Optica Applicata, Vol. XXXIX, No. 4, 2009

An impact of the state and type of surface layer on magnetic properties of Cu/Ni and Ni/Cu multilayers

Barbara GĄGOROWSKA, Marta DUŚ-SITEK*, Marcin NABIAŁEK

Institute of Physics, Częstochowa University of Technology,
Armii Krajowej 19, 42-200 Częstochowa, Poland

*Corresponding author: m.sitek0@op.pl

This paper presents the results of investigation of magnetic properties in Cu/Ni multilayer systems. Based on the investigation of Ni/Cu and Cu/Ni systems with different thickness of magnetic and non-magnetic layers it was proved that the presence of ferromagnetic (F-F) and antiferromagnetic (A-F) exchange couplings depends on the quality of layers in artificial superlattice and on the state and type of free surface, superlattice structure and its roughness.

Keywords: multilayer systems, antiferromagnetic coupling, ferromagnetic coupling.

1. Introduction

Multilayer metallic magnetic systems, due to their wide use in practice, have been of a great interest. One of the greatest discoveries in the domain of metallic magnetic superlattices, *i.e.*, discovery of oscillating magnetic coupling between two layers of metal with good ferromagnetic properties, separated with a layer of non-ferromagnetic metal, turned out to be of particular interest to scholars [1, 2].

Initial investigations carried out for Ni/Cu and Cu/Ni superlattices with different thickness of magnetic and non-magnetic layers indicate that ferromagnetic (F-F) and antiferromagnetic (A-F) exchange couplings depend on the quality of artificial superlattice layer and on the state and type of free surface in superlattice structure, its roughness and the structure [3].

The investigations concerning observations of the domain structure in these systems revealed that the domain structure in magnetic field could be found only for two Ni/Cu bilayers. In the case of reverse order of Cu/Ni deposition there are no magnetic domains present. One of the reasons for this might be the fact that if the free surface in the superlattice investigated is Ni (reverse order of multilayer Cu/Ni system deposition), it is subject to rapid oxidation and creates a thin, almost monomolecular layer of nickel oxide, which is an antiferromagnetic material.

The present investigation was aimed to determine an impact of the state and type of surface layer on magnetic properties in Cu/Ni and Ni/Cu multilayers.

2. Material and methods

The following multilayer systems were investigated:

– A system with variable thickness of ferromagnetic Ni layer; (10 Å ≤ t_{Ni} ≤ 60 Å) with 100 repetitions of Cu/Ni layers. Individual series encompassed Cu/Ni bilayers repeated 100-times, with thickness of [Å]: 20/10, 20/12, 20/16, 20/20, 20/25, 20/30, 20/60;

– A system with variable thickness of non-magnetic Cu layer; (8 Å ≤ t_{Cu} ≤ 20 Å) with 100 repetitions of Ni/Cu layers. Individual series contained Ni/Cu bilayers repeated 100-times, with thickness of [Å]: 20/9, 20/12, 20/18, 20/20;

– A system with constant and equal thickness of Cu and Ni layers; ($t_{Ni} = t_{Cu} = 20$ Å) and variable number of repetitions of Ni/Cu and Cu/Ni bilayers (×10, 20, 50, 100).

The samples were obtained by means of two methods; those with variable Ni thickness were manufactured by means of ion sputtering in face-to-face sputtering configuration in the Institute of Molecular Physics at Polish Academy of Sciences, Poznań, Poland. Other multilayers were deposited by means of potentiostatic electrochemical deposition in the Institute of Material Engineering at Częstochowa University of Technology, Poland.

The investigation of magnetic properties of Cu/Ni multilayers was conducted using a vibrating sample magnetometer at room temperature. The measurements were taken with sample surface positioned parallel to the external magnetic field.

3. Results and discussion

Examples of magnetic hysteresis loops as a function of external magnetic field in samples with the thickness of ferromagnetic layer $N(t)$ from 60 to 10 Å, with unchanged thickness of non-magnetic Cu interlayer (20 Å), are presented in Fig. 1.

The analysis of the results revealed that:

– For the sample with Ni layer thickness of 10 Å a linear dependence of $M(H)$ was obtained, which proves that this system is diamagnetic at room temperature. One should expect that twice lower Ni layer thickness, as compared to Cu layer, produces, through diffusion of both elements, an Ni–Cu alloy, which does not display ferromagnetic properties (or shows poor properties in magnetic field with low intensity). Such a dependence of magnetization as a function of external magnetic field, is typical of diamagnetic materials.

– The shape of magnetic hysteresis loop obtained for $t_{Ni} = 12$ Å corresponds, in terms of its shape, to the loop of A-F I coupling [4]. This loop is saturated at high field values ($H_S = \pm 800$ kA/m), while magnetic remanence equals zero.

