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Thermoresistive Properties of Film Systems with Elements of Granular State

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The question about the conditions of formation granular solid solutions (systems based on components with limited or unlimited solubility) or peculiar quasigranular films (systems with mutual solubility of the components and the formation of intermetallic phases in the bulk samples). On example of the first film (Ag/Fe/S) and second (Fe/Pt/Fe/S, $[Fe/Pt]_8$ /S) films types the temperature and concentration dependences of the resistance and thermal coefficient of resistance (TCR) were studies. It is concluded that the value of TCR will always depend on the composition (type of crystal lattices) termostabilize film material, rather than on the efficiency of electron scattering in granules or quasigranular because they will most likely realized ballistic charge transport mechanism.

Keywords: Solid solution, Granule, Quasigranule, Granular alloy, Thermal coefficient of resistance.

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1. INTRODUCTION

Observation of giant magnetoresistance phenomena (GMR) in the granular film alloys [1] has served incentive to find new film of materials with elements of the granular state. Since in work [1] film systems based on Co and Cu is characterized by unlimited solubility component, it is important to know to what extent this process is possible in systems with limited solubility component. From general considerations it can be argued that the ferromagnetic nanogranules in a non-magnetic matrix (this should be limited to solid (diluted) solution (s.s.) or unlimited s.s.) will be formed at an excess concentration of ferromagnetic components (Δc_{ss}). This process starts with the layered condensation of a non-magnetic layers (bottom layer) and the ferromagnetic component or simultaneous condensation. When layered condensation will occur more intensive grain boundary diffusion (diffusion coefficient D_{gb}) and less intense in unlimited solubility of component (diffusion coefficient D_v).

On the Fig.1 shows a qualitative scheme of the formation of granular s.s. during layer of condensation. It is clear that the concentration of granules and their size is completely determined by excess concentration of atoms Δc_G in s.s.

$$\Delta c_{ss} = c_{com} - c_{gb}^{\lim} - \Delta c_G ,$$

where c_{com} - common concentration of ferromagnetic components atoms in film systems.

Experimental results are very many works (see, eg, [2 - 6] and [7] and the literature cited in it) indicate that under the scheme granules are formed in the solid solutions based on Co and Cu, Ag, Au; Fe and Cu, Ag, Au. In the same film systems granular state is formed and the simultaneous condensation component, regardless of their degree of mutual solubility.

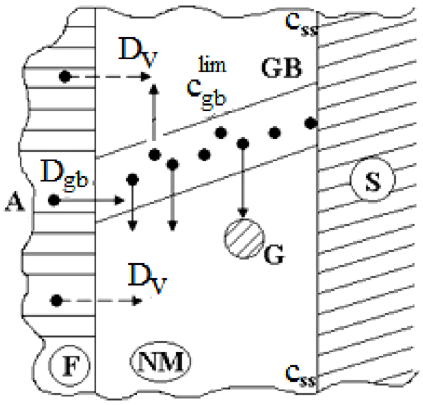

Fig. 1 – The qualitative scheme of the formation of ferromagnetic grains in the matrix ss with non-magnetic layers of condensation (NM) and ferromagnetic (F) component. c_{ss} - the concentration of the magnetic component in s.s.; $c_{gb}^{\lim}$ - the concentration of saturation of the ferromagnetic components on grain boundaries (GB); A - ferromagnetic metal atom; S - substrate

From the literature data is also known [8, 9] that the granules can be formed and a somewhat different mechanisms, which took place in the three-layer films or multilayers $[Pt/Fe]_n$/S with layers of condensation, when the interaction between Pt and Fe atoms is formed magnetic phase FePt ($L1_0$) in the volume of a three-layer system or multilayer. Note that in the case [10] the samples generated in the form of a continuous Fe film / island film Pt / continuous Fe film or as multilayers $[Fe(3\text{-}5)/Pt(3\text{-}5)/Fe(3\text{-}5)]_8$/S (in parentheses thickness in nm), that in both cases the Pt layer representation island films is present.

In our view such a kind quasigranular film systems can be attributed to the third period (in number of multilayers and traditional granulated their alloys) materials with possible spin-dependent scattering of electrons.

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The purpose of our work is to study the electrical properties (resistance, TCR) film systems based on Fe and Ag, where the granular state is stabilized by the scheme presented in Fig. 1 and quasigranular three- and multilayers based on Fe and Pt.

