# Magnetic and transport properties of granular Co-Cu glass-coated microwires

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During last years studies of glass-coated magnetic microwires attracted considerable attention owing to a number of outstanding magnetic properties suitable for various technological applications [1-2]. These microwires with typical metallic nucleus diameters 1 - 30 $\mu$m and the thickness of the glass coating 0,5 - 20 $\mu$m are produced by so-called Taylor-Ulitovsky method allowing fast quenching from the melt and therefore fabrication of microwires with amorphous, nanocrystalline, microcrystalline or granular structure [1,2]. Amorphous and nanocrystalline microwires usually exhibit excellent soft magnetic properties such as the magnetic bistability (MB) and the giant magnetoimpedance (GMI) effects [1-3]. On the other hand, rapid solidification allows further expand the limits for obtaining of novel magnetic materials, since it may lead to textures, amorphous to crystalline transitions and nanocrystalline structures [3]. Recently Taylor- Ulitovski technique allowed preparation of granular microwires [3,4], microwires with magnetocaloric effect, MCE, [5] and even Heusler type microwires [6].

It is well established, that the microstructure of such Co-Cu granular alloys consists of small (few nm) Co grains embedded in paramagnetic Cu matrix. The Giant Magneto-resistance (GMR) effect in granular alloys is interpreted considering mixed ferromagnetic-paramagnetic microstructure and spin-dependent scattering of the electrons on grain boundaries between these two phases [7].

Consequently in this paper we present results on fabrication of Co-Cu glass-coated microwires with granular structure and GMR effect and on their structural and magnetic properties. $Co_x$-$Cu_{100-x}$ ($5 \le x \le 40$ at %). Structure and phase composition have been checked by using a Siemens-500 X-ray diffractometer with Cu $K_\alpha$ ($\lambda$=1.54 Å) radiation. Magnetic and magneto-transport properties have been measured within 5 - 400 K using suitable options of PPMS by Quantum Design and using SQUID Quantum Design MPMS XL. Heat treatment has been performed in a conventional furnace up to 1073K. Magnetoresistance (MR) has been defined as: $\Delta R/R(\%)$ = (R(H)-R(0))x100/R(0)

Typical magnetic field, H, dependence of $\Delta R/R$ of studied microwires is shown in the Fig 1a. $\Delta R/R$(H) dependence showing monotonous decay with H should be attributed to the GMR, related with the existence of a single domain ferromagnetic particles embedded in an immiscible medium. We observed considerable MR in $Co_{10}Cu_{90}$, $Co_{20}Cu_{80}$ and $Co_{30}Cu_{70}$ microwires (Figs. 1a, 1b and 2). In most cases, cooling resulted in increasing of $\Delta R/R$, indicating, that GMR is a major contribution in total MR. As previously reported elsewhere [2,3,8] $\rho$–ratio affects strength of internal stresses induced during the rapid solidification of composite wire and also quenching rate when using Taylor-Ulitovsky method.
Therefore, we measured $\Delta R/R$(H) in $Co_xCu_{100-x}$ microwires as a function of temperature with chemical composition and $\rho$-ratio ($\rho$=d/D) as a parameters (see Fig 2). For the samples with concentration of cobalt x=20 and 30 $\Delta R/R$(H) dependences showed non-monotonic behavior, exhibiting $\Delta R/R$ increase with H at low H values (up to 10 kOe), as was also previously reported for $Co_{29}Ni_{25}Mn_1Cu_{45}$ microwires [3,4].
We assumed that the anisotropic contribution should be attributed to the ferromagnetic nature of Co-rich phase while the negative longitudinal MR should be related with the single domain ferromagnetic particles embedded in an immiscible metallic medium [4]. This assumption has been recently confirmed by studying the contrast of bulk CuCo ribbons made by melt spinning through TEM [8]. Such results, confirm, that the structure of these materials is not exactly granular (as many works assume) but of a spinodal decomposed material [9]. That is, Co atoms in these materials are mainly distributed on a periodic profile within the Cu phase. Additionally, we recently observed that glass-coated microwires exhibit a contrast very similar to that seen in the ribbons, but with smaller wavelength due to internal stresses induced by the fabrication technique [8] and anomalous temperature dependence, observed in some Co-Cu microwires has been attributed to such effects [3]. Consequently, variation of MR with $\rho$-ratio should be attributed to the corresponding changes of the microwire structure.
Experimental data obtained using measurements of ZFC and FC magnetization M on temperature T dependences: we did not observe any difference for $Co_5Cu_{95}$ microwires, and significant difference on ZFC and FC curves for $Co_{20}Cu_{80}$. For $Co_{10}Cu_{90}$ microwires small difference has been observed at quite low temperatures, indicating possibility of existence of some amount of small Co-grains.

