ELSEVIER

Journal of Magnetism and Magnetic Materials 196–197 (1999) 83–84

Journal of magnetism and magnetic materials

Low temperature enhancement of the magnetic anisotropy in Fe/Si multilayers

R. Zuberek[a,]*, K. Fronc[a], R. Szymczak[a], M. Baran[a], E. Mosiniewicz-Szablewska[a], S.L. Gnatchenko[b], A.B. Chizhik[b], F. Stobiecki[c], H. Szymczak[a]

[a]*Institute of Physics of the Polish Academy of Sciences, Al. Lotnikow 32/46, 02-668 Warszawa, Poland*
[b]*Institute for Low Temperature Physics & Engineering, National Academy of Sciences of Ukraine, 310164 Kharkov, Ukraine*
[c]*Institute of Molecular Physics of the Polish Academy of Sciences, 60-179 Poznan, Poland*

Abstract

The FMR and SQUID investigation of the magnetic anisotropy of Fe/Si multilayers are presented. The multilayers, with various thicknesses of iron and a thick layer of silicon (in order to eliminate the coupling between Fe layers), have been grown by DC sputtering on single crystal GaAs substrates. Low temperature enhancement of the easy-plane anisotropy, especially below 50 K, was observed. This anisotropy seems to be of magnetoelastic origin. The coercivity was shown to decrease with temperature. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Magnetic anisotropy; Fe/Si multilayers

In the past few years, the Fe–Si system in its multiple forms: amorphous, polycrystalline and epitaxial thin films, multilayers, superlattices, etc. (see Refs. [1,2] and references therein), has attracted much attention, leading to a better understanding of interesting phenomena, as for example, the possibility of antiferromagnetic interlayer coupling in Fe/Si.

In this paper, we have studied Fe/Si multilayers with rather thick Si-spacer in order to avoid effects of interlayer coupling and to study the effect of interface. The Fe/Si multilayers have been studied by means of FMR spectrometer and SQUID magnetometer which have allowed to separate bulk and interface effects.

The Fe/Si multilayers were prepared by a sequential DC sputtering with high argon pressure of around 0.1 mbar. The high argon pressure makes the energy of the atoms reaching the substrate sufficiently low and hence favours a homogeneous layer thickness and a sharp interface. As substrates, single crystal plates of GaAs with (0 0 1) orientation were used. The temperature of the substrates was room temperature. For all the samples the Si layer was 10 nm thick, the Fe layer thickness was varied from 1.5 to 17 nm. The number of bilayers is given in Table 1. The thickness of the layers was determined by quartz monitors and later controlled by the X-ray fluorescence method [3].

The magnetization hysteresis loops of these films have been measured at $T = 5$ K and at room temperature using a SQUID magnetometer with the applied field H, parallel to the film plane, varying between -5 and 5 kOe. The temperature dependence of saturation magnetization was measured from $T = 5$ K to room temperature with the applied field $H = 5$ kOe. Fig. 1, shows the temperature dependence of saturation magnetization of Fe/Si multilayers as a function of $T^{3/2}$ for one thickness of iron layer ($t_{\mathrm{Fe}} = 17$ nm) as an example. The deviation from the simple Bloch dependence of $M(T)$ indicates that the sample is not homogeneous. This conclusion is confirmed by the results presented in Fig. 2.

Fig. 2 shows the saturation magnetization of the Fe/Si multilayers as a function of inverse iron layer thickness

---

*Corresponding author. Fax: +48-22-843-09-26; e-mail: zuber@ifpan.edu.pl.

0304-8853/99/$ – see front matter
PII: S0304-8853(98)00670-2

Table 1
The coercivity field for different iron layer thicknesses in Fe/Si multilayers at $T = 5$ K and at room temperature (RT)

Fe layer thickness (nm)	Number of bilayers	H_c at RT (Oe)	H_c at $T = 5$ K (Oe)
17.0	4	140	484
7.5	4	54	268
4.4	6	12	560
1.5	8	20	135

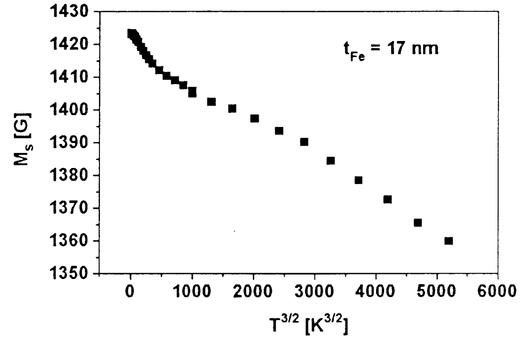

Fig. 1. The temperature dependence of saturation magnetization of Fe/Si multilayer with $t_{Fe} = 17$ nm.

