Low Magnetostriction in Annealed NiFe/Ag Giant Magnetoresistive Multilayers

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***Abstract*—Systematic changes were observed in magnetostriction and magnetoresistance ratio for NiFe/Ag multilayers as a function of annealing temperature. Optimal multilayer configurations (number of bilayers and Ag layer thickness) can be engineered to achieve zero magnetostriction concurrent with high magnetoresistance sensitivity. This feature makes the NiFe/Ag multilayers potentially useful for high-performance magnetic recording read-sensors.**

I. INTRODUCTION

Among the many giant magnetoresistive (GMR) material systems currently being studied, the NiFe/Ag multilayer system [1, 2] appears to be attractive because, after annealing (previous work [1] showed GMR in as-deposited states also), it exhibits a high MR ratio together with a low saturation field H_s, resulting in large field sensitivities. A possible mechanism to explain the onset of GMR after annealing is the diffusion of Ag along the columnar grain boundaries; this diffusion effectively breaks up the NiFe layers into grains that interact magnetostatically [3, 4].

To be useful for read head applications, GMR films must be magnetically soft. The saturation magnetostriction λ_s is one of the key soft magnetic properties, which must be low and tightly controlled because it often induces undesirable anisotropy of magnetoelastic origin during head fabrication [5]. The magnetoelastic anisotropy can shift the optimal biasing point of head operation if the sensor structure possesses high λ_s.

The purpose of this study was to investigate systematic changes in λ_s and GMR as a function of annealing temperature T_{an} and multilayer configuration. In addition, we have assessed the effect of NiFe/Ag bilayer number and Ag spacer layer thickness on λ_s and GMR. An optimization of NiFe/Ag multilayer performance could be achieved with careful material design based on the understanding of the microstructural evolution in thin films.

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II. EXPERIMENTAL

Multilayers were deposited by dc magnetron sputtering with $Ni_{82}Fe_{18}$ and Ag targets onto 76 mm diameter Si wafers coated with 150 nm of thermal SiO_2. The basic film structure used in this study with varying bilayer number N and Ag thickness t_{Ag} was:

$$Si/SiO_2(150\ nm)/Ta(4.5\ nm)/Ag(0.5t_{Ag})/NiFe(2\ nm)$$
$$/[Ag(t_{Ag})/NiFe(2\ nm)]_{N-1}\ /Ag(0.5t_{Ag})/Ta(11\ nm)$$

Table I shows the multilayer configurations. A total of seven sample sets were prepared and annealed with a rapid thermal annealing furnace from 320 to 400°C.

TABLE I
SAMPLE SETS PREPARED WITH DIFFERENT NUMBER OF NiFe/Ag BILAYERS (N), AND Ag SPACER LAYER THICKNESS (t_{Ag})

Sample Set	N	t_{Ag} (nm)
A1	5	3.3
A2	5	4.4
B0	7	2.2
B1	7	3.3
B2	7	4.9
B3	7	5.5
C1	9	3.3

The details of film deposition, annealing conditions can be found in our previous work [6]. λ_s was measured at room temperature by a high-precision optical tester [7] which employs an in-plane rotating magnetic field and laser-beam deflection technique [8].

III. RESULTS AND DISCUSSION

Before we explore λ_s behavior, GMR characteristics of annealed NiFe/Ag multilayers are discussed. Fig. 1 shows the effect of annealing temperature T_{an} on the MR ratio ($\Delta R/R_s = (R - R_s)/R_s$, where R_s is the saturation resistance) for sample set A2. The annealing dependence of the MR response is very similar to that reported by Hylton et al. [2] for samples having N = 5 and t_{Ag} = 4.0 nm. As T_{an} is increased, $\Delta R/R_s$ increases to a peak value of 5.2% for T_{an} = 340°C, and then decreases as T_{an} is increased further. For brevity, $\Delta R/R_s$ refers to the

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amplitude of the MR curve. Unannealed samples do not exhibit GMR.

