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Domain Studies of Electroplated High Moment CoFe and $Ni_{45}Fe_{55}$ on Test Structures

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DOMAIN STUDIES OF ELECTROPLATED HIGH MOMENT CoFe AND $Ni_{45}Fe_{55}$ ON TEST STRUCTURES

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ABSTRACT

Magnetic properties of high moment magnetic materials for write head applications were measured for various geometries and anneal conditions. CoFe and $Ni_{45}Fe_{55}$ were electroplated on different test structures with 3–D topography as well as flat surfaces. Stripes of magnetic material with different width ranging from 5 μm to 50 μm are formed using a photo lithographic process. The resist thickness is 3 μm and the seed layer was 800 Å $Ni_{45}Fe_{55}$ sputtered onto 47mmx47mm glass substrates. The thickness of the electroplated CoFe is between 0.8 μm and 1.8 μm and the electroplated $Ni_{45}Fe_{55}$ is approximately 1.2 μm. Both B-H loops and domain imaging confirm that the easy axis of the films switches to a direction parallel to the stripes after plating although a magnetic field of 700-1200 Gauss was applied perpendicular to the stripe direction during plating. Another test structure design consists of two layers of photo resist stripes with 20 μm width. These two layers of photo resist stripes are oriented perpendicular to each other. A $Ni_{45}Fe_{55}$ seed layer was sputtered between these layers to provide a conductive surface for electroplating. Domain studies reveal that the preferred transverse domain orientation can be achieved by optimizing the hard–bake conditions for the first layer of photo resist, and for different high moment materials, these conditions need to be optimized individually. This study has potential applications for the domain control in the yoke of write heads for high density and high data rate magnetic recording.

1. Introduction

Ultra high density magnetic data storage [1,2,3] requires high coercivity magnetic storage media with static coercivities of 4000 Oe and higher were the effective dynamic coercivity [4] in the regime of very high data rates beyond 1 Gbit/sec is even significantly higher. In order to reliably write data on these media high moment soft magnetic materials with a saturation magnetization greater then 2 Tesla are required for the write head to provide an adequate write field. Various alloys, deposited by electroplating as well as by sputter deposition have been proposed among which are Fe-N, iron rich NiFe alloys, and binary and ternary CoFe alloys like CoFe, CoFeCu and CoNiFe [5,6,7,8,9,10,11]. For high data rate write head designs, besides write field amplitude considerations, the control of the magnetic domain structure in the yoke is critical. An orientation of the net magnetization perpendicular to the flux propagation path is desirable to achieve fast flux reversal and good high frequency efficiency [12,13,14].

Because in general these high moment materials exhibit high magnetostriction constants, mechanical stresses need to be considered in order to optimize the micromagnetic structure of the write head [15,16,17,18,19,20]. We have used a variety of simple test structures which allow to optimize the domain configuration by mechanical stress control for a given magnetic thin film geometry that resembles the write head yoke. This approach proves itself useful by avoiding a full head built in the course of evaluating and optimizing new write head designs and materials.

2. Film Preparation

In this experiment we have investigated two Fe–alloys that provide a high saturation moment M_s. Magnetic films of composition $Ni_{45}Fe_{55}$ and $Co_{36.2}Fe_{63.8}$ were deposited using electroplating. Films were grown in the presence of a field of 1200 G on a 1 mm thick glass substrate covered by a Ta layer and a $Ni_{45}Fe_{55}$ seed layer of 100 Å and 800 Å thickness respectively and the films were finally protected by a 100 nm thick Al_2O_3 overcoat. A final anneal was performed for two hours at a temperature of 240^0C and in the presence of a field of 12 kG.

Magnetic thicknesses for both alloys ranged from 0.9 μm to 1.8 μm. The following magnetic properties were measured for the continuous films: $H_c = 2.7Oe$, $M_s = 1.8T$ for the $Ni_{45}Fe_{55}$ films and $H_c = 11Oe$, $H_k = 16.5Oe$, and $M_s = 2.4T$ for $Co_{36.2}Fe_{63.8}$ unstructured films. The magnetostriction constant is $\lambda = 6 \cdot 10^{-6}$ for $Co_{36.2}Fe_{63.8}$ and $\lambda = 2.4 \cdot 10^{-6}$ for $Ni_{45}Fe_{55}$.

1. Test Structures

Stripes of magnetic material were created by plating into a resist matrix with various spacings resulting in 5 μm, 10 μm, 20 μm, and 50 μm wide stripes with equal stripe separation (Figure 1). A subsequent anneal was performed by applying a field perpendicular to the long axis of the stripes which is the preferred easy axis direction. The 3 μm thick resist and the $Ni_{45}Fe_{55}$ seed layer were removed after plating. A second test structure consists of stripes of magnetic material on a topography created by orienting the magnetic stripes orthogonal to the resist stripe orientation and plating on a second layer of resist of the same thickness (Figure 2). Figure 3 shows a micrograph of the actual test structure with the $Co_{36.2}Fe_{63.8}$ stripes oriented horizontally and the resist bars oriented vertically.

