UDC: 539.216:544.003.26

STRUCTURE AND MAGNETORESISTIVE PROPERTIES OF THREE-LAYER FILM SYSTEMS CoNi/Ag(Cu)/FeNi

V. B. Loboda, Cand. Sci. (Phys.-Math.), Prof.;
V. O. Kravchenko, Cand. Sci. (Phys.-Math.);
S. M. Khursenko, Cand. Sci. (Phys.-Math.), Assoc. Prof.
Sumy National Agrarian University

We present the investigation results of the structure-phase state and magnetoresistive properties (anisotropic and giant magnetoresistances) of three-layer nanocrystalline film systems CoNi/Ag(Cu)/FeNi in conditions of ultrahigh oil-free vacuum

***Keywords**: Crystalline structure, Phase composition, Three-layer nanocrystalline films, Anisotropic and Giant magneto-resistance*

1. Introduction

Further knowledge extension in the field of thin film physics is in the area of multilayer film systems based on layers (both magnetic and nonmagnetic) with dispersed structure: amorphous, nano-, and microcrystalline films. The main feature of an electron transport in multilayer magnetic films (MMF), in comparison with bulk conductors, is the interaction between charge carriers and internal boundaries of layers. They influence on the dependence of kinetic coefficients versus the layer thickness and the external fields [1]. Among a variety of effects observed in MMF the effect of GMR, discovered in 1988, is one of the striking and important ones from the point of view of its practical application. The GMR effect is observed in multilayer samples, which are composed of alternately deposited layers of ferromagnetic and nonmagnetic metals, and consists in reduction of the sample electrical resistance (parallel to its boundaries) under action of the relatively weak external magnetic field with induction of the order of 100 mT [2,3]. The practical importance of this effect can be scarcely overestimated. Extremely high sensitivity of multilayer conduction (even at the room temperatures) before switching on of a weak magnetic field makes them to be a prospective application in different electronic devices of the new generation [4].

Thus, investigations of structure and transport effects in multilayer magnetic film systems are of a great interest both from the fundamental and practical points of view, that is confirmed by a large number of scientific publications. In particular, it is not definitely clarified what mechanism - spatial, interface or their superposition—is a dominant one during the amplitude formation of the GMR effect.

2. Experimental technique

Film samples were obtained by the resistive (Cu, Ag) and the electron-beam (CoNi and FeNi alloys) evaporation methods in the vacuum 10^{-4} Pa at the substrate temperature T_s = 300 K. For evaporation we used bulk alloys of the specified composition (50 mass percentage of Co, 50 mass percentage of Ni; permalloy 50N). Glass polished plates with deposited copper contacts with Cr sublayer were used as the substrates for electrical conduction study. Condensation rate of metal layers was 0,5-0,8 nm/sec for CoNi and FeNi and 1-1,5 nm/sec for Ag. We used the universal digital voltmeter V7-46/1 for estimation the electrical resistance *R* with the relative error 0,025%. Temperature control was realized using the chromel-alumel thermocouple, connected with the digital voltmeter. The layer thickness *d* was determined by the interferometric method (MII-4 device) with the measurement accuracy 10% at d > 50 nm. We used the nichrome masks for holding the length (a) and the width (b) of a sample.

Measurements of the film magnetoresistance (MR) were performed in a special plant in conditions of ultrahigh oil-free vacuum (10^{-7} Pa) in magnetic field up to 150 kA/m at the room temperature [5].

3. Results of experimental investigations and discussion

3.1. Microstructure of three-layer films

The carried out electron-microscope study of the CoNi/Ag(Cu)/FeNi system (Fig. 1) points that the unannealed films are in a polycrystalline state with a small crystallite size (less than 5 nm). Blurred lines, which belong to the fcc phase (CoNi-fcc and FeNi-fcc), and faint lines of Ag-fcc are fixed on the electron-diffraction patterns of the unannealed films. For films with copper sublayer due to close interplanar spacings for Cu, permalloy, and CoNi- alloy the lines, which belong to these phases, are not distinguished. Lattice constants of the phases in an accuracy range coincide with parameters for the single-layer film CoNi (a = 0,355-0,357 nm) and FeNi (a = 0,359-0,361 nm) alloys with corresponding concentration.