2. METHODIC AND TECHNIC OF EXPERIMENT

For the formation of thin films and multilayers based on Fe and Pt or Ag used vacuum chamber type VUP-5M (vacuum ~ ~10^{-3}–10^{-4} Pa). The layered condensation was carried out by thermoresistive method with rate ω = 1 – 1,6 nm/s at temperature sytall substrate (S): $T_s \cong$ 300 K (system based on Fe and Pt) and $T_s \cong$ 500K (systems based on Fe and Ag). The geometrical dimensions of the mask (2,5x10) mm^2. Annealing was carried out on the temperature range $\Delta T \cong$ 300 – 900 K for two thermal stabilization cycles «heating ↔ cooling». The value TCR (β) was calculated on the basis of resistance data obtained in the second cycle thermal stabilization by cooling the sample.

Measurement of electrical resistance was carried out automatically by means of hardware and software [11]. Process control software annealing carried by ensuring style MDI interface (Fig.2), developed in environment of graphical programming LabVIEW. Measurement of electrical resistance conducted by four-point scheme with the use of 8 channel 16 bit sigma-delta ADC ADAM-4018 and ADAM-4118 [11].

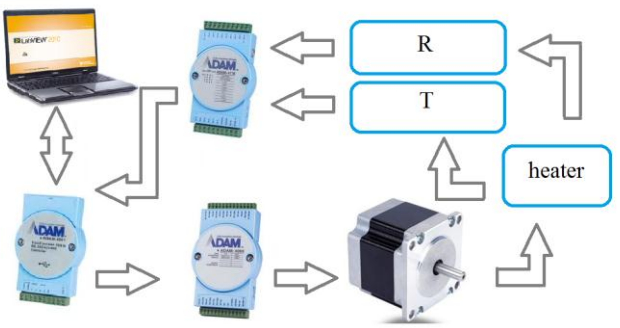


Fig. 2 – Block-scheme of automatic system for investigation of thermoresistive properties of film materials

On the front panel of the program are elements and control output data, which include plotting window for visualization temperature resistance $R_i(T)$ and changes in temperature over time $T(t)$, read of the data table and displays the current indicators of temperature and the current resistance patterns. To determine the resistance value of each sample was designed separate measuring circuit based on constant high-end precision resistors.

The thickness of the layers during deposition controlled by quartz resonator. As thickness gauges used quartz plate WP-08 with the resonance frequency of 10 MHz that connects to the scheme generator. To control the total thickness of the multilayer samples used interferon metric method (Linnyk interferometer).

The crystal structure and phase composition of the samples was investigated by electron microscopy and electron diffraction (microscope TEM-125K).

3. CONCENTRATION AND TEMTERATURE DEPENDENCE OF THERMAL COEFFICIENT OF RESISTANCE

3.1 Film systems based on Fe and Ag

The study of structural and phase state and electrophysical properties of two-layer films of Ag/Fe/S indicate (see, eg, [12]) that if layered condensation followed by annealing in this system is stabilized diluted s.s.-(Ag, Fe), since the phase composition of the films is responsible s.s. + bcc-Fe (Fig.3). This is also evidenced by electron decryption under which it can be concluded insignificant solubility of Fe atoms in the film Ag, since the average parameter ($\bar{a}$ = 0,4083 nm) of fcc lattice s.s.-(Ag, Fe) has a value slightly lower compared to single-layer film of Ag (a =0,4086 nm).

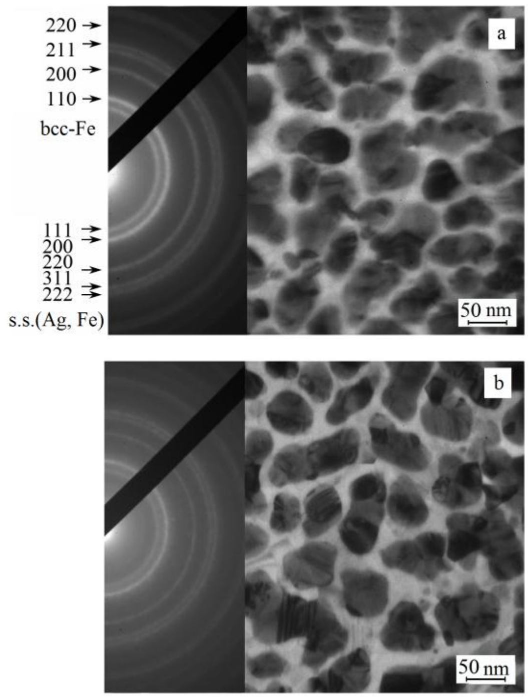


Fig. 3 – Microstructure and electronograms from non-annealing (a) and annealing to T=800 K (b) film Ag(30)/Fe(30)/S. T_s = 500K

In addition, the relative importance of specific resistance and, consequently, low TCR value (Fig.4) also qualitatively indicate the formation of limited s.s.

At the varying the thickness of the Ag from 10 to 50 nm and Fe - 30 to 40 nm (the total concentration of atoms c_{Ag} = 15-55 at.%); TCR is (0,2 – 1,0)·10^{-3} K^{-1}, together with the high temperature stability of Ag/Fe/S lets talk about the possibility of their use as elements of thermistors.

