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Effect of carbon overcoat implantation on the magnetic and structural properties of Perpendicular Recording Media

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Carbon overcoats play an important role in the corrosion protection of recording media used in hard disk drive technology. Filtered cathodic vacuum arc (FCVA) has been studied in the past as a potential technology for depositing media overcoat. In order to achieve desired property of FCVA carbon, it is essential to apply a suitable bias voltage, which results in an energetic carbon deposition on the magnetic layer of the recording media. In this paper, we focus our attention on the implantation effects of energetic carbon on the magnetic and structural properties of recording media of two types; AFC and a single layer, in order to gain a meaningful insight on the implantation and its effect. The studies reveal that the energetic deposition alters the anisotropy constant of the magnetic layer, resulting in a reduction in the coercivity and thermal stability factor.

Index Terms— magnetic recording, carbon overcoat, implantation, areal density, recording media, magnetic anisotropy

I. INTRODUCTION

HARD DISK DRIVES have shown an areal density increase by a factor in the past decade. Although this is a significant progress, it is still inferior to an increase of 100x seen in the previous decade. The slow-down in areal density is due to the fact that the technology is operating at the peak of physical limits or engineering challenges. For example, the grain size of recording media is around 9 nm and any reduction of which is a materials challenge and is also limited by the physical limit of superparamagnetic effect [1-5]. In almost every aspect of the hard disk components/technology, such challenges are faced. For achieving high areal density, there is a need to reduce the magnetic spacing, the shortest spacing between the magnetic elements of the media and the reader. Magnetic spacing is one of the limiting factor, which decides the read-sensitivity, resolution and hence the ultimate recording density [6-8]. However, carbon overcoats (COC), which are used to protect the recording media from corrosion and mechanical wear, contribute to the magnetic spacing. Therefore, the overcoats must be thin but at the same time it is essential that they can protect the media even when they are thin.

Amorphous carbon thin film with high fraction of sp^3 bonding hybridization is an ideal choice as media and head overcoat in hard disk drive (HDD) technology due to the high density, outstanding mechanical properties and chemical inertness [9]. According to both subplantation and stress-induced mechanisms for the stability of sp^3 hybridization, the sp^3 content of the carbon thin films is determined by controlling the deposition energy of the carbon ions (in ionic based deposition techniques such as filtered-cathodic vacuum arc (FCVA) or mass selected ion beam (MSIB) deposition) or other carbonaceous precursors (such as hydrocarbon in plasma enhanced chemical vapour deposition (PECVD)) [10-13]. Techniques such as facing-targets sputtering and hybrid facing-targets sputtering have been employed to take advantage of the deposition energy in improving the properties of carbon overcoat [14-15]. Depending on the deposition techniques, there is an optimum deposition energy at which

the highest sp^3 content and density can be achieved. It should also be noted that besides excellent mechanical properties, tetrahedrally amorphous carbon (ta-C) films with high sp^3 content have outstanding thermal stability suitable for overcoat applications in heat-assisted magnetic recording (HAMR) media, which is emerging as the next generation technology [16-17]. We have recently reported the preliminary results of damage caused on antiferromagnetically coupled (AFC) media layer based on XPS and some magnetic characterization techniques [18]. In this paper, we focus our attention on the implantation effects of energetic carbon on the magnetic and structural properties of recording media of two types; AFC and a single layer, in order to gain more meaningful insight on the implantation and its effect.

II. EXPERIMENTAL DETAILS

The recording media samples were prepared at room temperature by dc magnetron sputtering using Intevac Lean 200B production type sputtering tool. Figure 1 shows the schematic illustration of the two types of samples in this study. In single layered (SL) sample, the magnetic layer had a thickness of 4.5 nm. In AFC sample, the 4.5 nm magnetic layer was antiferromagnetically coupled to another magnetic layer of thickness 12 nm through a thin Ru layer. Samples were prepared without the soft underlayers for characterization using alternating gradient magnetometry (AGM). Typical seedlayers of perpendicular media were used. The carbon overcoat using FCVA was deposited using double bend DC filtered cathodic vacuum arc (FCVA). To control the deposition ion energy, DC negative bias was applied to the substrate during the deposition. Alternating gradient force magnetometry (AGM) was used to study the magnetic properties of the films. Time-dependence remanent coercivity measurements were carried out to estimate thermal stability factor. X-Ray Diffraction (XRD) θ - 2θ scans were employed to study the crystallographic orientation and to estimate the lattice constants. SRIM (Stopping and Range of ions in materials) simulations were performed in order to understand the effect of bias voltage/energy of the ions on the implantation and its effects [19].