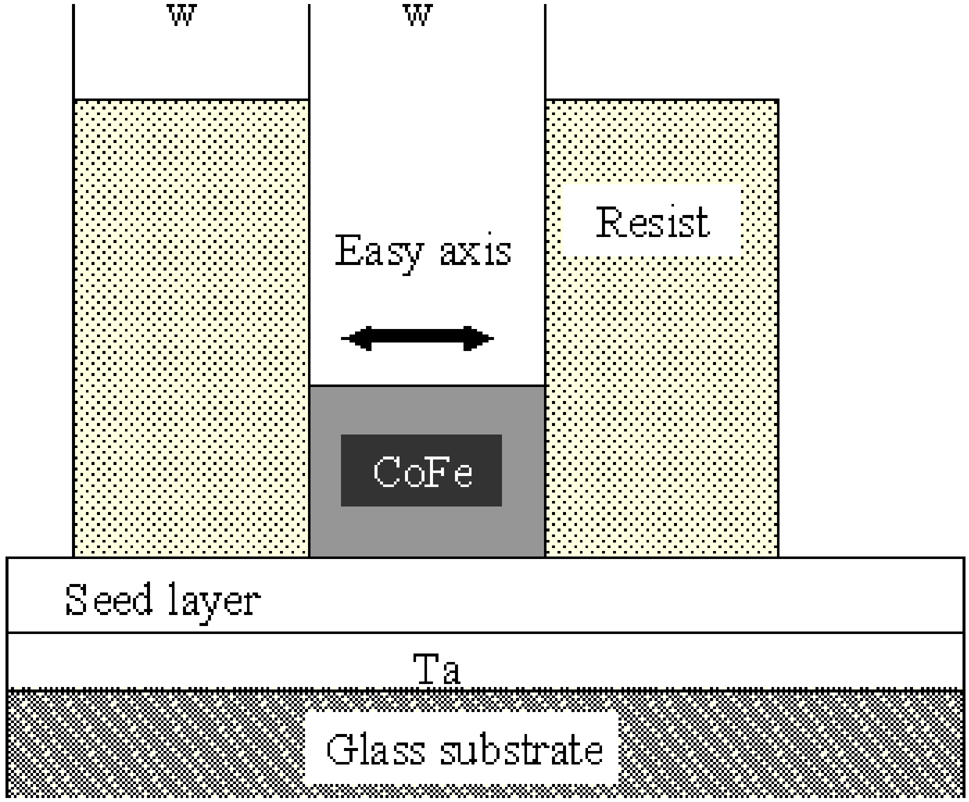

Figure 1.) Test structure consisting of electroplated stripes with stripe-width and spacing w = 5 µm, 10 µm, 20 µm and 50 µm. Resist is lift-off after plating and the seed-layer is removed by ion milling

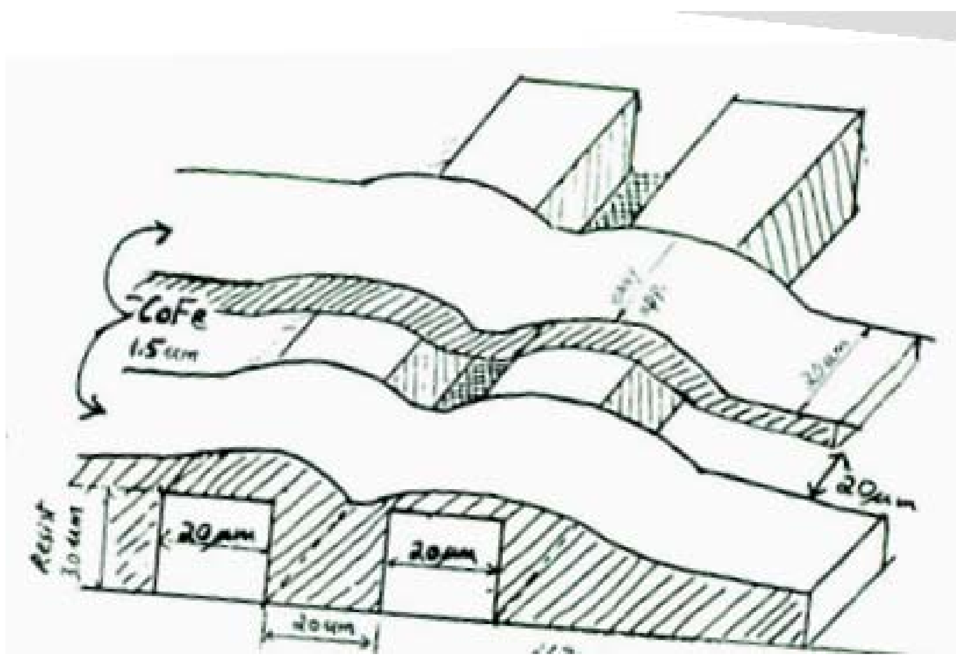

Figure 2.) Schematics of stripes plated on resist topology. Resist thickness: 3 µm, stripe-width: 20 µm

