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# The Temperatures' Influence of Substrate and Annealing on a Surface Relief and Diffusion in Multilayer Film Systems

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The topography's change of surface films Fe/S and Cu/Fe/S was investigated and the diffusive profiles' analysis of three-layer films Co/Cu/Fe/S was performed after theirs annealing. The influence of mean-square roughness and interdiffusion on a size of giant magnetoresistance (GMR) effect was established.

**Keywords:** Surface Topography, Mean-square Roughness, Diffusion, Atomic-force Microscopy.

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## 1. INTRODUCTION

It is known that the quality of interfaces influences on electro-physical and magnetoresistive properties of film systems to a great extent, including roughness. As to the clarification of influence on these features of interfacial boundaries we have a huge number of works (look, for example, [1, 2]), results of which have different interpretation. An attempt to make the theoretical analysis of this problem is found in works [3, 4]. It is shown, when spin asymmetries for volume and interphase mechanisms of electrons' dispersion are identical, the amplitude of effect of GMR increases monotonously with increasing of rough edges. In case, when they are different, the amplitude of GMR effect has a minimum by some parameters of rough edges. Therefore the most expedient analysis is the topography analysis of a surface of interphase borders and diffusive profiles of three-layer systems Co/Cu/Fe/P in which the GMR effect is observed.

## 2. METHODS OF SAMPLE MANUFACTURING AND ANALYSIS

Three-layer polycrystalline films Co/Cu/Fe/S with $d_{\mathrm{Co,Fe}} = 30 \div 40$ nm and $d_{\mathrm{Cu}} = 3 \div 15$ nm were derived in vacuum setting VUP-5 (the gas pressure of remanent atmosphere is $10^{-4}$ Pa) by the method of staged condensation of metals' layers under substrate temperatures $T_{sub} = 300$ K, 400 K, 550 K and 700 K. The films Fe(30 nm)/S та Cu(15 nm)/Fe(30 nm)/S ($T_{sub} = 300$ K) were derived by this method too. Films' condensation was effected on glass polished substrates with previously deposited copper contact squares .The layers' thickness during deposition was rated by the time and speed ($\omega = 0{,}5 \div 1$ nm/sec) of condensation and furthermore was determined with the help of interferiometric device MII-4. The magnetoresistance estimating and heat treatment of items was performed in special setting in conditions of ultrahigh oilless vacuum ($10^{-7}$ Pa).

The exploration of the surface relief of not annealed and annealed films Fe/S та Cu/Fe/S under the temperatures $T_{an} = 550$ K and $T_{an} = 700$ K is performed with the help of Scanning Probe Microscope Nano Scope IIIa Dimension 300TM in the mode of periodic contact. The computing (determination of mean-square roughness and average diameter of grain) was performed with the help of applied programme «Femto Scan Online» and processing modulus of pictures NT-MDT «Image Analysis 3.5» with usage of source 2-D image.

The exploration of diffusion was effected by SIMS (secondary and ion mass-spectrometry) method with the help of mass-spectrometer MX 7201.

## 3. RESULTS OF EXPERIMENTAL INVESTIGATIONS

Atomic force microscope (AFM) is widely used for the exploration of microstructure and topographical peculiarities of surface of various samples. In case of thin films, it helps to define size and form of microparticles of its surface as well as its roughness, it is important for understanding of electroconductive properties of multilayer films.

On the Fig. 1 we see the AFM-image of relief of not annealed and annealed substrates of films Fe/S i Cu/Fe/S. It is shown in the Fig. 1 a, b that the layer of copper changes surface topography of the film Fe. So if maximal differential of profile for not annealed films is about 40 nm than it is 20 nm for not annealed films Cu/Fe/S and the diameter of grains decreases from $D = 150 \div 200$ nm (Fe) to $D = 25$-$60$ nm for Cu/Fe/S (see Table. 1). After the process of annealing in the extreme oilless vacuum under the temperature 550 K we can observe grains with average diameter $D = 85 \div 100$ nm on the surfaces of film Fe, but there are grains with average diameter $D = 40 \div 70$ nm on the surface of Cu/Fe/S (see Fig. 1c). The magnitude of surface roughness Fe is $S_q = 6{,}828 \div 7{,}476$ nm, but it increases to $S_q = 8{,}965$-$9{,}482$ nm for the surface of Cu/Fe/S.

