Electrical Transport in metallofullerene nanotube peapods

P. W. Chiu[1], S. F. Yang[2], S. Yang[2], and S. Roth[1]

[1]Max-Planck Institut für Festkörperforschung, Heisenbergstr. 1, D-70569 Stuttgart, Germany
[2]Department of Chemistry, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China

Single-wall carbon nanotubes (SWNTs) have opened up a new possibility for novel components in miniaturized electronic devices. SWNTs are one-dimensional structure that exhibit metallic or semiconducting behavior. Semiconducting nanotubes have been shown to function as field-effect active channels[1], nanorectifiers[2]. Due to the doping effect of adsorbed oxygen molecules and the charge transfer with defined electrodes, pristine SWNTs show p-type semiconducting behavior. For complementary logic circuitry, various chemical modification achieved by doping semiconducting nanotubes have been demonstrated[3,4]. However, the stability of alkali-metal doped nanotubes[3,4] is sensitive to the ambient environment. Therefore, ambient stable chemical doping by metallofullerene will be a good starting point for the band engineering of carbon-based nanoelectronics.

The mono-metallofullerene encapsulating a single lanthanide element, $Ln@C_{82}$ (Ln = Ce, Nd, Gd, Dy, ...), has been confirmed by electron spin resonance and UV-Vis-NIR adsorption spectra to show charge transfer from the encaged atom to the C_{82} cage,[5] resulting in the charge state of $Ln^{3+}@C_{82}^{3-}$. The insertion of metallofullerenes into the nanotube is therefore expected to lead to further charge transfer from the C_{82} cage to the tube and the electrical properties of the carbon nanotubes would be substantially modified.

The insertion of $Dy@C_{82}$ into the inner hollow space of the SWNTs host was carried out by gas phase diffusion of $Dy@C_{82}$.[6] The individual metallofullerene peapods were deposited on a degenerately doped silicon substrate with SiO_2 insulating layer on top and predefined electrodes. Fig. 1 shows the transport measurement in one single tube. At room temperature, the doped nanotube shows p-type behavior as seen from the response to a back gate. As the temperature decreases, the conductance becomes n-type. It reveals that the $Dy@C_{82}$ molecules function as electron donors and transfer charge to the carbon nanotube host. The amount of charge transferred varies with temperature. At T < 215 K metallic behavior is observed, indicating the degenerate state by doping. Below about 75 K, single-electron charging phenomena dominate the transport and show irregular Coulomb blockade oscillation, implying that the insertion of $Dy@C_{82}$ splits the tube into a series of several quantum dots.

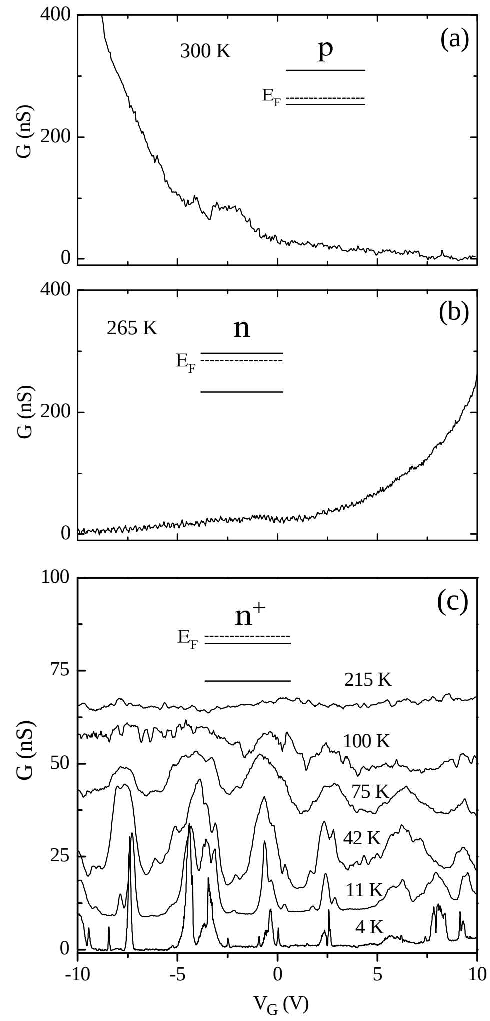

Fig. 1 (a)-(c) Gate voltage dependence of conductance measured at V_{DS} = 4 mV at various temperatures. The curves in (c) are displaced for clarity. The insets are schematic plots of the band diagram.

[1] S. J. Tans, A. R. M. Verschueren, and C. Dekker, Nature **393**, 49 (1998).
[2] R. D. Antonov and A. T. Johnson, Phys. Rev. Lett. **83**, 3274 (1999).
[3] L. Grigorian, G. U. Sumanasekera, A. L. Loper, S. Fang, J. L. Allen, and P. C. Eklund, Phys. Rev. B **58**, R4195 (1998).
[4] J. Kong, C. Zhou, E. Yenilmez, and H. Dai, Appl. Phys. Lett. **77**, 3977 (2000).
[5] For a review, see H. Shinohara, Rep. Prog. Phys. **63**, 843 (2000).
[6] K. Suenaga, M. Tence, C. Mory, C. Colliex, H. Kato, T. Okazaki, K. Hirahara, S. Bandow, and S. Iijima, Science **290**, 2280 (2000).