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Magnetic Properties and Interactions of Nanostructured CoCrTa Thin Films

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Abstract: *Magnetic properties of CoCrTa alloy thin films were studied as function of the deposition pressure. Films deposited at low deposition pressure showed low coercivity and high loop squareness ratio. At relatively higher deposition pressurean increase in the samples' coercivity, and decrease in both the magnetic loop squareness ratio, andthe strength of the exchange interaction amongst the grains of the films were recorded. The observations indicate the films to have properties quite suited for recording media application as well as magnetic memory devices.*
Keywords:*sputtering pressure, magnetic domains, magnetic interactions, nanostructure, Lorentz microscopy*

I. Introduction

There has, recently, been much interest in the development of materials in which the characteristics length scale of the composing units approaches (or are in) the nanometer range [1 – 5]. Device and component miniaturization is a good driver for such interest, e.g. [1,2]. However, understanding the fundamental physics behind the arising novel physical properties of these materials and their applications for future devices contributes as much to this interest [3 – 5].

The development of nanostructured magnetic materials promises the facilitation of good understanding and control of magnetic properties such as magnetization direction/reversal domain structure and the correlation of the many intrinsic material properties such as anisotropy, saturation magnetization etc. with the nano/micro-structural setting of the material. This understanding has become essential now for further development of the many applications of cobalt-based alloy thin films such as in hard disk drives, spintronics components, data storage devices, magneto-resistance random access memory, sensors, etc. [6 – 11]

The fabrication of nanostructures is achieved by several methods – old and novel [12 – 14] including deposition within the pores of porous materials [15, 16]. In a recent work, nanostructures were exhibited in films deposited on ultra-flat glass substrates at moderate sputtering pressures [17]. The evolution of the microstructure as the deposition pressure is varied showed nano-grained magnetic 'particles' dispersed in non-magnetic material. This structure evolution is well suited for the investigation of the magnetic properties and the characterization of the interactions existing amongst the grains of the films. In this work, the evolution of these properties with the deposition pressure is reported.

II. Method

Thin films of $Co_{78.6}Cr_{18.9}Ta_{2.5}$ were deposited from solid CoCr alloy and Ta targets onto Nippon glass disk substrates by magnetron sputtering process with no substrate bias or heat treatment. Background pressure in the chamber before deposition was 1.0 x 10^{-6} mbar or better. Argon gas sputtering pressure was varied between 2.0 to12.0 x 10^{-3}mbar. Specimen composition and thickness were determined on Jeol scanning electron microscope using the energy dispersive analysis of x-ray spectra (EDAX).

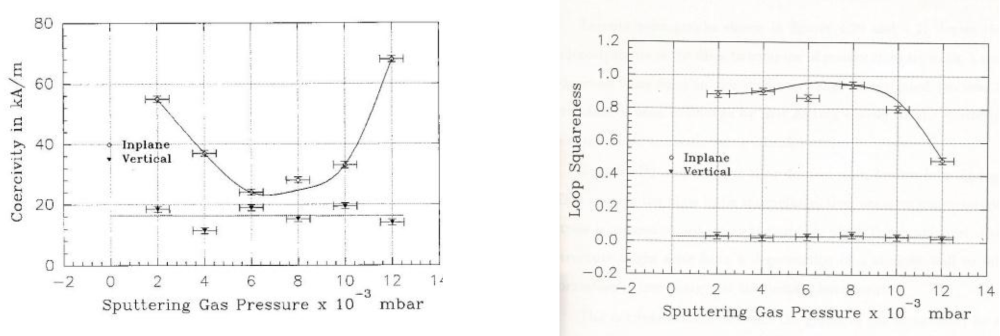
The magnetic microstructure of the films were observed on a Jeol transmission electron microscope operating at 200 kV, static magnetization measurements were conducted on a vibrating sample magnetometer (VSM) and remanence measurements were performed on alternating gradient field (AGF) magnetometer. Table 1 below summarizes the coating structure of the samples studied.

