

Coercive and anisotropy fields in patterned amorphous FeSi submicrometric structures

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Amorphous $\text{Fe}_x\text{Si}_{1-x}$ films have been prepared on Si substrates in order to fabricate submicrometric magnetic structures with soft magnetic behavior. The magnetic properties compositional dependence of the unpatterned samples has been analyzed to select the Fe content ($x=0.7$) with the lowest coercive and anisotropy fields values. Arrays of $\text{Fe}_{0.7}\text{Si}_{0.3}$ lines have been fabricated by electron beam lithography combined with a liftoff technique, with typical dimensions of 200 nm linewidth and 1 μm line spacing. These arrays present coercive fields parallel to the line direction as small as 9 Oe. © 2000 American Institute of Physics. [S0021-8979(00)38808-9]

I. INTRODUCTION

Ordered magnetic structures of submicrometric size are attracting a lot of interest in the field of Material Science. They allow us to study the physical properties of the material in a controlled geometry and reduced dimensions, and they also provide a good tool to control the material behavior in the small scale needed for future applications in magnetic recording technology. Recently, different lithographic techniques have been developed in order to pattern magnetic materials in this small scale, such as x-ray lithography,¹ laser interference lithography,² scanning tunneling microscopy assisted techniques,³ and electron beam lithography.⁴

In this way, different kinds of magnetic arrays of lines and particles have been fabricated in the last few years to analyze the influence of the reduced dimensions in fundamental magnetic properties as, for example, magnetization reversal processes^{5,6} or domain wall magnetoresistance.⁷ Most of these studies have been performed in samples made of pure transition metals or NiFe alloys either in the form of epitaxial^{1,8} polycrystalline⁵⁻⁷ patterned films. These structures have shown novel properties and are a new tool to test micromagnetic predictions; however, in general, a hardening of the magnetic material is observed as the lateral dimensions decrease below 1 μm , so that the coercive and saturation fields of the structures increase by at least one order of magnitude respect to the unpatterned material, presenting typical values easily above a hundred Oersted.^{8,9} This result could be an undesirable effect to fabricate certain devices for applications. The material crystalline microstructure with its particular defects is an important factor that could play a role in this behavior; for example, when the pattern dimensions are reduced to the 100 nm range, the grain size can become relevant influencing the magnetization reversal processes. For these reasons, it is interesting to prepare submicrometric structures of amorphous magnetic materials. Their high density of defects and disorder results in an effective averaging

in a scale much smaller than the minimum accessible pattern size.

In this work, we have fabricated submicrometric structures of amorphous $\text{Fe}_x\text{Si}_{1-x}$ in order to obtain magnetic arrays with low coercivity. The compositional dependence of the coercive field in the unpatterned samples has been analyzed in our system to carefully select the lowest values, so that the magnetic behavior of the submicrometric patterns is optimized to be as soft as possible.

II. RESULTS AND DISCUSSION

$\text{Fe}_x\text{Si}_{1-x}$ thin films have been obtained by dc magnetron sputtering on Si(100) substrates. The samples are grown at room temperature with a sputtering Ar pressure of 10^{-3} mbar (the system base pressure is 10^{-8} mbar) up to a film thickness of 40 nm. The alloy is prepared from high purity Fe and Si targets, and the composition is varied by controlling the relative power of the sputtering guns. The final composition has been calibrated using x-ray microanalysis. Also, the sample microstructure has been analyzed by x-ray diffraction to check the absence of crystalline phases in the films; only for Fe contents above $x=0.8$ diffraction peaks corresponding to polycrystalline Fe have been detected in the samples, in good agreement with previous results.¹⁰