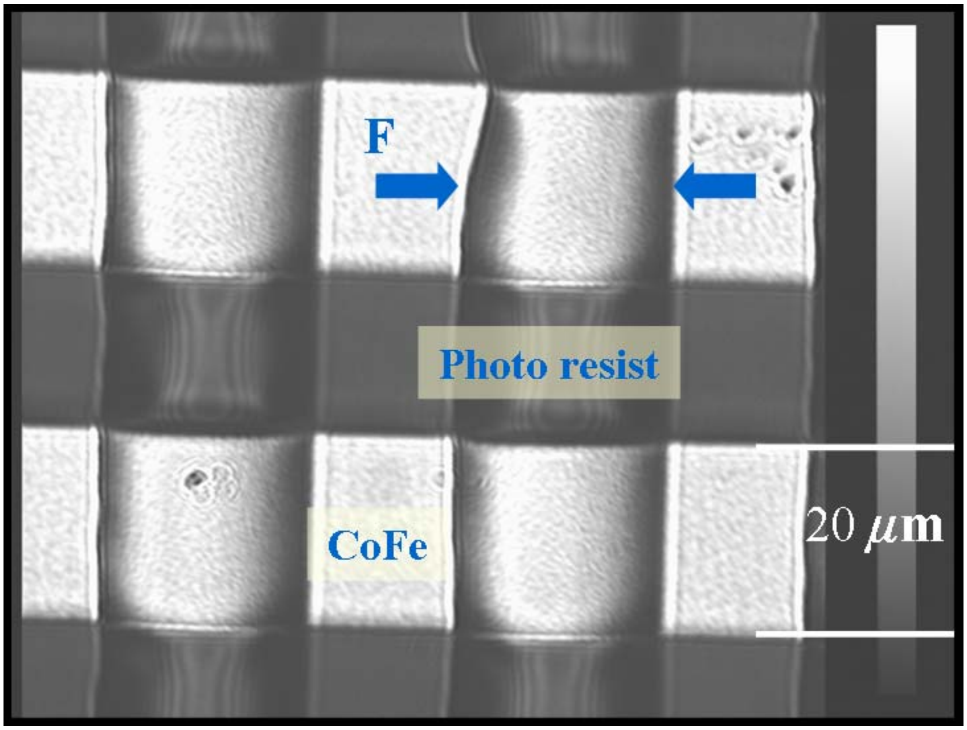

Figure 3.) Plated CoFe stripes on resist topology after final anneal. Resist hard-bake 1 hr @ 180^o C. *F* indicates the force acting on the magnetic material due to resist shrinkage.

2. Characterization

1. Kerr imaging

Kerr images of 20 μm thick $Co_{36.2}Fe_{63.8}$ stripes deposited on a flat surface (Figure 4) reveal an orientation of the remanent magnetization along the long axis of the stripes, i.e. perpendicular to the anneal direction. This orientation was found for all stripe geometries. On the other hand the magnetization is aligned in the preferred direction parallel to the anneal field in the un-patterned area of the test structure (Figure 5) indicating that the remanent state in the stripes is dominated by the demagnetizing field.
Furthermore, domain structures in the $Co_{36.2}Fe_{63.8}$ stripes deposited on a resist topology strongly depend on both hard-bake time of the photo resist and on the final anneal conditions. For 6 hr and 2 hr hard-bake duration the magnetization is still aligned parallel to the long axis of the stripes (Figure 6 and Figure 7) whereas vertical domains are formed for a 1 hr hard-bake time after subsequent anneal (Figure 8). The Kerr images were generated by subtracting images of a saturated and a remanent state.

The cause of the easy axis rotation is stress induced anisotropy due to a shrinkage of the photoresist during the anneal process. Shrinkage is more pronounced for shorter hard-bake times, which leaves the resist in an uncured state. After anneal the shrinking resist gives rise to a compressive force in the direction of the long axis of the stripe (Figure 3) consequently resulting in an induced anisotropy perpendicular to the stripe for a magnetic material with positive magnetostriction constant. In the area of magnetic material residing over topology domain walls are narrowly spaced and small closure domains are formed indicating a high induced anisotropy (Figure 9). In comparison, the areas deposited in the trenches of the test structure show large edge-closure domains and a single domain wall indicating significantly lower local anisotropy. Similar results are found for $Ni_{45}Fe_{55}$ stripes subjected to the same process (Figure 10).

