Influence of seed layer on magnetic properties of laminated Co 65 Fe 35 films

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Citation: Journal of Applied Physics **103**, 07B514 (2008); doi: 10.1063/1.2832436
View online: http://dx.doi.org/10.1063/1.2832436
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/103/7?ver=pdfcov
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Influence of seed layer on magnetic properties of laminated $Co_{65}Fe_{35}$ films

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(Presented on 9 November 2007; received 11 September 2007; accepted 24 October 2007; published online 12 February 2008)

CoFe alloys have important applications in recording heads since they have a high M_S which enables writing to high coercivity media. They also can have a high coercivity which can hinder applications. Previous studies have attempted to reduce the coercivity by the use of seed layers, process conditions, or lamination. We have used a high target utilization sputtering system that allows control of grain size to study laminated $Co_{35}Fe_{65}$ films with 15 Å Al_2O_3 spacer layers. Samples were fabricated with Ru, $Ni_{81}Fe_{19}$, and Ta seed layers, as a single layer, a bilayer, or a trilayer. For samples with Ru and $Ni_{81}Fe_{19}$ seed layers, the grain size was reduced with increasing lamination resulting in a significantly reduced coercivity. Samples with a Ta seed layer showed the opposite trend and an increase of coercivity was found as the number of laminations increased.
 [DOI: 10.1063/1.2832436]

INTRODUCTION

CoFe alloys have become essential materials in the magnetic storage industry since they exhibit the highest magnetization known, making them ideal for use in read and write heads. As deposited CoFe films typically have high coercivity values in the range of 100–200 Oe, which can hinder applications. Previous studies have attempted to reduce the coercivity by using seed layers,[1,2] control of grain size,[3] and lamination using insulating layers.[4]

Jung *et al.*[1] studied the use of different seed layers and found that by using Cu, Ru, and Ta/NiFe, the typical high coercivities could be reduced. This was attributed to a reduction of the grain size in the CoFe layer. Vopsaroiu *et al.*[3] used a novel high target utilization sputtering system (HiTUS) to control the grain size in CoFe films and found that they could reduce the coercivity to 10 Oe for films with grain sizes less than 15 nm. Craig *et al.*[4] fabricated CoFe films laminated with Al_2O_3 and investigated the magnetization reversal in the samples with Lorentz microscopy. They found that laminated samples had a smaller coercivity than single layer films and attributed this to a lower grain size in the CoFe but mainly to uncorrelated growth of crystallites within individual layers, leading to a reduction in the local anisotropy. This coercivity reduction was found to be consistent with Hoffman's ripple theory.[5,6]

In this article, we investigate laminated $Co_{65}Fe_{35}$ films with different seed layers. The influence of seed layer on both structural and magnetic properties is reported.

EXPERIMENTAL

Samples with structure seed $(10\ \text{Å})/[Co_{65}Fe_{35}(x\ \text{Å})/Al_2O_3(15\ \text{Å})]\times n$ were fabricated via HiTUS[3] on $5\times 5\ \text{mm}^2$ Si substrates and carbon coated transmission electron microscope grids at a pressure of 3×10^{-3} mbar. The total thickness of each sample set was kept constant at 400 Å. The seed layers used were $Ni_{81}Fe_{19}$, Ru, and Ta. A field of approximately 500 Oe was applied at the substrate position in order to produce uniaxial anisotropy in the film. A quartz crystal oscillator was used to monitor the thickness of individual layers. For each sample set, the grain size of the CoFe layer was varied by changing the target bias voltage from 300 to 900 V.[7] Magnetic characterization of the samples was carried out using a PMC model 2900 alternating gradient force magnetometer. Selected samples were also subject to surface roughness measurements with contact mode atomic force microscopy (AFM). Transmission electron microscopy (TEM) was used to obtain high resolution images for each sample that were subsequently subject to grain-size analysis with a Zeiss particle size analyser.

RESULTS

Figure 1 shows the easy-axis hysteresis loops for samples with each seed layer where the CoFe layer was deposited at 900 V in order to promote a large grain size. Both $Ni_{81}Fe_{19}$ and Ru are effective in reducing the coercivity of CoFe in the single layer films to 10 and 7 Oe, respectively. However, when using Ru or NiFe and laminating the CoFe layer, one can reduce the coercivity even further, as shown in Fig. 2. Figure 1(c) shows the easy axis hysteresis loops for samples with a Ta seed layer which have much larger coercivities characteristic of CoFe alloys. The effect of lamination is to increase the coercivity from 120 to ~160 Oe.

In order to understand the trends in coercivity for the different samples, TEM images were taken. Figure 3 shows TEM images for each sample set with one, two, and three laminations. Grain size analysis was carried out on the images where 500 grains per sample were counted. Figure 4 summarizes the results of the grain size analysis. It can be seen that depositing the CoFe at low or high target bias voltage controls the grain sizes.[7] There is also a clear difference in the dependence of grain size on lamination between NiFe or Ru and Ta seed layers. For samples with NiFe and Ru seed layers, the grain size is constant with lamination within error.

