EFFECT OF TANTALUM ADDITION TO THE MAGNETIC PROPERTIES OF CoCr ALLOY THIN FILMS

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ABSTRACT
The effect of tantalum on the magnetic properties of Co-alloy thin film is investigated. Samples in which the tantalum substitutes into the hcp crystal structure of the alloy as well as samples in which it is segregated to the grain boundaries are studied. Grain boundary segregation (grain isolation) was found to decrease media parameters responsible high media noise. Neither isolation nor substitution was found to improve saturation magnetization.

Keywords: *Magnetic domains, magnetocrystalline anisotropy, recording media, segregation, magnetic interactions.*

1. INTRODUCTION

The strong growth the information society has been fueling the demand for high density hard disk drives [1]. These are mainly used as secondary memory of computers. Newer demands for applications in other devices such as video camera recorders, portable music players, cellular phones are also emerging. There has also been remarkable development in HDD recording density. Disks with area density of around 70 Gb/in2 are already in the market and in the laboratory density of 150 Gb/in2 has been demonstrated [2,3]. The rate at which the recording capacities have been increasing seems to exceed the projection of Moore's law![1], Figure 1a demonstrates the pace of this development. Further development largely depends on the development of media with very low media noise and good thermal stability [4 –6]. These are two conflicting characteristics – thermal stability decreases with decrease in media noise. Materials with high saturation magnetization, M_s (and therefore high uniaxial anisotropy constant K_u) would promise good thermal stability while isolated and fine grained films have been predicted to support high transition signal-to-noise ratio, SNR, that is, reduced media noise [7 – 9].

To support low noise several materials have been proposed. In particular CoCr alloy thin films have been extensively studied. In this alloy, chromium is often thought to segregate forming a non-magnetic rich layer around the magnetic, cobalt rich, grains [10 – 12]. This structure ensures the high M_s values required as well as providing for the grain isolation that decrease interactions between the magnetic units of the media. Addition of tantalum to the CoCr alloy could also lead to the segregation of the tantalum as it has a much larger atomic size [13].

There were attempts to study the effect of the addition of tantalum to the structure of CoCr thin films [13,14]. Segregation was reported [13] as well as tantalum substitution (or accommodation) into the grain crystal structure [14]. In a study that attempts to remove the influences of deposition conditions, both segregation and substitution were established [15]. In this work, the magnetic properties of the alloy films have been studied. Samples in which tantalum substituted as well as samples in which there is segregation form part of the study.

2. METHOD

Samples were deposited by dc triode sputtering with a back-ground pressure in the chamber, before deposition, of 1.0×10^{-6} mbar or better and an argon gas sputtering pressure of 5×10^{-3} mbar. Target power and deposition rate were 300 watts and 1.5 nm/s respectively.

Specimen compositions were determined using Rutherford Back Scattering (RBS) spectrometry and confirmed by energy analysis of x-ray spectra (EDAX) on scanning electron microscope.

Magnetic measurements were conducted on vibrating sample magnetometer (VSM) and the Lorentz images of the samples were recorded on transmission electron microscope operating at 200 kV.

Table 1 indicate the compositions and thicknesses of the samples studied

[1] Predicts a doubling of semiconductor integration in every year and a half.

Table 1: Coating parameters of the samples studied

sample	Thickness (nm)	Composition	Segregation/Accomodation
A1	40.1	$Co_{81}Cr_{19}$	Accommodation
A2	50.3	$Co_{80.5}Cr_{18.5}Ta_{1}$	Accommodation
A3	54.8	$Co_{78.6}Cr_{18.9}Ta_{2.5}$	Segregation
A4	44.9	$Co_{77.6}Cr_{18.3}Ta_{4\cdot1}$	Segregation
A5	49.8	$Co_{76.3}Cr_{18.4}Ta_{5.3}$	Segregation
A6	39.1	$Co_{73.5}Cr_{18.2}Ta_{8.3}$	Segregation
A7	50.2	$Co_{72.5}Cr_{16.5}Ta_{11}$	Amorphous
A8	59.6	$Co_{68}Cr_{17}Ta_{15}$	Amorphous

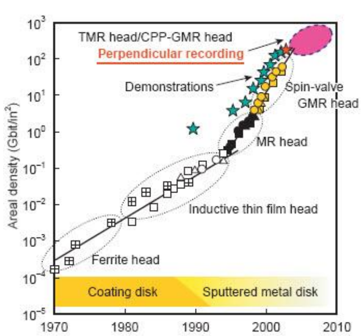
3. RESULTS AND DISCUSSION

The saturation magnetization values of the alloy are seen in figure 1 (b) to decrease with increasing tantalum content. The segregation of non-magnetic elements to the grain boundaries of the alloy has been reported to enhance M_s [16]. This is attributed to the increased concentration of the magnetic element within the grains of the film. On the other hand, substitution of a non-magnetic element into the grain structure of the alloy will cause a decrease in the concentration of the magnetic element of the alloy thereby reducing the saturation magnetizations.