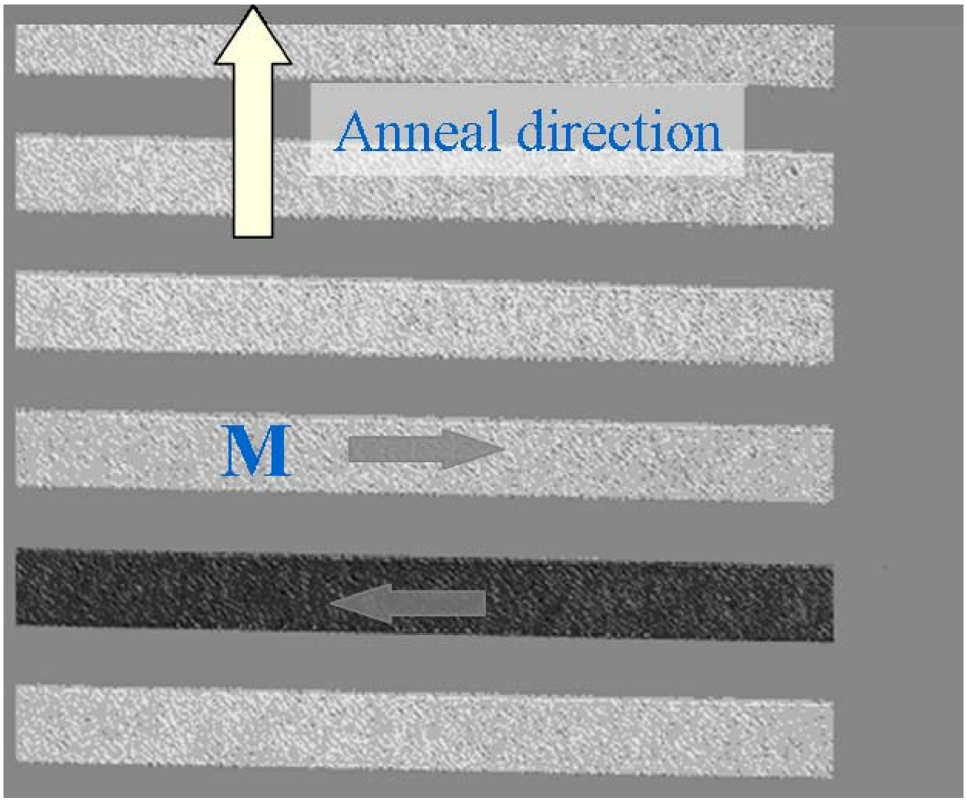

Figure 4.) Longitudinal Kerr image of the remanent state of 20 µm wide CoFe stripes. Anneal direction is vertical and the Kerr sensitivity is horizontal

Optimization of the domain configuration for a real write head also requires considering additional mechanical stress contributions from an Al_2O_3 over-coat. Figure 11 and figure 12 depict the remanent domain structure of $Co_{36.2}Fe_{63.8}$ stripes covered by a final layer of Al_2O_3. The additional stress introduced by the over-coat further increases the local anisotropy in the flat region as well as on the topography indicated by the narrow wall spacing and reduced edge closure domain size.

The results show that a narrow, but for practical applications sufficient window of hard-bake/anneal conditions exists to achieve the preferred domain configuration.

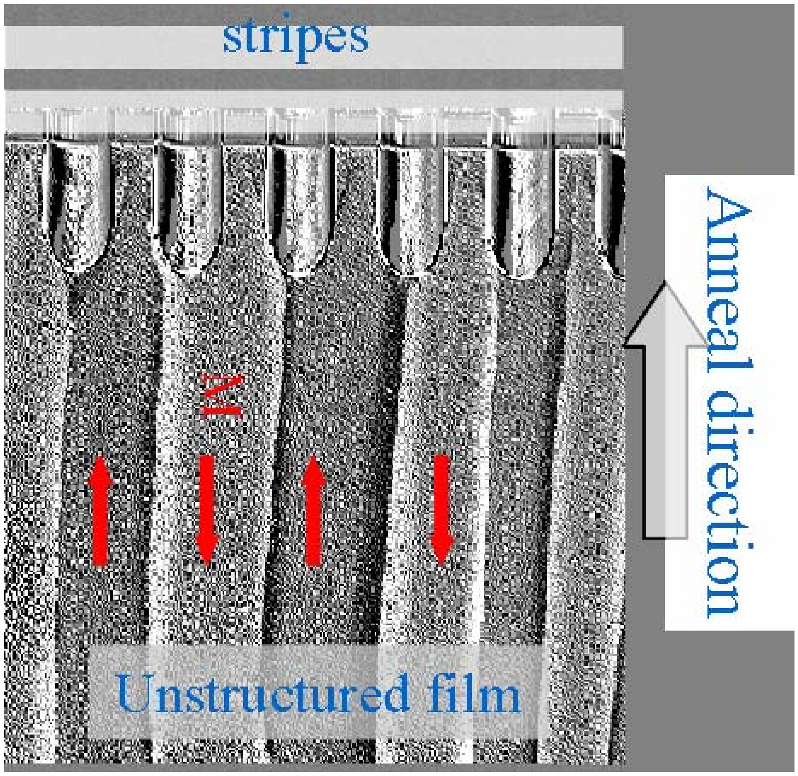

Figure 5.) Longitudinal Kerr image of the remanent state of a CoFe film on flat surface (lower half of the picture). Anneal direction is vertical and the Kerr sensitivity is horizontal (note the stripe pattern is oriented horizontally).

