Magnetic Properties and High-Frequency Responses of High Moment FeTaN/AlN Laminates for High-Data-Rate Magnetic Recording

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***Abstract*—Soft magnetic FeTaN and novel FeTaN/AlN multilayer films with a saturation flux density of ~20 kG are obtained on both *planar* and *sloping* substrates. Flat frequency responses extend over 500 MHz for as-deposited 1000 Å-thick FeTaN films. The 3 dB roll-off frequency for as-deposited 1 μm-thick $(FeTaN/AlN)_{10}$ laminates is only ~330 MHz. However, when the laminates are patterned into 20 μm-wide strips along the hard axis, the frequency response improves and the 3 dB roll-off frequency is over 500 MHz, which offers the promise of data rates of over 1 Gb/sec.**

***Index Terms*—High saturation magnetic materials, thin-film magnetic recording heads, magnetic/dielectric laminates, frequency dependent permeability**

I. Introduction

High permeability at high frequencies is required for high data rates in magnetic recording. Highly resistive materials and laminated magnetic films such as Fe-based nitride multilayers with SiO_2 and Al_2O_3 spacers have been fabricated to satisfy this requirement [1][2]. We found that FeTaN films and FeTaN/AlN laminates show soft magnetic properties and high-frequency responses suitable for ultra-high density and high-data-rate magnetic recording. This paper reports the magnetic properties and high-frequency responses of FeTaN films and FeTaN/AlN laminates.

II. Experimental Procedures

We deposited FeTaN and FeTaN/AlN multilayer films up to a thickness of 1 μm on *planar* and *sloping* Si substrates by reactive RF sputtering in an N_2 and Ar environment. The sloping substrates simulate the top-pole geometry in thin-film inductive heads. Using an Fe target with Ta coupons, we obtained about one atomic percent of Ta in FeTa films. We varied the N_2/Ar flow rate ratio from 0 to 0.17 to optimize the soft magnetic properties. Since the minimum coercivity was found at a flow rate ratio of 0.11, we deposited all multilayer films at this condition, and we varied the thickness of the AlN spacer in the double layers of $(FeTaN_{1250Å}/AlN_t/FeTaN_{1250Å})$ from 20 Å to 100 Å to obtain a continuous AlN layer and to optimize the soft magnetic properties. We also varied the FeTaN thickness to increase the number of FeTaN/AlN periods, while keeping the total thickness close to ~1 μm and the AlN thickness at 30 Å. The base pressure was below 3×10^{-7} Torr and the RF input power was 800 watts. We characterized the films using a B-H loop tracer, a VSM and an AC magnetostriction tester. Using a permeance tester capable of measuring up to 500 MHz [3], we measured the AC permeability of as-deposited films and after-patterned films which were etched into 20 μm-wide strips along the hard axis. We also performed X-ray θ-2θ scans and χ-scans.

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III. Results and Discussion

A. Magnetic properties and microstructures

We obtained FeTaN single-layer films with soft magnetic properties and saturation flux densities over 20 kG on *planar* and *sloping* surfaces without applying substrate bias. Our findings are summarized in Table I. We observed a hard axis coercivity of 0.68 Oe, an easy axis coercivity of 1.57 Oe and an anisotropy field of 9.9 Oe for the films deposited at a N_2/Ar flow rate ratio of 11%. When N is incorporated into $Fe_{99}Ta_1$ matrices, the resistivity is increased but the saturation magnetic flux density is decreased, as expected. The resistivity is 53.6 μΩ-cm and the saturation magnetization flux density is 20.7 kG for the film deposited at the N_2/Ar flow rate ratio of 11%. The variations in the resistivity and the saturation magnetic flux density at several flow rate ratios are shown in Fig. 1(a). The saturation magnetostriction increases as the flow rate ratio increases, as shown in Fig. 1(b). When films are deposited at a 45° slope, a hard axis coercivity of 1.13 Oe, an easy axis coercivity of 2.87 and an anisotropy field of 15.7 Oe result. The saturation magnetic flux density is 20.1 kG and the resistivity is 86.2 μΩ-cm.

The microstructures of the FeTaN films are similar to those of the FeRhN films [4]. When the film shows the lowest coercivity, both α-Fe and γ-Fe_4N phases are observed in the film. The amount of the γ-Fe_4N phase is increased when the flow rate ratio is increased. The χ scans for the (110) planes of the film at the N_2/Ar flow rate ratio of 11% show that strong (110) planes are developed along the film normal. Soft magnetic properties are often associated with the (110) texture [5].

When the films are deposited on sloping surfaces, we also

TABLE I. MAGNETIC PROPERTIES OF FETAN SINGLE-LAYER AND FETAN/ALN MULTILAYER FILMS.

