PROBING THE CHARACTERISTICS OF CARBON NANOTUBE BASED DEVICES THROUGH THE AHARONOV-BOHM PHASE

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Introduction

The exceptional low-dimensionality and symmetry of carbon nanotubes (CNT) are at the origin of their spectacular physical properties governed by quantum effects. Ajiki and Ando [1] predicted that an axial magnetic field would tune the band structure of a CNT between a metal and a semiconductor, owing to the modulation of the Aharonov-Bohm (AB) phase of the electronic wave functions. Here we report on observation of this phenomenon using three devices made in the configuration of a standard CNT field-effect transistor with a metallic or quasi-metallic CNT forming the conduction channel.

Experimental Results and Discussion

We measured the DC conductance as a function of the gate voltage G(Vg) at a small constant bias voltage (~1mV) at temperatures from 4.2K up to 290K under magnetic fields up to 33T. Suppression of the conductance around Vg* ~ 1V indicates a small band gap (of the order of 10 meV) that is characteristic for non-armchair metallic nanotubes. Evolution of G(Vg) curves with axial magnetic field clearly shows a decrease of such a gap until B reaches ~6T and increase with magnetic field above that point.

Magnetoconductance curves, shown in Fig. 1(b), were obtained at the gate voltage Vg=Vg*. For the magnetic fields above approximately 10T, a strong exponential magnetoresistance is observed. At temperatures below 80K, the conductance drops by more than three orders of magnitude while the magnetic field is changed by 20T. To our knowledge, such a large magnetoresistance in CNT has never been reported before.

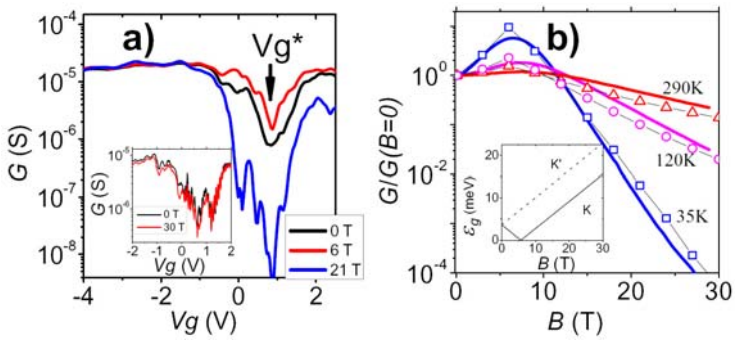

Figure 1. (**a**): effect of axial magnetic field on transfer characteristics G(Vg). Inset: perpendicular magnetic fields do not significantly change the device conductance (**b**): Normalized magnetoconductance G(B) measured at Vg=Vg* (solid lines). Calculated dependence of normalized conductance on magnetic field parallel to the CNT axis (symbols). The inset shows the band gaps of K and K' bands as function of magnetic field.

To analyzed obtained results we simulated the electrical behavior of a Schottky-barriered CNT-based field effect transistor (CNT-FET) using analytical modeling of a simplified CNT-FET with a back-gate structure [2], taking into account that the magnetic field lifts degeneracy between the K and K' bands of electron spectrum [1]. Thus the energy gaps are described by $\varepsilon_{g(K,K')}=\lambda|B \pm B_0|$, where + and – signs correspond to different bands (see Fig. 1b). With an increase of the magnetic field above 6T, the gap is progressively opened increasing the Schottky barrier height for electrons and producing a thicker depletion region. Our calculations reproduce principal experimental findings (see Fig. 1(b)) confirming that observed strong exponential magnetoresistance in a quasi-metallic CNT occurs due to the field induced opening of the band gap and modulation of the Schottky barriers at the CNT/metal interfaces.

References

[1] H. Ajiki and T. Ando, J. Phys. Soc. Jpn. **62**, 1255 (1993)
[2] Jimenez, D. et al. Nanotechnology (in press). Also in cond-mat/0610882.