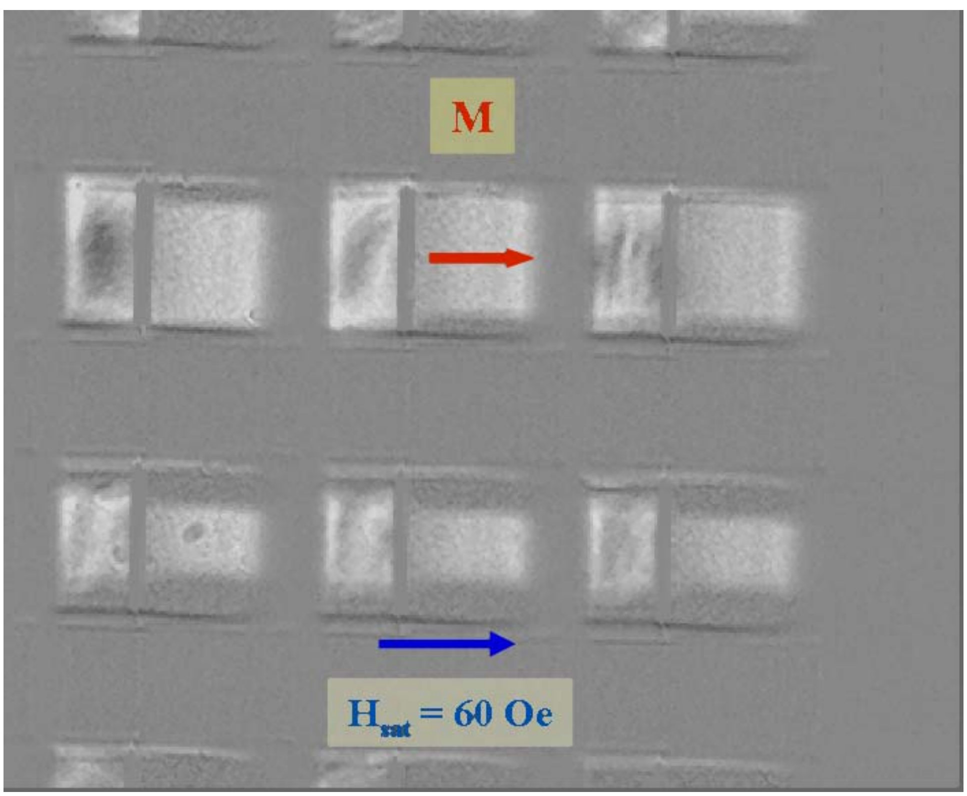

Figure 6.) Longitudinal Kerr image of the remanent state of 20 μm wide CoFe stripes after application of a horizontal field of 60 Oe. Hard-bake time: 6 hrs., no anneal. The Kerr sensitivity is horizontal.

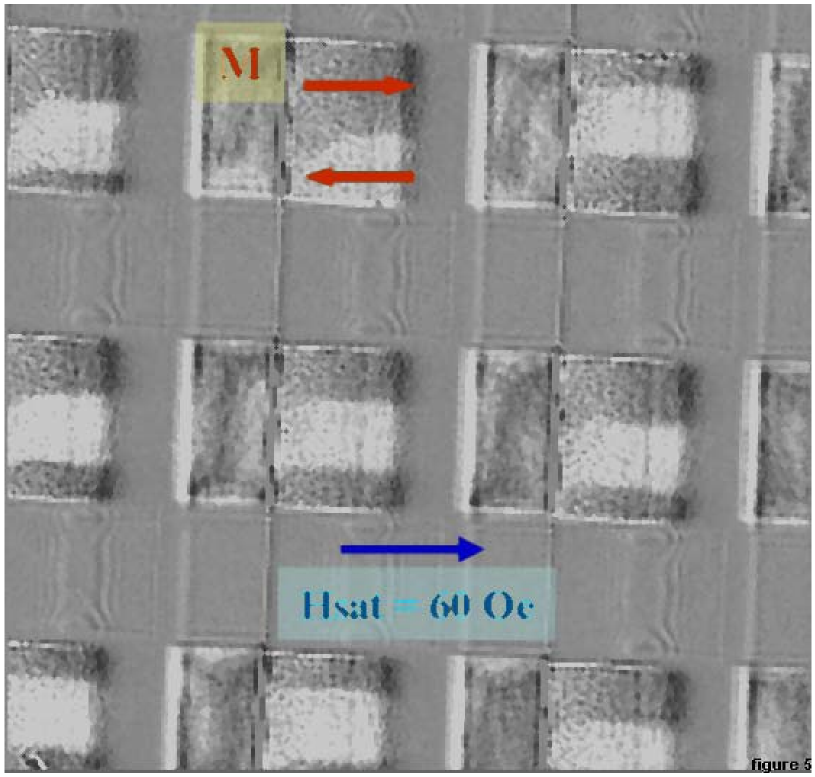

Figure 7.) Longitudinal Kerr image of the remanent state of 20 µm wide CoFe stripes after application of a horizontal field of 60 Oe. Hard-bake: 2 hrs., anneal: 2 hrs. The Kerr sensitivity is horizontal

2. B–H Loops

BH–loops for $Co_{36.2}Fe_{63.8}$ stripes on topology are depicted in Figure. 13. The squareness of the easy–axis loops decreases with decreasing hard–bake time of the resist structure reflecting an increase in stress induced anisotropy. For the annealed stripes, the domain reversal process is clearly dominated by wall nucleation at the stripe edges and subsequent wall displacement (circled area in Figure. 14). After applying a saturation field of 70 Oe domain walls nucleate at -10 Oe and the reversal is complete at approximately -28 Oe.

3. Conclusions

The results show that it is possible to optimize the magnetic domain structure in highly magnetrostrictive magnetic materials by control of the external mechanical stresses introduced by the write head processing. The simplicity of the test structures used in this experiment allows for a short turnaround time for the optimization of the micromagnetic properties of write head yokes prior to the full head built. It shows that for these very highly magnetostrictive materials the domain structure critically depends on

