$Co_{1-x}Cr_x$/Pt multilayers as perpendicular recording media

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We have investigated $Co_{1-x}Cr_x$/Pt multilayers as potential perpendicular media capable of high-density magnetic recording. The films exhibited strong perpendicular anisotropy, coercivity values ranging from 0.3 to 6.9 kOe, and a range of coercive squareness (S^*) from 0.21 to 0.96. Magnetic and atomic force microscopy were used to correlate the grain and magnetic domain structures. The degree of intergranular exchange is clearly dependent on the deposition temperature and, to a lesser extent, Cr content. $Co_{1-x}Cr_x$/Pt multilayers are ferromagnetic at room temperature for $x>30\%$, which is not observed in thick $Co_{1-x}Cr_x$ films. Initial recording results determined a S_ONR ratio of 23 dB for a $[Co(4\ Å)/Pt(5\ Å)]_{10}$ multilayer recorded at 10 kiloflux changes per millimeter using a standard longitudinal ring head. © *2000 American Institute of Physics.* [S0021-8979(00)46108-6]

I. INTRODUCTION

As magnetic recording pushes to higher areal densities, perpendicular media[1] may have advantages in thermal stability over longitudinal media, and thus help to delay the arrival of the superparamagnetic limit.[2] Co/Pt multilayer films demonstrate strong perpendicular anisotropy[3] and high remanence squareness, and have been used as perpendicular media for magneto-optic applications.[4] Recent experiments[5] of domain wall motion suggest that Co/Pt multilayers could potentially sustain 400 Gbits/in^2. However, long-range exchange coupling often results in higher thermal stability but lower signal-to-noise recording. In $Co_{1-x}Cr_x$ films, weakly or nonmagnetic Cr-rich regions form at the grain boundaries that reduce the intergranular exchange coupling and result in lower medium noise. Therefore, it may be expected that doping Cr into the Co layers may also act as a segregant to reduce media noise. Following the work by Lairson *et al.*,[6] we investigated the viability of $Co_{1-x}Cr_x$/Pt multilayers as stable perpendicular media capable of high recording densities. We present the structure, magnetic, and recording properties of $Co_{1-x}Cr_x$/Pt multilayers as a function of growth parameters and chemical composition. In particular, we are interested in understanding the segregation process in these structures. In $Co_{1-x}Cr_x$/Pt multilayer films with perpendicular magnetization, the individual $Co_{1-x}Cr_x$ layers are less than 10 Å thick. We found that the segregation dynamics differ significantly from that in thicker $Co_{1-x}Cr_x$ films.

II. EXPERIMENT

The present multilayer films were deposited by magnetron sputtering from elemental sources onto glass substrates. The substrates were mounted onto a holder, backed by a quartz lamp heater, that can achieve stable elevated temperatures and can rotate ($\sim$1 Hz) to improve film uniformity. The addition of chromium to the cobalt layers was achieved by cosputtering from elemental Co and Cr sources. The Cr addition is thought to serve as a segregant to reduce the intergranular coupling, which is a primary source of transition media noise. Each film had a 200–300 Å Pt underlayer to serve as a template to attain the required microstructure for perpendicular magnetization and high coercivity. Films with a range of Cr compositions ($0 \leqslant x \leqslant 60$ vol. %), sputtering pressures (3 and 10 mTorr), and deposition temperatures (30–330 °C) were explored. The multilayer films with the structure $[Co(a\ Å)/Pt(b\ Å)]_N$ were deposited where $4 \leqslant a \leqslant 6$, $2 \leqslant b \leqslant 17$, and $N=10$ or 12. The Cr addition was performed by substituting Cr for Co such that the $Co_{1-x}Cr_x$ film thickness was held constant. As an oxidation barrier, the films were capped with a 30 Å Pt layer. Film thickness values were calibrated using x-ray diffraction, and controlled during deposition by a computerized shutter system. The Cr content of several films was verified using Rutherford back scattering (RBS) measurements.

III. RESULTS AND DISCUSSION

Low-angle x-ray reflectivity curves shown in Fig. 1 confirm the multilayer structure and bilayer periodicity of films grown at several deposition temperatures. Due to the short bilayer periodicity ($\sim$11 Å) and enhanced interfacial roughness of the films, only the first superlattice peak is observed. High-angle diffraction measurements indicate a weak (111) texture with a single superlattice reflection. We find no significant differences in the structure with Cr content. The intensity of the superlattice peak, however, decreased with increasing deposition temperature, as seen in Fig. 1. This indicates that the reduction of the layered structure is due to greater interlayer diffusion or alloying.