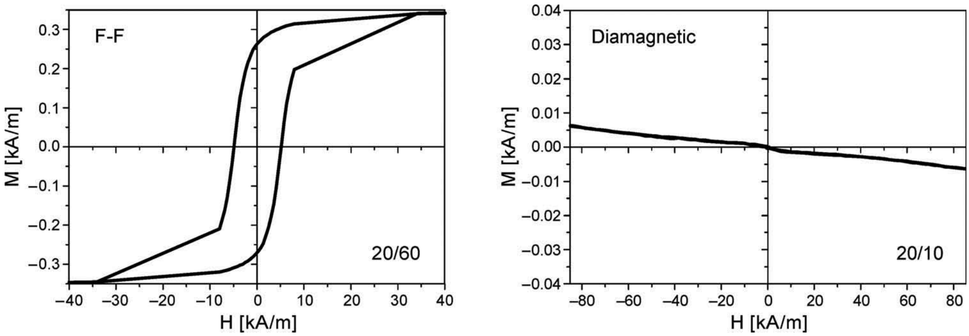

Fig. 1. Magnetic hysteresis curves for multilayer 100×[Cu(20 Å)Ni(t)] systems for selected thickness of ferromagnetic layer, t = 60 Å and t = 10 Å.

– Loops obtained for the samples with thickness of ferromagnetic layer of 14, 15 and 16 Å reveal antiferromagnetic coupling; magnetic remanence equals zero.

– For the Ni layer thickness of 20 Å and 25 Å, magnetic hysteresis loops show mixed coupling (partly A-F and F-F). This type of coupling is characterized by a non-zero value of magnetic remanence, lower than the saturation magnetization value ($M_r < M_s$).

– Hysteresis loops with ferromagnetic F-F coupling were obtained for the thicknesses of Ni layer equal 30, 40, 60 Å. These loops are characterized by a particular value of coercivity while saturation magnetization is approximately equal to magnetic remanence ($M_s \approx M_r$).

The values of coercivity H_c and magnetic remanence M_r for different thicknesses of ferromagnetic layer, obtained from magnetic hysteresis loop as a function of external magnetic field in the investigated multilayer systems, are presented in Fig. 2.

The rise in Ni layer thickness is accompanied with an increase in saturation magnetization of multilayer systems caused by rising thickness of ferromagnetic Ni layer in the sample. The value of M_r equals zero for t_{Ni} = 16 Å–12 Å.

If ferromagnetic layers in a multilayer system are coupled antiferromagnetically (A-F), hysteresis loop is linear within the range of $\pm H_S$, with zero value of magnetic

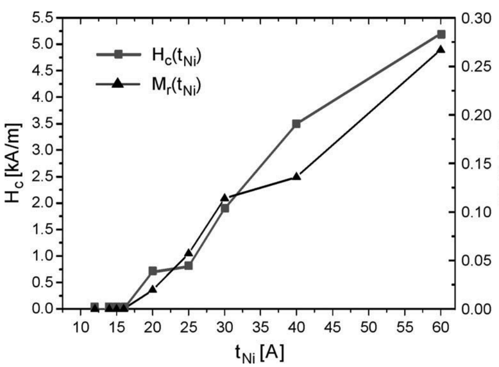

Fig. 2. Coercivity H_c and magnetic remanence M_r as a function of Ni layer thickness for multilayer systems of 100×[Cu/Ni].

remanence. A degree of A-F coupling is determined with the parameter of oscillating exchange coupling between ferromagnetic layers separated with a non-magnetic layer of F_{AF} multilayers

$$F_{AF} = 1 - \frac{M_r}{M_s}$$

where M_r is the magnetic remanence, M_s is the saturation magnetization.

If the value of F_{AF} parameter equals 0, ferromagnetic (F-F) coupling of magnetic layer occurs, while for $F_{AF} = 1$ antiferromagnetic coupling (A-F) occurs.

There are also mixed couplings (partially antiferromagnetic and ferromagnetic). A hysteresis loop for such oscillating exchange couplings is characterized by a non-zero value of magnetic remanence M_r while F_{AF} parameter ranges from 0 to 1.

Thus, the dependence of changes in oscillating exchange coupling parameter between ferromagnetic layers separated with non-magnetic layer of F_{AF} multilayers from the ferromagnetic Ni layer causes that the curve obtained reveals maximum for t_{Ni} = 14 Å and t_{Ni} = 15 Å, which corresponds to the value of F_{AF} = 1. This dependence is presented in Fig. 3.

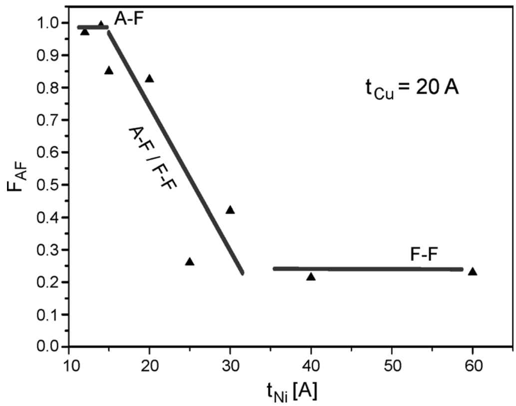

Fig. 3. Oscillating exchange coupling between ferromagnetic layers separated with non--magnetic layer of F_{AF} multilayers as a function of the thickness of ferromagnetic Ni layer.

