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DLC deposition parameters optimization for head disk design interface with a thermal protrusion slider from tribological point of view

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ABSTRACT

This paper will study the effects of plasma enhanced chemical vapor deposition (PECVD) parameters (source gas type, gas flow rate, substrate bias voltage and emission current) of diamond-like carbon (DLC) films on tribological properties with a thermal protrusion slider for use in designing next generation disk. The purpose of the study is to achieve robust tribological properties between the HDI optimized by using the Taguchi experimental design method and Grey relational analysis. This study will investigate the microstructure, hardness and lubricant bonded properties of the DLC film which will be correlated to the wear resistance of the disk and slider of the HDI. Based on the analysis, the deposition process parameters of the source gas type and substrate bias voltage are the most significant factors on SNR related to I_d/I_g, hardness and lube bonded ratio of DLC films, disk wear density and head slider delta touch-down power, respectively. DLC film with a higher hardness and lube bonded ratio can enhance the disk wear resistance. The higher lube bonded ratio and the lower hardness of DLC films result in lower slider delta touch-down power (or a better slider wear resistance). There is a good correlation among I_d/I_g, lube bonded ratio, disk wear density and slider delta touch-down power. Simultaneously, to optimize the disk wear density and the slider delta touch-down power for head disk design interface with a thermal protrusion slider, the optimum wear resistance of disk and slider were obtained using a C_2H_2 source gas, 25 sccm flow rate, −60 V substrate bias voltage and 0.5 A emission current, respectively.

1. Introduction

Magnetic storage hard disk drives (HDDs) have been used widely in industry and keep an annual 10% growth rate per year in volume. The disk arial recording density of HDDs will also continue a 50% growth rate per year [1]. Consequently, to be able to develop a higher recording density disk with good reliability performance is becoming more important in order to meet future storage requirements. Reducing the mechanical spacing between the head and disk in HDDs is critical for achieving ultra-high recording densities. There are two approaches to achieve a lower read/write gap of the head/disk interface (HDI) [2], one is with a continuous read/write fly height reduction between the HDI, another is with a diamond-like carbon (DLC) thickness reduction of the disk protective layer.

Realizing a flying interface with less than 2 nm clearance will be a significant challenge due to the instability induced by the adhesive forces between the slider and disk [3]. In-contact recording scheme [4], is a possible choice. But, the conventional air bearing surface (ABS) designs for in-contact recording will induce higher contact forces between the slider and disk, which may cause serious wear and slider vibrations in fly-height. To overcome the above-mentioned drawbacks, a new HDI scheme [5], i.e. fly-contact interface, is proposed by combining the major advantages of the fly and the in-contact recording schemes. This allows most of slider's ABS to fly while having a tiny read/write head area in contact with the disk surface, as defined and illustrated in Fig. 1, which is the schematic of a head disk design interface with a thermal protrusion slider. The head dynamic flying reliability with thermal protrusion slider technology can help to achieve the fly-contact scheme with a contact-on-demand mechanism [6]. Therefore, the read/write gap of the head/disk is reduced by using head dynamic flying (DFH) reliability with a thermal protrusion slider, but this is complicated due to the tiny thermal protrusion slider being more easily damaged by the disk DLC film, and additionally, the tiny thermal protrusion slider can also easily damage the disk DLC, which results in wear and read/write issues in next generation disks.

DLC with 3–4 nm thickness is the most common currently used protective layer between the HDI [7]. Hence, regarding the development of disk DLC overcoats, how can we avoid the wear between a head thermal protrusion slider and disk? These are the core and important topics addressed in this paper. Compared with

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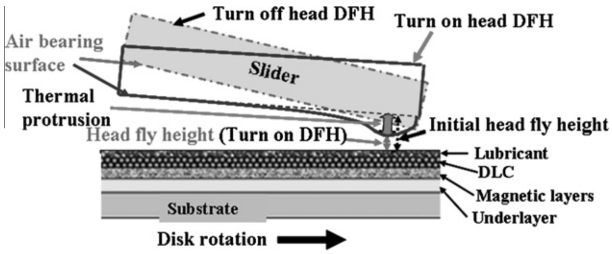

Fig. 1. Schematic of head disk design interface with a thermal protrusion slider (illustrates the head fly height was reduced from 10 down to 1.5 nm after turn on head DFH).

sputtering and ion beam deposition techniques, plasma enhanced chemical vapor deposition (PECVD) [8–10] is a good candidate to further improve the durability performance of the media by using thinner overcoats. Regarding the structure [11], physical [12], chemical [13,14] and mechanical properties [15] of PECVD DLC films, as studied by many researchers. 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 hardness, chemical inertness, thermal conductivity and electrical conductivity [16,17]. Ito [18] and Roy [19] illustrated that a lower hydrogen content in DLC films will enhance its thermal stability and tribological properties. Park [20] illustrated that increasing the deposition bias voltage from 0 to 300 V resulted in a higher density and hardness of DLC films. However, it has not yet been investigated whether or not improving the disk and thermal protrusion slider wearing resistance can be achieved by manipulation of the deposition conditions. Therefore, this paper will study the effects of PECVD DLC deposition parameters (source type gas, gas flow rate, substrate bias voltage and emission current) on disk wearing density and slider delta touch-town power with a thermal protrusion slider, in next generation hard disks. The microstructure, hardness, lubricant bonded ratio of DLC film, which is directly correlated to their disk wearing density and slider delta touch-town power of HDI, shall be investigated.