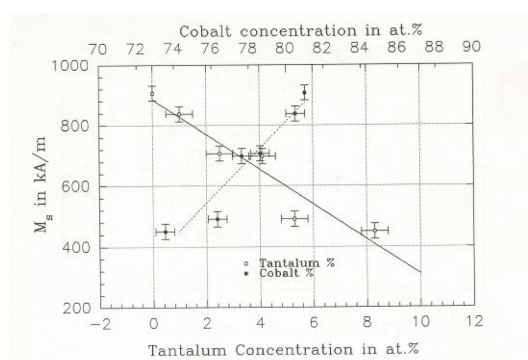
In figure 1(c), in-plane and perpendicular coercivities initially decrease with increasing tantalum, reach a peak at 2.5 at.% (of tantalum) and then drop. Perpendicular coercivity could be seen to be higher than the in-plane component. The theory of coherent magnetization reversal may indicate the samples to have a large component of their magnetization lying perpendicular to the film plane (easy axis normal to the film surface). However, this theory does not account for the existence of domain structure within the films.

Lorentz electron micrographs, shown in figure 2, indicate an increasing strength in the in-plane component of magnetization as the amount of tantalum in the film increases. The ripple structure is seen to be coarse in sample A1 and A2 indicating strong dispersion in the magnetization directions. Samples A3 could be seen to have a smoother ripple structure that indicates less dispersion and therefore more uniform magnetization direction. These micrographs also show an indication that sample A3 will have a relatively higher in-plane coercivity than the previous two. This agrees well with the measurement shown in figure 1(c). However, no evidence of perpendicular anisotropy could be seen in any of the samples, contrary to the conclusion that could be drawn from figure 1(c).

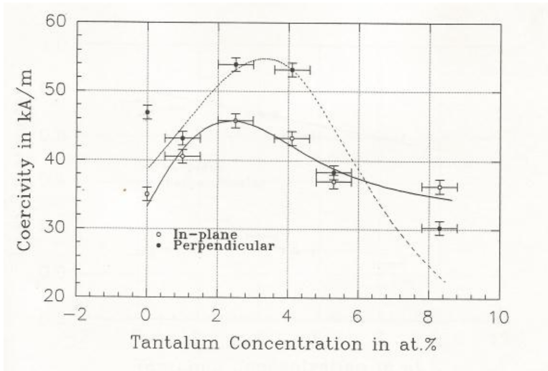
Initial susceptibility, measured from initial magnetization curves, decreases with increasing tantalum concentration. It has its minimum value at 4.1 at.% of tantalum. This supports the conclusion from the Lorentz micrographs that the strength of the in-plane component of magnetization increases with increasing tantalum concentration. It was earlier indicated that decrease in initial susceptibility is often accompanied by a decrease in the coarseness of the magnetic microstructure [17], and the initial susceptibility to be inversely proportional to the film coercivity.



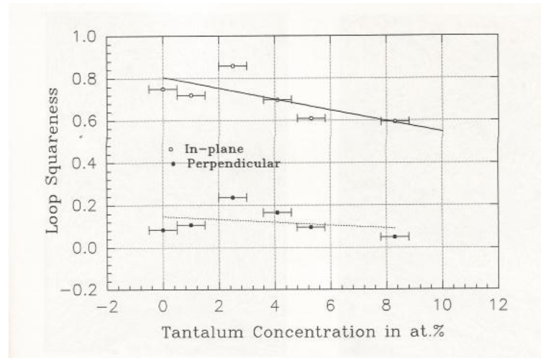
(a)



(b)



(c)



(d)

Figure 1: (a) Trend in recording density development, after Kaitus [1] and Static magnetization measurements (b) Saturation magnetization in KA/m (c) in-plane and perpendicular coercivities and (d) loop squarenes as functions of tantalum concentration.

The variation of remanence coercivity H_r and average switching field H'_r, with tantalum concentration are shown in table 2. Both are seen to be consistent with the static magnetization measurements. The same table shows the variation in the remanence saturation field H_s^r, it is seen to be in agreement with the domain structures observed; there are many possible nucleating centers through which the magnetization may relax after the removal of the aligning field.