The magnetic behavior has been characterized by magneto-optical transverse Kerr effect (TKE) measurements in a experimental setup reported elsewhere.¹¹ The hysteresis loops reveal the presence of an uniaxial magnetic anisotropy. The compositional dependence of the coercive field (H_C) measured along the easy axis is shown in Fig. 1. With increasing Fe content, H_C decreases by an order of magnitude down to a minimum value $H_C=1.2\text{Oe}$ in the range $x=0.7-0.75$. For $x=0.8$ the coercive field increases again due to the presence of polycrystalline phases. Figure 1(b) shows the anisotropy fields H_K of the samples as a function of Fe content, measured by transverse susceptibility. It is

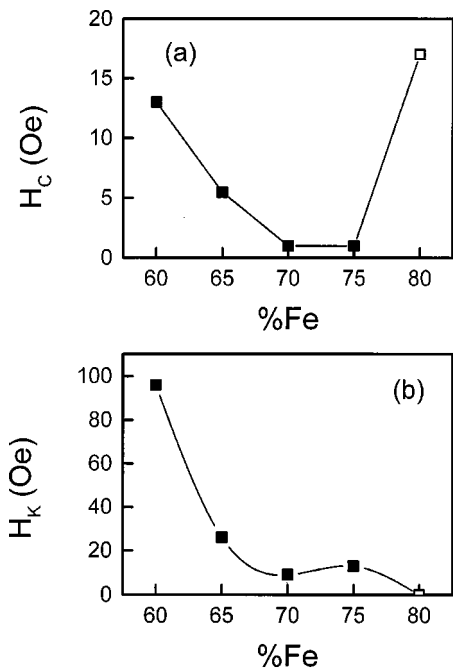


FIG. 1. (a) Compositional dependence of the coercive field along the easy axis of 40 nm thick Fe_xSi_{1-x} films. (b) Compositional dependence of the anisotropy field measured by transverse susceptibility of 40 nm thick Fe_xSi_{1-x} films. Filled symbols indicate amorphous samples and hollow symbols correspond to a film with polycrystalline phases.

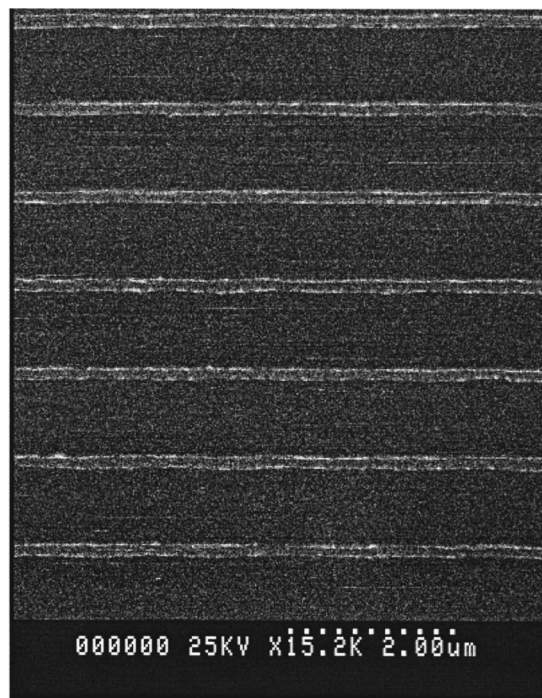


FIG. 2. SEM image of an array of Fe_{0.7}Si_{0.3} lines prepared by electron beam lithography. The lines are 180 nm wide, 250 μm long, and spaced by 1 μm.

found that, in the amorphous samples, the uniaxial anisotropy is the weakest for $x=0.7$ ($H_K=9$ Oe). Therefore, in order to prepare the submicrometric structures a composition Fe_{0.7}Si_{0.3} has been selected.