3.2 Film systems based on Fe and Pt

We investigated film systems with different total concentration of Pt atoms: Fe(30nm)/Pt (3; 5 nm)/Fe(30nm)/S (c_{Pt} = 5 i 8 at.%); Fe(30)/Pt (10; 20; 25)/Fe(30)/S (c_{Pt} = 14; 25 i 29 at.%) and multilayers [Fe(3)/Pt(3)]$_8$/S та [Fe(5)/Pt(5)]$_8$/S (c_{Pt} = 46 - 47 at.%).

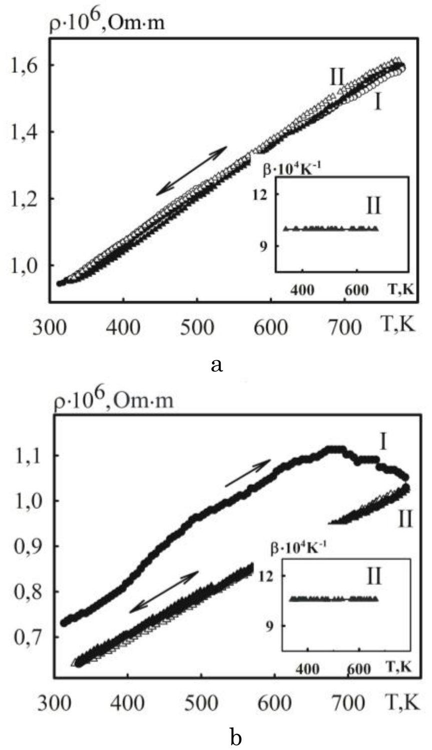
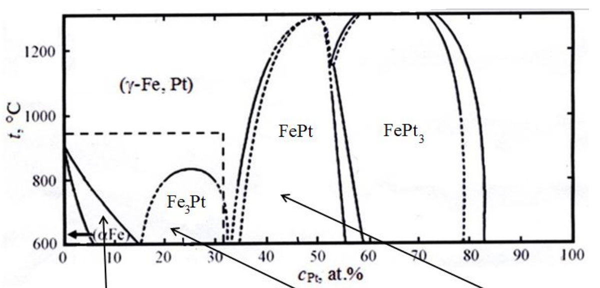


Fig. 4 – Themperature dependence of resistivity and TCR for systems Ag(10)/Fe(30)/S (a) i Ag(30)/Fe(30)/S (b). The total concentration of atoms Ag in film systems is 17 (a) and 37 (b) at.%. I and II – the number of annealing cycles

On Fig.5 presented fragment diagram state for the system Fe-Pt, exposing film systems that meet a certain range of concentrations Pt atoms, which made it possible to homogenize the corresponding phase composition.



Fe(30)/Pt(3)/Fe(30)S, c_{Pt}=5 at.%; Fe(30)/Pt(5)/Fe(30)S, c_{Pt} =8 at.%.	Fe(30)/Pt(10)/Fe(30)S, c_{Pt} =14 at.%; Fe(30)/Pt(20)/Fe(30)S, c_{Pt} =25 at.%; Fe(30)/Pt(25)/Fe(30)S, c_{Pt} =29 at.%.	[Fe(3)/Pt(3)]$_8$/S, c_{Pt} =46 at.%; [Fe(5)/Pt(5)]$_8$/S, c_{Pt} =47 at.%.

Fig. 5 – A fragment of the phase diagram of state for system Fe-Pt and samples in which there is a certain total concentration of Pt atoms

The thickness of the individual layers was chosen so that, in accordance with the phase diagram of state for Fe-Pt for bulk samples Fe-Pt in film systems have stabilized following phases (Fig.5): dilute s.s. Pt atoms in the bcc -Fe (this is the so-called phase (α-Fe); concentration c_{Pt}< 8 at.%); Fe_3Pt (фаза $L1_2$; $c_{Pt} \cong$ 14 - 30 ат.%) and FePt (phase $L1_0$; $c_{Pt} \cong$ 46 ат.%).

Electron diffraction studies indicate that the phase composition annealing samples corresponding to the projection. Calculation of TCR is based on the temperature dependence of the resistance (in Fig.6 shows typical dependences for different film systems).

