CEMS STUDY OF THE SUBSTRATE TEMPERATURE DEPENDENCE OF THE MAGNETIZATION IN NANOSTRUCTURED OXIDIZED IRON FILMS

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The transition metal/transition metal oxide (TM/TMO) nanostructures with a ferromagnetic (FM) metal and one or some of its antiferromagnetic (AFM) oxides can show an anisotropic exchange giving rise to enhanced coercivity and low temperature exchange bias, if the oxide has a sufficiently large anisotropy. Furthermore, exchange anisotropy can provide thermal stabilization of the magnetization and increased superparamagnetic blocking temperatures [1]. The oxidized sputtered Fe thin films present such a magnetic behaviour [2]. These films are produced by sputtering Fe on a Si substrate kept at a constant temperature, T_s, and subsequently they are oxidized in O_2 atmosphere at room temperature and capped with a protective layer of Au or SiO_2. X-ray diffraction and EXAFS experiments have shown that all samples are polycrystalline, but T_s alters the microstructural and magnetic properties: while the in-plane average grain width is almost independent of T_s, the out-of-plane average width decreases from 9 nm for T_s =300 K to 7 nm for T_s =200 K [3,4]. From hysteresis loops and magnetothermal measurements it has been deduced that the T_s =300 K films are formed by strongly interacting grains allowing for a magnetically percolated system behaviour. In contrast, the magnetic data of the films grown at T_s =200 K are consistent with a weakly interacting particle system with random easy magnetic axes [5], in spite of the slight particle non-sphericity and an expected system of particles with easy axes aligned. This different magnetic behaviour has been attributed to differences in the oxidized part, which is larger in the T_s =200 K film than in that of T_s =300 K, and to a broad distribution of the particles size [5]. The oxides are more homogeneously distributed in the T_s =200 K film than in the T_s =300 K one, which has the oxides concentrated in the upper part of the film [5].

Mössbauer spectroscopy can contribute to the study of the magnetic state of these films, in particular to check the behaviour of random distribution of easy magnetization axes. Specifically, Conversion Electron Mössbauer Spectroscopy (CEMS), a spectroscopy method which probes the surface up to about 200 nm, is suitable for this purpose. The measurements were carried out at room temperature (RT). The samples were two oxidized iron films with a nominal Fe thickness of 100 nm, which were prepared at Ts=200 K and Ts=300 K.

The spectra of Fig. 1 show two components: a sextet produced by metal α-Fe and a doublet. For a random distribution of magnetic domains, the relative intensity of the sextet peaks are 3:*x*:1:1:*x*:3, with *x*=2. The intensity of the 2nd and 5th peaks with respect that to the inner (3rd and 4th) peaks, *x*, is related to the relative direction between the magnetization direction and the incident beam (Fig. 2).

$$x = \frac{4\sin^2\theta}{1+\cos^2\theta} \ .$$

x goes from 0 to 4 for magnetization directions from parallel to perpendicular to the beam, respectively. In the present films, the fitted *x* values correspond to θ=69º and 53º for T_s=200 K and 300 K, respectively. The film shape anisotropy, which should produce a magnetization parallel to the film plane, competes with the particles shape anisotropy. This would promote a magnetization perpendicular to the film's plane, because of the columnar growth of the Fe particles. Then, the decrease in the out-of-plane width of the T_s=200 K particles is consistent with a decrease in the particle shape anisotropy and a shift of the magnetization directions towards the film plane (increasing θ). The hyperfine parameters of the doublet do not correspond to any paramagnetic Fe oxide or hydroxide. It can be assigned to superparamagnetic oxide layers around the α-Fe cores. The role of the oxides on the anisotropy is to be studied at low temperature.

References:

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Figures:

Figure 1: RT CEMS spectra of oxidized Fe films, with substrate temperatures Ts=200 K and 300 K.

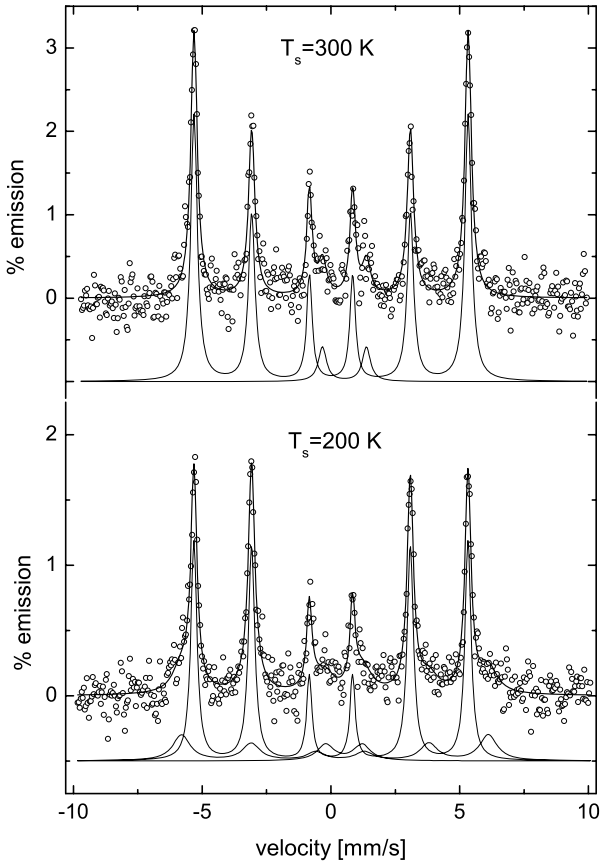

Figure 2: Relative angle between the magnetization and the incident beam direction, derived from CEMS spectra intensities.