After film annealing at 700 K the broadened lines, which belong to the fcc phase, are observed on the electron-diffraction patterns as well. The line broadening both for films with copper and silver sublayers can be explained by the superposition of diffraction maximums from different phases.

The main reasons for magnetic and magnetoresistive hysteresis is the irreversible displacement of domain walls, irreversible rotation of spontaneous magnetization, and delay in formation and growth of magnetic reversal centers. For all observable CoNi/Ag/FeNi samples with nonmagnetic layer width up to 2 nm the positive longitudinal magnetoresistive effect is observed (resistance increases under applied external magnetic field), that is the characteristic of the usual anisotropic magnetoresistance (AMR), proper to the uniform ferromagnetic materials. The reason for AMR is an interaction between the conduction and the outer shell electrons, spin moments of which condition the spontaneous magnetization [7]. We should note, that the value of MR for the unannealed CoNi, FeNi films and CoNi/ Ag(Cu)/FeNi with the AMR is very small and it does not exceed 0,15% at the room temperature. In [8] shown, that at small width of nonmagnetic sublayer in three-layer films there is the direct exchange interaction between magnetic layers through ferromagnetic junctions in nonmagnetic sublayer. Such a film can be considered as a two-layer one with $2d_F$ width with silver or copper islands between the ferromagnetic layers. We did not discover the GMR in such films.

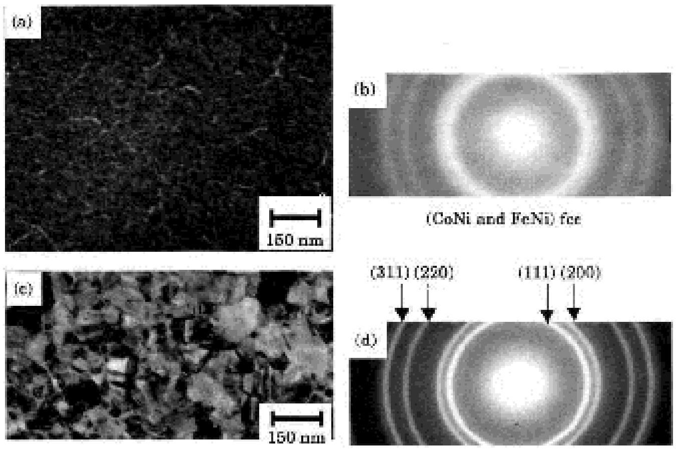

Fig. 1 : Microstructure (a, c) and electron-diffraction patterns (b, d) of the unannealed (a, b) and the annealed (c, d) at 700 K three-layer CoNi(25 nm)/ Ag(7 nm)/ FeNi (25 nm) structure

For the unannealed three-layer films with sublayer width d_A = 3-15 nm (Fig. 2) the reduction of electrical resistance only is observed, irrespectively of the direction of applied magnetic field, current, and sample orientation (absence of the MR anisotropy). Sign "–" denotes, that electrical resistance is reduced, if magnetic field is applied to the demagnetized sample. This fact is the feature of GMR, the presence of which implies about the magnetic heterogeneity of an object and the change of a relative orientation of its magnetic moments.

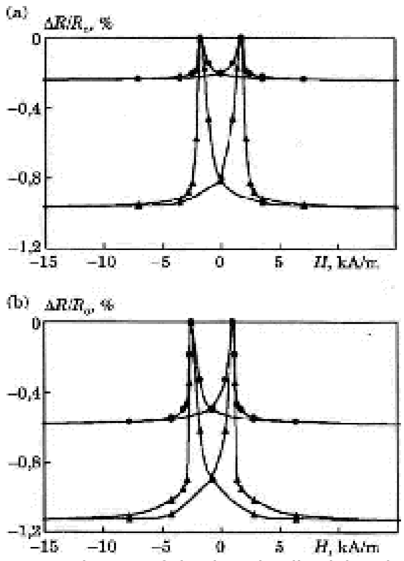

Fig. 2: Dependence of the longitudinal (• • •) and the transverse (▲▲▲) MR versus the external magnetic field strength for the fresh-condensed three-layer CoNi/ Ag/FeNi structure (d_{CoNi}=30 nm, d_{Ag}=5 nm, d_{FeNi}=30 nm), temperature of measurements: 300 K (a), 150 K (b)