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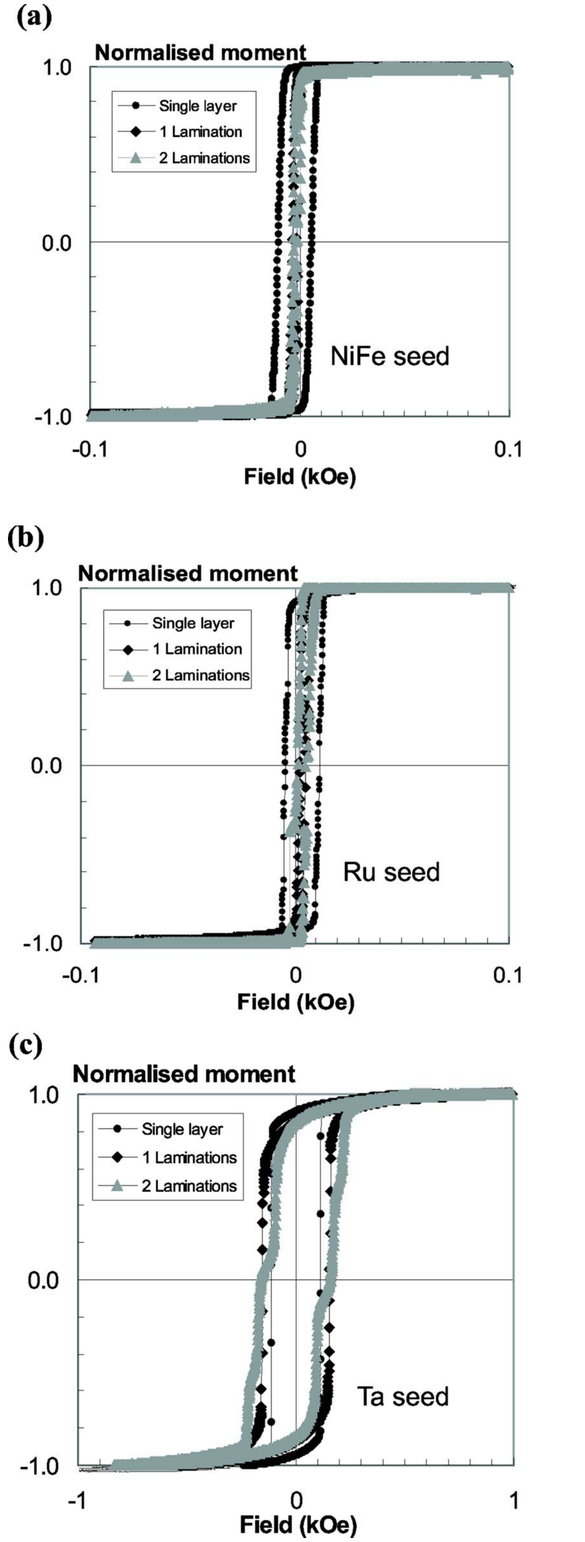

FIG. 1. (Color online) Easy-axis hysteresis loops for single layer and laminated samples with (a) $Ni_{81}Fe_{19}$, (b) Ru, and (c) Ta seed layers. The $Co_{65}Fe_{35}$ sputter target bias was fixed to 900 V.

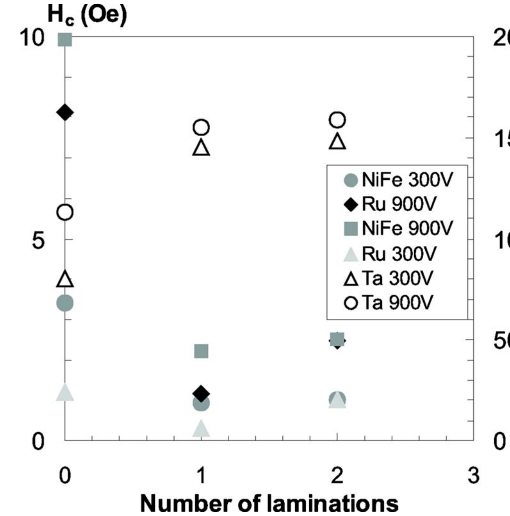

FIG. 2. (Color online) (a) Variation of coercivity with lamination for samples with $Ni_{81}Fi_{19}$, Ru, and Ta seed layers. For each sample set, the $Co_{65}Fe_{35}$ sputter target bias was fixed to 300 or 900 V. Note open shapes should be used with *y*-axis on right.