Annealing of theses samples under the temperature 700 K (Fig. 1d) results in some increasing of the grains' diameter $D = 110 \div 120$ nm (for Fe) and $D = 60$-$90$ nm (for Cu/Fe/S). But in case of Fe film the film's surface is significantly smoothing ($S_q = 0{,}170 \div 0{,}332$ nm) concerning the surface of film Cu/Fe/S ($S_q = 3{,}027 \div 3{,}443$ nm), but at the same time it causes the emersion of microholes in the cooper surface (see Fig. 1d) which denotes the disturbances in structural integrity of nonmagnetic layer (appearing of «bridges» which help to bind next layer of ferromagnetic metal with previous layer of Fe) which result in disappearing of GMR effect.

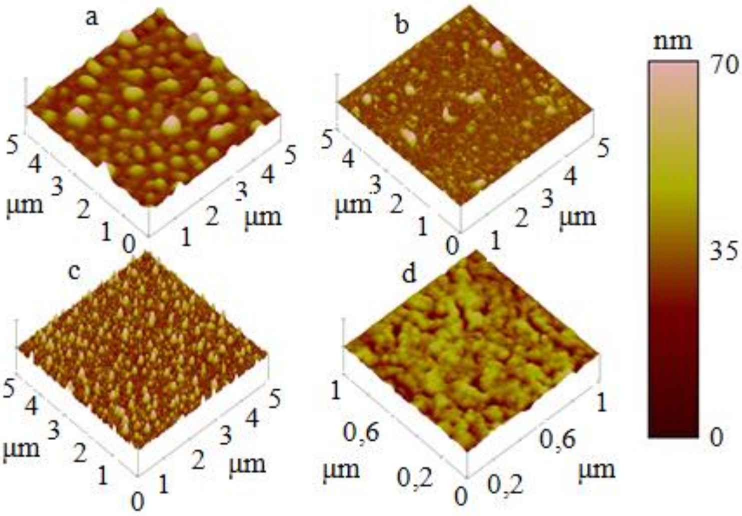


**Fig. 1** - AFM - the image of surface relief: a – not annealed film Fe/S, b – not annealed film Cu/Fe/S, c – annealed (550K) film Cu/Fe/S , d – annealed (700 K) film Cu/Fe/S

**Table 1** – Index of average diameter size of grain D and mean-square roughness Sq

| $T_{an}$ | Fe/П | | Cu/Fe/П | |
|---|---|---|---|---|
| | $S_q$, nm | $D$, nm | $S_q$, nm | $D$, nm |
| 300 K | 7,523-8,840 | 150-200 | 3,134-3,957 | 25-60 |
| 550 K | 6,828-7,476 | 85-100 | 8,965-9,482 | 40-70 |
| 700 K | 0,170-0,332 | 110-120 | 3,027-3,443 | 60-90 |

The annealing of these samples under the temperature of 550 K within 30 min., reduces to further mutual penetration of atoms Co, Fe and Cu to the neighbor layers (see Fig. 2b), but overall the system remains three-layer. It can be explained by insignificant subsequent diffusion on borders of grains, and bending of atoms of a diffusant over borders of grains to the volume of crystallites. It should be noted that one of features of these systems is ability to create fine-grained formations (granules) of Co and Fe in nonmagnetic Cu matrix.
Therefore it is possible that such granulated condition is realized in the annealed films of nonmagnetic layers.

The received results is qualitatively coordinated with particular electron-diffraction researches of phase structure of these systems according to which both not annealed and annealed under 550 K film samples can be considered as three-layers. One more proof, that in three-layers systems Co/Cu/Fe/S remains identity (integrity) of layers after annealing under 550 K, is realization in such films an effect of a giant magnetoresistance with amplitude 0,5-0,8% .

