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Magnetoresistive Properties of Three-Layer Systems on the Basis of Thin Metal Films Fe and V or Ni and V

V.V. Bibik, T.M. Grichanovskaya, A.S. Grischuk, L.A. Sheshenya

Sumy State University, 2, Rymsky Korsakov Str., 40007 Sumy, Ukraine

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The paper deals with the methods of forming three-layer structures by layer condensation of nanoscale films Ni, Fe and V. Investigated the magnetoresistive properties of the samples as well as their dependence on annealing temperature and the thickness of nonmagnetic layer. The correlation of magnetoresistance effect with structural-phase state of film system and its components are defined.

Keywords: Phase composition, Three-layer film systems, Magnetoresistance, Size dependence.

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1. INTRODUCTION

The development of modern nanoelectronics is closely connected with new technologies of magnetic memory devices, intelligent sensors and transmitters. From the practical point of using of huge magnetoresistive effect (MRE) it is important to find the materials which will provide as large values of magnetoresistive ratio as possible (R – Rs)/R, (where R - maximum resistance of the sample in the magnetic field, Rs - resistance at saturation) [1-5]. The high level of minimization of film elements requires taking into account the displays of their different kinds of size effects [6, 7]. Thus, the limitation of geometrical dimensions of the film and/or crystalline grains causes the reduction in the mean length of free path of electric current carriers. In addition spin-dependent scattering of electrons in antiparallel magnetic moments of individual ferromagnetic layers or magnetic moments of granules or impurity atoms appear in magnetic non-uniform film materials. In the heating process of such film samples or the influence of the magnetic field additional changes in the mean length of free path of electric current carriers and conductivity appear [8, 9]. Shown the above phenomena are manifested in the size dependence of many characteristics as well as magnetoresistance ratio.

The aim of the study has become the research of magnetoresistive properties of three-layer films of Ni(50nm)/V(dv)/Ni(10nm) and Fe(40nm)/V(dv)/Fe(10 nm) (d_V =1-16 nm) and detection of size dependence of magnetoresistive effect.

2. EXPERIMENTAL

Thin metal films Ni, Fe, and three-layer systems Ni/V/Ni, Fe/V/Fe were obtained by thermal evaporation method in the vacuum of 10^{-3}-10^{-4}Pa. The plates of amorphous glass ceramics were used as substrates in the magnetoresistive studies. Layers deposition of the materials was realized out of two evaporators on the heated substrate (350 – 400 K). The thicknesses of some layers were defined with the method of quartz resonator and also were tested with the interferometric method. The samples were annealed in the temperature range from 300 to 800 K.

Electron microscopy and electron diffraction investigations were carried out using TEM - 125 k

Magnetoresistive characteristics were determined at the room temperature in the alternating external magnetic field with induction from 0 to 600 mT.

The magnetoresistance was measured for the following geometries:- longitudinal, when the vector of magnetic induction B is collinear to the direction of current;- transverse when vector B lies in the plane of the sample and it is perpendicular to the direction of current; - perpendicular when vector B is perpendicular both to the plane of the sample and the direction of current.

3. RESULTS AND DISCUSSION

State diagram of Ni-V in the range of high temperatures is rather complex and characterized by the presence of intermediate phases. Two-layer films on the basis of Ni and V in the unannealed state had phase composition bcc-V + fcc-Ni. The lattice parameter a = 0.304 nm (film V) and a = 0.351 nm (film Ni), which is close to the lattice parameters of single-layer films and bulk samples V and Ni. Note, that grains size of just condensed film is 15-20 nm. Annealing at the temperature of T<700 K does not make changes the phase composition of the samples and noticeable processes of recrystallization. In the films annealed at the temperature of 700 $\leq$ T<800 K, there is a slight increase in the lattice parameter of Ni to the value a = 0.353 nm and the decrease in the lattice parameter of V to the value a = 0.301 nm.

All the samples of Ni(50nm)/V(dv)/Ni(10nm) were obtained under identical technological conditions. Electron diffraction and electron microscopy investigations confirmed that all the thin film systems had the phase composition of bcc-V + fcc-Ni, the polycrystalline structure.

Experimental studies of magnetoresistive properties of thin film systems have shown that the unannealed samples with vanadium layer thickness of dv < 3 nm had anisotropic magnetoresistance, and magnetoresistive hysteresis loops for such systems are similar to the corresponding loops for single layer films of ferromagnetic metals (Ni, Fe). The value of the longitudinal and transverse magnetoresistance (MR) does not exceed 0.01-0.05 %. Annealing of these samples at the temperature of T = 600-650 K is accompanied by a slight increase of value MR.

The absolute values MR of unannealed samples with the thickness of nonmagnetic layer dv = 3-11 nm are an order of magnitude larger than the previous ones, and significantly depend on the phase composition and concentration of the components of the film system. In the samples where it could avoid the formation of solid solution, MR grows with increasing annealing temperature and for the films annealed at 650 K is 0.2-0.6% for the longitudinal and 0.1-0.5% for the perpendicular MR.

For the film systems with concentration of C_{Ni}=86-88 at. % observed isotropy of the magnetoresistive properties, which is in reduction of electrical resistance in the magnetic field, regardless of the geometry of the taken measurements, what can be considered one of the signs of giant magnetoresistance [1-5].