Electron beam lithography combined with a liftoff technique has been used to prepare the patterned magnetic arrays.^{12,13} Briefly, the Si substrates are first covered with a 300 nm thick electron sensitive PMMA resist layer; then, the pattern is defined with the electron beam of a Hitachi S-800 scanning electron microscope (SEM), so that, holes are made in the exposed regions of the PMMA resist after the sample is developed. Finally, a 40 nm thick Fe_{0.7}Si_{0.3} film is grown on top of this resist template and the submicrometric structure is obtained by a liftoff process in acetone. In this way, arrays of lines have been obtained over areas of 250 μm × 250 μm with typical spacings of 1 μm and line-widths below 500 nm. Figure 2 shows a SEM image of one of these arrays of Fe_{0.7}Si_{0.3} lines. In this case, the well straight and parallel lines are 180 nm wide and are separated by 1 μm.

The TKE hysteresis loop of an array of Fe_{0.7}Si_{0.3} lines with H field parallel to the lines is shown in Fig. 3, where it is compared with the loop of a reference unpatterned film of the same composition. Previous results in similar structures of pure transition metals or NiFe alloys show hysteresis loops with typical coercive and saturation fields above 100 Oe; for example, Shearwood *et al.*⁸ find $H_C \approx 500$ Oe in 1 μm spaced lines made of epitaxial Fe(001), and Adeyeye *et al.*⁹ obtain values of $H_C \approx 200$ Oe in 2 μm separated polycrystalline Ni_{0.8}Fe_{0.2} lines. In our case, the magnetic behavior in the array of Fe_{0.7}Si_{0.3} lines is also harder than in the un-

patterned reference sample, with an increase of H_C of almost one order of magnitude. But the observed coercive field $H_C=9$ Oe is still much smaller than the previously reported values in the literature with other materials. The saturation field (H_S) of 40 Oe is also relatively small; however, as the magnetic field is tilted away from the direction parallel to the lines, the saturation field increases sharply. This must be related to the high value of the demagnetizing field (H_D) in

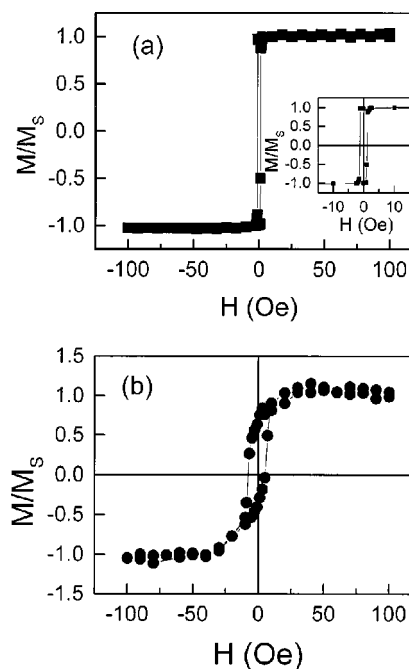


FIG. 3. TKE hysteresis loops of (a) unpatterned Fe_{0.7}Si_{0.3} reference film, (b) array of Fe_{0.7}Si_{0.3} lines 180 nm wide, 250 μm long, and spaced by 1 μm.

the direction perpendicular to the lines, which can be estimated¹⁴ as $H_D = M_S * t \alpha(s/w) / w = 2510 \text{ Oe}$, where M_S is the saturation magnetization, t is the film thickness, w is the linewidth, s is the interline distance and the function $\alpha(s/w) \approx 1$ in our line geometry. It is interesting to note that as the width of the lines is smaller than the line spacing, this kind of structure can be considered as an array of noninteracting wires.¹⁴ Actually, preliminary results in our samples indicate that there is not any significant change in the coercive field as the interline distance is reduced from $1 \mu\text{m}$ to $0.6 \mu\text{m}$.

III. CONCLUSIONS

In summary, submicrometric structures of amorphous FeSi have been prepared by electron beam lithography combined with a liftoff technique. After carefully optimizing the composition to obtain the softest magnetic behavior, coercive field values as low as 9 Oe can be observed in arrays of noninteracting $\text{Fe}_{0.7}\text{Si}_{0.3}$ lines with 180 nm width. These values are one order of magnitude smaller than previously reported coercive fields for similar structures made of polycrystalline and epitaxial magnetic materials.

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