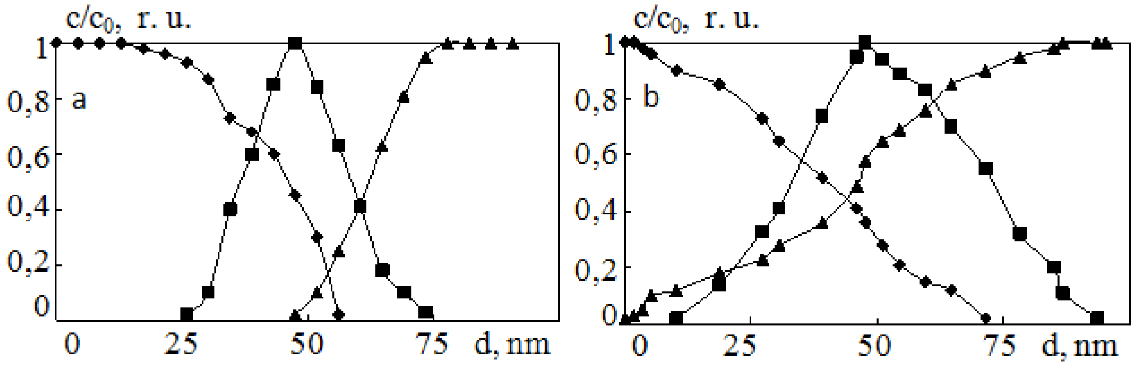


**Fig. 2 -** Diffusive profiles for films Co(40 nm)/Cu(15 nm)/Fe(40 nm)/S (♦♦♦ Co, ■■■ Cu, ▲▲▲ Fe) received under the surface temperature $T_{sub}$ = 400 K in fresh-condensated and annealed condition under temperature 550 K (b)

It is interesting, that for all not annealed samples of Co/Cu/Fe/S which were received under temperature 400 K, the anisotropic magnetoresistance (AMR) is observed. Though for the same samples, but received at the indoor temperature with thickness of not magnetic layer of 3-15 nm, GMR is observed up to 1,2%. Further annealing of samples Co/Cu/Fe/S ($T_{sub}$=400 K) with $d_{Cu}$ = 5-15 nm reduces to emergence of GMR. In our opinion, such movement of magnetoresistance can be explained by following ideas

In general the magnetoresistive effect is caused by a super position of AMR (connected with spin-orbit interaction) and GMR (connected with spin-dependent dispersion of electrons). During condensation of films on substrate warmed up to 400 K, a roughness of the boundaries section of layers is less, then during condensation with the indoor temperature. After annealing the roughness and the size of grains on film's surface increases. As a result the area of the boundary section of layers increases too. It results in alignment of the spin-asymmetries of volume and interphase dispersion of electrons of conductivity, so and in increasing of GMR amplitude.

## 4. CONCLUSIONS

1. During the annealing under $T_{an}$ = 550 K the mean-square roughness of a film of Cu/Fe/S increases to 8,965-9,482 nm and after annealing under $T_{an}$ = 700 K decreases to 3,027-3,443 nm.

2. Film systems of Co/Cu/Fe/S which were received under the temperature of substrate $T_{sub}$=400 K keep identity of layers. The annealing of these samples under the temperature $T_{an}$ = 550 K doesn't make any considerable changes of diffusive profiles.

3. For all samples Co/Cu/Fe/S ($T_{sub}$ = 400 K) GMR is observed. The annealing under $T_{an}$ =550 K reduced to emergence of GMR effect with amplitude 0,8%.

## REFERENCES


1. J. Ben Youssef, K. Bouziane, O. Kochkina et al, J Mag. Mag Mater. **165**, 288 (1997).
2. M.M.H. Willekens, Th.G.S.M. Rijks, H.J.M. Swagten, W.J.M. de Jonge, J. Appl. Phys. **78** No12, 3950 (1995)
3. J. Barnas, G. Palasantzas, J. Appl. Phys. **82** №8, 7202 (1997).
4. L.V. Dekhtyaruk, *Visnyk SumDU. Seriya Fizyka, matematyka, mekhanika* **2**, 120 (2007) [in Russian].
5. M.V. Belous, S.M. Voloshko, A.D. Krasyuk y dr., Metallofyzyka y noveyshye tekhnolohyy **8** No5, 54 (1986) [in Russian].