Thickness Dependency of the Structure and Laser Irradiation stability of Filtered Cathodic Vacuum Arc Grown Carbon Films for Heat Assisted Magnetic Recording Overcoat

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Abstract:

The thickness dependency of the bonding structure and laser irradiation stability of filtered cathodic vacuum arc grown carbon films have been studied. When the thickness is lower than 10 nm, the bonding structure of the films strongly depends on the film thickness. Decreasing the film thickness increases the sp^2 content of the film which can be explained by the subplantation theory. The laser irradiation stability of the films is also related to the film thickness as well as the irradiation frequency and power. Higher irradiation power and frequencies result in more severe graphitization due to higher temperature and accumulative heating respectively. Thicker films are also shown to be more stable upon laser irradiation.

Keywords:

Amorphous Carbon, Overcoat, Bonding Structure, Laser Irradiation, Raman Spectroscopy

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Introduction:

As the media grain size shrinks to increase the storage density, the grains become superparamagnetic which results in thermal instability of their magnetic states [1]. This phenomenon imposes a substantial challenge to further increase the storage density in the conventional magnetic recording technology. To overcome this barrier, the current magnetic medium should be replaced with higher magnetic anisotropy materials (such as $L1_0$ FePt)[2]. Theoretically, by decreasing the grain size to a few nanometers, storage densities of upto 100 Tb/in^2 can be achieved [2]. However, the coercivity of FePt alloy is much larger than the magnetic field that can be supported by a conventional recording head. Heat assisted magnetic recording (HAMR) is considered as a promising solution to tackle this problem and further increase the magnetic recording density [3]. During the HAMR writing process, a heating source (a nanosecond laser pulse) is used to heat up the high coercivity media layer to temperatures slightly lower than its Curie temperature. Heating the media decreases its coercivity which facilitates the writing process [2].

Despite interesting and wide studies and improvements on different aspects of HAMR such as optical design [3] and media fabrication [4, 5], the feasibility of using the conventional overcoat [6] and lubricant [7] for this emerging technology is still under a noticeable question mark. Currently, ultrathin bilayer of hydrogenated (a-C:H) and nitrogenated (a-C:N) carbon is used as the media overcoat [8] while a single layer of pure amorphous carbon (a-C) is used as the head overcoat [9]. Technically, the overcoats are responsible for mechanical protection and corrosion resistance. Plasma enhanced chemical vapour deposition (PECVD) grown a-C:H and Filtered cathodic vacuum arc (FCVA) grown a-C have suitable mechanical properties to protect the media and head surfaces against possible mechanical damages such as wear and scratch [10]. The a-C:N is an essential complementary layer to media overcoat in order to increase the surface energy and enhance the lubricant/overcoat bonding [11]. However, the application of carbon based films for HAMR requires a careful study on the laser irradiation and thermal stability of the overcoat.

The media overcoat is subjected to direct and short laser irradiation. However, the head overcoat is heated up due to incident laser absorption. Besides, the head near field transducer which is used to further concentrate the focused optical spot needs to be as close as possible to the magnetic write pole which results in noticeable heating of the pole [12]. B. Xu et al. showed that the transducer temperature depends on the power absorbed by the transducer as well as the transducer/pole spacing [12]. It was shown that in the extreme conditions (10 nm transducer-pole spacing) the transducer temperature varies between 300 to 500^0C (depending on the power absorbed by the transducer). Besides, it should be noted that the head overcoat is subjected to continuous heating throughout the head lifetime while the media overcoat experiences multiples of nanosecond pulses.

Based on the above, the thermal stability of the carbon based overcoat is an essential point which needs to be studied in detail. It is worth mentioning that the mechanical properties of the carbon films are directly related to their bonding structure [13]. a-C films are mixture of sp^2 and sp^3 bonded atoms. It is well-known that the mechanical properties of different types (pure, hydrogenated, nitrogenated etc.) of carbon films are directly related to the carbon terminated sp^3 hybridization. Tetrahedral amorphous carbon (ta-C) is pure amorphous carbon film containing more than 80% sp^3 hybridization. Neutron diffraction studies of McKenzie shows that by proper selection of plasma parameters, carbon thin films with 86% sp^3 hybridization can be deposited [14]. The mechanisms for the stability of such a high amount of metastable sp^3 hybridization will be discussed in more detail in the following discussion section. As it was shown by Ferrari et al. 70 nanometers thick FCVA grown ta-C films are stable at 1100^0C while at higher temperatures graphitization occurs [15].