Fig.1. Layer structures of the samples in this study

III. RESULTS AND DISCUSSION

A. AFC Samples

Figure 2 shows the hysteresis loop of an AFC sample, without carbon film (solid line) and for the sample with carbon deposition at a bias voltage of 300 V (dotted lines). It can be noticed that both the samples show a kink near remanence. Except for the kink, the hysteresis loops of the two samples overlap with each other and hence no differentiation can be made between the two samples at any other region. The kink is centred at around 0 Oe for the sample without carbon film, whereas the kink for the sample deposited with 300V carbon is offset towards the first quadrant of the hysteresis loop.

A kink in the hysteresis loops is a common feature of AFC samples and it occurs due to the magnetization reversal in one of the layers (the layer with the lowest coercivity) [20-22]. The position of the kink (whether it occurs in the first or second quadrant) is determined by the coercivity (H_c) and the exchange field (H_{ex}), as reported earlier [20-22]. The inset in figure 2 shows the minor loops of the two samples. It can be noticed that the H_{ex} of the two samples are not significantly different, but the H_c is quite high for the sample deposited without COC.

Fig. 2. Hysteresis loops of AFC sample without carbon (solid line) and with carbon, deposited at 300 V bias (dashed

lines). The inset shows the minor loops of the two samples.

In our previous study on the set of AFC samples, we have reported that the H_c decreases as a function of the bias voltage applied during the deposition of Carbon film [18]. This was reported to be due to the implantation of Carbon in the magnetic layer, as confirmed by the XPS analysis. However, the value of H_{ex} was reported to be almost unchanged with respect to the bias voltage. This is surprising because,

$$H_{ex} = J/(M_s t) \quad (1)$$

Where J is the exchange coupling constant, t is the thickness of the thinner layer of AFC sample and M_s is the saturation magnetization. Mixing of carbon with magnetic layer is expected to reduce M_s and hence increase H_{ex} , if J remains unchanged. However, from the observation that H_{ex} was unaffected, it was expected that the J is also decreased.

Even though the value of J depends on the magnetic material, the value of J will also decrease if the Ru layer is also implanted with carbon atoms. However, the earlier XPS investigations did not show diffusion of Carbon. Since energy of the peaks in XPS corresponding to Ru and Carbon are closer, XPS is not a good tool to understand the mixing of Ru and Carbon in contrast to what was reported earlier [23]. Therefore, we performed SRIM simulations and XRD measurements to understand this effect.

Figure 3 shows the C ion profile in the magnetic layer for two cases (a) only CoCrPt layer (b) CoCrPt/Ru. Figure 3 (c) and 3(d) shows the zoomed-in images of C+ ion profile for cases (a) and (b). It can be noticed that the presence of a heavy element, such as Ru helps to reduce deep implantation of C+ to certain extent, but it does not stop the C+ implantation completely. Time-dependent studies of H_c and H_{ex} of the minor loops were carried out. H_{ex} was found to be time-independent, which is not surprising as H_{ex} depends mainly on J . Since the thinner layer is stabilized due to AFC, the time-dependence minor loop H_c did not show significant trend as a function of bias voltage.

These results, together with the XPS results from our earlier study, indicate that the implantation of Carbon in the CoCrPt layer is the cause of reduced H_c of the thinner layer of the AFC sample. The SRIM results indicate that the reduction in M_s and J , due to the diffusion of C+ ions into the Ru layer is the cause of unchanged values of H_{ex} in the AFC samples.