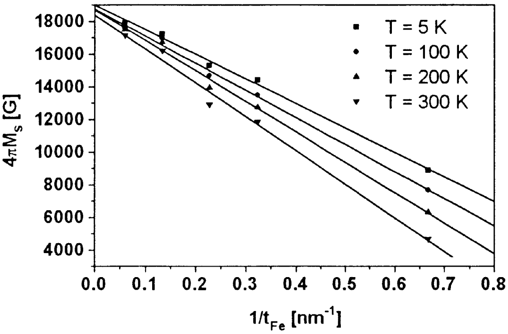

Fig. 2. The saturation magnetization of Fe/Si multilayers as a function of inverse Fe layer thickness for different temperature.

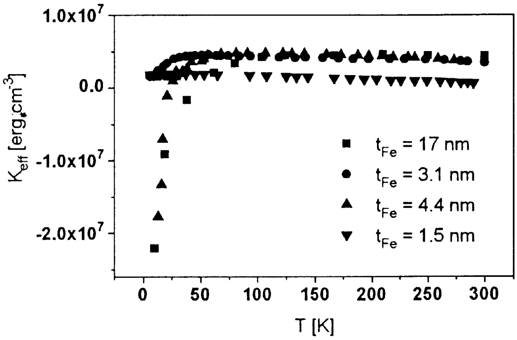

Fig. 3. The temperature dependence of the effective magnetic anisotropy of the Fe/Si multilayers.

for different temperatures. It is seen that an almost linear dependence is fulfilled. It means that because of diffusion of Si atoms into Fe, Fe–Si alloy is formed at the interface. Assuming that this alloy is magnetically 'dead' [4] one can estimate the thickness of this additional phase. The obtained result (1.1 nm) is in agreement with polarized neutron reflectivity data (1.2 nm, Ref. [4]).

In Table 1 the results of measurements of the coercivity field (H_c) for the iron layer thickness varied from 1.5 to 17 nm at $T = 5$ K and at room temperature are presented. H_c is much larger at $T = 5$ K than at room temperature for all the samples.

The FMR measurements have been performed in the parallel configuration in the temperature range from liquid helium to room temperature using a conventional X-band EPR spectrometer. The observed spectra are fairly broad, especially in the low-temperature region. The observed large linewidth seems to be related to the dipole–dipole interactions and to the effects of the interface roughness. The unusual shapes of the broad lines are due to the fact that their linewidths are of the same order of magnitude as the reasonance fields. The results of the effective anisotropy constanat, K_{eff}, of the measured samples are shown in Fig. 3. The effective anisotropy consists of two contributions: bulk anisotropy – due to internal stresses and surface (or interface) anisotropy –due to the reduced symmetry of atoms at the surface (interface). The effect of the surface anisotropy depends on the thickness of the magnetic layers. The strong enhancement of the magnetic anisotropy is observed in the low temperature region. It means that the anisotropy should be related to Fe phase rather than Fe–Si. The fact that the enhancement of the anisotropy is strongly temperature dependent indicates the magnetoelastic origin of this effect and very strong internal stresses.

This work was supported in part by the State Committee for Scientific Research in Poland under Grant No. 2 P03B 031 09.

References

[1] J.J. de Vries, J. Kohlhepp, F.J.A. den Broeder, R. Coehoorn, R. Jungblut, A. Reinders, W.J.M. de Jonge, Phys. Rev. Lett. 78 (1997) 3023.
[2] A. Chaiken, R.P. Michel, M.A. Wall, Phys. Rev. B 53 (1996) 5518.
[3] J. Baszynski, F. Stobiecki, B. Szymanski, K. Chrzumnicka, Phys. Stat. Sol. A 141 (1994) K23.
[4] J.F. Ankner, C.F. Majkrzak, H. Homma, J. Appl. Phys. 73 (1993) 6436.