

CONDUCTIVITY OF THE NANOCARBON MATERIAL, WHICH CONTAINS THE NANOTUBES

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Introduction

It is known, that the nanocarbon material (NCM) besides the carbon nanotubes (CNT) can contain in the different concentrations the particles of amorphous carbon, nanographite, and also the metal-catalyst particles. In this work the studies of the NCM electrical resistance of different structural-phase composition were conducted. The purpose of the work was revelation of the mechanisms of NCM electrical conductivity depending on the relative content of different phases.

Experimental Results

NCM (AP-SWCNT samples of Carbonsolution firm), obtained by the catalytic decomposition method was used for the studies of electrophysical properties. The structural-phase analysis, carried out by the methods of X-ray diffraction and transmission electron microscopy (TEM) showed that the initial NCM contains the CNT bundles with diameter (3-6) nm, the particles of amorphous carbon with sizes (10-30) nm, and also an insignificant quantity of nickel particles. A study of NCM electrical resistance was carried out in the temperature region from 4.2 to 293 K by the standard four-probe method.

The volumetric NCM samples, obtained by the cold pressing method without the bonding agent (sample #1), with the use the bonding PVA agent (18% of mass.) (sample #2) were prepared for measuring the electrical resistance. For changing the relative relationship of a quantity of CNT and amorphous carbon the initial NCM was also exposed to the thermochemical action according to the scheme: the triple boiling in 2.5 M solution of nitric acid during 2 hour with the subsequent annealing in air during 20 minutes. This action, as the TEM data showed, led to the essential destruction of CNT structure, and, as a result, to an increase in the relative content of amorphous carbon phase. At that the sizes of the amorphous carbon particles are decreased.

The volumetric sample with the bonding PVA agent (18% of mass.) (sample #3) was also

prepared by the cold pressing of above NCM.

Fig. 1 gives the temperature dependences of electrical resistance for three NCM samples.

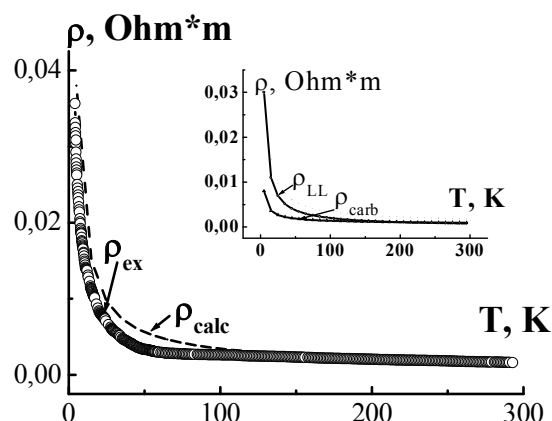


Fig. 1. $\rho(T)$ dependences for the NCM samples of different structural-phase composition.

As one can see, for all NCM samples the identical form of the $\rho(T)$ dependence is observed: a sharp decrease in the resistance at a temperature to 50 K and further a weak dependence of ρ from the temperature. However, the values of ρ are different for these CNT samples at room temperature: $\rho_r \sim 5 \cdot 10^{-4}$ Ohm·m for the sample #1, $\rho_r \sim 1.5 \cdot 10^{-3}$ Ohm·m for the sample #2 and $\rho_r \sim 4 \cdot 10^{-2}$ Ohm·m for the sample #3. Essentially different is also the relation $\rho_{4.2}/\rho_r$: $\rho_{4.2}/\rho_r \sim 95$ for the sample #3, $\rho_{4.2}/\rho_r \sim 28$ for the sample #2 and $\rho_{4.2}/\rho_r \sim 22$ for the sample #1.

Discussion

As has already been indicated above, the CNM contains several structurally different phases, each of which is characterized by their conductivity type. The CNT are interacting 1D systems, for which electronic properties, in particular electrical conductivity, are described within the framework of Luttinger liquid theory with the form of the temperature dependence $\rho \sim aT^{-\alpha}$, where the exponent α is connected with Luttinger parameter g by the expression: $\alpha = (g + g^{-1} - 2)/8$. Furthermore,

the CNT junctions have the metallic nature of conductivity. Amorphous carbon is characterized by hopping with the variable length of jump, for which the resistance in the three-dimensional case is described by the formula: $\rho = \rho_0 \exp(T_0/T)^{1/4}$, where T_0 and ρ_0 are the constants. For describing the electrophysical properties of the carbon material, which has sections with the hopping and metallic conductivity, we proposed the model of the series connection of sections with the different conductivity type [1]. The similar models of electrical conductivity were considered in a number of the works, for example [2], in which the conductivity of CNT mats was studied. Let us consider the obtained experimental data $\rho(T)$ for the CNM samples within the framework of model [1]. Fig. 2 gives $\rho(T)$ for the sample #1 in the coordinates of $\ln \rho = f(\ln T)$ and $\ln \rho = f(T^{-1/4})$.

