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QUANTUM LOCALIZATION AND COULOMB-GAP TRANSPORT IN CARBON NANOPARTICLES SYSTEM

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Abstract: Strong localization of spins at low temperature region is observed within nanographitic units of activated carbon fibers (ACF). To describe electronic properties of ACF, the model of localization of spins at nanographitic units is proposed. The model is a fusion of two approaches: Curie law behavior studied by electron paramagnetic resonance (EPR) and granular metal model observed in conductivity measurements of a single fiber. The problem of inner or outer connections of such a system push us to modify the polyacrylonitrile-based fibers by a perfect nanowires: multi-walled-carbon-nanotubes. Changes in transport properties of such carbon system define new conditions for quantum dots matrix with nanotubes as a contact-nanowires. Results are discussed in the frame of the model of electric transport in granular metals.

Carbon fibers in our experiment are composed of graphite-like fragments of different shape, size and distance between graphene sheets and the fragments. These fragments are sometimes called the basic structural units (BSU) [1]. BSU are usually turbostratic and disordered, so the structure of carbon fibers is defined rather as a texture - three dimensional arrangement of BSU - than the crystalline one.

Special arrangement of graphite-like nanoparticles is observed in ACF. The structure of ACF consists of more ordered system of nanographitic units, each of the size of approximately 2.5 nm in diameter and several graphene layers thick. These units are linked structurally to constitute porous system with the mean pore size of approximately 1.4 nm.

Our EPR experiment showed that integral intensity of the EPR signal, which is proportional to the number of spins, increases with lowering temperature in ACF. If there is a constant number of non-interacting localized spins, integral intensity of EPR signal is described with Curie law resulting from Langevin paramagnetism.

Four-probe electric conductivity experiment showed that for ACF it is necessary to modify Curie law, because the number of free carriers changes with temperature lowering. Mott-like behavior observed for the single fiber defines strong localization of carriers at low temperature region. The electric conductivity depends on temperature as in granular metal model, where conduction mechanisms characteristic of quantum dot systems are observed: Coulomb-gap, energy-limited tunneling and variable-range hopping [2]. To describe electronic properties of ACF we propose the model of localization of spins at nanographitic units. The model is a fusion of two approaches: Curie law behavior studied by EPR and granular metal model observed in conductivity measurements of a single fiber. The activation energy for hopping between two neighbouring particles in these experiments is approximately 320 K [3]. Pulsed electron spin resonance measurements of pristine ACF and after nitrobenzene adsorption (dipolar guest) in porous structure of ACF confirm this model with two-level tunnelling states approach. This approach is discussed in order to verify and define the nature of observed paramagnetic centers [4].

Possible spin population control in BSU system by means of temperature changing or host-guest interaction in the porous structure of ACF [5] together with the TLS model, enable us to treat nanographitic units as quantum wells (dots) separated by potential barriers. The architecture of such quantum dots matrix till now is out of control. This problem pushed us to modify carbon fibers with perfect nanowires - multiwalled nanotubes (MWNTs) - which can conduct electric current ballistically without heat dissipation [6]. The experiment was performed in order to find changes in transport properties of modified carbon fibers, as well as to test connections between MWNTs and BSU. Results are discussed again in the frame of the Coulomb-gap transport model observed in granular metals. Electric transport as a function of temperature of PAN-based fibers before and after modification is shown in Fig. 1.

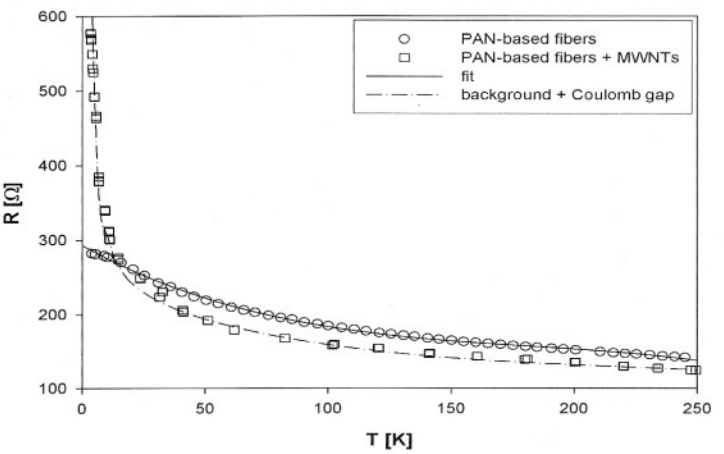

Fig.1. Electric resistivity versus temperature for pristine PAN-based fibers and modified with MWNTs

The activation energy for carrier hopping in case of modified PAN-based fibers is two order of magnitude lower (approximately 3 K) than observed for nanographitic units in ACF. This estimation positively verifies the possibility of using MWNTs as nanowires in carbon based quantum dots matrix with controlled architecture in the future molecular electronic or spintronic devices.

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