Dependences of the longitudinal and the transverse MR versus the external magnetic field strength for three-layer CoNi/Ag/FeNi system with d_F = 30 nm and d_{Ag} = 5 nm, obtained at different temperatures, are represented in Fig. 2. As seen from this figure, the abrupt change of MR in the field range from –2 to 20 kA/m and explicit saturation behavior in stronger fields are characteristic features for all $(\Delta R/R_0)(H)$ dependences.

Thus, as seen, the relatively weak magnetic field converts system from the antiferromagnetic ordering to the ferromagnetic one, that leads to the decrease of conductor resistance, i.e., the GMR is realized. The GMR effect is conditioned by the spin-dependent electron scattering on the film interfaces [9] and within the metal layers [10].

Besides, the existence of the GMR itself carries some information about parameters of heterogeneous system. In particular, the characteristic size of magnetic elements, responsible for GMR, and the average distance between them should not essentially exceed the mean free path of conduction electrons [11-13]. In our case the magnetic layers, divided by thin enough nonmagnetic sublayers, are such elements. Probably, at the width of silver layer d_{Ag}>3 nm an interlayer becomes a structurally continuous one and ferromagnetic layers are not connected by the direct exchange interaction in such films no more. In this case the value of GMR, which is the relative difference between the maximal and the minimal values of resistance per one magnetization cycle in a field with maximal strength 1,5 kE, reaches 1% at the room temperature.

During further increase of the silver sublayer width (d_{Ag}=3 nm) the isotropy of field dependences is maintained, but the value of GMR decreases ($\Delta R/R_0$<0,5%).

Under sample cooling to 150 K (Fig. 2b) the form of hysteresis loops of the MR effect does not practically change (independently of the layer width). Increase of the effect amplitude and slight displacement of the peaks on the ($\Delta R/R_0$)*(H)* dependence to the region of strong fields are only observed. Decrease of the effect amplitude at temperature rise connected with the electron-phonon scattering (especially in nonmagnetic sublayer), reduces the importance of spin-dependent scattering processes, which form an amplitude of the effect, and impedes an electron passage from one ferromagnetic layer into another as well [14]. Presence of the transverse magnetoresistive effect only is the feature of MR of the unannealed samples with copper sublayer (Fig. 3).

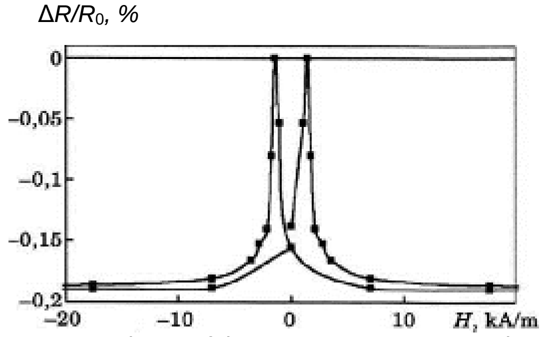

Fig. 3: Dependence of the transverse MR versus the external magnetic field strength for the unannealed three-layer CoNi/Cu/FeNi structure

We suppose that the absence of the longitudinal effect is connected with appearance of insignificant spin-dependent scattering of charge carriers. But it is difficult to assert about realization of the GMR effect in given three-layer films, because the specific character of GMR is the isotropy of field dependences.

Under film annealing at the temperature 550 K the appearance of the longitudinal (up to 0,08-0,1%) and the transverse (up to 0,3–0,4%) MR is observed. Peaks of the field dependences displace to the stronger field region. Annealing at 700 K leads to further growth of the AMR (Fig. 4a). We suggest, that the reason of MR increase at high-temperature annealing (T_{ann}=550 K, T_{ann}=700 K) is the crystallite size increase and the atom interdiffusion into adjacent layers. With temperature decrease to 150 K the value of MR increases 1,2-1,3 times, and peaks of the field dependences displace to the stronger field region (Fig. 4b).