The important feature of magnetic nanostructures is an oscillation of the exchange link between the ferromagnetic layers, depending on the thickness of the nonmagnetic layer, which in its turn leads to oscillations of magnetic and magnetoresistive properties of the film structures. Some of the important characteristics that give qualitative information on the behavior of the film sample in the process of reversal of magnetization is the coercive force (Hc) and the saturation field (Hs). Since the valuea Hc determined by the magnetoresistive loops do not coincide with the values defined by the magnetic hysteresis loops, a number of authors suggested, by analogy with the Hc and Hs, to use the induction of the magnetic field required to complete demagnetization of the sample (Bc) and saturation induction (Bs).[9]. The results of the influence of the indirect exchange link between ferromagnetic layers of Ni on the value of the coercive force of Ni(50nm)/V(dv)/Ni(20nm) is illustrated in Fig. 1. Maxima of demagnetization induction Bc were observed at dv ≈ 3 nm and dv ≈11 nm , which corresponded to the maxima of the saturation induction Bs, i.e, one can talk about the antiferromagnetic link of ferromagnetic layers of Ni in these film systems.

The system Fe-V is characterized by continuous solubility in the liquid and solid states, so it was rather difficult to get the systems Fe(40 nm)/V(d_V)/Fe(10 nm). In the samples with d_V < 10 nm the presence of vanadium wasn't revealed by electron diffraction investigation, and the Fe lattice parameter was a = 0,289 nm. In the samples with d_V = 10-12 nm the calculation of electron diffraction showed that the lattice parameter of Fe did not change, and the lattice parameter of V is a = 0.302 nm. Annealing at the temperature of 650 K did not change the phase state and the lattice parameters. The analysis of crystal structure showed that all the samples in the unannealed state are nano-dispersive with an average crystallite size of less than 5 nm. Annealing at the temperature of 650-700 K results in slight recrystallization processes: it the average crystallite size increases to 5-10 nm.

Anisotropy of field dependence in the systems with layers dv < 2 nm turned out to be similar to the films of Fe with dominance of the value MR in the longitudinal geometry in comparison with other geometries.

For three-layer films systems with the concentration C_{Fe} = 83-85 at. % is observed isotropy of the magnetoresistive properties. The reduction of the electrical resistance in the magnetic field was observed regardless of the geometry of the measurements.

The feature of the samples Fe (40 nm) / V (dv) / Fe (10 nm) is that the highest values of MR correspond to transverse and perpendicular geometries up to (0,12-0,14%), whereas for the longitudinal geometry magnetoresistive ratio is 0,03-0, 06 %, or not at all.

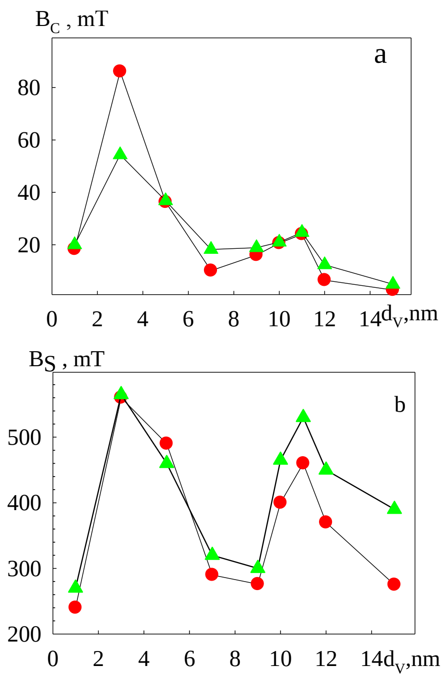

Fig. 1 – The dependence of the demagnetization induction (a) and saturation induction (b) from the thickness of the layer V of film system Ni(50nm)/V(dv)/Ni(10nm) unannealed (0) and annealed (Δ) at 650 K

Field dependence typical for the spin-valve structure could be obtained for the sample Fe(40)/V(10)/Fe(12) in transverse geometry (Fig.2). The presence of a horizontal section on the dependence of ΔR/Rs on vector B shows the independent reversal of magnetization of the upper and lower layers.

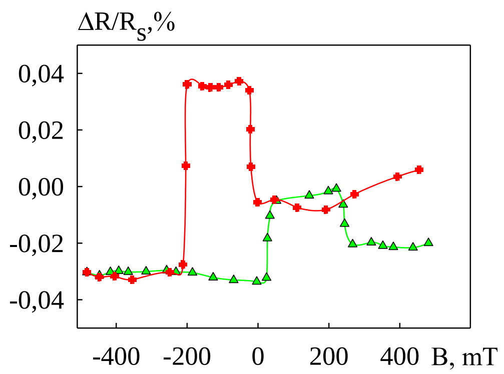

Fig. 2 – Field dependence of the magnetoresistance of Fe (40 nm)/(10 nm)/Fe(10 nm) in the unannealed state

4. CONCLUSIONS

The investigation of structural and magnetoresistive properties of the film systems Ni(50nm)/V(d_V)/Ni(10nm) and Fe(40nm)/V(d_V)/Fe(10 nm) (d_V =1-16 nm) was carried out. It was shown that at annealing of the systems in the temperature range 300-650 K, they retain their structural and phase stability. These systems Fe(40nm)/V(d_V)/Fe(10 nm) (d_V ≈ 10 nm) have isotropic magnetoresistance and they can be used as the spin-valve structures.

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