Impossibility of superconducting state in multiwall carbon nanotubes and single crystal graphite

Anatoly I. Romanenko [a,1], Alexandr V. Okotrub [a], Lubov G. Bulusheva [a], Olga B. Anikeeva [a], Nikolai F. Yudanov [a], Cheng Dong [b], Yongming Ni [b]

[a] *Institute of Inorganic Chemistry, Siberian Branch of Russian Academy of Science, Novosibirsk, Russia*

[b] *National Laboratory for Superconductivity, Institute of Physics CAS, Beijing, China*

Abstract

The magnetic susceptibility χ as of pristine and brominated arc-produced sample of multiwall carbon nanotubes (MWNTs) so single crystal graphite (SCG) was measured from 4.5 to 400 K. An additional contribution $\Delta\chi(T)$ to diamagnetic susceptibility $\chi(T)$ of carbon materials was found at T < 50 K for all samples. It is shown that $\Delta\chi(T)$ are dominated by quantum correction to χ for interaction electrons (interaction effects-IE). The IE shows a crossover from two-dimensional to three-dimensional at $B = 5.5$ T for MWNTs and always three-dimensional for SCG. The effective interaction between electrons for interior layers as MWNTs so SCG are repulsion and the electron-electron interaction λ_c was estimated to be $\lambda_c \sim 0.26$ for MWNTs and $\lambda_c \sim 0.06$ for SCG.

Key words: Electron-electron interaction; Carbon nanotubes, Single crystal graphite; Brominated carbon nanotubes

From the time of discovery nanotubes one of the most important problems is the possibility of a superconducting state in them. There are the superconductivity in single-walled carbon nanotubes up to 20 K [1] and the possiblity of superconductivity above 400 K in MWNTs [2]. The nature of a superconducting state is the electron-electron interaction. On the other hand electron-electron interaction is exhibited in electronic transport properties of conductors in normal state - so-called quantum interference effects - interaction effects (IE) [4,3]. IE are connected with the correction to density of states of conduction electrons in a results of quantum interferences of electrons at their diffuse motion in random conductors. But in such systems the one-particle processes, so-called weak localization (WL) [4] and weak antilocalization (WAL) [5], always accompany with IE. The observation of IE corrections (IEC) to χ is very important for partition of including of WL, WAL, and IE to different physical properties. From all these corrections only IE contributes to χ.

For observation of IEC to χ it is necessary to divide the contributions connecting with IEC and much more on quantity a magnetic susceptibility of sample, and to exclude the contribution of paramagnetic impurities. Earlier, with the using of relaxation processes in Mo_2S_3 [6], we changed the contribution connected with IE correction to χ by quenching of high-temperature metastable state of a sample. As a result, with the using of difference contribution to χ in equilibrium and metastable states, we received the IEC to χ in the pure state [7]. In this work, with the using of chemical modification of a MWNTs sample (brominated), we singled out IEC to χ in laminated structures based on MWNTs and SCG.

The material which contained MWNTs was synthesized by arc discharge graphite evaporation. A nanotube content in the inner part of carbon deposit grown on the cathode was estimated by transmission electron microscopy to reach about 80% [8]. Tubes have from 2

[1] Corresponding author. Present address: Institute of Inorganic Chemistry, Siberian Branch of Russian Academy of Science, Novosibirsk, Russia. E-mail: romanenk@casper.che.nsk.su

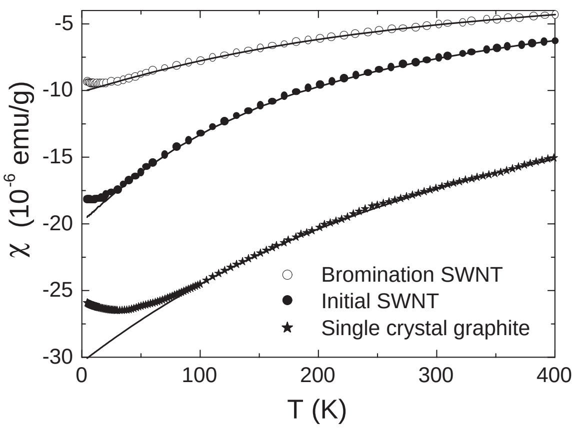

Fig. 1. The temperature dependence of magnetic susceptibility χ of SWNT, bromination SWNT, and SCG measurement at H=0.01 T.

to 30 shells with an outer diameter of 60-150 Å. Scanning electron microscopy revealed a predominant orientation of MWNTs was perpendicular to the deposit growth axis.

According to experimental and theoretical data, the basic contribution in χ of quasi-two-dimensional graphite gives orbital magnetic Susceptibility χ_{or} connected with extrinsic carriers n_0 [9]. Fig. 1 presents the magnetic susceptibility χ of investigation samples as a function of temperature. The data in Fig. 1 show that at T<50 K there is an additional contribution $\Delta\chi_{or}(T) = \chi(T) - \chi_{or}(T)$ to $\chi(T)$. According to theoretical calculations [3] only electron-electron interactions can contribute to magnetic susceptibility. Absolute value of $\triangle\chi_{or}(T)/\chi_{or}(T)$ at all magnetic fields applied to the pristine sample increases with decreasing temperature that has been predicted for IEC in the systems characterized by electron-electron repulsion [3]. Hence, at B = 5.5 T a transfer from two-dimensional IEC to three-dimensional one takes place for MWNTs. At lower magnetic field the interaction length $L_I(T) = (\hbar D/k_B T)^{1/2}$ is much less than the magnetic length $l_B = (\hbar c/2eB)^{1/2}$, which in turn becomes dominant at high field. An estimation of the characteristic lengths gives respectively the value of $L_I(4.2K)$ = 130 Å and the value of l_B = 100 Å at B = 5.5 T. IE correction for SCG was three-dimensional at all fields.

In summary, we have investigated the additional contribution to temperature dependence of $\Delta\chi_{or}(T)/\chi_{or}(T)$ of lamination structure of MWNTs and SCG at T < 50 K. It is shown that $\Delta\chi_{or}(T)/\chi_{or}(T)$ is connected with quantum correction to magnetic susceptibility for interaction electron. At low field this correction is two-dimensional for MWNTs. At $B = 5.5$ T was observed three-dimensional correction to magnetic susceptibility. IEC for SCG remain three-dimensional at low fields up to 0.001 T. The crossover of IEC from $2d$ to $3d$ for MWNTs is connected with decreasing of magnetic length up to value less then typical mean diameter of nanotubes. It is shown that bromination of samples leads to increasing of n_0 from $n_{0ini} \sim 3{\times}10^{10}$ cm^{-2} for prestine sample up to $n_{0Br} \sim 10^{11}$ cm^{-2} for brominated samples. But $\Delta\chi_{or}(T)/\chi_{or}(T)$ did not changed when n_0 increases, what is in full agreement with theoretical predictions. From $\Delta\chi_{or}(4.5K)/\chi_{or}(4.5K)$, we estimated the constant of electron-electron interaction $\lambda_c \sim 0.26$ for MWNTs and $\lambda_c \sim 0.06$ for SCG. This interaction is repulsion for interior layers, which give the domination contribution to $\Delta\chi_{or}(T)/\chi_{or}(T)$ as a integration value. The repulsion character of electron-electron interaction exclude the possibility of superconducting states in interior layers of MWNTs and SCG.

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