The ability of deposition techniques such as FCVA [13], ion beam [16] and pulsed laser deposition (PLD) [17] to fabricate carbon films with high sp^3 hybridization is due to their ion based plasma. Considering the mechanical properties and thermal stability of FCVA grown ta-C films, they are a promising candidate for HAMR media and head overcoat (provided that the microparticle problem is resolved [18]). However, most of the reported data in the literature have studied the properties of relatively thick films (tens of nanometers). As it will be discussed later, the microstructure of the carbon films strongly depends on the film thickness. Since the thermal stability of the a-C film is also

directly related to the bonding structure, the thermal stability of the films may also alter by the film thickness. In this paper, using our in-house developed far field HAMR media tester, the thermal stability of ultrathin FCVA grown carbon films under laser irradiation is investigated.

Materials and Methods:

Off-plane double bend FCVA was used to deposit carbon on FePt based HAMR media. HAMR media structure and fabrication process have been discussed in detail elsewhere [5]. During the carbon deposition, the substrate was subjected to 100V negative substrate bias to control the bonding structure of the film. Our HAMR media disk consists of three layers. A 35 nm NiTa layer followed by a 10 nm MgO and finally a 12 nm FePt which were deposited on glass at 700^0 C.

An in-house developed HAMR tester was used to irradiate the disks to HAMR operating conditions. The details of the HAMR tester can be found elsewhere [7]. In summary, a 785 nm continuous wave laser was used to irradiate the samples. An objective lens was used to focus the laser beam onto the sample. The schematic of the laser beam profile is shown in Figure 1. It is crucially important to focus the laser spot on the surface. However, it is practically impossible to assure that the laser spot is exactly focused on the sample. To make sure that the sample is on the focal plane of the laser, the laser is mounted on a high precision motorized stage. During the test, the laser focussing point moves back and forth while the disk is also spun. The range of the movement of the laser is about 30 μm. Using this technique and by synchronizing the laser focus point and the spinning speed of the disk, a track will be formed on the disk surface (Figure 1-d). The disk experiences the highest temperature when it is exactly located at the laser focusing point. The temperature is gradually reduced when the disk is moving far and farther from the focal point. Hence the disk undergoes a continuous and decreasing temperature profile centred by the laser focal point. Using this technique and by controlling the disk spinning and laser movement speed, some key parameters such as laser heating rate and duration can be controlled.

The bonding structure of the samples was examined by Raman spectroscopy and X-ray photoelectron spectroscopy (XPS) while the laser irradiation tracks were monitored by optical surface analyser (OSA).

Results and Discussion

Figure 2(A) shows the Raman spectra of the carbon films of 2, 4 and 10 nm thick. The spectra are normalized, baseline subtracted and fitted by Breit-Wigner-Fano (BWF) and Lorentzian spectra as the G and D bands respectively. The G band centre position and the $I_D\backslash I_G$ is shown in figure 2(B). A shoulder at 1400 cm^{-1} can be observed in the Raman spectra. The intensity of the shoulder is decreased by increasing the film thickness which results in decreasing the $I_D\backslash I_G$. Larger $I_D\backslash I_G$ shows the presence of larger sp^2 clusters in the microstructure of the films [19]. This can be better understood by considering the depth profile XPS analysis of 20 nm carbon film deposited on silicon at the same conditions (Figure 3). As it can be observed from the XPS spectrum deconvolution the bonding structure of the film can be divided into two regions. At the top layer (the first 20 minutes of XPS depth profile etching corresponding to about top 10 nm of the film) the sp^3 content of the film is almost constant. However, in the second region the sp^3 content of the film decreases continuously. As it can be observed the sp^2 content is increasing slightly. Besides, noticeable amount of carbide is formed in this region which reduces the sp^3 content significantly. It should also be noted that due to argon plasma etching which may result in graphitization of the film, the real sp^3 content of the film might be higher than that deduced from the XPS spectra.

Variation of the bonding structure in ultrathin carbon films can be discussed by the subplantation induced mechanism for the stabilization of the sp^3 hybridization proposed by Lifshitz et al. [20]. At the initial stages of the formation of the film, the bonding structure of the film strongly depends on the properties of the underlying substrate which works as a mold for the subplantation of the impinging carbon ions. Hence, besides the deposition parameters, the bonding structure at the nucleation stage depends on the substrate properties. During the deposition, the initial substrate/carbon interface at the

growth frontier is being replaced by carbon/carbon interface. The carbon film which is working as the substrate for the deposition of the impinging ions determines the bonding structure of the next layer. Therefore, at the early stages of the film growth, the film structure is under a continuous change.