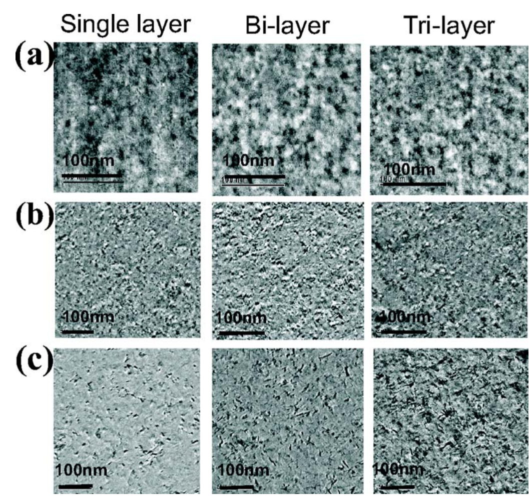

FIG. 3. (Color online) Plan view transmission electron microscope images of single layer and laminated samples with (a) $Ni_{81}Fe_{19}$, (b) Ru, and (c) Ta seed layers. The $Co_{65}Fe_{35}$ sputter target bias was fixed to 900 V.

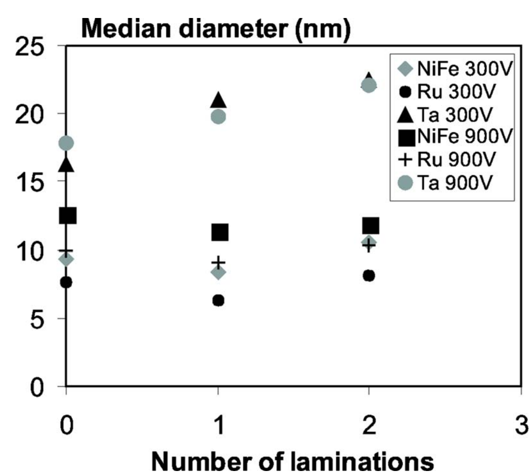

FIG. 4. (Color online) Median grain size as a function of lamination for samples with $Ni_{81}Fi_{19}$, Ru, and Ta seed layers. For each sample set, the $Co_{65}Fe_{35}$ sputter target bias was fixed to 300 or 900 V.

For samples with Ta seed layers, the grain size is much larger and can be seen to increase with lamination. It should be noted that the properties of most polycrystalline magnetic materials are critically dependent on grain volume; hence, the two Ru-based samples differ in volume by a factor of 2 and the Ta-based samples have grain volumes typically an

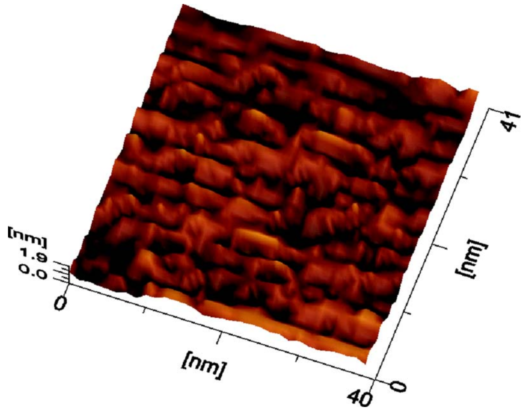

FIG. 5. (Color online) Atomic force microscope image of a single $Co_{65}Fe_{35}$ layer with Ru seed. The $Co_{65}Fe_{35}$ sputter target bias was fixed to 900 V.

order of magnitude larger in volume than the other samples. Finally, Fig. 5 shows a typical AFM image for a Ru-based sample. Samples with a Ru seed layer show very little difference in roughness between single layers and those that are laminated, whereas samples with NiFe seed layers show a large increase in roughness. These data are summarized in Table I.

DISCUSSION

Previous studies have demonstrated that lamination of CoFe films can significantly reduce the coercivity. The decrease in coercivity was partially attributed to reduced grain sizes, but mainly due to an increase in the anisotropy dispersion. This study has shown that the choice of the correct seed layer is an important factor in reducing coercivity. Figure 4 shows that NiFe and Ru seed layers control grain growth dominating the effect of the growth rate which was previously controlled via the dc target bias.[3] However, lamination does reduce the coercivity as it directly reduces the grain volume. It should be noted that for this effect to occur the use of insulating interlayers is essential to avoid interlayer RKKY (Ruderman-Kittel-Kasuya-Yosida) coupling. For the case of Ta-based samples, the seed layer does not control the grain diameter which increases monotonically with growth rate, controlled via the target bias. The increase in grain diameter thus leads to an increase in grain volume which is greater than any reduction caused by lamination. Hence, the coercivity rises from an already high value due to a simple grain volume effect in agreement with our previous work.[3]

TABLE I. Root mean square roughness values for single layer and laminated trilayer samples where the seed layer was either $Ni_{81}Fi_{19}$ or Ru.

Sample	R_{rms} (nm)
Ru seed, single layer	0.31
Ru seed, trilayer	0.22
NiFe seed, single layer	0.22
NiFe seed, trilayer	1.75

In conclusion, we have conducted a detailed investigation of the seed layer and lamination effects on the coercivity of the CoFe films. We find that all the effects observed can be understood in terms of the grain size dependence of the coercivity once the grain size is determined to sufficient resolution. We believe that other factors such as ripple[6] are secondary effects to the dominant role of grain volume.

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