Room-temperature perpendicular magnetization measurements were performed using the polar magneto-optical Kerr effect (MOKE) and a superconducting quantum interference device (SQUID) magnetometer. Films deposited at 3 mTorr Ar exhibited perpendicular magnetization but low coercivity ($H_C<1$ kOe) even at elevated deposition temperatures. Films deposited at 10 mTorr Ar exhibited full remanence ($M_r=M_S$) and large coercivity values (up to 6.9 kOe) particularly at elevated deposition temperatures. Enhanced coercivity due to elevated sputtering pressures has been ob-

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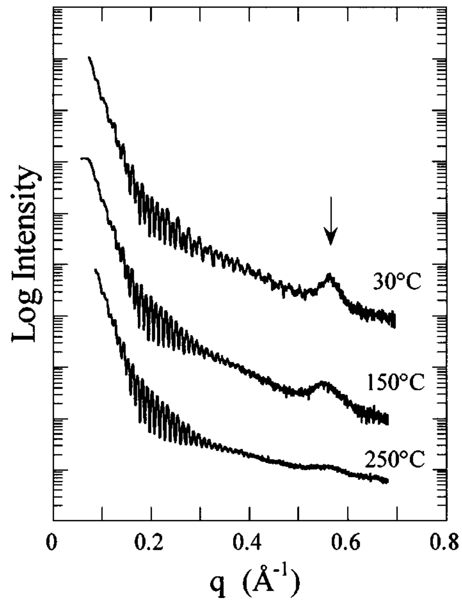

FIG. 1. Low angle x-ray reflection measurements of $[Co(4\ Å)/Pt(7\ Å)]_{12}$ films deposited at 30, 150, and 250 °C. The arrow indicates the position of the first superlattice peak. The short wavelength oscillations are due to the film thickness.

served in the Co/Pd system.[7] Shown in Fig. 2 are the MOKE loops for $[Co(4\ Å)/Pt(7\ Å)]_{12}$ multilayers deposited at 30, 150, and 250 °C. The coercivity H_C and squareness (S^*) of the magnetization loops are a nonmonotonic function of the substrate temperature. Co/Pt films grown at 150 °C consistently exhibited very square loops ($S^* \sim 0.95$) and slightly reduced H_C. With increasing deposition temperature above 150 °C, an increase in H_C and a decrease in S^* was observed.

A series of $[Co_{1-x}Cr_x(4\ Å)/Pt(7\ Å)]_{12}$ films with different Cr concentrations were deposited at various deposition temperatures: 30, 150, and 250 °C. The addition of Cr, in general, increased S^* of the magnetization loops. The coercivity of Cr doped samples deposited at 30 and 150 °C were comparable. The coercivity, however, was considerably enhanced when the deposition temperature was increased to 250 °C. H_C values decreased slightly with increasing Cr

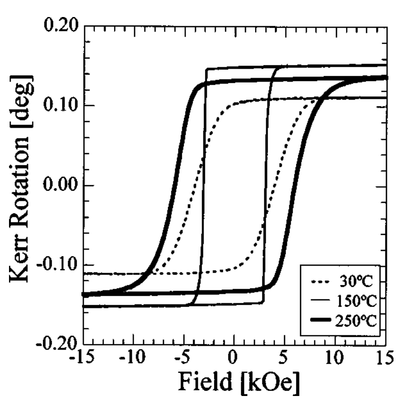

FIG. 2. Polar MOKE loops of $[Co(4\ Å)/Pt(7\ Å)]_{12}$ films deposited at 30, 150, and 250 °C. The coercivity and squareness of the loops is clearly dependent upon the deposition temperature.

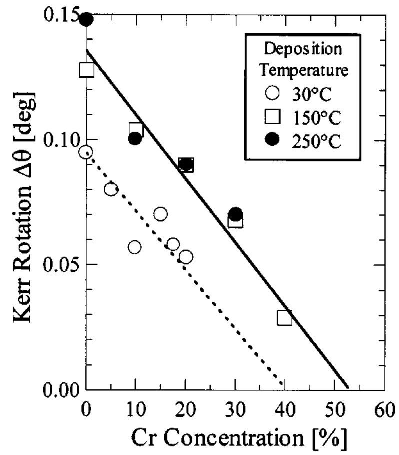

FIG. 3. Kerr rotation amplitude dependence on the Cr concentration of $[Co_{1-x}Cr_x\ (4\ Å)/Pt(7\ Å)]_{12}$ films deposited at 30, 150, and 250 °C.

concentration up to 20% and then decreased more rapidly above 30% Cr.

Figure 3 shows the polar Kerr rotation amplitude dependence on the Cr concentration. The polar Kerr rotation, which is linearly dependent on the magnetization to first order[8], decreases linearly with increasing Cr concentration. The Kerr rotation is smaller for films deposited at 30 °C than at elevated deposition temperatures. Extending the Kerr rotation curves in Fig. 3, the thin CoCr layers deposited at 30 °C become nonmagnetic at ~40% Cr. For the elevated deposition temperatures, however, a ferromagnetic signal is observed for the $Co_{60}Cr_{40}/Pt$ film and may persist for Cr concentrations greater than 50%. These concentrations are considerably higher than previously observed in either bulk $Co_{1-x}Cr_x$ alloys or $Co_{1-x}Cr_x$ films which are paramagnetic for Cr compositions greater than 24% and 34%, respectively.[9] This suggests that the very thin $Co_{1-x}Cr_x$ layer thicknesses in these structures (~4 Å) or the proximity to the Pt layers enhance the chemical segregation of Co and Cr. In the CoCr phase diagram, there is a magnetically driven segregation of ferromagnetic and paramagnetic hexagonal-close-packed (hcp)-CoCr phases. However, this is limited to the hcp region of the phase diagram ($x < 37\%$). The structural transition to a sigma phase for $x > 37\%$ is thought to limit the segregation process.[9] However, for the thin layers in the CoCr/Pt multilayers, the CoCr structure is determined by the Pt layers, so the magnetic segregation process may extend to much higher Cr concentrations. This result is consistent with recent observations of chemical segregation in ultrathin Co–Cr films on *W* substrates.[10]

