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MAGNETIC ANISOTROPY IN Co/Nd MULTILAYERS WITH DEPTH-SELECTIVELY INSERTED ^{57}Fe PROBE LAYER

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Multilayers of Co/Nd with probe layer of 2 Å of ^{57}Fe evaporated in UHV conditions were studied by means of vibrating sample magnetometry and Mössbauer spectroscopy at $T = 4.2$ K. Isomer shift, hyperfine field distribution and direction was obtained from the Mössbauer data computer fitting. Magnetic anisotropy was studied and discussed. The easy magnetization direction was close to the perpendicular direction for both samples but the tendency to perpendicular anisotropy was stronger when the Fe probe layer was placed in the vicinity of Co/Nd interface.

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1. Introduction

Transition metal rare-earth (TM/RE) multilayers were intensively studied during last years for reasons of scientific interest and possible applications for magneto-optical recording. Most of these papers were however devoted to Fe/RE multilayers due to the existence of perpendicular anisotropy in such systems. There are relatively less papers concerning Co/RE multilayers. Givord et al. [1] have studied magnetization reversal in Co–RE sandwiches, other authors reported on magnetic properties of ferrimagnetically ordered Co/Dy [2] and Co/Gd [3] multilayers. Takahashi et al. [4] reported on perpendicular magnetic anisotropy in ferromagnetically coupled Co/Nd multilayers and Co/Nd amorphous binary alloys [5]. In order to compare with Fe/Nd system we have replaced in the studied samples iron for cobalt which has much higher anisotropy energy but at the same time at a different depth in cobalt layers, i.e. in the middle and just below the Co/Nd interface, the probe layer of 2 Å of ^{57}Fe was deposited which enabled us to use the Mössbauer spectroscopy and study the influence of the depth-selectively inserted Fe layers on magnetic anisotropy in the studied system.

2. Experimental details

The studied multilayers were deposited in ultra-high vacuum chamber with base pressure of 10^{-9} Tr, where e-guns were used as evaporation source. The samples of the following configuration and thickness expressed in Å:

glass/(Co15/Fe2/Co15/Nd30) × 50/Co100 (sample J1) and

(Co28/Fe2/Co2/Nd30) × 50/Co100 (sample J2)

were deposited at room temperature. The modulated structure was confirmed by grazing incidence X-ray reflectivity measurements. Magnetization study using a vibrating sample magnetometer (VSM) and transmission Mössbauer spectroscopy were performed on studied multilayers at 4.2 K when RE element is below its critical temperature.

3. Results and discussion

Magnetization as a function of applied magnetic field in both configurations i.e. parallel and perpendicular to the film plane was measured by VSM up to $H = 2$ T. Hysteresis loops at the temperature of 4.2 K for the sample J1 are represented in Fig. 1a and for the sample J2 — in Fig. 1b.

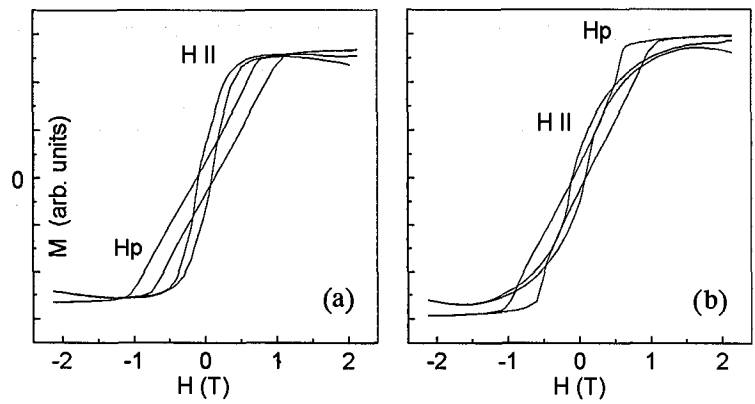

Fig. 1. Hysteresis loops measured at the temperature $T = 4.2$ K with the applied field direction parallel and perpendicular to the film plane for the sample J1 (a) and J2 (b).

For both samples the easy magnetization direction is close to the perpendicular direction but the tendency to perpendicular anisotropy is stronger for the sample J2. We believe that it can be due to the difference in the interface region between the two samples: for J2 film Fe probe layer is situated very close to the Co/Nd interface (2 Å below) and it seems that in this multilayer the interface region is different and thicker than in J1. Such thin layers of Fe and Co can be intermixed and/or not continuous containing some RE atoms. Moreover, this assumption is confirmed by grazing X-ray reflectivity results where the Bragg peak due to the modulated structure is sharper and more pronounced for J1 than for

J2 sample. One can also observe from the presented hysteresis loops and remanent magnetization values that easy magnetization direction lies closer to the film plane for J1 than for J2 film but it is somewhere in-between the two applied magnetic field directions. By placing the probe layer of 2 Å of ^{57}Fe at different depths within the cobalt film we are able to trace the magnetic moment at the precise distance from the interface with RE element. In Fig. 2a and b the Mössbauer spectra taken at 4.2 K temperature are shown for J1 and J2 sample, respectively.

