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

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Since the discovery of the giant magnetoresistance (GMR) effect in Fe/Cr multilayers many experimental and theoretical studies have been performed. Till now, however, the role of interface roughness in GMR is still not well understood. In the present experiment we have used 200 keV Ar-ion irradiation to affect the interface quality in Fe/Cr multilayers in a controlled way. The influence of ion irradiation on the microstructure, interlayer coupling and magnetoresistance in the model Fe/Cr system was studied by the conversion electron Mössbauer spectrometry (CEMS), vibrating sample magnetometry (VSM), magnetoresistivity and electrical resistivity measurements, supplemented by the small-angle X-ray diffraction (SAXRD), for the Fe-1.4nm/Cr-t_{Cr} multilayers with t_{Cr} ranging from 0.73 to 1.85 nm. Irradiation dose was varied from 0.5×10^{13} to 2×10^{14} Ar/cm^2. The increase of the fraction of Fe atoms at interfacial positions detected by CEMS indicates an increasing interface roughness due to ion irradiation. This modification of microstructure is accompanied by clear changes in magnetization reversal indicating a gradual loss of antiferromagnetic (AF) coupling correlated with the degradation of GMR effect.

Two mechanisms responsible for observed changes in magnetic properties were detected. (i) At lower ion doses ($0.5 - 4\times10^{13}$ Ar/cm^2) the increase of the interface roughness causes the formation of pinholes: ferromagnetic bridges between the Fe layers. This effect depends on the thickness of the Cr interlayer and is considerably stronger for smaller t_{Cr} at a given ion dose. Formation of pinholes is confirmed by the distinct correlation between the decrease of the GMR effect and of the AF coupled fraction in investigated samples. (ii) At higher ion doses (exceeding 4×10^{13} Ar/cm^2) clear changes observed in the shape of the CEMS spectra strongly suggest that efficient ion-beam mixing leads to the formation of the alloyed Fe-Cr layers at interfaces. The volume intermixing seems to be a supplementary mechanism responsible for further decrease of AF interlayer exchange coupling and GMR. For thinnest Cr spacer layers the GMR vanishes completely for Ar-ion dose of about 8×10^{13} Ar/cm^2, while it remains still significant (about 1.5 at.% room temperature) for t_{Cr} larger than 1 nm. Formation of alloyed layers is confirmed by the increase of electrical resistivity. Due to the increasing number of defects in the multilayer structure the mean free path of electrons decreases reducing the GMR effect.

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