4-ая Международная научная конференция «Материалы и структуры современной электроники», 23–24 сентября 2010 г., Минск, Беларусь
С.215–218

ELECTRIC PROPERTIES OF NI-NANOPARTICLES ARRAYS

V. K. Ksenevich[1], T. A. Dauzhenka[1, 2], I. A. Bashmakov[3], A. D. Wieck[4]

[1]*Physics Department,Belarus State University, ksenevich@bsu.by*
[2]*Laboratoire National des Champs Magnétiques Intenses-Toulouse; Université Paul Sabatier, (Toulouse, France)*
[3]*Research Institute for Chemical Problems, Belarus State University*
[4]*Department of Physics and Astronomy, Bochum Ruhr-University (Bochum, Germany)*

INTRODUCTION

The metal nanoparticles arrays possess unusual electrical, chemical, magnetic and magnetotransport properties, which significantly differ from those of bulk materials [1, 2]. Moreover the interest toward investigation of magnetic metal nanoparticles arrays is caused by the prospects of their application in magnetoelectronics [3] and in biotechnology [4]. Magnetic nanostructured materials are known as well to be most prospective for development of information storage devices [5] and magnetoresistive sensors. Metal nanoparticles arrays can be used also to study the charge transport peculiarities (specifically, effects of weak localization and electron-electron interactions) in disordered and low-dimensional systems. There are a number of techniques used for the fabrication of metal nanoparticles arrays: ion etching of metal films through arrays of polymer nanoparticles fabricated by self-assembling using direct surface absorption or through Langmuir-Blodgett technique [6, 7], deposition of island-like metal films using sputtering [8], ion-beam metal cluster preparation technique [9]. In recent years a variety of chemical methods find more and more wide applications in fabrication of both magnetic and nonmagnetic nanoparticles arrays. We proposed earlier methods of fabrication of 2*D* layers of metal nanoparticles in carbon matrix based on ion-exchange reactions and thermoconversion of polymer precursor [10, 11]. Possibility to vary electrical properties of these structures from insulating to metallic ones was demonstrated. In this paper we present electrical properties of the Ni nanoparticles arrays in the vicinity of metal-insulator transition.

EXPERIMENTAL DETAILS

The arrays of nickel nanoparticles on the surface of carbon films were synthesized using 3-stage process: 1) introduction of Cu^{2+} cations in thin polymer films by means of ion-exchange reaction and thermolysis of metal-polymer precursor in vacuum at 500 °C during 30 minutes, 2) successive treatment of obtained metal - carbon film in a water solution of palladium chloride during 15 minutes, resulting in contact reduction of palladium ions by metal particles, 3) precipitation of magnetic nickel nanoparticles on catalytically active palladium particles embedded in carbon film by means of treatment of palladium containing carbon films in nickel developer during 5–11 minutes. As a result dense arrays of nickel nanoparticles were fabricated. Preparation procedure of Ni nanoparticles arrays is described in details in [11].

Transport properties of the Ni nanoparticles arrays were measured using standard four-probe dc-technique in the temperature range 4,2–300 K. Electrical contacts on the top of the layers were produced either by thermal evaporation of Al or by Ag paint.

RESULTS AND DISCUSSION

The temperature dependencies of the resistance for all 3 types of samples (subjected to treatment by the Ni physical developer at the final stage of fabrication procedure during 5, 8 and 11 minutes) are shown in Fig. 1 and represents typical behavior for disordered systems. The negative temperature coefficient of the resistance ($dR/dT < 0$) in the whole investigated temperature range (4,2–300 K) was observed. In all samples coefficient R(4,2 K/R(300 K) is slightly greater than 1. The given ratio is nearly 1,3, 1,1 and 1,03 for samples subjected to treatment by the Ni developer during 5, 8 and 11 minutes, respectively, as one can see in the Fig. 1.

