Interdiffusion and Grain Isolation in Co/Cr Thin Films

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***Abstact*--In this work, interdiffusion and grain isolation in Co/Cr films have been investigated by studying the dependence of the magnetic properties on the substrate preheating temperature as well as on post-deposition annealing processes. By choosing pure Co instead of a Co-alloy, the possibility of grain isolation caused by the segregation of solute atoms from within the magnetic layer has been eliminated. It is found that both post-deposition thermal annealing and substrate preheating can effectively increase the isolation of the Co grains.**

I. INTRODUCTION

In order to reduce media noise, it is critical that the grains of the magnetic layer be magnetically isolated from each other [1], [2]. The magnetic grains can be isolated either geometrically [3], [4] or compositionally by inhomogeneities in the magnetic layer [5]-[7]. The most widely studied processes which may lead to compositional isolation include chemical segregation of nonmagnetic second phases [5] or solute atoms [6] to the grain boundaries, as well as phase separation within each grain [7]. These processes occur within a magnetic layer. Recently, T. Kawanabe et al. [8] and M. Sato et al. [9] found that the coercivity of Co-ternary alloy/Cr films increased after annealing. This increase in coercivity was considered to be caused by grain isolation, which is enhanced by Cr atoms diffused from the underlayer into the grain boundaries in the Co alloy layer. However, as mentioned above, grain boundary segregation processes are also possible within the Co alloy layer. This may also improve the grain isolation and lead to an increase in coercivity.

In this work, interdiffusion and grain isolation of magnetic films composed of pure Co and Cr layers are investigated. By choosing pure Co instead of a Co-alloy, the compositional imhomogeneities caused by the solute atoms within the magnetic layer is eliminated.

II. EXPERIMENTAL

All films were RF sputter deposited in an LH Z-400 sputtering system on Corning 7059 glass substrates. Unless otherwise specified, the films studied in this work are composed of three layers, a 1000 Å Cr underlayer, a 400 Å Co layer and a 200 Å Cr overlayer. The impurity of the Co target is less than 0.01%. The Cr overlayers were used to prevent the Co layers from being oxidized during annealing. The magnetic properties were measured with a VSM. The substrates were heated to various temperatures before deposition or the films were annealed at various temperatures in vacuum after deposition by a resistance heater.

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III. RESULTS AND DISCUSSION

A. Post-Deposition Thermal Annealing

Four samples were annealed in vacuum. Starting from 300 °C, the samples were annealed at the series of temperatures, 300+50n °C (where n=0,1,2,3,4,5) for one hour. After annealing at each temperature, the samples were removed from the furnace, and their magnetic properties were measured at room temperature. The sputtering conditions of each sample are listed in Table 1. Depending on the sputtering conditions, the Cr underlayer had either the (110) or the (002) crystallographic texture [10] (see Table 1).

The magnetic hysteretic properties of the samples changed significantly with thermal annealing. In Fig. 1, the ratio of M_s of the film after annealing to that of the as-deposited state is plotted against the annealing temperature. For each sample, the M_s decreases with thermal annealing. Since M_s is an intrinsic property of the magnetic material, the change in M_s indicates a change in the composition of the magnetic material. Because increasing Cr concentration in Co strongly reduces the Co magnetic moment [11], the significant decrease in M_s demonstrates that Cr atoms diffused into the Co grains when the samples were annealed. On the other hand, for different samples, the rates at which M_s decreased were different, although they had similar M_s values before any annealing. Since each film was deposited under different conditions, they had different microstructures. Therefore, the difference in the rates of decrease of M_s implies that the interdiffusion depends on the thin film's microstructure. As suggested in Fig. 1, the interdiffusion in sample 2 is much

TABLE 1. SPUTTERING CONDITIONS AND TEXTURE OF THE ANNEALED FILMS

Sample	Ts (°C)	Bias on Cr Underlayer (V)	Texture of Cr Underlayer
1	RT.	none	(110)
2	260	none	(002)
3	RT.	-200	(110)
4	260	-200	(110)

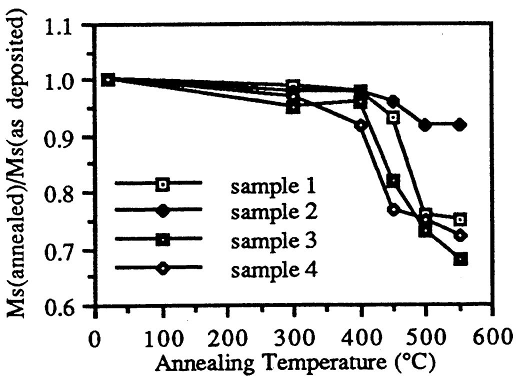

Fig. 1. Decrease of M_S with increasing annealing temperature.