The need for improved product manufacturing has driven engineers to search and find an optimal recipe for processing. The Taguchi method [21,22] and the Grey system theory [23] were used to analyze the experimental results in order to obtain the optimal DLC overcoat deposition parameters for maximizing simultaneously the disk and thermal protrusion slider wear resistance between head disk design interface.

2. Experimental procedure

Glass substrates 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. The 2 nm thickness of overcoat films was measured with an N&K optical analyzer, which was correlated to transmission electron microscopy cross-sections. After sputtering, all media were coated with a commercially available Z-Tol lubricant of 1.2 nm thickness which was sequentially deposited on the DLC films of the disk to provide lubrication during head-disk contacts. 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. In this study, a PECVD system for DLC hydrogenated carbon films was utilized for coating on the top magnetic layer. These coatings were carried out while varying the following control factors: (A) source gas type; (B) gas flow rate; (C) substrate bias voltage and (D) emission current. The key parameters using the four factors with three levels (L9) orthogonal array of experimental layout are listed in Table 1. The Taguchi method is known to be a very good tool for parameter study, and was 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.

Raman spectroscopy and X-ray photoelectron spectroscopy (XPS) were utilized 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 disorder (D) and graphite (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. All the XPS measurements were carried out with PHI Quantera II spectrometer with a monochromatic X-ray source of Al Kα (1485.0 eV). The chamber was pumped to a pressure of 1×10^{-8} Pa and the measurement was carried out at room temperature. A step with 0.05 eV energy intervals was used to acquire the XPS spectra of the C 1s and C–H 1s. The energy scale was calibrated using the reference binding energies of Cu $2p_{3/2}$ at 932.5 eV and Cu $3p_{3/2}$ at 75.0 eV. To minimize uncertainties in the binding energy measurements, we employed a fully automated charge neutralization technique which equalized a surface potential of insulated sample by patented dual beam of low energy electron and Ar ion. The samples were analyzed without Ar^+ ion bombardment for sputter cleaning before XPS analysis. The film compositions were determined by analyzing XPS spectra and using published sensitivity factors. The sp3 content of all samples was determined by electron energy loss spectroscopy (EELS). EELS measurements were carried out on a scanning transmission electron microscope with a dedicated parallel EELS spectrometer of the McMullan design.

In order to measure the composite hardness of a specimen with a DLC film, a nano indenter (UMIS, Australia) was utilized with the maximum indentation load varying in the scale of mili-Newton (mN) such that the maximum indentation depth was varied in the range of 15–25 nm. In this study, since it is quite difficult to measure the hardness of 2.0 nm ultra thin DLC films, the hardness of overcoats is defined as a ‘‘composite’’ value of an ultra thin films/magnetic layer system. The 1.2 nm lubricant layer thickness was measured by Fourier Transform Infrared (FTIR) spectrometer. The amount of the lubricant bonded to the overcoat surface was measured by FTIR on the disk surface before and after solvent washing. The lubricant bonded ratio was defined as the ratio of bonded lubricant thickness to the 1.2 nm total lubricant thickness.

The wear resistance test of disk DLC films was conducted using a thermal protrusion slider in a tribological tester. (Testing procedure Step 1: start disk at rotating speed of 7200 rpm with 50% relative humidity and 23 °C temperature. Step 2: load head slider on 22 mm of disk radius position. Step 3: adjust tribological tester chamber pressure to 30 kPa. Step 4: perform on track tribological test of slider/disk interface for 10 min.) After test, each disk was scanned with an optical surface analyzer to examine the worn surface quality and measure the disk wear density. The disk wear density shall be obtained from the integrated density of worn surface reflective image by optical surface analyzer. The lower disk wear density correlates to a better wear resistance of the disk DLC film. Meanwhile, each slider after test was examined with optical microscopy and SEM/EDS to examine the slider surface cleanness, respectively. The wear resistance test of the thermal protrusion slider was performed using a head burnish sweep testing procedure (Step 1: slider loading site is 22.30 mm of disk radius position, then move to 17.30 mm and check the stability of head touch-down system. Step 2: test touch-down power and apply extra 40 mW for overstress. Step 3: slider sweeps from 17.30 to 27.18 mm, and back