The unconventional electronic properties of multiwall carbon nanotubes

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Abstract

We have investigated the field and the bias-voltage dependencies of the electrical conductance, as well as the temperature dependence of the thermoelectric power of multiwall carbon nanotubes. Consistent picture has been obtained which indicates that electron-electron strong correlation is a major rhythm at low temperatures.

Key words: carbon nanotubes; electron transport properties; strongly correlated systems

The discovery of carbon nanotube provides us an intriguing system to study electron-electron (e-e) interaction at low dimensions. It has been shown that the electrons in a single wall nanotube (SWNT) have a strongly correlated ground state, characterized as a Luttinger liquid instead of a Fermi liquid [1]. For the electrons in a multiwall nanotube (MWNT), however, the situation is rather complicated. With increased conduction channels and defect scattering, it becomes a puzzle as to whether or not the electrons in a MWNT still form a Luttinger liquid. Previously, the tunneling measurement seemed to indicate an unconventional feature for the electrons in a MWNT [2] on the one side, but the transport measurements indicated a conventional Fermi liquid property of electron weak localization on the other side [3,4]. To clarify this puzzle, here we report our investigations on the thermoelectric power, the tunneling conductance, and the magnetoconductance of multiwall carbon nanotubes. A consistent picture of electron strong correlation is reached from our these investigations.

The samples used are bundles of MWNT synthesized by chemical vapor deposition method [5]. We have measured the magnetotransport properties of these bundles using a standard four-terminal technique, and found that at temperatures above ∼15 K the magnetoconductance $G(H)$ (where H is the magnetic field) can be well described by the theory of two-dimensional weak localization. Below ∼15 K, however, deviation to that theory can be noticed (Fig. 1).

To further clarify the magnetotransport data, we also examined the field dependence of the dI/dV versus V characteristics, namely the four-terminal differential conductance dI/dV versus bias voltage V across the voltage contacts, and found that the Coulomb-gap-like zero-bias-anomaly, which is presumably caused by e-e strong interaction, is essentially unchanged except for a slight shift by the magnetic field (Fig. 2). The result clearly indicates that, by subtracting the conductance $G(H)$ with that in zero magnetic field, $G(0)$, as one usually does when examining the weak localization behaviors, the effect of e-e interaction is largely subtracted.

Our thermoelectric power (TEP) measurement on bundles of MWNTs provides further support that the electrons in a MWNT form a non-Fermi liquid. With a high-sensitivity ac method, we were able to resolve a logarithmic suppression in the temperature dependence of TEP at low temperatures, as shown in Fig. 3. Although a logarithmic correction in TEP was predicted two decades ago by C. S. Ting et al. [6] based on a perturbation treatment for two-dimensional weakly

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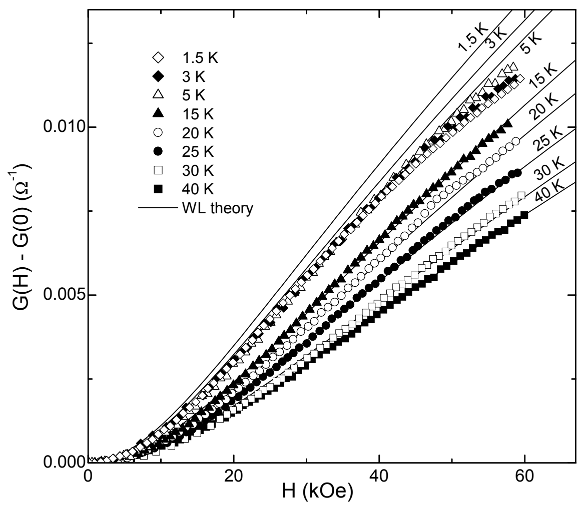

Fig. 1. The magnetoconductance of multiwall carbon nanotube bundle measured at different temperatures. The solid lines represent the theoretical predictions of two-dimensional weak localization (WL) with e-e interaction as the dominant scattering mechanism.

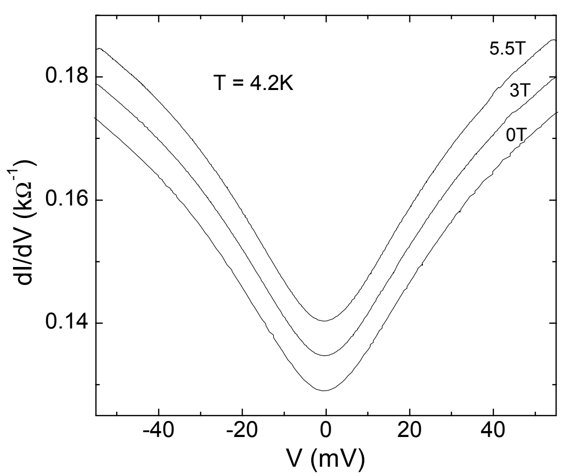

Fig. 2. The four-terminal differential conductance dI/dV versus bias voltage V curves measured in different magnetic fields. It turns out that the zero-bias anomaly, which is a characteristic of electron-electron strong interaction, dose not change with the magnetic field. The shift of the curves with field is due to the magnetoconductance effect.

localized electrons, a dominant logarithmic behavior at low temperature is beyond the expectation of that theory. The logarithmic law would in fact indicate the absence of a particular energy scale in that temperature range, indicating that the system being examined is in a critical fluctuation regime, presumably caused by the strong e-e interaction. We find that our data are in qualitative agreement with the recent non-perturbative theories [7,8]. By examining the interplay of e-e interaction and electron-defects scattering, these

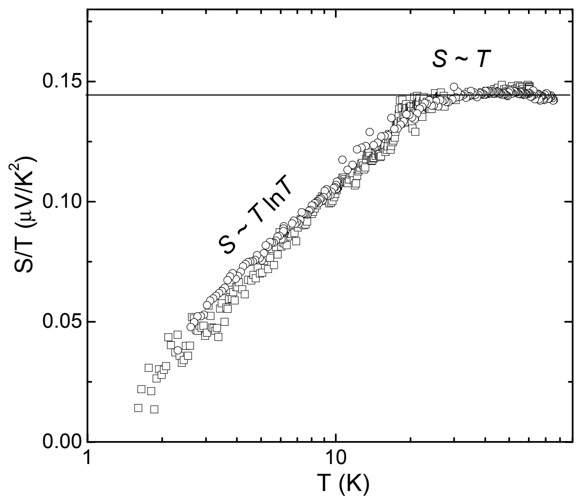

Fig. 3. Thermoelectric power S over temperature T, as a function of logarithmic temperature. A well-defined logarithmic behavior occurs below ∼20 K.

theories show that electron transport in a MWNTs will be suppressed by the formation of a Coulomb gap or a Coulomb blockade mechanism at low energies. We believe that this accounts for the zero-bias anomaly in conductance and the low-temperature suppression in TEP we observed.

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