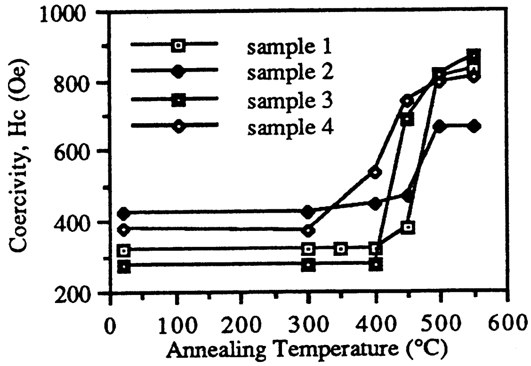

Fig. 3. Increase of H_C with increasing annealing temperature.

slower than that in other samples. It is very interesting to note that sample 2 is the only one in the group with the (002) textured Cr underlayer.

For each sample, the coercivity squareness, S*, decreases, and the magnetic coercivity increases along with annealing, as shown in Figs. 2 and 3 respectively (except that the S* of sample 2 does not change significantly with annealing). These changes of hysteretic properties with annealing are believed to be the result of weakening of the exchange and/or magnetostatic interactions among Co grains [12, 13]. In other words, the Co grains are more isolated after annealing. This is also confirmed by comparing the ΔM measurements before and after annealing of each sample [14, 15]. The peak value of the ΔM of each sample was reduced by annealing, as shown in Table 2.

B. *Effect of Substrate Preheating Temperature*

The dependence of microstructure and magnetic properties upon the substrate temperature has been reported by several groups [16], [17]. However, in those works, the interdiffusion between Cr and Co-based alloy layers during deposition was largely ignored. Here, interdiffusion of Cr from the underlayer is examined by studying the effect of substrate temperature on the magnetic properties of three groups of films composed of

TABLE 2. PEAK VALUE OF ΔM BEFORE AND AFTER ANNEALING

sample	as deposited	annealed
1	1.4	0.8
2	1.4	1.1
3	1.5	0.3
4	1.3	0.2

pure Co and Cr layers. The films in Group A are single 400 Å thick Co layers on substrates. The films in Group B and C have the same configuration as we discribed in the experimental section. The Cr underlayers of the films in Group C were deposited with -200 V substrate bias while those in Group B were deposited without applying any substrate bias.

In Fig. 4, M_s of the three groups of films are plotted vs. substrate preheating temperature. The M_s of Group A films does not depend on substrate temperature. This shows that the deposition rate does not vary with T_s and that surface oxidation is negligible. Within Group B and C, the M_s decreases as substrate temperature increases. As explained in the previous section, this indicates interdiffusion between Co and Cr layers.

For films in Group B and C, the dependence of hysteretic properties on the substrate temperature suggests that elevated substrate temperatures improve grain isolation. Both S* and S decrease with increasing T_s, as shown in Figs. 5 and 6 respectively, while H_c increases with T_s, as shown in Fig. 7.

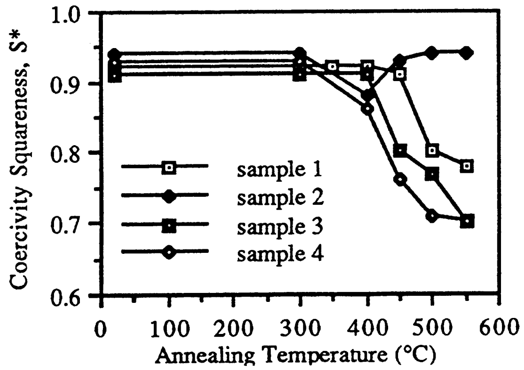

Fig. 2. Change of S^* with increasing annealing temperature.