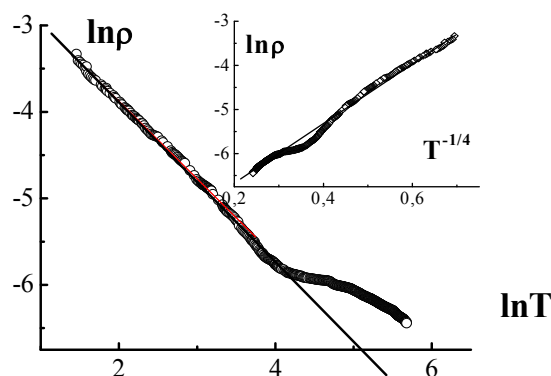


Fig. 2. $\rho(T)$ dependence for the sample #1 in the coordinates of $\ln \rho = f(\ln T)$ and $\ln \rho = f(T^{-1/4})$ (inset).

As one can see, the linear form of the $\rho(T)$ dependence is observed in the represented coordinates in the different temperature regions. The values of a , g , α , T_0 and ρ_0 constants for all CNM samples were determined (Table 1).

Table 1.

#	Hopping		Luttinger liquid		
	ρ_0 , Ohm·m	T_0 , K	α	g	a
#1	$5.4 \cdot 10^{-5}$	$7.4 \cdot 10^3$	0.98	0.103	0.05
#2	$2.9 \cdot 10^{-4}$	$2.7 \cdot 10^3$	0.90	0.110	0.1
#3	$7.0 \cdot 10^{-3}$	$8.9 \cdot 10^3$	0.88	0.112	0.5

The temperature dependences of resistance for the sections with the different conductivity type in each of the samples were calculated using the

obtained above coefficients (Fig. 3 for the sample #2). Equivalent scheme of CNM is the series-connected effective resistances, which correspond to carbon phases with the different conductivity type. Thus, the CNM resistance can be written in the form $\rho = \rho_0 \exp(T_0/T)^{1/4} + aT^{-\alpha}$. The theoretical curves $\rho(T)_{\text{calc}}$ were calculated by this formula (Fig. 3 for the sample #2). For the best agreement of the calculated resistance with experimental one it is necessary to consider for the low-resistance samples #2 and #1 the resistance of the sections of the CNT connection in the form $\rho = b \cdot T$, where b has a value of an order of magnitude of resistance in the pure single-crystal graphite.

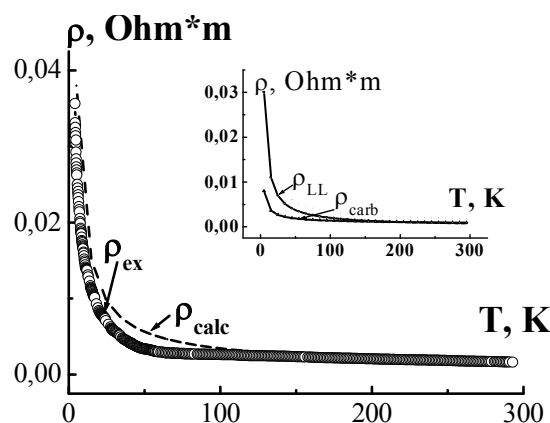


Fig. 3. The calculated $\rho_{LL}(T)$, $\rho_{carb}(T)$ (inset) and total $\rho = \rho_{LL}(T) + \rho_{carb}(T)$ dependences for the sample #2.

Conclusion

Thus, the proposed model of CNM conductivity as the series connection of the effective resistances, which correspond to the sections with the different conductivity type, satisfactorily describes the experimental $\rho_{carb}(T)$ dependence of CNM, which contains CNT.

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References

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