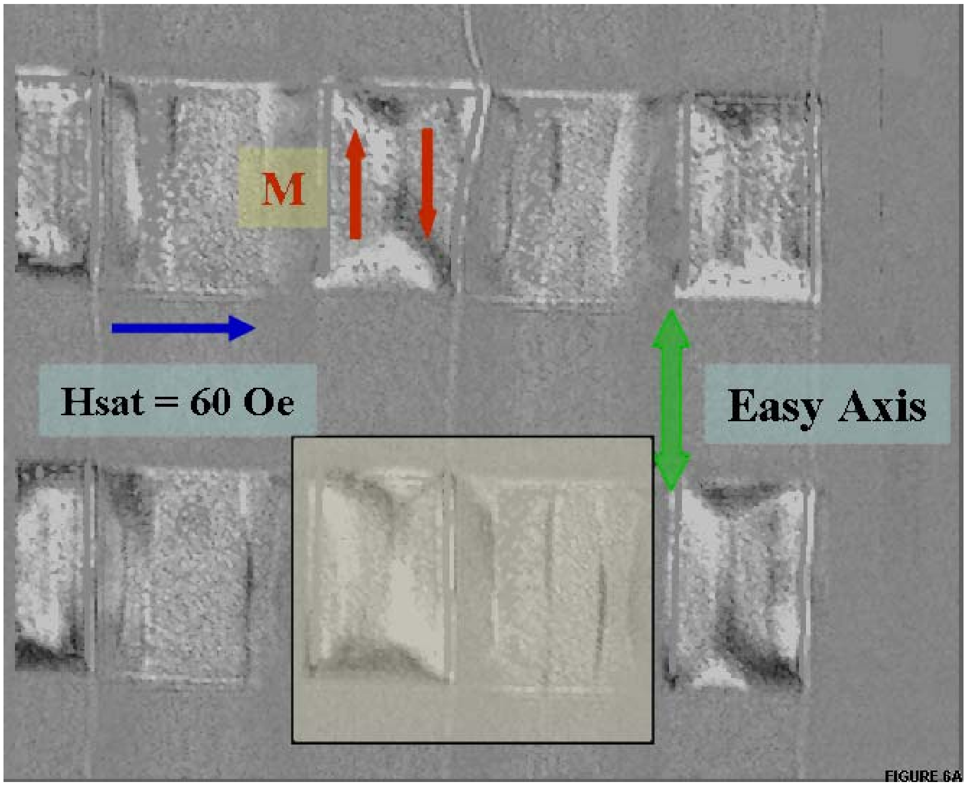

Figure 8.) **Longitudinal Kerr image of the remanent state of 20 µm wide CoFe stripes after application of a horizontal field of 60 Oe. Hard-bake: 1 hr., anneal: 2 hrs. The Kerr sensitivity is horizontal.**

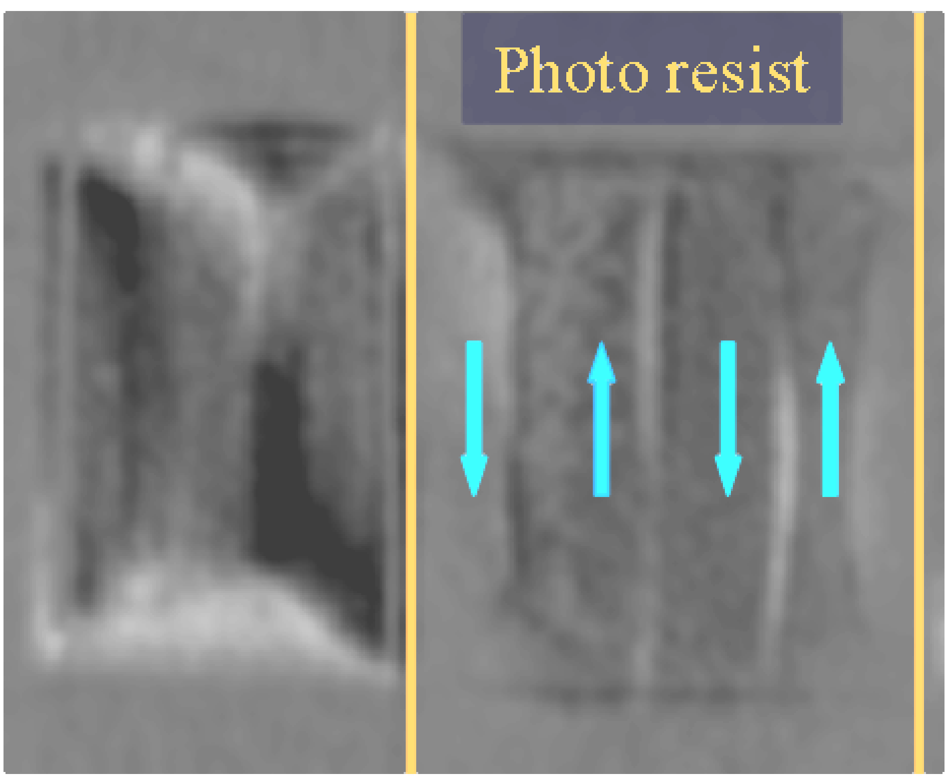

Figure 9.) **Enlarged Kerr image of the shaded area in figure 8**

the processing parameters, and in general, only fairly narrow windows for the generation of a favorable domain state can be expected. For the evaluated test structure the optimum hard-bake time for the resist is found to be between one hour and two hours. The necessity to consider the impact of an Alumina overcoat has also been shown.

