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Damage layer study of the overcoat deposited on the top magnetic layer of hard disks

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ABSTRACT

This paper presents the effect of nanoscale damage layer on magnetic results obtained from the optimization of media overcoat deposition parameters on the top magnetic layer on magnetic hard disks. We have investigated the effects of interface interaction between the overcoat deposition parameters on the top magnetic layer on the media by using a plasma enhanced chemical vapor deposition (PECVD) on next generation hard disks. The goal is to achieve a reduced damage layer, lower head media spacing (HMS) and a higher spectrum of signal to noise ratio (SpSNR) optimized by using Taguchi experimental design with a four-factor three-level (L9) orthogonal array. An analysis of variance (ANOVA) was carried out to interpret the measured coercivity (Hc), HMS and SpSNR. It was found that source gas type is the most significant factor with a percentage contribution effect of 59.8% on HMS and 51.7% on SpSNR. The bias voltage is the second most significant factor with its percentage contribution being 24.2% on HMS and 31.0% on SpSNR. Overall, the optimum SpSNR was obtained using a C_2H_2 source gas, -100 V bias voltage, 50 V anode voltage and 20 sccm gas flow rate, respectively.

1. Introduction

Magnetic storage hard disk drives (HDD) have been and are used widely to provide storage of digital information in modern computer systems and consumer electronic products. The disk arial recording density of hard disk drives will continue at a 50% growth rate per year as the video-audio digital applications and data storage capacity demands keep increasing [1]. Consequently, to be able to develop a higher recording density disk with good reliability performance is becoming more and more important in order to meet future storage requirements. Further increases in the magnetic storage density and head read/write performance for future HDD will necessitate an improvement in magnetic layer design [2,3] and a reduction in the head media read/write spacing (HMS) [4,5]. A lower HMS will improve the media as this results in a lower head fly height, thinner diamond-like-carbon (DLC) overcoat thickness and a reduced damage layer thickness (as defined and illustrated in Fig. 1). The damage layer results from the interface interaction between the protective overcoat and top magnetic layer (TML). The deposition of DLC overcoat damages the TML, by producing a nanoscale damage layer which in turn results in an increase of the head/media read/write interface gap. The higher thicknesses of the overcoat film and damage layer are usually associated with a higher HMS which can lead to a reduction in head media read/write sensitivity [6]. In general, HMS decreases and wear resistance decreases with a decrease of the DLC overcoat thickness [7]. The HMS of media correlates well with its magnetic performance [8]. This also indicates that a lower HMS results in a higher spectrum and better signal to noise ratio (SpSNR). Therefore, developing a thinner DLC, and providing better reliability, and a thinner damaged layer with better magnetic performance is a necessity to meet the challenges of future HDD technology.

Li and Bhushan studied the micromechanical and tribological characterization of hard amorphous carbon coatings as thin as 5 nm for magnetic recording heads [9]. Disk DLC with 3–4 nm thickness is the most common currently used protective layer between the head/disk interfaces [10]. Tribology and wear resistance will encounter more challenges when the overcoat thickness is lowered to an ultra-thin level (<3 nm). Hence, regarding the development of disk DLC overcoats, how can we avoid the wear between a head and disk? These are the important topics addressed in this study. Regarding the mechanical properties of DLC films, as studied by many researchers [11,12]. The source gas with a different C/H ratio will result in different sp^2/sp^3 ratio of the DLC films, which correlated to their friction coefficients and wear rates [13]. Sharma [14] illustrated that the lower hydrogen content in DLC films will enhance the scratch resistance and tribological properties. Niakan [15] illustrated that increasing the deposition bias voltage resulted in a higher density and hardness of DLC films.

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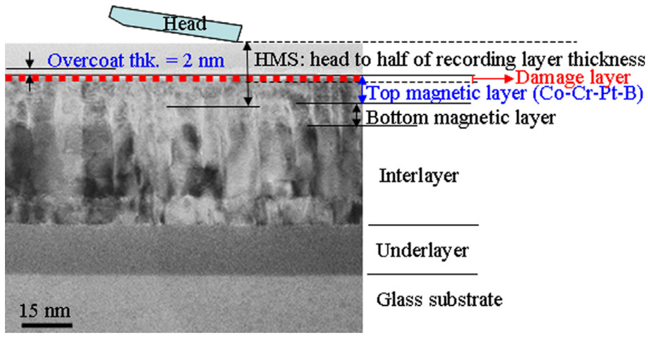

Fig. 1. HRTEM cross-section image of various deposition layers on the substrate (illustrates the damaged layer between the overcoat and top magnetic layer).

Magnetic properties may be improved by forming two or more layers of the magnetic layers [16,17], and by providing each layer with different functions. The TML of magnetic layers are also coated with DLC overcoats to protect against chemical reactions and mechanical impacts. The DLC overcoats design concept is not only considered better for the reliability properties but also reduces the damaged layer thickness which results in better magnetic properties. Most of the literatures mention only the mechanical damage [18,19] or the corrosion effects [20–22] of the DLC overcoat films. Until now, the damage layer interaction between overcoat deposition and TML had not been investigated.