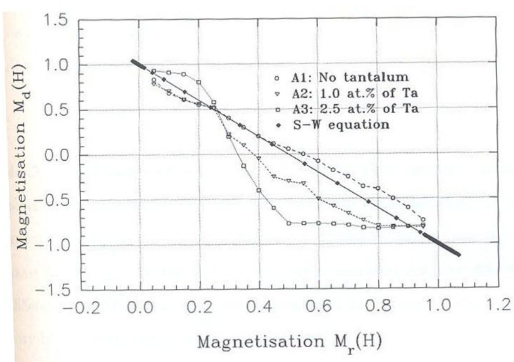
(a)

(b)

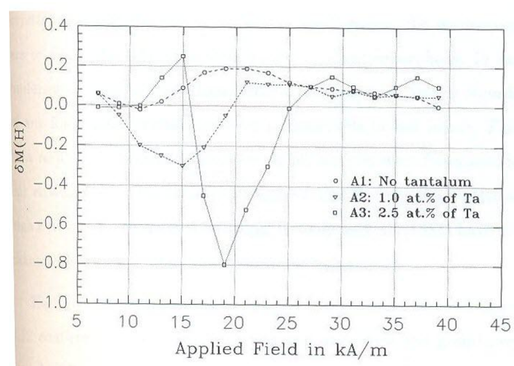
(c)

(d)

Figure 2: Lorentz electron micrographs of sample (a) A1, (b) A2, (c) A3 and (d) sample A4 , with tantalum concentration of 0, 1, 2.5 and 4.1 at.% respectively.



(b)



(b)

Figure 3: Remanence magnetization measurements (a) Henkel plot and (b) Delta M (δM) plot.

Table 2: Remanence properties of some of the samples; Switching Field distribution (SFD), evaluated by dividing the Full Width at Half Height (FWHH) by the coercive field of the samples. Field values are in kA/m

Sample	SFD (irm)	SFD (dcd)	CF (%)	IFF (%)	H_s^r (irm)	Hr	H'_r
A1	2.38	2.41	61.1	22.6	45.2	21.5	13.6
A2	3.03	2.38	66.6	18.5	62.9	21.0	13.5
A3	3.48	2.83	57.0	14.0	62.9	26.2	19.8

In the absence of interactions between the grains of the film, the switching field distribution evaluated from the two remanence curves – the isothermal remanence curve and the dc demagnetization curve – should be equal and follow the Wohlfarth equation [18]

$M_d(H) = 1 – 2M_r(H)$

Table 2 shows the difference to be minimum for sample A1. Similarly, the plot Md versus Mr, the Henkel plot, shown in figure 3(a) indicates least deviation from the straight line described by the Wohlfarth equation in this sample. Deviations from this line are associated with the degree of interactions among the magnetic grains of the film. The net interaction in the case of sample A3 is seen to be demagnetizing while, although very minimal in sample A1, it is magnetization. A delta M (δM) plot shown in figure 3(b) supports the Henkel plot. It suggests net positive interactions among the CoCr sample making the film easier to magnetize from a demagnetized state Md (H) > 1 – 2Mr(H). this is also seen to follow from the saturation field of the samples shown in table 2

Switching field distribution also shown in table 2 indications that the distribution tends to gets broader as the interactions in the material becomes more negative. This is consistent with the study on Barium Ferrite particles [19]. The table (table 2) also summarizes the measure of interaction in the samples via two different parameters, the coercive factor CF and the Interaction Field Factor IFF, measured around the coercive field.

4. CONCLUSION

Addition of tantalum to CoCrTa alloy thin film leads to both the substitution and segregation of the tantalum atoms. Substitution occur only at very low concentration, 1 – 2 at.%, while beyond 2.5 at.% segregation was dominant.[15]. Samples in which the segregation was established (A4 – A6) showed decreases in loop squareness and initial susceptibility and reduced inter-granular interactions among the (isolated) crystallites of the samples as compared with those in which substitution was recorded (A2 and A3). This is a good indication that grain isolation achieved through the segregation of non-magnetic elements like tantalum could lead to significant reduction of media noise and improved performance of the alloy films in magnetic recording applications.

As regard to the thermal stability of media made out of the alloy, there is no indication that the segregation could improve the uniaxial anisotropy of the media. The values of the saturation magnetization continue to decrease monotonically as the concentration of tantalum increases. The segregation does not seem to increase the amount of the magnetic element, cobalt, within the crystallites.

5. REFERENCES

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