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Magnetoresistance in cobalt-contacted multi-wall carbon nanotubes

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Abstract

We present results for magnetotransport measurements on multiwall-carbon nanotubes (MWCNT) contacted by cobalt electrodes. By measuring the *V*(*I*) characteristics at constant magnetic fields and different orientation of the magnetization directions in the Co electrodes, we were able to determine both current and voltage dependences of the magnetoresistance (MR) effects. These tunneling MR values are compared with the directly measured MR at constant current with sweeping magnetic field. The *V*(*I*) curves show an ohmic behavior at 295 K and a non-linear tunneling behavior at 4.2 K. With decreasing bias current the MR increased up to 60% at 4.2 K, and with decreasing bias voltages even up to 175%. The MR disappears at high bias current (voltages) and temperatures higher than 40 K. For most of the samples the current dependences of the MR were found to be nearly symmetric upon reversing the current direction. However, in some cases we also observed a sign change of the MR as function of the applied current, which suggests an inversion of the spin polarization in one of the Co interfaces.

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Keywords: Nanotubes; Tunneling; Magnetoresistance; Spin-polarized transport

1. Introduction

The unique transport properties of carbon nanotubes (CNTs) enable applications in field effect or single-electron transistors, or in molecular electronics [1]. Moreover, the large spin scattering lengths reported in CNTs also point out their potential for the development of future spin electronic devices [2,3]. Spin-dependent magnetoresistance (MR) effects in Co-contacted multi-wall CNTs (MWCNTs) were first observed by Tsukagoshi et al. [4]. This experiment and the subsequent studies by other groups also using single-wall CNTs [5–7] show, that the interfaces between the CNT and the electrodes, the contact resistance and the nanomagnetic properties of the ferromagnetic electrodes play a decisive role for the magnitude of MR and the magnetic switching behavior. High MR values are only measured at 4.2 K or lower temperatures and the effect disappears for temperatures higher than ~40 K. A strong bias current dependence of the MR was found, too.

In this paper, we present studies of the current and the voltage variations of the MR at 4.2 K on a Co-contacted MW CNT by means of measurement of the *V*(*I*) characteristics at constant magnetic fields and different directions of the magnetization.

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2. Experimental details

In this work, we used the same technique for the preparation of the devices as described in Ref. [5]. The MWCNTs synthesized by an arc discharge method with diameters of 10–40 nm were ultrasonically dispersed in ethanol and placed onto the surface of an oxidized silicon wafer with prestructured Cr/Au leads. The contact pattern between the CNT and the Cr/Au leads was defined by electron beam lithography. The 80 nm thick ferromagnetic Co electrodes with a contact distance of about 200 nm were prepared by electron beam evaporation.

The electrical characterization of the samples mounted in chip carriers were performed by using a variable temperature inset in a superconducting magnet system. The magnetic field direction was pointed perpendicular to the tube axis in the plane of the substrate. The $V(I)$ characteristics and the two-terminal resistance were measured by using a Keithley SMU 6430 as a constant current source and a nanovoltmeter 2182 to measure the voltage drop. Both were connected to a data acquisition system. Two methods were used for the determination of MR: (i) the resistance was measured at constant current as the magnetic field was swept from 200 to –200 mT and back, and (ii) the $V(I)$ characteristics were measured at constant magnetic fields, but different directions of the magnetization after changing the magnetic field. The MR was then determined as a function of current and voltage using the resistance values calculated from the measured $V(I)$ curves.

3. Results and discussion

The magnetotransport characteristics of the Co-contacted CNTs vary from sample to sample as discussed in Ref. [3]. In Fig. 1, the MR for a sample with a so-called minor loop behavior is plotted as $\mathrm{MR} = [R(H) - R(-0.2\,\mathrm{T})]/R(-0.2\,\mathrm{T}) \times 100$ vs. the magnetic field for three different bias current values at 4.2 K. Such a switching behavior has been also observed in planar tunnel junctions at small magnetic fields, when the magnetization of only one of the electrodes changed its direction. This suggests that the pinning of the magnetic domains in one contact area is very strong in this sample, as we could not observe a switching at magnetic fields up to –1.5 T. MR reaches the highest values of 55% for a bias current of 1 nA. The enhancement of MR is connected with the enhancement of device resistance. At 300 K the $V(I)$ curve is linear with a device resistance of 190 kΩ. This resistance is dominated by the contact properties of the Co-MWCNT junctions and is much higher than the intrinsic resistance of MWCNTs. The voltage (V)–current (I)

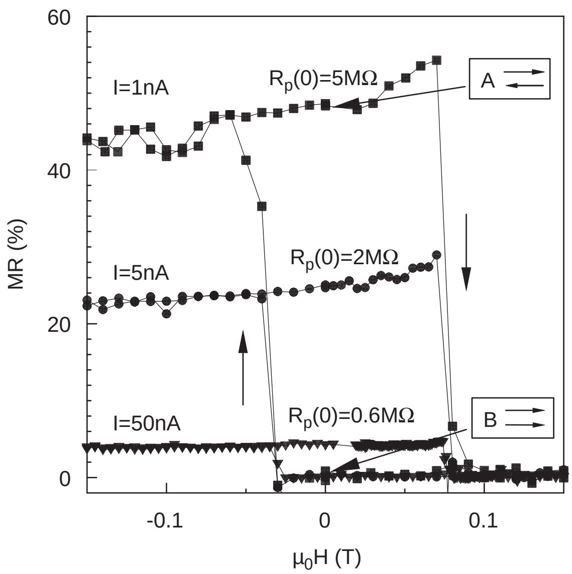

Fig. 1. MR curves of a Co/MWCNT/Co junction at 4.2 K for different bias current values. The arrows mark the points (A, B) at $H = 0$, at which the $V(I)$ curves of Fig. 2 are measured.

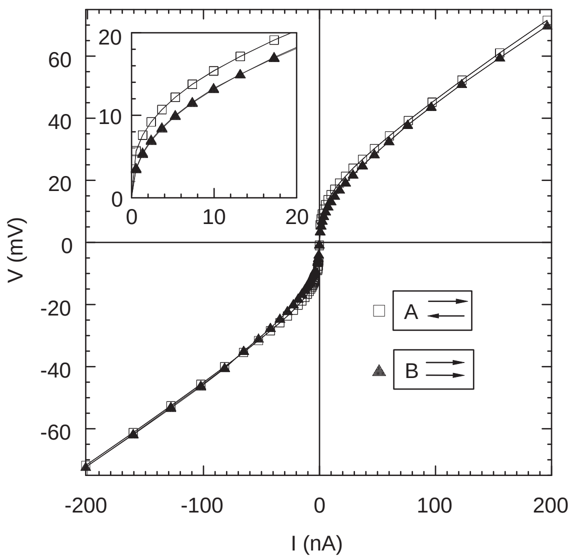

Fig. 2. $V(I)$ characteristics at $H = 0$ and antiparallel (A) and parallel (B) magnetization configurations in the Co electrodes (see also Fig. 1). The inset shows the curves in the low bias region.

characteristics (Fig. 2) at 4.2 K demonstrate the large current dependence of resistance. The strong zero bias anomaly is characteristic for a tunnelling transport mechanism with Coulomb blockade behavior at low temperatures for this two-terminal device [5]. The MR curves in Fig. 1 show, that at $H = 0$ two stable MR values exist depending on the magnetic field sweeping