Table 1: coating parameters of samples studied

Sample	Thickness (nm)	Deposition Pressure x 10^{-3}*mbar*
B1	41	2.0
B2	39	4.0
B3	42	6.0
B4	40	8.0
B5	43	10.0
B6	38	12.0

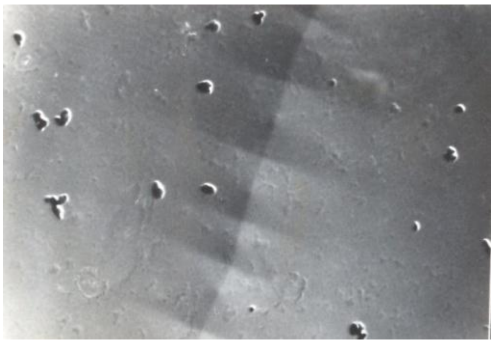
III. Results and Discussion

Out of plane (perpendicular) coercivity could be seen in Fig.1 (a) to remain independent of the deposition pressure while the In-plane coercivity initially decreases as the deposition pressure is increased;it went through a minimum before increasing. Two types of interactions are thought to govern the magnetic properties nano-structured materials. These are the demagnetizing-like dipolar interactionand the magnetizing-like exchange interaction [18, 19]. From the micro-structural character of thefilms, which showed enhanced grain isolation as the deposition pressure is increased, (reported in [17]),low values of in-plane coercivity could be expected in samples that showed continuous microstructure. In continuous and fine grained films, uniform or good orientation of the magnetic microstructure may be expected. This magnetic microstructure would favor co-operative switching of magnetization as a result of the high degree of exchange coupling (enhanced exchange interactions) amongst the uniform and continuous grains of the samples. When the microstructure becomes non-uniform, with the magnetic micro-structural units separated by voids or other non-magnetic materials as reported, it would be expected that the degree of exchange coupling will decrease. The switching mechanism will no longer be by pure coherent rotation but a mixture of it and other mechanisms the like nucleation and domain wall movement. This later microstructure is expected to show larger coercivity values compared with the continuous one. The presence of voids hinders free domain wall motion – pinning of domain walls [20].

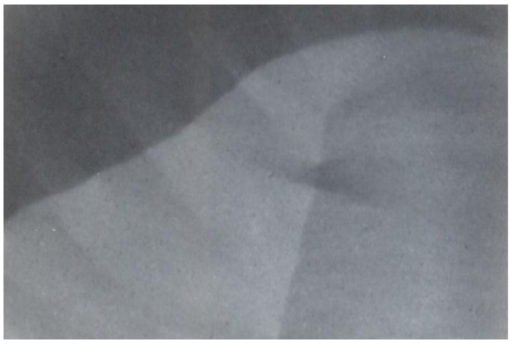


(a) (b)

Figure 1: Static magnetization measurements (a) in-plane and perpendicular coercivities (b) loop squareness as functions of the deposition pressure



(a)



(b)

(c) (d)

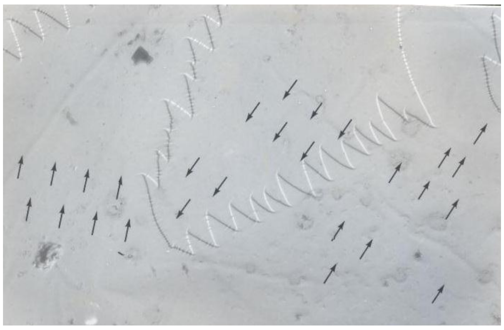
Figure 2: Magnetic microstructure: Foucault images of samples (a) B1 (b) B2 (c) B4 and (d) B6 deposited at argon sputtering pressures of 2.0, 4.0, 8.0 and 12.0 x 10^{-3}*mbar* respectively. Magnification × 25, 000

Magnetic (hysteresis) loop squareness ratio (Mr/Ms) could be seen in Fig. 1 (b) to have slightly higher values for samples deposited with low (relative) sputtering pressure, this is consistent with the suggestion of high degree of exchange coupling among films with continuous microstructure. Similarly, the samples that showed isolated grains (samples B4 and B6) have lower squareness values; in a way confirming a decrease in the strength of the exchange coupling. This corroborates with the recent works of Dospial and Plusa [21] and that of Zhang et al [22] where rough-grained films showed lowsquareness ration but uponannealing the ratio deteriorates.