Types of coupling for particular ferromagnetic layer thickness values are also marked on the curve obtained. The graphical dependencies clearly indicate the fact that the extent of exchange coupling in the systems investigated depends on the thickness of ferromagnetic layer.

Similar considerations were carried out for multilayer Ni/Cu systems obtained by means of potentiostatic electrochemical method. Typical magnetic hysteresis loops in Ni/Cu multilayers are presented in Fig. 4.

The analysis of the results obtained indicates that, independent of the thickness of non-magnetic Cu interlayer in multilayer Ni/Cu systems, the value of coercivity is constant and amounts to *ca*. 1.4 kA/m. Moreover, in the Ni/Cu systems obtained by means of electrochemical deposition, one can conclude, from the dependence of

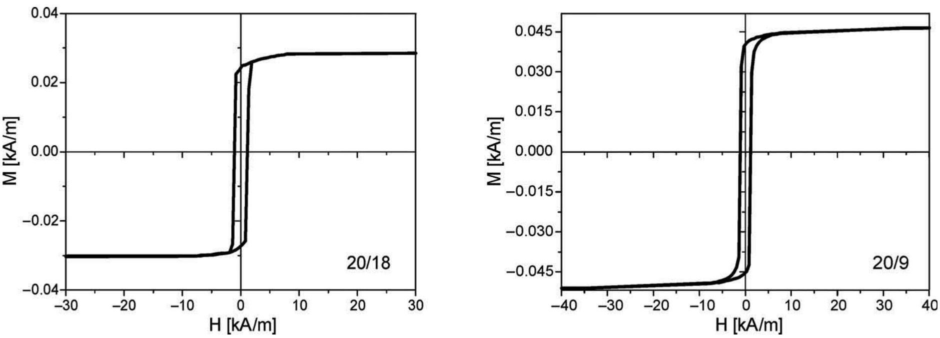

Fig. 4. Magnetic hysteresis loops in Ni/Cu multilayers for selected thicknesses of non-magnetic interlayer, t_{Cu} = 18 Å and t_{Cu} = 9 Å.

antiferromagnetic F_{AF} fraction on the thickness of Cu layer, that rather mixed or ferromagnetic interlayer coupling occurs. Absence of antiferromagnetic coupling in the case of electrochemical multilayers is mainly caused by a considerably higher value of interface roughness RMS as compared to the roughness of multilayer systems obtained by means of ion sputtering.

Observations of domain structure revealed that this structure is susceptible to local stress and interface roughness [5]. The observations of domain structure with and without magnetic field were possible only for bilayers with nickel being deposited on cuprum (Ni/Cu). In the case of reverse order of layer deposition (Cu/Ni) the assumption that the domains cannot be observed since Ni layer is deposited rapidly thus oxidizing and creating NiO (antiferromagnetic) nickel oxide was confirmed.

4. Conclusions

The results obtained in this work proved that occurrence of antiferromagnetic exchange coupling in multilayer Ni/Cu systems depends on the structure of an artificial superlattice and on the state and type of surface layer (manufacturing quality). In order to generate such couplings one should employ vacuum technologies for deposition of thin layers since they permit smoother surface as compared to electrochemical deposition methods.

References

[1] SCHULLER I.K., KIM S., LEIGHTON C., *Magnetic superlattices and multilayers*, Journal of Magnetism and Magnetic Materials **200**(1–3), 1999, pp. 571–582.

[2] KATINE J.A., ALBERT F.J., BUHRMAN R.A., MYERS E.B., RALPH D.C., *Current-driven magnetization reversal and spin-wave excitations in Co/Cu/Co pillars*, Physical Review Letter **84**(14), 2000, pp. 3149–3152.

[3] STOBIECKI T., GŁADYSZEWSKI G., CHOCYK D., CZAPKIEWICZ M., WRONA J., ŻARDECKI D., *Structure and oscillatory coupling in NiFe/Ag multilayers with low coercivity*, Journal of Magnetism and Magnetic Materials **215/216**, 2000, pp. 570–572.

[4] KUBOTA H., SATO M., MIYAZAKI T., *Anomalous temperature dependence of the giant magnetoresistance in Ni/Cu,* $Ni_{95}Co_5$*/Cu and* $Ni_{95}Fe_5$*/Cu multilayers films*, Journal of Magnetism and Magnetic Materials **167**(1–2), 1997, pp. 12–20.
[5] GĄGOROWSKA B., *Właściwości fizyczne wielowarstw Cu/Ni na podłożu krzemowym*, Doctoral Thesis, Częstochowa University of Technology, Poland, 2008 (in Polish).

Received June 23, 2009
in revised form October 19, 2009