Plasma enhanced chemical vapor deposition (PECVD) [23] is a good candidate to further improve the durability performance of the media by using thinner overcoats because it has the advantage of offering better control of the chemical composition and bonding structure in the deposited thin films. But it can also cause excessive media surface roughness if the source gas used has too high of a molecular weight. On the other hand, if a source gas with too small of a molecular weight is used, the deposited layer will penetrate into the TML, resulting in a damaged layer which results in an increase of the read/write gap in the head/disk interface. Except for the deposition source gas type of PECVD, there are many deposition parameters which will be investigated. It has also not yet been investigated whether reduced damage layer (enhanced magnetic performance) and remained wear properties can be achieved through manipulation of the deposition conditions, i.e. optimization of source gas, substrate bias voltage, anode voltage and gas flow rate.

The need for improved product manufacturing has driven engineers to quickly find an optimal recipe for processing. Therefore, the Taguchi method [24,25] was introduced as a useful engineering methodology to optimize the process conditions. Selecting a proper orthogonal array, the study of 4 factors at 3 levels as mentioned above can be conducted with only 9 experimental runs. This results in less experiments being required in order to study all levels of input parameters and also filters out some effects due to statistical variation [26].

Therefore, the purpose of this research is to study the effects of interface interaction between the ultra-thin overcoat PECVD parameters (source gas, substrate bias voltage, anode voltage and gas flow rate, overcoat film thickness) on TML in next generation hard disks utilizing the Taguchi method. The coercivity (Hc), nucleation field (Hn), HMS, spectrum of signal to noise ratio (SpSNR), nanohardness and microstructure, which is correlated to damage layer, magnetic and wear resistance, shall be investigated. Finally, this optimization of deposition parameters of DLC films on TML will be confirmed, and the media magnetic characteristics and wear resistance of optimized DLC film deposition will be analyzed.

2. Experimental procedure

A glass substrate with a diameter of 65 mm and a thickness of 10 mm were utilized in this study. All substrates were sequentially deposited with under layers, inter layers of Cr, CrMoB and CrMo, a Ru layer, bottom magnetic layer of CoCrB and top magnetic layer of CoCrPtB with various DLC overcoat films (2 nm in thickness) using an Intevac 250B disc DC sputtering system. After sputtering, all media were coated with a 1.2 nm thickness lubrication layer. Except for the overcoat deposition parameters and structure, all the media studied here had the same under layers, inter layers, Ru layer and magnetic layers. The total thickness of all magnetic layers is 14 nm. In this study, a PECVD system for DLC hydrogenated carbon films coating on the TML were carried out the following control factors: (1) source gas; (2) substrate bias voltage; (3) anode voltage; and (4) gas flow rate. The key parameters using the four factors with three levels (L9) orthogonal array of experimental arrangements are listed in Table 1. The Taguchi method is known to be a very good tool for parameter study, and is applied in the present work. This method is powerful and effective in helping researchers design their products and processes as well as to solve troublesome quality problems. After using Taguchi experimental design, the factorial effect and contribution ratio of each factor of each property are presented.

Raman spectroscopy was used to study the bonding states of various phases of carbon and the structural quality of the DLC films. In the analysis of the Raman spectrum, both the Gaussian and Lorentzian distribution functions are able to identify the D and G peak positions from the deconvolution of the spectra, and thus one can obtain the intensity ratio (I_d/I_g) as a quality characteristic. The Raman spectroscopy is obtained using a Horiba S320C MKII system with Ar laser at 514 nm wavelengths. The thickness of overcoat films was measured with an N&K optical analyzer, which was correlated to transmission electron microscopy cross-sections. In order to measure the nanohardness of a specimen coated with DLC films, a nanoindenter (UMIS, Australia) was applied with the maximum indentation load varying at the scale of milli-Newton (mN). In this study, the 0.015 mN and 30 mN were used for initial contact and maximum load, respectively. Tribological performance of disks was evaluated by contact-start-stop (CSS) testing in Hot/Wet environments with 30 °C and 80% relative humidity. After CSS durability test, the wear resistance of overcoat films was observed by optical microscopy (OM). A vibrating sample magnetometer (VSM) was used to measure the Hc and Hn for each of the Taguchi experiments. The HMS and the SpSNR were measured by using a Guzik write/read tester. The HMS includes a pole tip recess, DLC overcoat on head slider, head flying height, thickness of lube and DLC overcoat on the media, and around half of the recording layer thickness [27,28]. The HMS value is adjusted by subtracting a same

Table 1
Taguchi experimental layout using L9 orthogonal array of deposition conditions (current process parameters – Condition 2: CH_4 source gas, −200 V bias voltage, 100 V anode voltage and 30 sccm gas flow rate).

Cond.	Factor A Source gas	Factor B Bias voltage (V)	Factor C Anode voltage (V)	Factor D Gas flow (sccm)
1	CH_4	−100	50	20
2	CH_4	−200	100	30
3	CH_4	−300	150	40
4	C_2H_6	−100	100	40
5	C_2H_6	−200	150	20
6	C_2H_6	−300	50	30
7	C_2H_2	−100	150	30
8	C_2H_2	−200	50	40
9	C_2H_2	−300	100	20