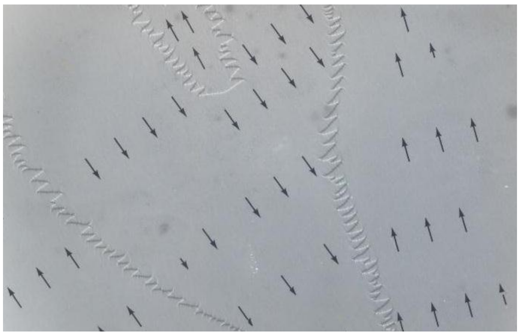
Low values of the squareness ratio do indicate that the strength of a read/write signal made of out this material be substantially low. The operation/performance of a magnetic read/write head device require high values of the squareness ration. This suggests that the material may be effective in magnetic random access memory MRAM and magnetic memory device applications

Micrographs of the magnetic microstructures of the samples studied are shown in Fig.s 2 and 3. The in-focus (Foucault) micrographs, usually good for investigation magnetic domain patterns, is shown in Fig. 2. These images (Foucault) resemble Kerr images but the resolutions they provide far surpass the optical resolution of the Kerr method. The domain structure supports the conclusion drawn from the static magnetization measurement. Micrograph of sample B1, shown in Fig. 2a, could be seen to compose of large domains. Vast in extent that, at this magnification, only to oppositely orientated domains are visible within the region shown. In samples B2 and B4, Fig. 2b and 2c respectively, the number density of the domains could be seen to increase. In Fig. 2d, showing the micrograph of sample B6, not only does the density increases the domain structure becomes complex. Samples in which there are strong exchange interactions, single domain structure is expected unless the sample size becomes large. Multiple domains are formed in large samples to reduce stray field energy. In samples with reduced inter-granular exchange interactions, the formation of many and randomly oriented domains will be expected [23].

In Fig. 3, the de-focused micrographs of the samples are shown. This mode of magnetic microstructure imaging (Lorentz microscopy) provides excellent opportunity of studying or investigating domain walls and their structures. The samples have cross-tie walls as their dominant wall structure. This wall structure is common for films in the thickness range investigated. Samples B1 and B2 could be seen to have their extended domain wall broken into zigzag structures. Large (long) walls often broke into zigzag structures to avoid the occurrence of charged walls. Charges are distributed in the space between the zigzags.



(a)



(b)

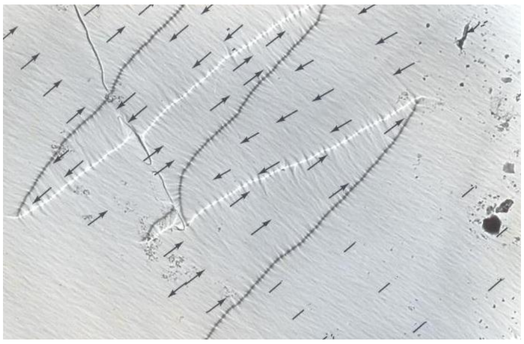
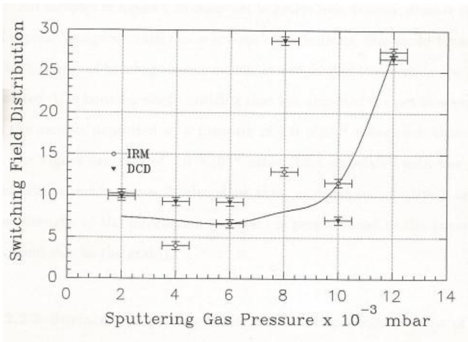