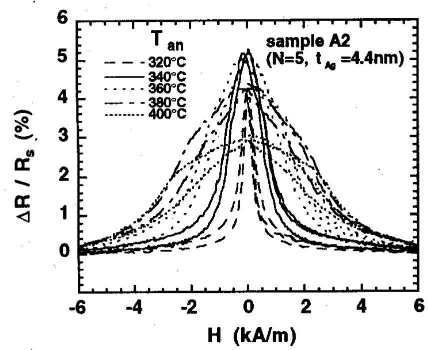
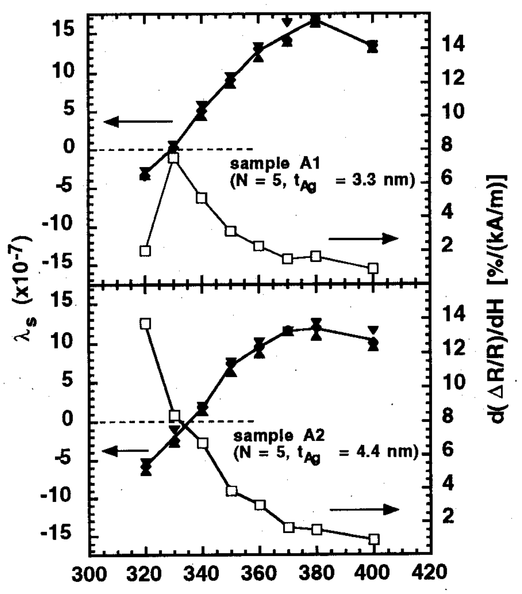
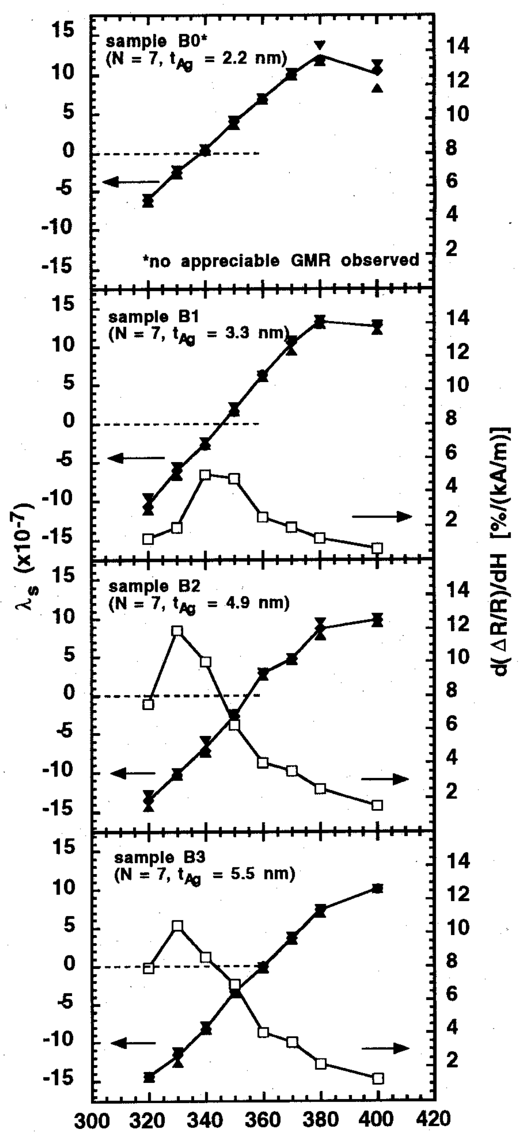


Fig. 1. Room-temperature MR data for sample set A2, having N = 5 and t_{Ag} = 4.4 nm. The data show a peak in the magnitude of $\Delta R/R_s$ for a 5 minute, 340°C anneal.

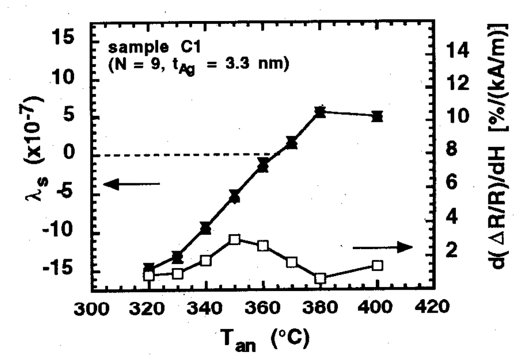
Fig. 1 also shows MR hysteresis, which is approximately 0.16 kAm^{-1} (2 Oe) wide at half the saturation field for T_{an} = 320°C and increases with increasing T_{an}. The plausible mechanisms to explain the initial increase in $\Delta R/R_s$ with T_{an} at zero field, and the reduction in $\Delta R/R_s$ for high T_{an} have been previously discussed [6].