Figure 3 SRIM simulations to study the implantation of carbon in CoCrPt and CoCrPt/Ru layer

B. Single Layer Samples

In the previous section, we indicated that the time-dependence minor loop H_c did not show significant trend as a function of bias voltage. It has been reported in the past that the thinner layers of AFC structure can be stabilized by the AFC coupling with the thicker layer. Therefore, the time-dependence study of minor loop H_c is not suitable to see the changes in thermal stability factor of recording media. In single-layered samples also, the trend may not be easily seen if the layers are thick. Therefore, we made thin layers of single-layered recording media as shown in figure 1(b) and investigated their magnetic structural properties.

Figure 4 shows the hysteresis loops of single-layered (SL) sample, as-deposited and that coated with C at a bias voltage of 300 V. It can be seen that the sample exhibits a coercivity of more than 1000 Oe in the as-deposited state and that the coercivity drops to a few hundred Oe when highly energetic carbon was deposited. This trend is expected and is quite similar to that observed in the minor loops of AFC samples. The results can be explained based on the SRIM simulation results and the XPS investigations reported in the previous study. It can be noticed that the C+ ions are implanted in CoPt alloy layer to a depth that is proportional to the applied bias voltage. At low bias voltages, the carbon ions remain mostly at the surface of the magnetic layer. When the carbon overcoat is deposited at a high substrate bias voltage of 300 V (dashed line), the energy of carbon ions is about 400 eV. At this energy, the carbon ions can go through to the magnetic layer, with the concentration being highest at the middle of the magnetic layer. As a result, the anisotropy constant of the magnetic layer is reduced, resulting in a reduced coercivity for the sample (300 V C). If the anisotropy constant of the magnetic layer is reduced, this should also reflect in the time-dependent coercivity and the thermal stability factor ($K_u V/k_B T$) of these samples. Figure 5 shows the H_c and $K_u V/k_B T$ of the single layered samples for different bias voltage. It can be noted that the H_c and the $K_u V/k_B T$ reduces with the bias voltage as expected.

Figure 4. Hysteresis loops of SL sample, The solid line and the dashed lines represent the uncoated (No C) and Carbon coated

with a bias voltage of 300 V respectively. The inset shows the SRIM simulations at 100 and 400 V growth bias.

Figure 5. Coercivity and thermal stability factor ($K_u V/k_B T$) of SL samples deposited with C at different bias voltages.

In order to see if there are any structural changes in the CoCrPt alloy system due to the carbon ion implantation, we carried out XRD θ - 2θ scans. Figure 6 shows the hcp(00.2) peaks observed in two samples (0V, 300V) and a reference film which has only Ru seedlayer. It can be noticed that the Co(00.2) peak cannot be distinguished in all the samples. Considering that the thickness of CoCrPt alloy is only 4.5 nm, it is quite likely that the Co(00.2) peak overlaps with Ru(00.2) peak. Due to the slight lattice mismatch of the Co and Ru lattices, the hcp(00.2) peak appears at around 42.3 degrees, differing from the 42.2 degree peak of Ru(00.2). However, when C is sputtered at a bias voltage of 300 V, the hcp (00.2) peak shifts back to 42.2 degrees. This indicates a possible relaxation of Ru(00.2) lattice, as the CoCrPt alloy film becomes amorphous or undergoes a change in lattice parameter with higher concentration of C.

Figure 6. X-Ray θ - 2θ scans of samples and the dependence of Ru(00.2) peak position as a function of bias voltage used for C deposition.

IV. CONCLUSION

Effect of high-energy deposition of carbon overcoat on the magnetic properties of CoCrPt:oxides were studied in AFC and single-layer geometries. In the case of SL samples, it was found that the deposition of carbon leads to a reduction in the anisotropy, as evidenced by a decrease in $K_u V/k_B T$. The reduction in K_u also led to a reduction in the coercivity in AFC samples. The implantation of the carbon atoms in the magnetic layer also changes the structural property, as observed by XRD investigations in SL samples.

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