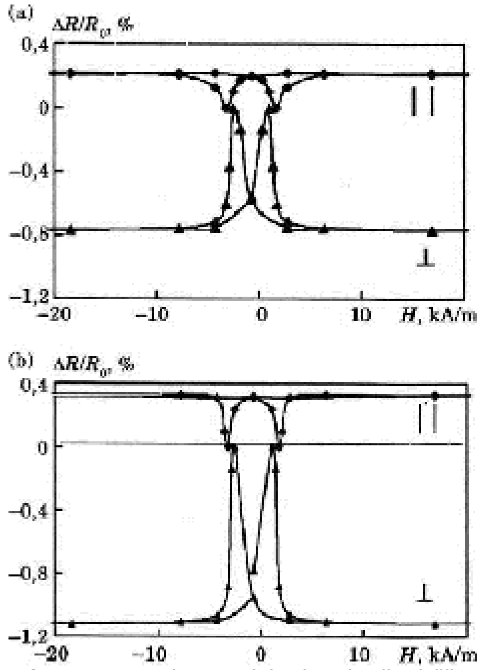

Fig. 4: Dependence of the longitudinal (||) and the transverse (⊥) MR versus the external magnetic field strength for the annealed at 700 K three-layer CoNi/Cu/FeNi structure; temperature of measurements: 300 K (a), 150 K (b)

Thus, based on the obtained results, sufficiently small saturation fields *(H_s* ~ 5 kA/m) are the main priority of asymmetrical systems. At these fields the GMR effect takes place that is important during the practical application of magnetoresistive elements.

4. Conclusions

We have studied the structure-phase state and the magnetoresistive properties of three-layer film systems, obtained by the alternate condensation method. The carried out investigations showed, that in the unannealed films with silver sublayer (d_{Ag}=5-15 nm) the GMR effect is realized. For the unannealed films with copper sublayer (d_{Cu}=5-15 nm) the longitudinal magnetoresistive effect is not observed. After three- layer film annealing at 700 K the transition from the GMR to the AMR takes place.

References:

1. Pul, Ch.P. and Owens, F.J. (2006). Nanotehnologii. Tekhnosfera, Moskov.
2. Fert, A., Grunberg, P. and Barthelemy, A. (1995). Layered magnetic structures: Interlayer exchange coupling and giant magnetoresistance. *J. Magn. Magn. Mater,* 140-144(1): 1-8.
3. Wang, Y., Levy, P.M. and Fry, J.L. (1991). Magnetic coupling in Fe/Cr superlattices. *J. Magn. Magn. Mater.* 93: 395-397.
4. Vasil'eva, N.P., Granovsky, A.B., Kasatkin, S.I. and Murav'ev, A.M. (1995). Remembering elements on the basis of MR of thin-film multilayered structures. *Zarubezh. Electron. Tehn.,* (1): 32-60.
5. Loboda, V.B., Shkurdoda, Yu.A. and Kravchenko, V.A. (2007). Structure and magnetoresistance of freshly condensed three layer FeNi/Cu(Ag)/FeNi films. *Functional materials.* 14(1): 37-41.

6. Kond, L., Pan, Q. and Cui, B. (1999). Magnetotransport and domain structures in nanoscale NiFe/Cu/Co spin-valve. *J. Appl. Phys.,* 85(8): 5492-5494.

7. Vonsovsky, S.V. (1971). Magnetizm. Nauka, Moskov.

8. Chebotkevich, L.A., Vorob'ev, Yu.D., Burkova, I.N. and Kornilov, A.V. (2000). Structure and magnetic properties of the annealed films of Co/Cu/Co. *Phys. Met. Metallogr.,* 89(3): 56-61.

9. Baibich, M.N., Broto, J.M. and Fert, A. (1988). Giant magnetoresistance of (001)Fe/ (001) Cr magnetic superlattices. *Phys. Rev. Lett.,* 61(21): 2472-2475.