Film	FeTaN Single layer		$(FeTaN/AlN)_{10}$ Multilayer	
Slope Angle (°)	0	45	0	45
H_k (Oe)	9.9	15.7	9.2	10.5
$H_{c\,(hard\,axis)}$ (Oe)	0.6	1.1	0.5	0.9
$H_{c\,(easy\,axis)}$ (Oe)	1.5	2.8	0.5	1.5

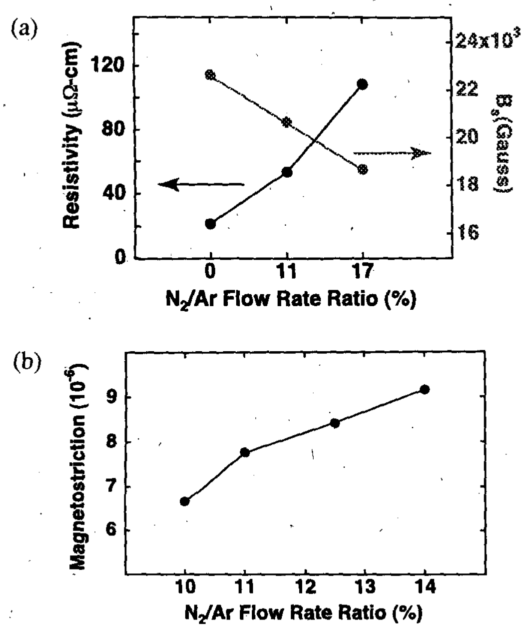

Fig. 1. Variations in (a) the resistivity and the saturation magnetic flux density and (b) the saturation magnetostriction of the FeTaN films when the N_2/Ar flow rate ratio is changed.

observe α-Fe and γ'-Fe_4N phases. However, in these films, the (200) peak intensity of the γ'-Fe_4N phase is comparable to the (110) peak intensity of the α-Fe phase. This is a different result from that obtained for the FeTaN films deposited on planar substrates described above. Fig. 2 shows the χ scans, which are similar to those of the film deposited on planar substrates. The strong (110) planes tend to stay along the film normal even for a slope angle of 45°, which can lead to soft magnetic properties.

The magnetic properties are not affected much by the change in AlN thickness from 2 to 10 nm. The magnetic properties of FeTaN/AlN multilayer films are also summarized in Table I. When FeTaN films are laminated with a 30Å-thick AlN spacer, their soft magnetic properties are improved on both planar and sloping substrates. This is probably due to the reduction of domain-wall energy by magnetostatic coupling between the magnetic layers and by the elimination of edge domains [6]. Both α-Fe and γ'-Fe_4N phases are observed in these films. The χ scans for the (110) planes of the multilayers also show strong (110) textures.

B. Frequency Responses

The 0.1 μm-thick FeTaN film has a better frequency response than the 0.1 μm-thick Permalloy as shown in Fig. 3(a). The permeability of the Permalloy starts to roll off around 350 MHz. In contrast, the permeability of the FeTaN film remains flat up to 500 MHz. As a matter of fact, the ferromagnetic resonance is expected at around 1.3 GHz for our 0.1 μm-thick FeTaN film. The observed permeability of the FeTaN film (~1400) is lower than its DC permeability (~2100). The effective anisotropy obtained by curve-fitting is 15.7 Oe based on the Landau-Lifshitz damping model [7]. This is ~50% larger than the DC value, 9.9 Oe. This difference can be accounted for by the internal demagnetizing field caused by the ripple effect [8]. The frequency response is degraded when the films become thicker because of increased eddy current loss. The 3 dB roll-off frequency is about 170 MHz for the 1 μm-thick FeTaN single-layer film (Fig. 3(b)). The permeability rolls off earlier than according to the model, as was observed by others as well [2, 9].

As shown in Fig. 4(a), when the films are multilayered with 10 periods of ($FeTaN_{100nm}/AlN_{3nm}$), the flat frequency response unexpectedly extends to only around 200 MHz, not to 500 MHz. The 3 dB roll-off frequency for the films is about 330 MHz, which is almost double that for the FeTaN single-layer films. The difference between the frequency response of

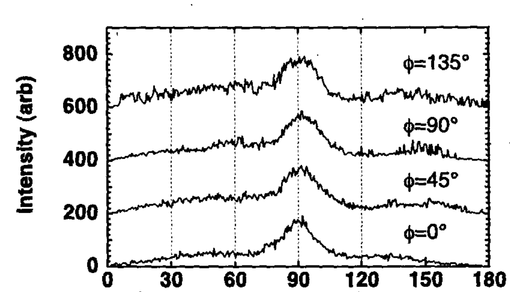

Fig. 2. X-ray χ-scans for the (110) planes of the FeTaN film deposited on a 45° sloping substrate at the N_2/Ar flow rate ratio of 11% with various φ angles. χ=90° corresponds to the film normal and φ=0° to the easy axis.