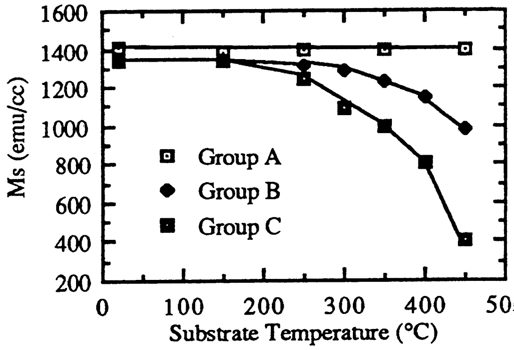

Fig. 4. Dependence of M_S on substrate temperature.

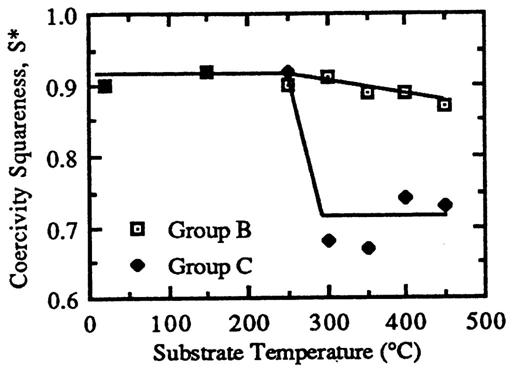

Fig. 5. Dependence of S^* on substrate temperature.

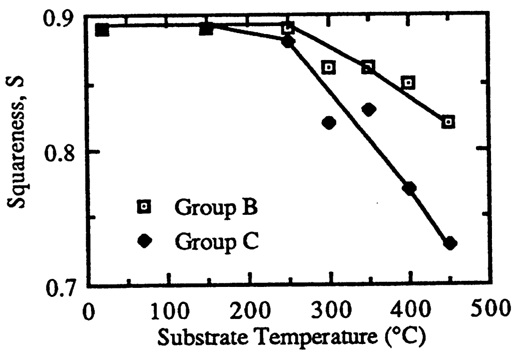

Fig. 6. Dependence of S on substrate temperature.

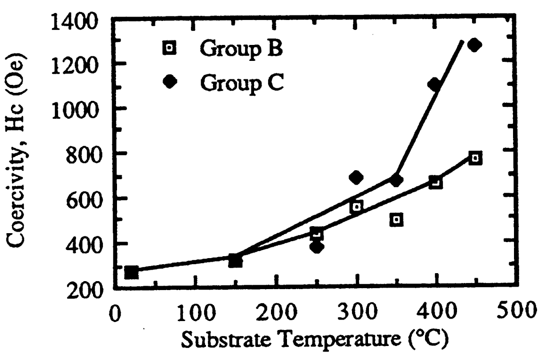

Fig. 7. Dependence of H_c on substrate temperature.

As we discussed in the last section, this indicates that the isolation of Co grains is enhanced with T_s. This is further confirmed by the ΔM measurements. For both Group B and C, the peak values of the ΔM decrease with increasing T_s, as shown in Fig. 8. This demonstrates that the magnetic exchange coupling between Co grains is weaker if the film is deposited at higher T_s. Comparing Group C with Group B, as the T_s increases, the decrease of the peak value of ΔM is more rapid within Group C. As shown in Fig. 4, the decrease of M_s as the T_s increases is also more rapid within Group C. Clearly, the grain isolation is closely related to the interdiffusion between Co and Cr layers.

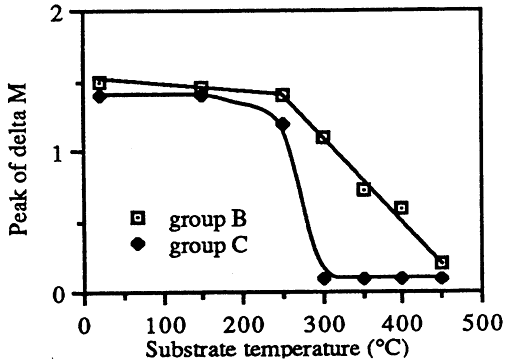

Fig. 8. Dependence of the peak value of ΔM on substrate temperature.

IV. Summary

In summary, interdiffusion between Co and Cr layers is significant when the film is annealed or deposited at elevated temperatures. This interdiffusion significantly increases the grain isolation. It is also found that the interdiffusion depends on the microstructure of the film.

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