Electrical resistivity of a carbon nanotube

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1. Introduction

In mesoscopic systems, in which the electronic energy level spacing is comparable or larger than k_BT at low temperature, quantum interferences induce time-independent, sample-specific fluctuations in the conductance.[1,2,3] The interference pattern results from the scattering of electron waves by the specific disordered configuration of scattering sites (impurities) in each sample. It is therefore possible to modify the interference pattern, and hence the conductance, by either applying a magnetic field or by changing the electron energy in order to tune the phase or the wavelength of the electrons respectively.

The theory predicts that the average amplitude of such conductance fluctuations (CFs) has a "universal" value $\Delta G \approx e^2/h$ for any metallic sample. CFs of this type have been observed experimentally in one-dimensional (1D) semiconductor devices, where they appear by tuning the chemical potential (gate voltage),[4] and in small metal wires by applying a magnetic field.[5]

In this work, we show that the same type of fluctuations appears in the magnetoresistance (MR) of a small carbon nanotube.

2. Results and discussion

Using scanningtunnelingmicroscope lithography,[6] two electrical contacts were attached to a carbon nanotube of 20 nm diameter in order to realize direct electrical resistance measurements.[7]

Representative MR data are shown in Figure 1. Below $T \approx 4$ K, a reproducible, aperiodic structure appears in the MR. The positions of the peaks with respect to magnetic field are temperature independent. Figure 2 shows that the amplitudes of these fluctuations, ΔG, are constant and of the order of 0.2 e^2/h up to 400 mK, and then decreases slowly with temperature as a weak power low $T^{-\alpha}$ with $1/2 \leq \alpha \leq 3/4$. This behavior is consistent with that predicted by the theory.[1]

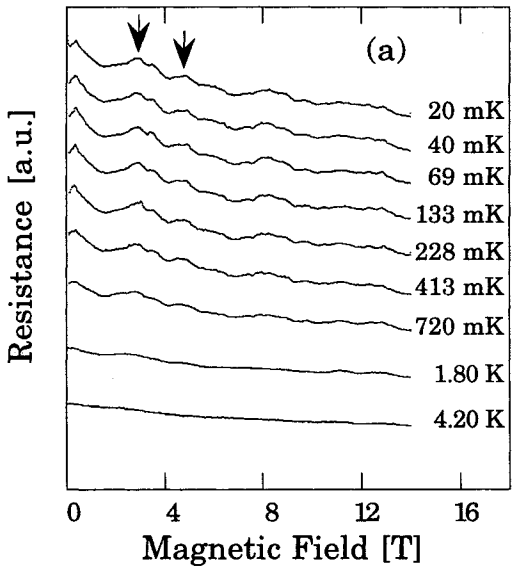

Figure 1: Magnetic field dependence of the magnetoresistance at the indicated temperatures.

The theoretical interpretation of all these features was derived by means of the perturbation theory.[2,3] At zero temperature, a given impurity configuration in the sample

gives a particular pattern in the MR. The energy correlation length, E_c, which measures the energy scale over which the pattern of CFs remains the same, is given by

$$E_c = \frac{h\pi}{2DL^2} \qquad (1)$$

where D is the diffusion constant and L the sample length. In other words, E_c is the energy separation between uncorrelated patterns.

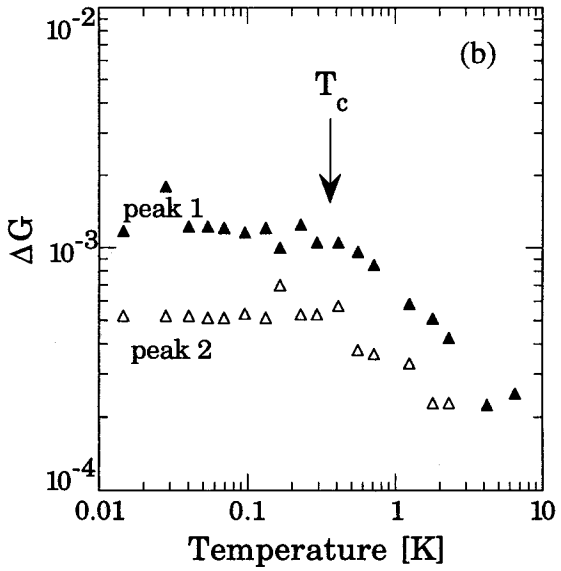

Figure 2: Temperature dependence of the amplitude of the CFs (ΔG) for the two selected peaks (see arrows Fig. 1).

At the finite temperatures, when k_BT is smaller than E_c, the pattern in MR remains unchanged. When k_BT becomes larger than E_c, the system averages over $N = k_BT/E_c$ uncorrelated patterns. Therefore, the amplitude of the fluctuations averages to zero as a weak power-law.

At temperature $T_c \approx 400$ mK, at which ΔG becomes temperature independent, $E_c = k_BT_c$. Using (1), we can then make an estimate of the diffusion constant $D \approx 50.10^{-4}$ m^2/s, which is precisely the value found by Song et al.[8] for a large bundle of nanotubes. It is worth noting that the turnover in the temperature dependence of the CFs occurs at quite a large temperature compared to what is usually found in metallic systems.

3. Conclusion

The study of the low-temperature magnetoresistance of a 20 nm diameter carbon nanotube revealed an aperiodic, time-independent structure for $T \leq 4$ K. The amplitude of these fluctuations is constant ($\Delta G \approx 0.2\ e^2/h$) up to 400 mK and then falls off as a weak power law, at higher temperature. These fluctuations, which we attribute to universal conductance fluctuations observed in mesoscopic systems, are representative of the specific disordered potential of the measured carbon nanotube.

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