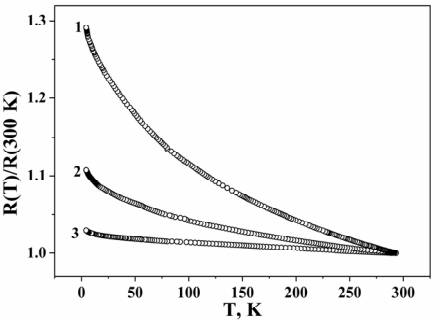

Fig. 1. The temperature dependence of the resistance of the Ni nanoparticles arrays obtained at different time of treatment by Ni physical developer: *1* – 5 minutes, *2* – 8 minutes, *3* – 11 minutes

Such types of $R(T)$ dependencies (with negative temperature coefficient of the resistance ($dR/dT < 0$) and ratio R(4,2 K)/R(300 K)~1–2) are inherent for different disordered systems (granular metals, semiconductors, amorphous alloys, conducting polymers etc.) in the vicinity of metal-insulator transition. Weak localization and electron-electron interactions effects defines temperature dependence of conductivity of these systems [12]. Temperature dependence of conductivity for 3D disordered systems follows the law:

$$\sigma = \sigma_0 + \alpha T^{1/2} + \beta T^{p/2}, \qquad (1)$$

taking into account both weak localization and electron-electron interactions effects [13]. The first term in this law is a constant related to residual conductivity of the system at $T = 0$ K, the second and the third terms describes influence of the effects of electron-electron interaction and weak localization on the conductivity, respectively. The interaction effects usually dominates at low temperatures while weak localization can be effective at relatively high temperatures. In the case if characteristic length parameters describing weak localization and electron-electron interaction effects (inelastic scattering length $L_\varphi = (D\tau_\varphi)^{1/2}$ and thermal length $L_T = (D\hbar/k_BT)^{1/2}$, respectively, where D is diffusion constant, τ_φ is a inelastic scattering time) exceeds thickness of the system, temperature dependence of the resistance follows behavior inherent for 2D disordered systems: $G \sim \mathrm{Ln}T$, where G is the conductance of the system. As far as L_φ and L_T – temperature dependent parameters which decrease with the temperature rise, crossover from the *G(T)* behavior typical for 2D systems to the behavior inherent for 3D disordered materials can be observed as the temperature increases. Assuming possibility of 2D–3D crossover we fitted *G(T)* dependencies of Ni nanoparticles arrays both by expression $G \sim \mathrm{Ln}T$ (in the low temperature range) and by law (1). We found that in the low temperature range (up to $T \sim 12$ K, ~14 K and ~48 K for the samples treated by Ni physical developer during 5, 8 and 11 minutes, respectively) the best fitting results were obtained at the approximation by law $G \sim \mathrm{Ln}T$. This fact assumes possibility of influence both weak localization and electron-electron interactions effects on the sample conductivity in the low temperature range. In the high temperature range best approximation for all 3 types of the samples was obtained for Eq. (1) with parameter $\alpha = 0$, assuming dominating of 3D weak localization effects. As was mentioned above, crossover from 2D to 3D weak

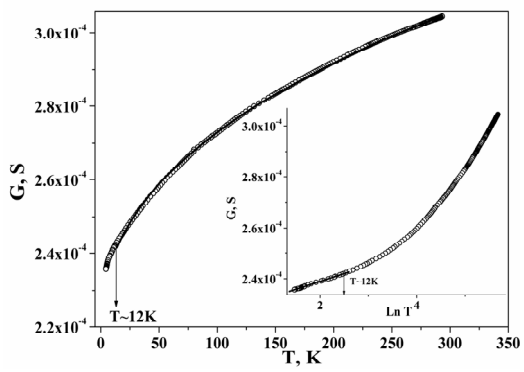

Fig. 2. The temperature dependence of the conductance of the Ni nanoparticles arrays obtained by treatment by Ni physical developer during 5 minutes (circles – experimental data, solid line –approximation by Eq. (1) with parameter $\alpha = 0$ at $T > 12$ K). The inset shows the *G(T)* dependence in *G*–Ln*T* scale (circles – experimental data, solid line – linear approximation at $T<12$ K)

localization can be explained by decreasing of inelastic scattering length as the temperature rises.

In the Fig. 2 typical temperature dependence of the conductance and fitting results for one type of the samples (Ni nanoparticles arrays obtained by treatment by Ni physical developer during 5 minutes) are shown.

CONCLUSIONS

We have investigated electrical properties of Ni nanoparticles arrays in the temperature range 4,2–300 K. The temperature dependence of the conductance of the samples in the low temperature range (at $T < 12$ K, $T < 14$ K and $T < 48$ K for samples obtained by treatment by Ni physical developer during 5, 8 and 11 minutes, respectively) was found to follow model taking into account weak localization and electron-electron interaction effects for 2*D* disordered systems. As temperature increases crossover to the behavior typical for 3*D* weak localization phenomena was observed due to decreasing of inelastic scattering length with the temperature rising.

The work was supported by National Research program NANOTEX (grant No. 5.17(3)), and BRFFI grant No. F10MS-062.