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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<sup>1</sup>. 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  $\ell_e$  larger than the constriction radius a. The effective sample size of a point contact is about 2a, since an applied voltage V drops almost

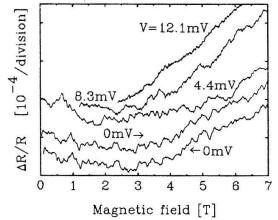


Fig.1 Magnetoresistance traces of an  $11\Omega$  Ag point contact for different applied voltages.

completely across the contact region<sup>2</sup>. 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<sup>2</sup>. 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~5nm) was patterned. In Fig. 1 we plotted magnetoresistance traces of an  $11\Omega$  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  $\delta G$  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  $\alpha^2 F_p$ . 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  $\delta G$  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

the contact resistance  $R_p = (4p_\ell/3\pi a^2)(1+0.82a/\ell_e)$ ) and elastic mean free path  $\ell_e \approx 240nm$  (determined from the resistance ratio of an Ag layer and of the point contact itself) indicates that impur-

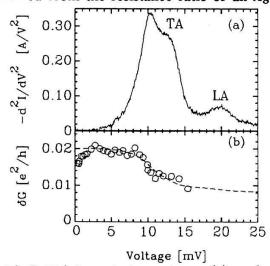


Fig.2 Point-contact spectrum (a) and rms amplitude  $\delta G$  as a function of bias (b). The dashed curve is calculated from the spectrum (see text).

ity scattering far away from the constriction area plays a minor role in the fluctuation phenomena. Following arguments of Lee<sup>3</sup> we can estimate the rms amplitude of the fluctuations  $\delta G$  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 a to outgoing channel  $\beta$  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  $|t_{\alpha\beta}|^2 = [1 - 0.82a/\ell_{\rm p}]/N$ . By calculating the variance of the conductance transforming these transmission probabilities to reflection probabilities we find the T=0 rms amplitude of the fluctuations  $\delta G \simeq 1.6(e^2/h)(a/\ell_{\rho})$ , which depends on effective sample size and degree of disorder. With a=5nm and  $\ell_{\rho}=240nm$  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  $\delta G$  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  $\delta G$  we multiplied by  $exp[-\ell_e/L_{in}]$ , the probability that an electron is inelastically scattered on a length scale  $\ell_e$ , 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 bias1. 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  $V_c \simeq lmV$ . Remarkably,  $\delta G$  is roughly constant up to l0mV, in contrast with diffusive mesoscopic systems, where for voltages exceeding  $V_c$  averaging over  $V/V_c$  coherent subsystems causes the amplitude  $\delta G$  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  $\delta G$  remains constant. A comparison of the correlation energy  $E_c \simeq \hbar/\tau$  (with  $\tau$  the time to traverse a coherent electron trajectory, in our case  $\tau \simeq \pi \ell_e / v_F$ ) with the observed correlation voltage  $V_c$  supp-

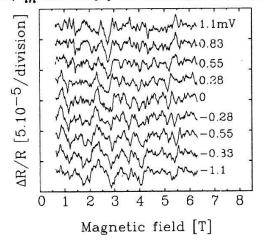


Fig.3 Magnetoresistance traces measured around V=0. The background has been substracted.

orts the idea of quantum interference on a length scale given by the elastic mean free path.

#### references.

<sup>1</sup>Reviews; S. Washburn and R.A. Webb, Adv. Phys. 35, 375 (1986); Quantum Effects in Small Disordered systems, edited by B. L. Al'tshuler, P.A. Lee and R. A. Webb (Elsevier, Amsterdam, 1990).

<sup>2</sup>A.G.M. Jansen, A. P. van Gelder and P. Wyder, J. Phys. C 13, 6073 (1980). <sup>3</sup>P.A. Lee, *Physica A*, 140, 169 (1986).