In our opinion it means that vast majority of Co is dissolved in matrix or aggregated in rather small clusters.

X-ray diffraction (XRD) results reveal that the structure of the metallic core is granular with two phases: the main one, *fcc* Cu (lattice parameter 3.61 Å), found in all samples and *fcc* α-Co (lattice parameter 3.54 Å) which presents in microwires with higher Co content. In the case of low Co content XRD indicates that Co atoms are distributed within the Cu crystals. The quantity and the crystallite size of the formed phases strongly depend on the geometry of the microwire. From XRD we can see that in $Co_{40}Cu_{60}$ $\alpha$-Co phase has been observed. At the same time we did not observe this phase in the sample $Co_{10}Cu_{90}$ (Fig.3).

Consequently observed experimental data on structure and properties of $Co_xCu_{100-x}$ microwires allows us to consider, that since Co and Cu are almost immiscible at room temperature rapid quenching of molten solution gives rise to formation of supersaturated solid solutions and partial precipitation of fine Co grains in as-prepared state. The residual concentration of Co dissolved in the Cu matrix and size of Co grains depends on the quenching rate and on internal stresses determined by the $\rho$ratio.

**References**


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**Figures**

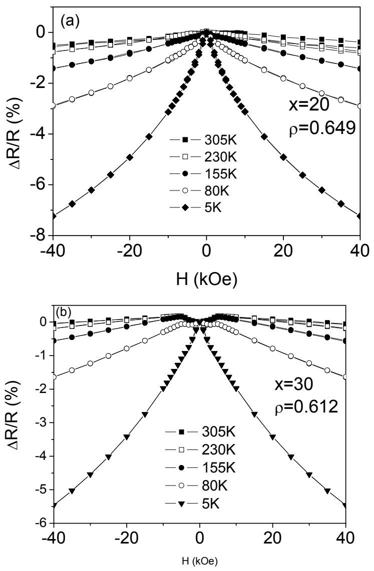


Fig.1 $\Delta R/R$ (H) of $Co_xCu_{100-x}$ microwires for x=20 (a) and x=30 (b)

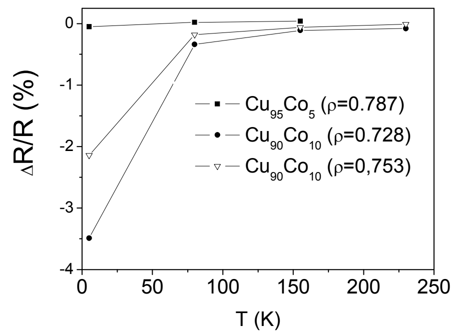


Fig. 2. $\Delta R/R$(T) determined from the $\Delta R/R$(H) with maximum field of 50 kOe for $Co_x$ $Cu_{100-x}$ (x = 5 and 10)

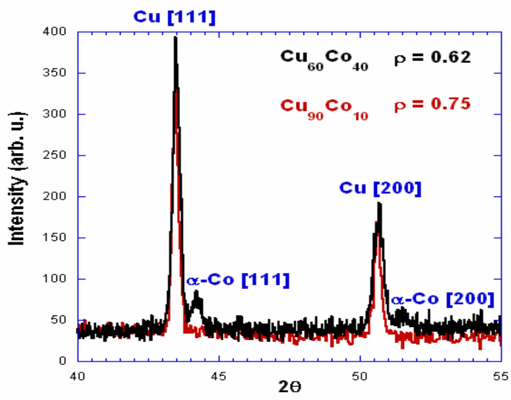


Fig. 3 XRD spectra of $Co_xCu_{100-x}$ (x = 10 and x=40)