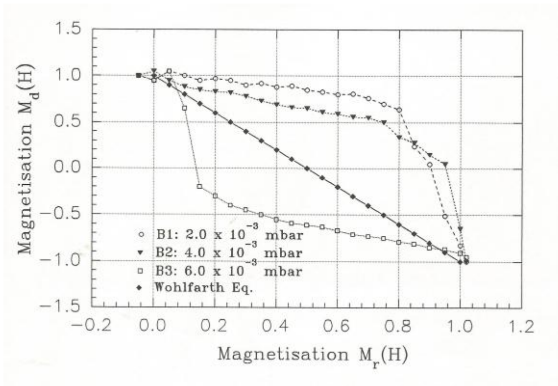
Figure 3: Magnetic microstructure: direct Lorentz images of samples (a) B1 (b) B2 (c) B4 and (d) B6 deposited at argon sputtering pressures of 2.0, 4.0, 8.0 and 12.0 x 10^{-3}*mbar* respectively. Magnification × 2.5×10^{6}

The increase in the complexity and random orientations of the domains of the samples as their grains becomes more isolated could also be seen from the wall structure of samples B4 and B6 of Fig. 3c and 3d.

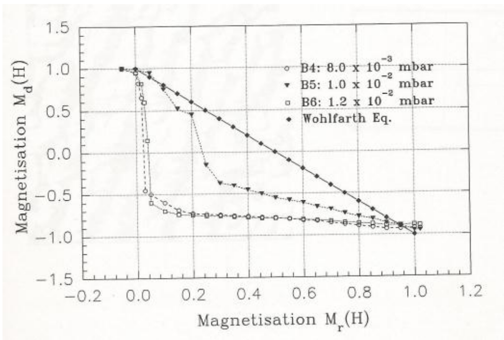
To further investigate the nature and character of the interactions amongst the grains of the samples remanence measurements were conducted on the sample. The remanence magnetization $M_r(H)$ – Isothermal Remanence Magnetization (IRM) is recorded after a (positive) field, H, is applied and remove while the remanence magnetization $M_d(H)$ – the DC Demagnetization (DCD) is recorded on a previously saturated sample after the application of a reverse (negative) field H. Switching Field Distribution, measured from these two principal remanence curvesshows, Fig. 4 (a), the distribution getting broader as thepressure is increased; sharp distributions often imply strongly (exchange) coupled grains while broaddistributions are associated with little or weak exchange coupling [24, 25].



(a)



(b)



(c)

Figure 4: Remanence magnetization measurements (a) Switching field distribution andHelkel plots of samples deposited at sputtering pressures of (b) 2.0, 4.0, 6.0 (c) 8.0, 10.0 and 12.0 x 10^{-3}*mbar* respectively

The net interactions between the grains of the films could be seen in the Henkel plot shown in Fig.4 (b) to be positive (large exchange component) in samples deposited at sputtering pressures of 2.0 and 4.0 x 10^{-3}*mbar* while that deposited at 6.0 x 10^{-3}*mbar* shows net negative interaction. All samples in Fig.4 (c) show net negative interactions; greater component of dipolar (magnetostatic) interactions contributions, this could be ascribed to a high degree of breakage in the exchange coupling of the films as the grains get isolated. It is however worth noticing that the degree of the net breakage is more in the sample deposited at a pressure of 8.0 x 10^{-3}*mbar* than that deposited at the higher pressure of 1.0 x 10^{-3}*mbar*. This correlates with the microstructure observed. It also supports the explanations of the strength of the interaction (dipolar) being proportional to the grain size [26].

IV. Conclusion

Cobalt based CoCrTa alloy thin films were deposited at different sputtering gas pressures. The static and remanence magnetic properties have been studied. The results showed that at low sputtering pressures, the

samples were characterized by low coercivity, high loop squareness ratio; these properties make these films good candidate for magnetic read/write head application in magnetic recording systems.
At higher deposition pressures, the films showed decreased loop squareness ratio, increase in coercivity and weakening of the strength of the magnetizing-like interactions amongst the grains of the films. These features are key to the development of material/ media for high density magnetic recording. The low (relatively lower) loop squareness ratio of samples deposited at these pressures also qualifies them as good candidate for magnetic memory and MRAM applications.

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