Available online at www.sciencedirect.com

SCIENCE DIRECT

Journal of Magnetism and Magnetic Materials 286 (2005) 437–441

Journal of magnetism and magnetic materials

www.elsevier.com/locate/jmmm

Modification of microstructure and magnetic properties of Fe/Cr multilayers caused by ion irradiation

M. Kopcewicz[a,*], F. Stobiecki[b], J. Jagielski[a,c], B. Szymanski[b], M. Urbaniak[b], T. Luciński[b]

[a]Institute of Electronic Materials Technology, Warszawa St. 133, Warszawa 01-919, Poland
[b]Institute of Molecular Physics, Polish Academy of Sciences, Poznań, Poland
[c]The Andrzej Sołtan Institute of Nuclear Studies, Świerk/Otwock, Poland

Available online 22 October 2004

Abstract

The influence of Ar-ion irradiation on the microstructure, interlayer coupling and giant magnetoresistance (GMR) effect in the model Fe/Cr system was studied by the conversion electron Mössbauer spectrometry (CEMS), vibrating sample magnetometry (VSM), and magnetoresistivity, for the Fe-1.4 nm/Cr-t_{Cr} multilayers with t_{Cr} ranging from 0.73 to 1.85 nm. The loss of antiferromagnetic coupling and the simultaneous degradation of GMR, observed for increasing ion dose, was caused by the formation of pinholes due to the increase of interface roughness and at high ion doses, by the ion-beam mixing leading to the alloying of Fe and Cr at interfaces.

PACS: 68.35.−p; 75.47.De; 75.70.Cn; 76.80.+y

Keywords: Ion irradiation; Mössbauer spectroscopy; Giant magnetoresistance; Interlayer coupling; Fe/cr multilayers

1. Introduction

In thin film technologies thermal annealing and ion irradiation are the supplementary post deposition treatments enabling a modification of the microstructure and, consequently, the magnetic properties. A lateral resolution can be easily realized with ion irradiation. Therefore, a correlation between changes in the microstructure induced by irradiation, the interlayer coupling and the giant magnetoresistance (GMR) effect of multilayers is of a substantial interest. Recently, it was shown that ion irradiation may lead either to the increase of GMR effect or to the degradation of GMR, depending on an ion dose. Irradiation with 500 keV Xe-ions [1,2] induced initial increase of GMR, however, at higher ion doses the GMR was destroyed. Also the 200 MeV Ag-ion irradiation led to a decrease of GMR effect [3].

*Corresponding author. Fax: +48 22 864 54 96.
E-mail address: kopcew_m@itme.edu.pl (M. Kopcewicz).

0304-8853/$ - see front matter
doi:10.1016/j.jmmm.2004.09.061

Epitaxial Fe/Cr/Fe(0 0 1) trilayers with small thickness of Cr spacer ($t_{Cr} \leqslant 0.7$ nm) irradiated by 5 keV He ions showed a monotonic decrease of the antiferromagnetic coupling strength with increasing ion dose [4]. In the present experiment we have used 200 keV Ar-ion irradiation to modify the interface quality in Fe/Cr multilayers in a controlled way. The influence of the interface microstructure on the magnetic properties (interlayer coupling, GMR, hysteresis loop, etc.) is studied for model Fe/Cr multilayers.

2. Experiment

The Fe-1.4 nm/Cr-t_{Cr} ($0.97 \leqslant t_{Cr} \leqslant 1.85$ nm—the thicknesses correspond to the first antiferromagnetic coupling range for Fe/Cr multilayers [5–8]) polycrystalline multilayers were deposited on oxidized Si wavers using UHV magnetron sputtering (DC and RF for Fe and Cr, respectively). Total thickness of the Fe/Cr film was about 100 nm. Samples were irradiated at room temperature (RT) with 200 keV Ar ions and doses D_{Ar} ranging from 5×10^{12} to 2×10^{14} Ar/cm^2. A penetration range of ions matched well with the total film thickness. The as-deposited and irradiated samples were characterized at RT by the conversion electron Mössbauer spectroscopy (CEMS) and vibrating sample magnetometer (VSM) hysteresis loops. Magnetoresistance and resistivity were measured at RT using the four-probe technique in CIP geometry. The GMR(H) dependencies were determined as GMR(H) = $100 \times [R(H)-R(H=2\,\mathrm{T})]/\mathrm{R}(H=2\,\mathrm{T})$ (where H is the magnetic field); the maximal value of GMR(H) determines the GMR amplitude.

3. Results and discussion

The CEMS spectra for as-deposited and irradiated samples were fitted in terms of the model [9] in which four individual magnetic components are associated with different iron environments: component $H_1 \approx 33$ T, corresponds to the bulk Fe sites; components $H_2 \approx 30$ T and $H_3 \approx 24$ T, are related to the "step" sites at the Fe/Cr interfaces, and $H_4 \approx 20$ T, corresponds either to the "perfect" interface sites or to some other "step" positions. For Fe/Cr multilayers with Fe layer thickness $t_{Fe} = 1.4$ nm characterized by ideally smooth interfaces the expected relative fraction of H_1 and H_4 components should be 71% and 29%, respectively, and the contributions of H_2 and H_3 components should be zero [10]. In fact even for as-deposited samples, the measured fractions of H_1 and H_4 components are significantly smaller than expected and H_2, H_3 fractions show nonzero values. The relative fraction of H_1 component of about 40% indicates that only 0.6 nm of each Fe layer corresponds to bulk Fe sites. The remaining Fe atoms, corresponding to H_2, H_3, and H_4 components, together with Cr atoms form the interface regions.

Typical CEMS spectra recorded for Fe(1.4 nm)/Cr(1.4 nm) multilayers after ion irradiation with ion doses indicated are shown in Fig. 1. The significant changes in CEMS spectra of Fe/Cr multilayers corresponding to microstructure modification caused by Ar-ion irradiation are already detected at ion doses $D_{Ar} \geqslant 5 \times 10^{12}$ Ar/cm^2. Nearly the same increase of the fraction of Fe atoms at interfacial positions (spectral contributions of H_2–H_4) accompanied by the decrease of bulk positions of Fe atoms (H_1 component) is observed for all Fe/Cr multilayers. Summarizing the CEMS measurements we can conclude that the interface roughness is similar for all samples in the as-deposited state and that it increases with increasing D_{Ar} independently of t_{Cr}.

For multilayers with small thicknesses of Cr spacers and with an uncorrelated interface roughness caused by grain boundary diffusion during deposition, there is a certain probability of creating ferromagnetic bridges (pinholes) across Cr layers. Their existence in antiferromagnetically coupled structures leads to a strong ferromagnetic coupling localized in the vicinity of pinholes [11,12]. As a result, the antiferromagnetically coupled fraction F_{AF} ($F_{AF} = 1 - M_R/M_S$, where M_R and M_S are the remanence and saturation magnetization, respectively) is smaller than one and the biquadratic component of interlayer coupling J_2 become significant (the relatively strong J_2 component is also observed for the