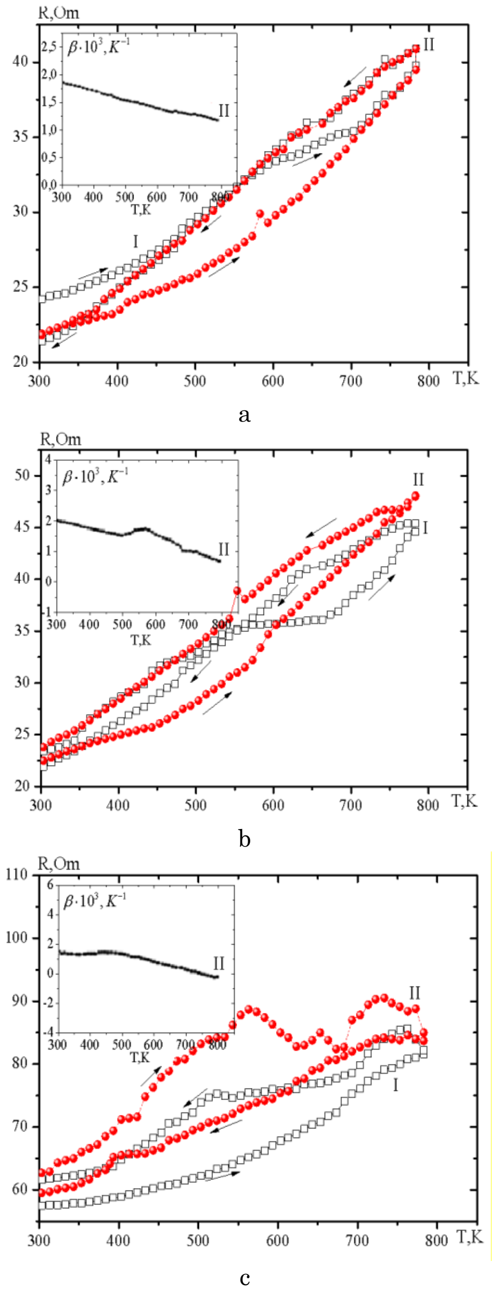


Fig. 6 – Temperature dependence of resistance and TCR for film systems Fe(30)/Pt(5)/Fe(30)/S(a); Fe(30)/Pt(20)/ Fe(30)/S(b) and [Fe(3)/Pt(3)]$_8$/S(c)

Have been established (see also [13]), the following features of the temperature and concentration dependence of TCR for the three mentioned phases. In all cases there is a dependence of TCR ~ 1/T on the range 300 - 700 K, although its value has a different meaning within the indicated three concentration ranges. His greatest value occurs in phase s.s.(α-Fe): from $2{,}5\cdot10^{-3}$ K^{-1} (300 K) to $1{,}4\cdot10^{-3}$ K^{-1} (700K), which is consistent with the value of TCR for single-films Fe. In phase $L1_2$ value TCR change from $2\cdot10^{-3}$ K^{-1} (300K) to $0{,}9\cdot10^{-3}$ K^{-1} (700K). The lowest value TCR occurs in phase $L1_0$ – $(0{,}2 – 0{,}8)\cdot10^{-3}$ K^{-1}, which can explain the process of ordering this phase. Fig.7 illustrates the features listed for TCR depending on the total concentration of atoms Pt.

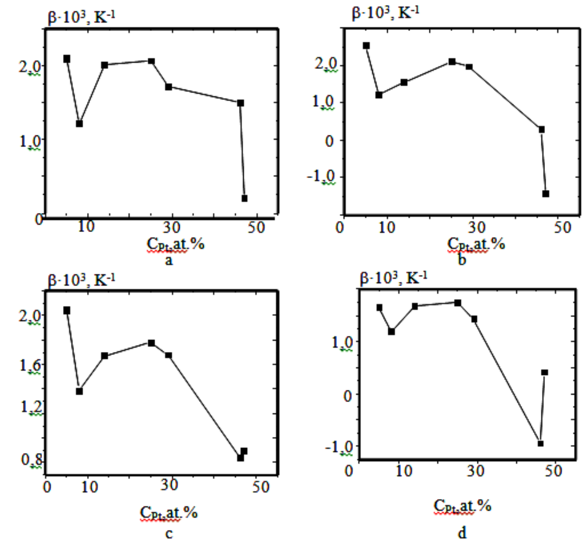


Fig. 7 – Dependence of TCR versus total concentrations Pt atoms. Annealing temperature of film systems T_a=300K (a); 400K (b); 500K (c) and 600K (d)

4. CONCLUSIONS

Based on the results of the study electrical properties of granular s.s. (the system Ag/Fe based on component of the limited solubility) or quasigranulare films (systems based on Fe and Pt with total solubility of the components and the formation of intermetallic phases in the bulk samples), the following conclusions.

Value TCR will always depend on the composition (type of crystal lattices) annealing film material rather than on the efficiency of electron scattering in granules or quasigranulare, because they will most likely realized ballistic charge transport mechanism. Analysis of this issue as an example strain effect made by us in [14].

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