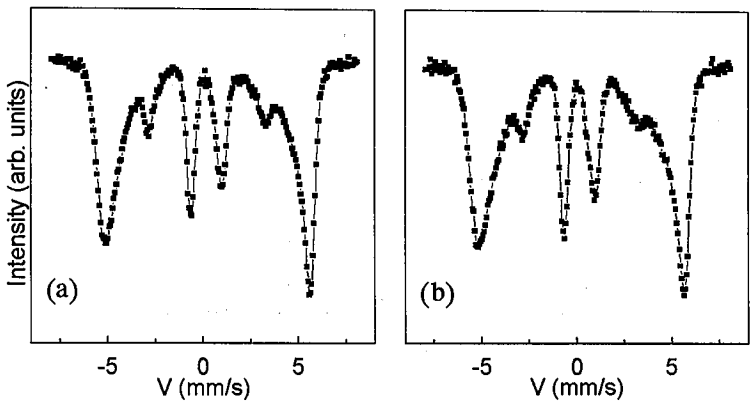

Fig. 2. The Mössbauer spectra of the samples J1 (a) and J2 (b) taken at $T = 4.2$ K.

First of all, it can be seen that the spectra are asymmetric, so not only a distribution of magnetic hyperfine field (HF) should be taken into account but also that of isomer shift (IS) and electric field gradient (EFG). However, this makes the situation very complicated as one has to consider the angle between the direction of EFG and the hyperfine field HF. The work in this direction is in progress but from the first tentative fittings we have seen that including the EFG and IS distribution makes the fitting better but it does not affect much the HF distribution obtained from standard symmetric fit. That is why we believe reasonable to present the results given by the latter method. Each spectrum was fitted with 41 subspectra with HF ranging from 0 to 400 kOe with a step of 10 kOe. Each subspectrum was composed of a sextet line with a line width of 0.3 mm/s. No smoothing for HF distribution was used. The angle between the incident gamma-ray direction and the HF was fixed for each fitting process and the obtained distribution curve was checked after each fitting. The angle was changed by a step of 5 degree. The isomer shift was fitted freely starting from an initial value of 0 mm/s. The EFG was fixed to 0 mm/s. The obtained results at $T = 4.2$ K are as follows: sample J1 — IS = 0.198 mm/s, angle = 30°, HF average = 306 kOe; sample J2 — IS = 0.179 mm/s, angle = 25°, HF average = 300.6 kOe. The difference in HF angle between the two studied samples was clearly visible if one compared the intensity of the second peak.

The Mössbauer spectroscopy has confirmed the VSM results that easy magnetization direction was in-between the film plane and perpendicular axis, specif-

ically at an angle of 60° and 65° from the film plane for the sample J1 and J2, respectively, which we have defined as an easy axis tendency towards perpendicular anisotropy. It is worth noting that in Fe/Nd multilayers with similar bilayer thickness [6] this angle was found to be 81°. The different hyperfine field directions in Co/Nd samples can be caused by a different type of interfaces in the vicinity of Fe probe layer in the two samples. For J1 only Co–Fe interface existed but for J2 film, very probably due to the intermixing, the Co–Nd–Fe region at the interface can be found, especially that from previously published papers [6] it is known that such interface region in Fe/Nd multilayers had about 5 Å in thickness. Therefore, for some iron atoms at the interface in J2 sample their nearest neighbors were not only Co atoms, as in J1, but also Nd atoms with strong crystal field effects, which is of course an additional effect to the usual in light rare-earth/transition metal multilayers ferromagnetic coupling between the two elements. In order to obtain more detailed picture of magnetism in the studied TM/RE type of thin films further work is in progress.

4. Conclusions

The Co/Nd multilayers were studied by means of VSM and Mössbauer spectroscopy at $T = 4.2$ K when RE element is magnetic. Easy magnetization direction in both samples was determined by both methods. The angle of 60° and 65° in respect of the film plane for J1 and J2 sample, respectively, was found. The possible explanation of different magnetic anisotropy behavior in the studied samples was proposed based on the different interface types in both multilayers. Neodymium crystal field modification at the Nd–Co interface is different than that at Co–Fe–Nd interface.

Acknowledgments

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