10. Tsymbal, E.Y. and Pettifor, D.G. (2001). Perspectives of giant magnetoresistance. *Solid State Phys.,* 56: 113-237.

11. Fedosyuk, V.M., Rivas, Kh.P. and Kasyutich, O.I. (1997). Investigation of the transition from multilayer to granular films in the cobalt-copper system. *Tech. Phys.,* 42(12): 1451-1453.

12. Inower, I., Ito, Kh., Asano, I., Oguri, A. and Maekava, S. (1995). Theory of electronic structures and magneto transport in multilayers. *Phys. Met. Metallogr.,* 79(1): 35-41.

13. Vas'kovskii, V.O., Yuvchenko, A.A., Lepalovskii, V.N., Shchegoleva, N.N. and Svalov, A.V. (2002). Elements of the granular state in multilayered Co/Cu films. *Phys. Met. Metallogr.,* 93(3): 232-248.

14. Dieny, B. (1994). Giant magnetoresistance in spin-valve multilayers. *J. Magn. Magn. Mater,* 136(3): 335-359.

Лобода В.Б., Кравченко В.О., Хурсенко С.М. Структура і магніторезистивні властивості тришарових плівкових систем CoNi/Ag(Cu)/FeNi

Представлені результати дослідження структурно-фазового стану і магніторезистивних властивостей (анізотропного і гігантського магнітоопору) тришарових нанокристалічних плівкових систем CoNi/Ag(Cu)/FeNi в умовах надвисокого безмасляного вакууму.

Ключові слова: *кристалічна структура, фазовий склад, тришарові нанокристалічні плівки, анізотропний і гігантський магнітоопір*

Лобода В.Б., Кравченко В.А., Хурсенко С.Н. Структура и магниторезистивные свойства трехслойных пленочных систем CoNi/Ag(Cu)/FeNi

Представлены результаты исследования структурно-фазового состояния и магниторезистивных свойств (анизотропного и гигантского магнитосопротивления) трехслойных нанокристаллических пленочных систем CoNi/Ag(Cu)/FeNi в условиях сверхвысокого безмасляного вакуума

Ключевые слова: *кристаллическая структура, фазовый состав, трехслойные нанокристаллические пленки, анизотропное и гигантское магнитосопротивление*

Стаття надійшла в редакцію: 21.08.2016
Рецензент: д.т.н., проф. Антошевський Б.

УДК 546.185:621.28

СИСТЕМНЫЙ АНАЛИЗ ВЛИЯНИЯ ПОЛЕЙ РАЗНОЙ ФИЗИЧЕСКОЙ ПРИРОДЫ НА РАСТИТЕЛЬНЫЕ (БИОЛОГИЧЕСКИ-АКТИВНЫЕ) ОБЪЕКТЫ: РЕЗОНАНСНЫЕ ВЗАИМОДЕЙСТВИЯ И НАНОЭФФЕКТЫ ПРИ КВЧ-ОБРАБОТКЕ ЗЕРНА И СЕМЯН

Д. Г. Войтюк, к.т.н. проф., чл-кор. НААН Украины;
Ю. В. Човнюк, к.т.н., проф. МКА;
Ю. О. Гуменюк, к.т.н., доцент,
И. Н. Сивак, к.т.н., доцент;
А. П. Гуцол, к.т.н., доцент
Национальный университет биоресурсов и природопользования Украины

Цель исследования. Установление основных закономерностей резонансного взаимодействия и наноэффектов при крайне-высокочастотной (КВЧ) обработке зерна и семян (несущая частота f≈60 ГГц).

Методы исследования. Для реализации поставленной цели были использованы методы комплексного математического и компьютерного моделирования с применением методов математического анализа, дифференциальных уравнений в частных производных и основных положений электродинамики.

Результаты исследования. Действие ЭМП на клеточную мембрану вызывает выведение семян из состояния покоя и стимуляцию их посевных показателей, а пробивание мембраны приводит к угнетению и гибели биологической клетки и биоорганизма в целом. Внутренний электрический потенциал клетки растет под действием внешнего ЭМП. Этот эффект стимулирует ин-