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MAGNETIC PROPERTIES OF NANOCRYSTALS OF Fe

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Abstract. – Magnetic granular solids consist of ultrafine metal granules of nanometer sizes embedded in an insulating medium. The magnetic properties are dictated by the nanostructure, which is process controlled. We report on results for granular $Fe-SiO_2$ films where the metal volume fraction and particle size have been systematically varied. Magnetic coercivities as high as 2 500 Oe at low temperatures and 1 100 Oe at room tempeature have been achieved.

1. Introduction

A magnetic granular solid is a unique artificial structure consisting of ultrafine single-domain ferromagnetic particles of nanometer sizes embedded in an insulating matrix [1]. With dimensions in the nanometer range, the small particles exhibit unusual properties inherent to their nanostructures. In this work, we will briefly describe some of the enhanced magnetic properties of Fe nanocrystals in a matrix of amorphous SiO_2.

2. Experimental results and discussion

The granular $Fe-(SiO_2)$ samples were fabricated using a high-rate rf magnetron sputtering system [2]. The sputtering targets were homogeneous mixture of pure Fe and SiO_2. The samples, a few μm in thickness, were deposited onto substrates kept at temperatures ranging from 77 K to 900 K. The composition of the samples were checked by atomic absorption and x-ray fluorescence. X-ray and Mössbauer spectroscopy show that the Fe nanocrystals are mainly bcc α-Fe. The granular structure was determined by transmission electron microscopy (TEM). Examples of TEM micrographs of $Fe_{60}(SiO_2)_{40}$ (metal volume fraction $p = 0.29$) are shown in figure 1. In each case, the distribution of particle sizes is rather narrow. Substrate temperature has a large effect on the particle size. The particle size for samples with $p = 0.29$ increases from 30 Å to 50 Å when the substrate temperature is raised from 300 K to 875 K. For the $Fe_{75}(SiO_2)_{25}$ samples ($p = 0.42$), the increase is much more pronounced; from 40 Å to 160 Å when the substrate temperature is increased from 400 K to 875 K [3]. Since the critical size for single-domain Fe particles is about 200 Å, all particles are expected to be single-domain [4].

Figure 2 shows the coercivity (H_c) at 2 K of granular $Fe-SiO_2$ films deposited on room-temperature substrates. Above the percolation threshold ($p_c \approx 0.6$), where the granules are in contact, the resultant H_c is only about 50 Oe, similar to that of bulk Fe. Be-

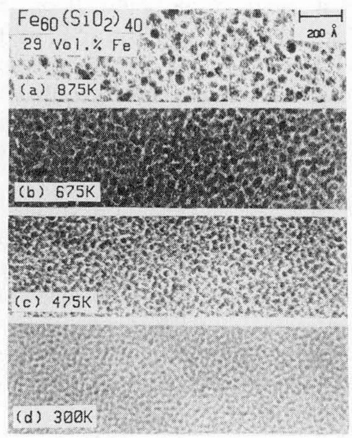

Fig. 1. – TEM micrograph of granular $Fe_{60}(SiO_2)_{40}$ (29 vol. % Fe) films prepared at various substrate temperatures: (a) 875 K, (b) 675 K, (c) 475 K, (d) 300 K.

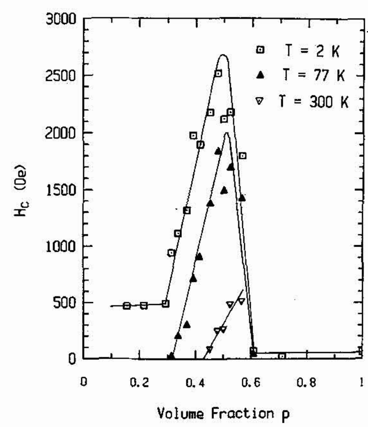

Fig. 2. – Magnetic coercivities at = 2 K, 77 K, and 300 K of granular $Fe-SiO_2$ films deposited onto room-temperature substrates as a function of Fe volume fraction.

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low p_c, the magnetic properties are dominated by isolated single-domain particles. Very large increases in H_c, by nearly two orders of magnitude, have been achieved [5]. For particles of only a few nanometers in size, superparamagnetic relaxation plays an important role. Ferromagnetic properties are observed at temperatures less than the blocking temperature (T_B). Spontaneous magnetization, remanence and coercivity decrease with temperature due to superparamagnetic relaxation and vanish at T_B, which is proportional to CV, where C is the total magnetic anisotropy energy per volume and V is the particle volume [4]. The values of T_B range from tens of K for small particles to hundreds of K for large particles. It has been found that the values of C $\left(\approx 10^7\ \mathrm{ergs/cm^3}\right)$, as determined from the values of T_B, are about two orders of magnitude larger than the magnetocrystalline anisotropy $\left(\approx 10^5\ \mathrm{ergs/cm^3}\right)$ for bulk Fe, indicating that the magnetocrystalline anisotropy is not the main contribution in ultrafine single-domain particles [2].

To further improve the enhanced magnetic properties, it is desirable to fabricate ultrafine particles of larger sizes. We have found that substrate temperature has a significant effect as mentioned above. The intrinsic values of H_c at low temperatures increases substantially for the larger particles obtained using higher substrate temperatures (Fig. 3). Equally important, the resulting T_B is much higher due to the larger particle sizes, so that high values of H_c, in excess of 1 000 Oe, have been realized at room temperature (Fig. 4). Together with a large magnetization of about 150 emu/g, granular Fe films offer attractive characteristics for magnetic recording applications.

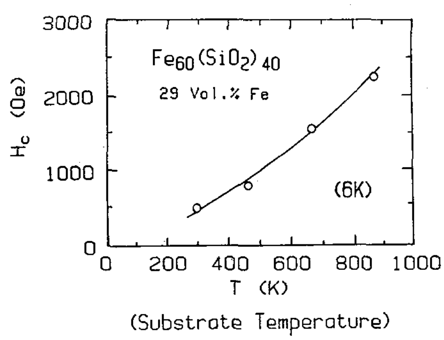

Fig. 3. – Variation of coercivity of $Fe_{60}(SiO_2)_{40}$ 29 vol. % Fe with substrate temperatures.

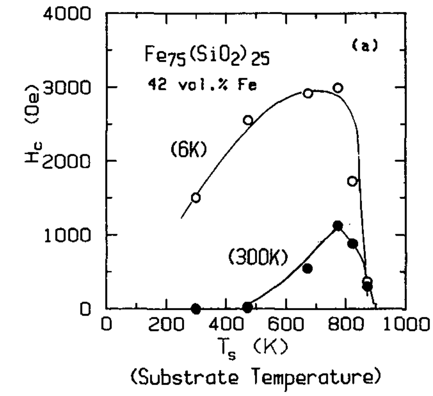

Fig. 4. – Variation of coercivity of $Fe_{75}(SiO_2)_{25}$ $p = 0.42$, at 6 and 300 K as a function of substrate temperatures.

Acknowledgements

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