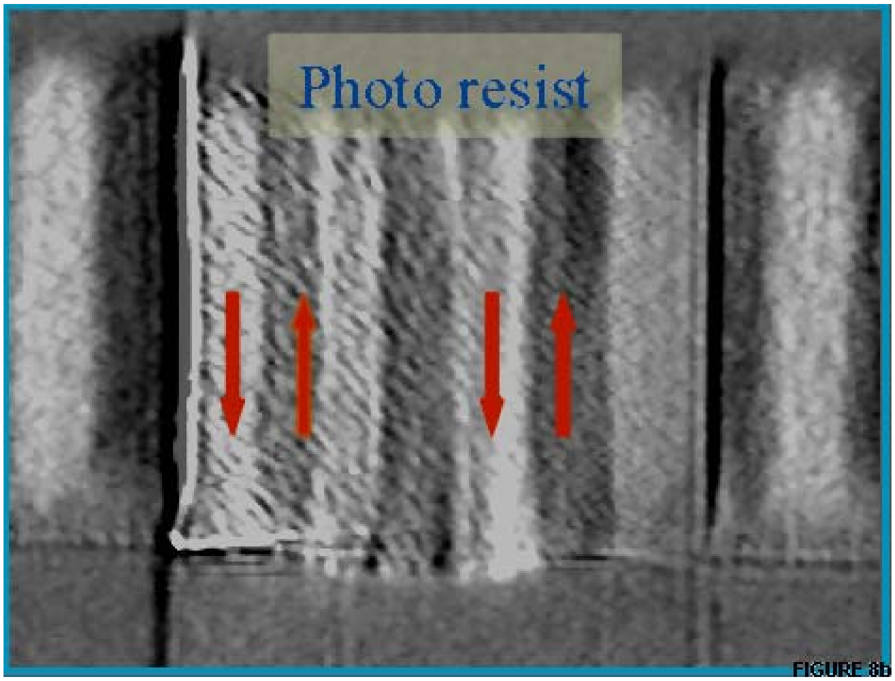

Figure 10.) Longitudinal Kerr image of the remanent state of 20 µm wide NiFe stripes after application of a horizontal field of 60 Oe. Hard-bake: 1 hr., anneal: 2 hrs. The Kerr sensitivity is vertical

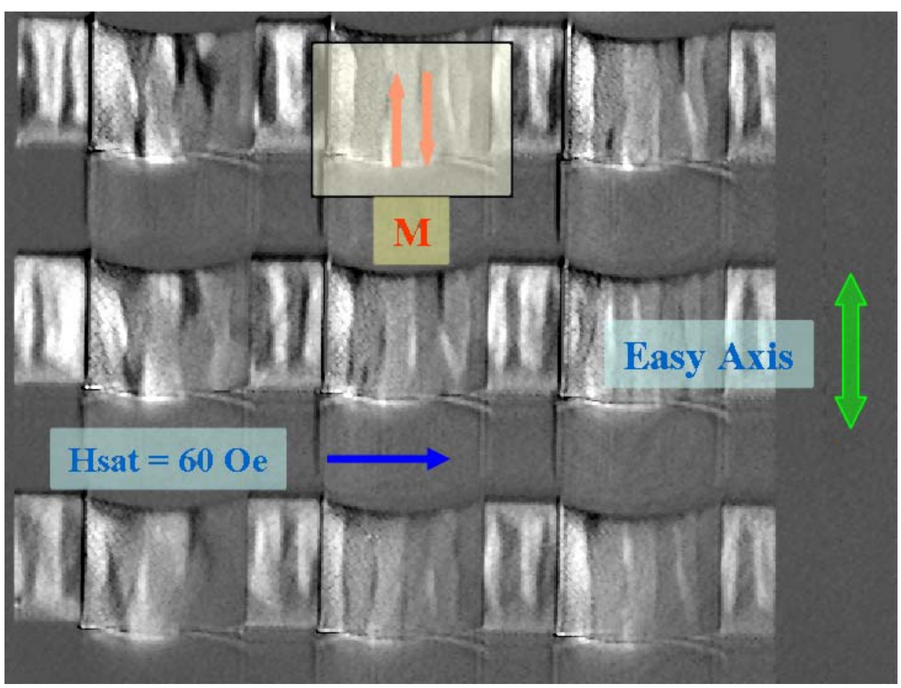

Figure 11.) Longitudinal Kerr image of the remanent state of 20 µm wide CoFe stripes after application of a horizontal field of 60 Oe. The structure is covered by an Al_2O_3 overcoat. Hard-bake:

1 hr., anneal: 2 hrs. The Kerr sensitivity is vertical

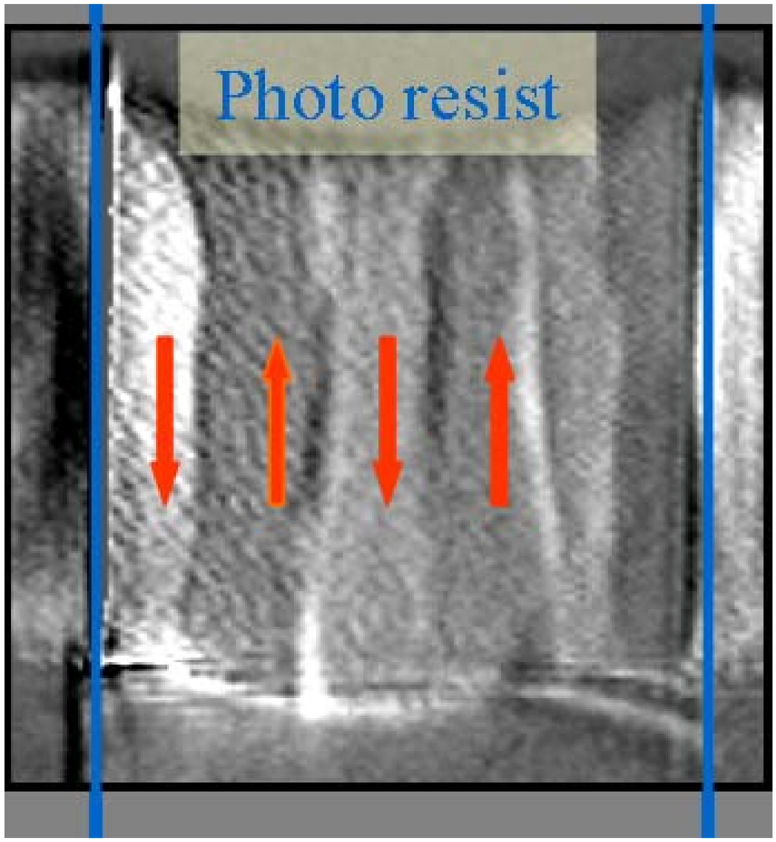

Figure 12.) Enlarged Kerr image of the shaded are in figure 11

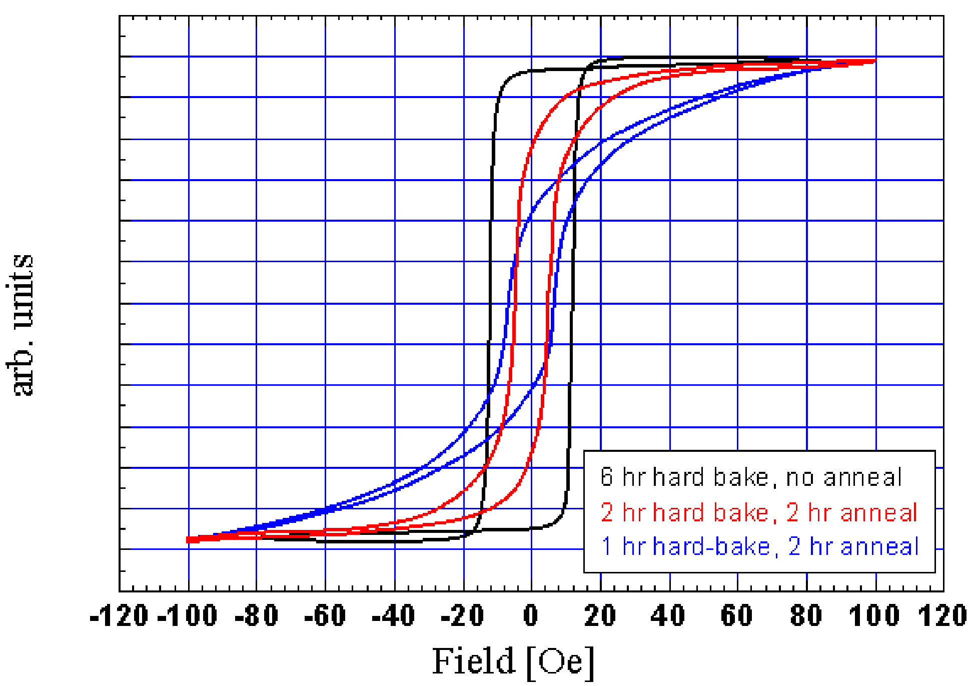

Figure 13.) Easy--axis loops for CoFe stripes for: 1.) 2 hr anneal, 1 hr hard-bake, 2.) 2 hr anneal, 2 hr hard-bake, 3.) no anneal, 6 hr hard-bake

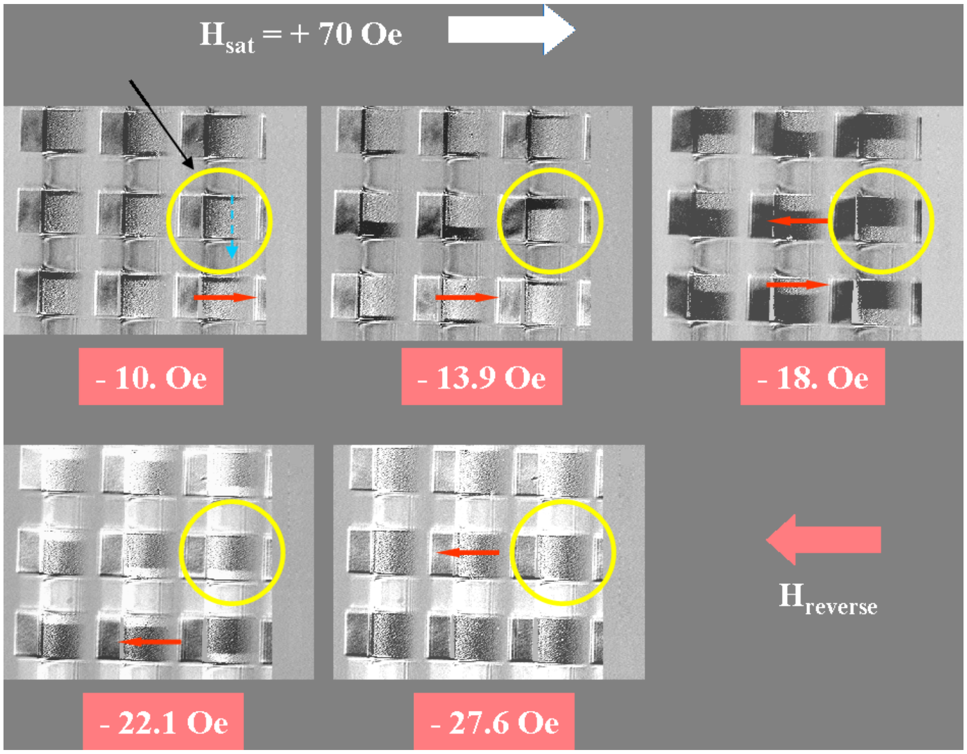

Figure 14.) Kerr images of the domain reversal process in CoFe stripes as used for the measurement in Figure 13 after application of a 70 Oe saturation field parallel to the long stripe axis: No anneal, 6 hr hard-bake

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