Thermal stability of the $Co_{1-x}Cr_x/Pt$ multilayer films was also measured using a SQUID magnetometer. The samples exhibited excellent thermal stability with typical logarithmic decay rates at 30 °C of only 0.05%–0.10% of the remanent moment per decade of time. The effect of Cr doping on thermal stability was not discernible at such small decay rates.

Magnetic and atomic force microscopy images of unmagnetized samples were used to correlate the grain and magnetic domain structures. The degree of intergranular segregation was clearly dependent on the deposition tempera-

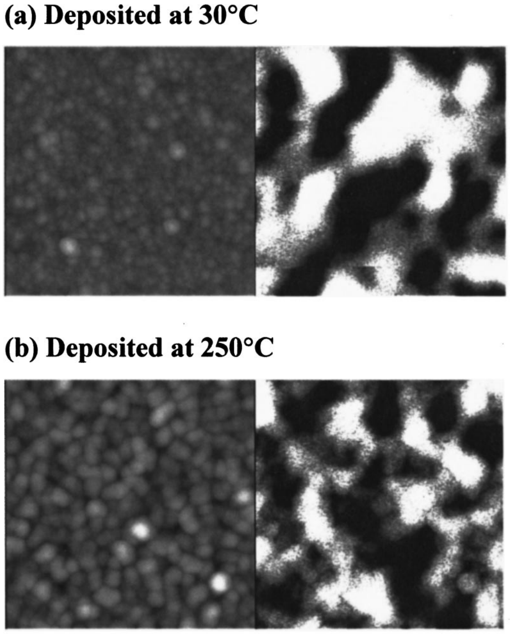

FIG. 4. AFM (left side) and MFM (right side) images of $[Co_{80}Cr_{20}(4\ Å)/Pt(7\ Å)]_{10}$ films deposited at (a) 30 and (b) 250 °C. The images represent sample areas of 1 μm by 1 μm.

ture. $Co_{1-x}Cr_x$/Pt films deposited at elevated temperatures exhibited smaller or finer magnetic domain structures presumably due to weakened intergranular exchange coupling. Figure 4 shows the atomic force microscopy (AFM) and magnetic force microscopy (MFM) images of $[Co_{80}Cr_{20}(4\ Å)/Pt(7\ Å)]_{12}$ films deposited at 30 and 250 °C. In the film deposited at 30 °C, the magnetic domains are comprised of cluster sizes of >20 grains, whereas the film deposited at 250 °C has clusters comprised of only 4–12 grains. The transition between the magnetic domains occurred at the grain boundaries.

Initial spin-stand measurements were performed using a Guzik test stand with a ring head for recording and a giant magnetoresistance (GMR) spin valve head for readback. However, the writing mechanism was not optimized for the perpendicular recording geometry. For each sample, S_ONR (isolated transition versus media noise at recording density) was measured for written transitions at a spatial frequency of 10 kiloflux changes per millimeter (kfc/mm) as a measure of comparison. Best results are 23 dB for a $[Co(4\ Å)/Pt(5\ Å)]_{10}$ film deposited at 330 °C. The S_ONR at 10 kfc/mm systematically decreased with decreasing deposition temperature, which is associated with higher S^* and lower H_C. For $[Co(a\ Å)/Pt(5\ Å)]_{10}$ films where $4 \leqslant a \leqslant 6$, increasing the Co layer thickness resulted in higher remanent moments and increased H_C, but decreased the S_ONR. In the films tested, the integrated media noise increased with increasing recording densities resulting from additional contributions of transition noise. The addition of Cr into $[Co_{1-x}Cr_x(\sim 5\ Å)/Pt(5\ Å)]_{10}$ films, where $13\% \leqslant x \leqslant 31\%$, increased the squareness of the loops. S_ONR, however, was not very sensitive to Cr addition in this compositional range.

IV. CONCLUSION

We have demonstrated the thermal stability and perpendicular magnetic recording capability of $Co_{1-x}Cr_x$/Pt multilayers. The multilayers films exhibited strong perpendicular anisotropy, coercivities as high as 6.9 kOe, and high thermal stability. The degree of intergranular exchange, which is reflected in the coercivity and squareness (S^*), is clearly dependent on the sputtering pressure, deposition temperature and, to a lesser extent, Cr composition of the multilayers. Differences in intergranular exchange were also reflected in the magnetic domain structure of the films and observed directly by MFM and AFM measurements. The $Co_{1-x}Cr_x$/Pt multilayers are ferromagnetic at room temperature for $x > 30\%$ which is not observed in thick $Co_{1-x}Cr_x$ films and indicates differences of the segregation process or Pt polarization effect in the ultrathin film limit.

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