(a)



(b)



(c)

Fig. 2. Saturation magnetostriction (λ_s) and field sensitivity as a function of annealing temperature: (a) N = 5 (A1, A2), (b) N = 7 (B0, B1, B2, B3), and (c) N = 9 (C1). No GMR was observed for B0. Field sensitivity is defined as the maximum d($\Delta R/R$)/dH.

The λ_s and MR sensitivity data are shown in Fig. 2 as a function of T_{an}. λ_s of as-deposited NiFe/Ag (sample sets B) is about $-3x10^{-6}$ (previous magnetosriction study [9] on Ni/Ag multilayers with a comparable Ni thickness also indicated a negative $\lambda_s = -20x10^{-6}$). For all sample sets, λ_s exhibits a zero crossover for anneals between 330 and 360°C, which for certain multilayer configurations, is also a region of relatively high $\Delta R/R_s$ and sensitivity values. This feature is extremely encouraging from a device manufacturing viewpoint.

λ_s changes linearly with strikingly similar slopes up to a certain temperature. At high T_{an}, λ_s is nearly constant or has a slight downturn. The behavior of λ_s with increasing T_{an} is consistent with microstructural changes accompanied by a reduction in the residual stress of the films. Vacuum-deposited films are, in general, in a state of residual stress. This residual stress can be relieved by changing the microstructure of the film with modest annealing. The microstructural evolution associated with post-deposition annealing includes recovery, nucleation, and grain growth. The residual stress change contributes to the change in magnetosriction. Both Ni and Fe show a gradual increase in λ_s as compression is increased or tension is decreased [10].

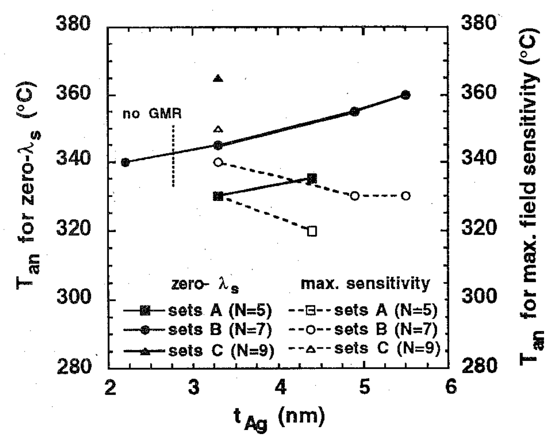


Fig. 3. T_{an} for zero-λ_s and maximum field sensitivity as a function of t_{Ag} for N = 5 (set A), N = 7 (set B), and N = 9 (set C).

To better understand the λ_s and sensitivity behavior, T_{an} for zero-λ_s and maximum sensitivity was replotted, as shown in Fig. 3, from the previous figure as a function of t_{Ag}. When we compare zero crossover temperatures for all film sets investigated, we observe systematic data trends: i) the zero-λ_s temperature decreases as t_{Ag} decreases, and ii) the zero-λ_s temperature decreases as the number of bilayers (N) decreases. Meanwhile, the temperature which offers the maximum field sensitivity behaves differently: i) it increases as t_{Ag} decreases, but ii) decreases as N decreases.

As shown in Fig. 3, the linear changes in T_{an} for zero-λ_s and maximum field sensitivity could be useful for designing multilayers to optimize the material performance. For example, to optimize λ_s and sensitivity, the optimal processing condition for N = 7 samples (set B) will be t_{Ag} = 2.8 nm and T_{an} = 343°C. Similarly, the optimal processing condition for N = 5 samples (set A) will be t_{Ag} = 3.3 nm and T_{an} = 330°C.

IV. CONCLUSIONS

We have investigated magnetostriction and giant magnetoresistance behaviors of annealed NiFe/Ag multilayered films. Systematic changes observed in magnetostriction and field sensitivity allow one to design multilayers and predict their performance. Zero magnetostriction with high magnetoresistance field sensitivity observed in the NiFe/Ag multilayers makes them potentially useful for high-performance read-sensor application.

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