contact spectrum $d^2I/dV^2(V)$ of the same device. This spectrum is proportional to the point contact variant of the electron-phonon Eliashberg function α^2F_p.[2] The clear resolved transverse (TA) and longitudinal (LA) acoustic phonon peaks together with the low background in the spectrum are a good indication that the transport through the contact is ballistic. A clear decrease in fluctuation amplitude δG at $V=10mV$ coincides with the first phonon peak in the spectrum. From B_c, obtained from the halfwidth of the auto correlation function, we can calculate a characteristic size $L=(\Phi_0/B_c)^{1/2}$ of flux enclosing paths and find $L\simeq245nm$ at zero bias and $L\simeq65nm$ at $V=12mV$ and higher. A comparison of L with radius $a\simeq5nm$ (calculated from

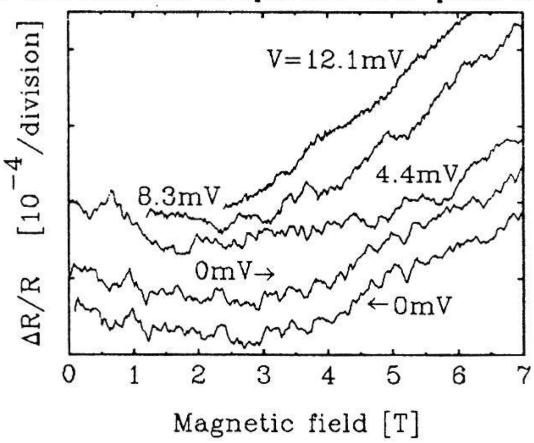

Fig.1 Magnetoresistance traces of an 11Ω Ag point contact for different applied voltages.

the contact resistance $R_p=(4p\ell/3\pi a^2)(1+0.82a/\ell_e))$ and elastic mean free path $\ell_e \simeq 240nm$ (determined from the resistance ratio of an Ag layer and of the point contact itself) indicates that impurity scattering far away from the constriction area plays a minor role in the fluctuation phenomena. Following arguments of Lee[3] we can estimate the rms amplitude of the fluctuations δG using the generalized Landauer equation for the conductance $G=(2e^2/h)\Sigma|t_{\alpha\beta}|^2$, where $|t_{\alpha\beta}|^2$ is the transmission probability from incoming channel α to outgoing channel β and the summation takes place over the number of channels $N=a^2k_F{}^2/4$. For a purely ballistic contact the transmission probability is $|t_{\alpha\beta}|^2=\delta_{\alpha\beta}$. In the presence of elastic impurity scattering around the constriction the ensemble averaged transmission probability $|t_{\alpha\beta}|^2=[1-0.82a/\ell_e]/N$. By calculating the variance of the conductance transforming these transmission probabilities to reflection probabilities we find the $T=0$ rms amplitude of the fluctuations $\delta G \simeq 1.6(e^2/h)(a/\ell_e)$, which *depends on effective sample size and degree of disorder.* With $a=5nm$ and $\ell_e=240nm$ we find $\delta G=3.3\ 10^{-2}e^2/h$ in fair agreement with the experimental zero bias result $\delta G=1.8\ 10^{-2}e^2/h$. The decrease of δG is explained by the enhanced electron-phonon interaction at $10mV$ and higher, leading to a reduced inelastic mean free path L_{in}, which results in destruction of the phase coherence of the larger interference loops. To include inelastic processes in our above derived expression for δG we multiplied by $exp[-\ell_e/L_{in}]$, the probability that an electron is inelastically scattered on a length scale ℓ_e, and we plotted the result as a dashed line in Fig.2 (L_{in} can simply be calculated from the spectrum). Because of the random distribution of impurities around the constriction the system lacks inversion symmetry, resulting in an asymmetric resistance with respect to a reversed bias[1]. This is clearly visible in Fig. 3 where the magnetofingerprint for $V=0$ evolutes to two different fingerprints for small positive and negative voltages. From the cross correlation of these curves we find a correlation voltage $V_c \simeq 1mV$. Remarkably, δG is roughly constant up to $10mV$, in contrast with *diffusive* mesoscopic systems, where for voltages exceeding V_c averaging over V/V_c coherent subsystems causes the amplitude δG to decrease. However, in a point contact the voltage drops off in the contact region and hence the impurity potential is not affected by the applied voltage. Therefor there is no averaging for $V>>V_c$, and δG remains constant. A comparison of the correlation energy $E_c \simeq \hbar/\tau$ (with τ the time to traverse a coherent electron trajectory, in our case $\tau \simeq \pi\ell_e/v_F$) with the observed correlation voltage V_c supports the idea of quantum interference on a length scale given by the elastic mean free path.

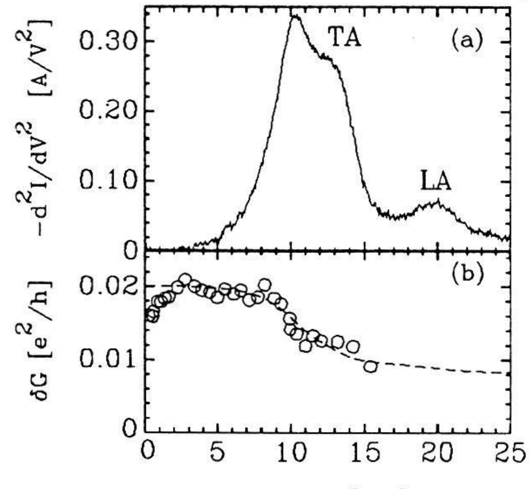

Fig.2 Point-contact spectrum (a) and rms amplitude δG as a function of bias (b). The dashed curve is calculated from the spectrum (see text).

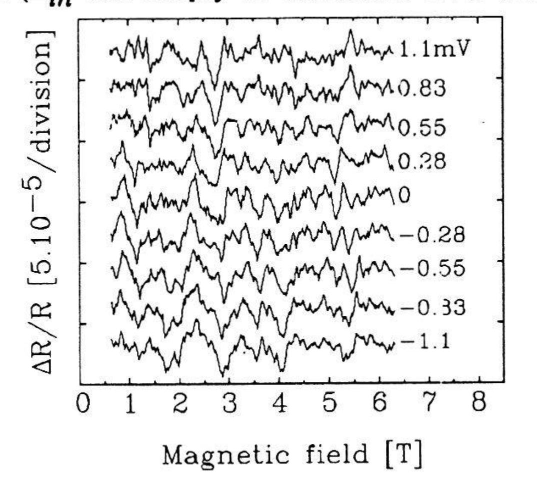

Fig.3 Magnetoresistance traces measured around $V=0$. The background has been substracted.

references.

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