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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 $\delta G=1.8\times 10^{-2} e^2/h$, 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 $L \simeq 245nm$ at zero bias and $L \simeq 65nm$ at $V=12mV$ and higher. A comparison of L with radius $a \simeq 5nm$ (calculated from

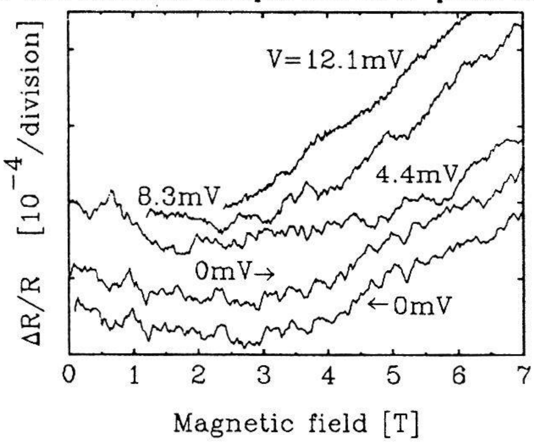

Fig.1 Magnetoresistance traces of an 11Ω Ag point contact for different applied voltages.

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).

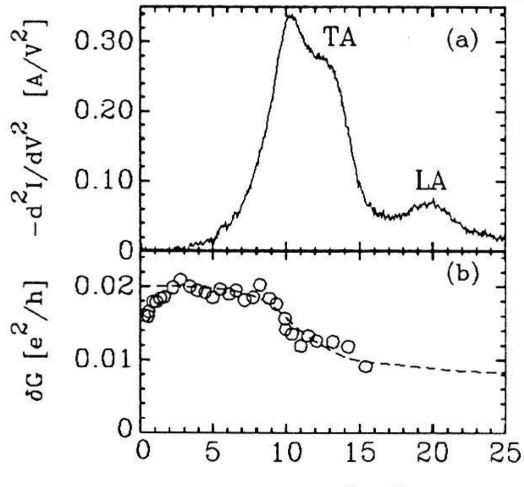

Fig.2 Point-contact spectrum (a) and rms amplitude δG as a function of bias (b). The dashed curve is calculated from the spectrum (see text).

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.

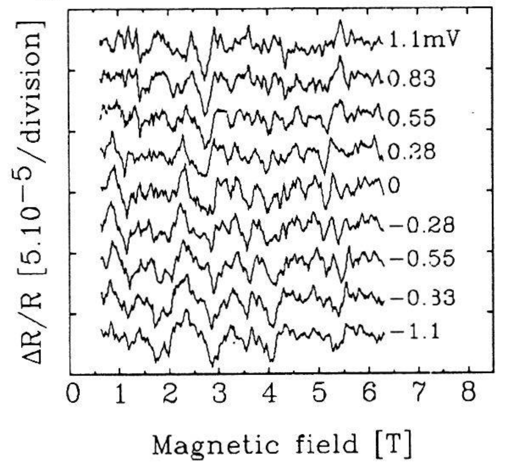

Fig.3 Magnetoresistance traces measured around $V=0$. The background has been substracted.

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