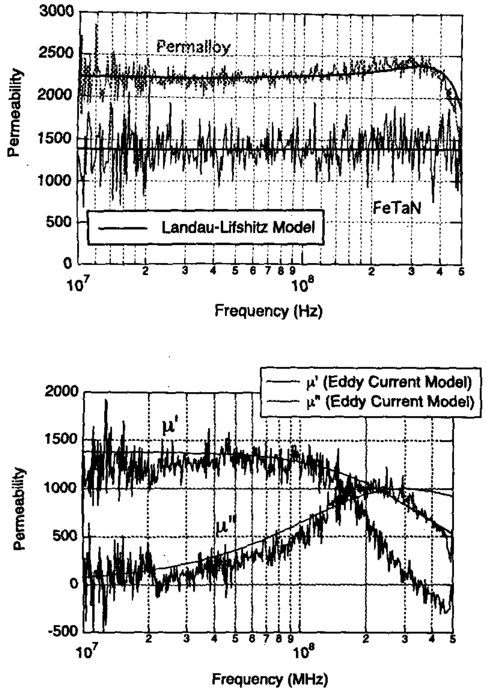

Fig. 3. (a) The real part of the permeability of the 0.1 μm-thick Permalloy and FeTaN films with curve-fitting (solid line) based on the Landau-Lifshitz model and (b) the permeability of the 1 μm-thick FeTaN single-layer with curve-fitting (solid line) based on the eddy current model.

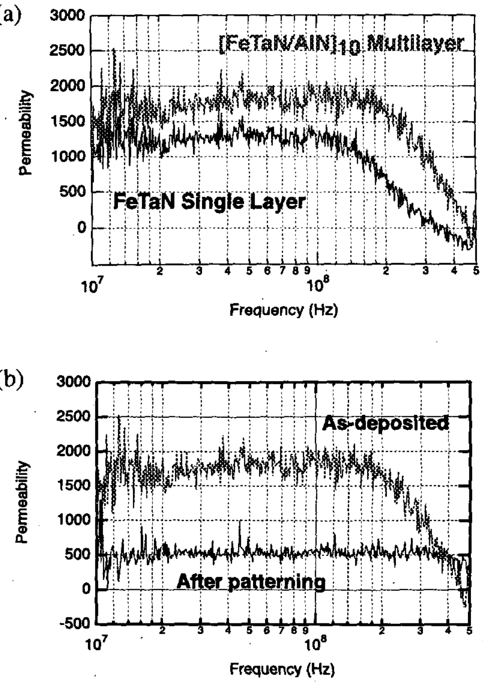

Fig. 4. (a) The real part of the permeability of the as-deposited 1 μm-thick $(FeTaN_{100nm}/AlN_{3nm})_{10}$ laminates and the 1 μm-thick FeTaN single layer deposited on planar substrates and (b) the real part of the permeability of the $(FeTaN_{100nm}/AlN_{3nm})_{10}$ laminates before and after the laminates are patterned into 20 μm-wide strips.

1000 Å-thick FeTaN films and of $(FeTaN_{100nm}/AlN_{3nm})_{10}$ laminates can be attributed to the capacitive coupling of eddy currents across the dielectric spacers [10]. After we pattern the laminates into 20 μm-wide strips with their long axis parallel to the hard axis, the frequency response improves, as shown in Fig. 4(b). The improvement is due to the elimination of the eddy current coupling through AlN spacers. The 3 dB roll-off frequency is over 500 MHz for the 1 μm-thick $(FeTaN/AlN)_{10}$ laminates, which can allow data rates of over 1 Gb/sec. Unfortunately, the magnitude of the initial permeability (~530) of the laminates after patterning is only about 1/3 of the as-deposited film's (~1770). This decrease can be attributed to the increased effective anisotropy field caused by the induced stress anisotropy developed after the laminates are patterned. We observe similar frequency responses for single-layer and laminated films deposited on sloping surfaces.

IV. Conclusion

We fabricated soft magnetic FeTaN and FeTaN/AlN laminated films with a saturation flux density of over 20 kG on both *planar* and *sloping* substrates. The 1 μm-thick laminates have an anisotropy field of around 10 Oe. The flat frequency response extends over 500 MHz for as-deposited 1000 Å-thick FeTaN films. The 3 dB roll-off frequency for the 1 μm-thick $(FeTaN/Al)_{10}$ laminates is over 500 MHz after they are patterned into strips, which can provide data rates of over 1 Gb/sec. The FeTaN and FeTaN/AlN laminated films show a strong potential for ultra-high density and high-data-rate magnetic recording.

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