Due to larger sp^2 cluster size in ultrathin carbon films, it is important to study their laser irradiation stability. Figure 4 shows the schematics of the laser pulse used in this study. During the laser irradiation, a magnetic field of 1200 gauss (equal to the writing field) was applied to the disk. The laser intensity was increased until the magnetic field-temperature combination was sufficient for writing the underlying media. In order to study the effect of accumulative heating resulted from multiple laser irradiation cycles, the heating cycle (time and intensity) was kept constant while the cooling time (*x*-6.5 ns in Figure 2) was varied. The laser power was kept constant at 57 mW. The total heating time was kept at 500 ns.

Figure 5 shows the OSA images of the laser irradiated areas of the carbon films. As it can be observed, the laser damage is more severe in the three nanometre film as compared to the ten nanometre film. Besides, the irradiated track is longer on the thinner film which confirms that compared to the ten nanometre film it is more susceptible to laser irradiation and undergoes structural changes at lower temperatures. In order to understand the structural changes upon laser irradiation, the bonding structure of the as deposited and irradiated films were studied by Raman spectroscopy.

Figure 6 shows the Raman spectra of the as deposited and laser irradiated carbon films of three and ten nanometre thick. As a general trend and as it was also observed before [21] laser irradiation results in graphitization of the films. Graphitization in itself can be considered as a two stage process namely the sp^3 to sp^2 conversion and crystallization of the sp^2 bonded atoms. As it can be observed (Figure 4 and Figure 6), although the heating cycle is kept constant the structural changes strongly depend on the total single pulse duration and hence the off time of the laser pulse. This suggests that at short pulse durations and high frequency irradiation, accumulative heating has a significant effect on the structural changes of the films. Deconvolution of the Raman spectra reveals that even at the longest cooling time (56 ns pulse cycle), there is an slight change in the microstructure of the film. The I_D/I_G

increases to 0.46 for the 10nm film irradiated by the laser pulse of 56 ns while the same amount for the non-irradiated film is 0.38. Decreasing the laser off time of the pulse enhances the graphitization significantly. Decreasing the total pulse time to 28.25 ns increases the I_D/I_G to 0.88 and 0.69 for the 3nm and 10nm films respectively. The G peak position has also shifted to 1561 cm^{-1}. Very high I_D/I_G ratio and the shift of the G band towards higher wavenumbers clearly show enlargement in the in-plane sp^2 cluster size and the conversion of sp^3 bonded atoms to sp^2 hybridization. Further decrease of the laser off duration in the pulse cycle enhances the graphitization in both the 3nm and 10nm films. As it can be observed, at very short pulses (14.13 ns) the 10nm film shows clear separate D and G bands with I_D/I_G of 0.98 which shows the transformation of the structure to nanocrystalline graphite. On the other hand, the 3nm film doesn't show any clear Raman spectra in the range of 1000-2000 cm^{-1}. This can be due to full oxidation of the carbon film as a result of high temperature. In summary, the Raman spectroscopy of the laser irradiated carbon films show that laser irradiation results in the graphitization of the films. Short pulse durations and hence high irradiation frequencies have more severe effects on the structure of the film which is thought to be due to accumulative heating. Short laser off time can even result in evaporation of the films in particular in ultrathin films.

The effect of laser irradiation power on the structural changes has also been studied. Irradiation profile similar to that of test two in Figure 4 (with total pulse time of 21.8 ns) was chosen for this study. The laser power was reduced and the structural changes were monitored by Raman spectroscopy. Figure 7 shows the Raman spectra of the three nm thick carbon film irradiated by different laser powers. As it can be observed, the graphitization of the film is more enhanced at higher laser powers. The carbon film is almost stable when the laser power is reduced to 34 mW.

The results show that the structural changes of the films strongly depend on both the laser irradiation power and also the irradiation frequency. Higher laser energy results in higher degree of graphitization due to inducing higher temperatures. On the other hand, higher irradiation frequency results in severe graphitization of the films which is thought to be due to accumulative heating of the films.

Conclusions:

In ultrathin carbon films the bonding structure depends on the film thickness. Raman spectroscopy and XPS results show that thinner carbon films possess higher sp^2 content with larger cluster size in their microstructure. This can be understood by considering the point that at the initial growth stages, the subplantation and deposition mold and surface is under a continuous change from the substrate material to the growing film.

The laser irradiation stability of the films has also been studied. It was found that the film thickness, irradiation frequency and power are among the important factors which govern the behaviour of the films upon irradiation. Thinner films in general are more susceptible to laser irradiation due to their different initial bonding structure. It was also found that higher irradiation frequency results in more severe graphitization which is considered to be due to accumulative heating of the films by repeating pulses. Higher irradiation powers, also leads to higher temperatures which in turn results in higher degrees of graphitization of the films.

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