Overcoat free surface modification for extremely high areal densities

Abstract
Amorphous carbon films are used as protective coatings on magnetic media to protect the magnetic layer from wear and abrasion caused by the read/write head during hard disk drive start-up and operation. A key requirement in increasing the storage capacity and reliability of hard-disk drives is improving the performance of these coatings. Due to an ever increasing demand for higher areal densities (number of bits/unit area on a disk surface) researchers have been continuously exploring various techniques to reduce the thickness of the overcoats which contribute to the magnetic spacing. Magnetic spacing is defined as the distance between the flying head and the media. The data storage density increases exponentially with the decrease in the magnetic spacing. Magnetic spacing can be reduced by decreasing the fly height for which the thickness of the carbon overcoats and the lubricant layer has to be reduced considerably. In this study, we propose to develop new surface modification techniques whereby the thicknesses of the overcoats can be reduced considerably without compromising their mechanical, tribological, anti-corrosion properties and enhanced performance under HAMR conditions in order to achieve areal densities in the range of 1.5 to 4 Tbit/in².

By
Prof. C. S. Bhatia¹,*
Dr. S. K. Sinha²
Dr. M. Abdul Samad¹

¹Department of Electrical & Computer Engineering, 4 Engineering Drive 3, National University of Singapore 117576, Singapore.
²Department of Mechanical Engineering, 9 Engineering Drive 1, National University of Singapore, 117576, Singapore
*Corresponding author
1. INTRODUCTION

Hard disk drives are magnetic storage devices in which data is recorded as magnetized bits on the surface of a thin layer of a ferromagnetic material. A read-write head flying a few nanometers above the surface of this magnetic media is responsible for writing and reading the recorded data. To prevent the magnetic medium and the head read-write elements from oxidation and wear, the surfaces of the media and head are coated with a thin carbon overcoat. In addition, media is coated with ultra-thin layer of lubricant, usually perfluoropolyether (PFPE), on top.

The demand for higher areal densities (number of bits/unit area on a disk surface) in magnetic hard disk drives has been consistently rising. In order to increase magnetic areal density one needs to reduce magnetic spacing (Figure 1), which is defined as the distance between the bottom of read/write element of a flying head and the top of magnetic media. According to the Wallace equation (Wallace 1951), magnetic signal increases exponentially with a decrease in magnetic spacing. Magnetic spacing can be reduced by decreasing thickness of the carbon overcoats and the lubricant layer has to be reduced considerably.

However, the overcoats are also expected to be atomically smooth, continuous, dense, chemically inert, thermally stable and hard in order to protect the magnetic material against wear and corrosion [Anders et al (2001), Robertson (2001)]. DLC coatings due its superior tribological and mechanical properties such as high hardness, high toughness, chemically inert and good compatibility with the lubricants have emerged as a potential material for the overcoats [Robertson (1991), Grill (1999), Roy et al (2006)]. Producing ultra-thin coatings of DLC with improved mechanical and tribological properties has been a subject of focus of many studies in the recent past [Andres et al (2001), Grill (1999), Donnet (1998), Zhngag et al (2009), Zhngag et al (2009)]. Various parameters such as the deposition techniques, the deposition parameters (ion energy, substrate bias etc) and the environment in which the deposition is carried out play an important role in governing the properties of the DLC coatings. Researchers have produced a variety of DLC coatings such as hydrogenated diamond-like carbon, nitrogen-doped amorphous carbon, hydrogen free amorphous carbon, silicon-doped amorphous carbon and metal-doped amorphous carbon with varying properties [Grill (1999), Fu et al (2005), Wang et al (2000)]. Different deposition techniques such as plasma beam deposition, plasma chemical vapor deposition, argon sputter deposition and filetered cathodic vacuum arc deposition have been reported for depositing DLC films. Thus
the ultimate challenge of ultrathin film synthesis is to deposit films as thin as possible which are continuous, smooth and hard without compromising their tribological and mechanical properties.

To achieve densities in the range of 1.5 - 4 Tbit/in², the magnetic spacing has to be reduced significantly for which the thicknesses of the overcoats have also to be reduced. A head-media spacing (magnetic spacing) of about 3.5 – 4 nm would be required to achieve densities beyond 1.5 Tbit/in², as compared to a magnetic spacing of 5 nm in 1 Tbit/in² disk drives of today. Thus in this study we propose to explore and develop surface modification techniques to reduce the overcoat thicknesses by retaining their good tribological and mechanical properties which in turn will help in achieving higher areal densities.

2. OBJECTIVES

2.1 Technical Objective
The technical objective of this study will be: To develop surface modification techniques whereby the thicknesses of the overcoats can be reduced significantly which in turn would help to attain data storage capacities of 1.5 - 4 Tbit/in² and beyond.
The technical challenge involves developing ultrathin coatings with good wear and anti-corrosion performance to meet the continuous increasing demand for higher data density in the hard disk market.

2.2 Scientific Objective
The scientific objective of this study will be: To understand the relationship between the various parameters of the developed surface modification techniques in terms of structure-property relationships, depositional parameters-property relationships and to make it reliable to be applied to hard disk media.
The scientific challenge involves the understanding of relationships between the results of various optical spectroscopies (Raman scattering, refractive index measurements, photoluminescence), physical properties and chemical composition (fraction of sp3 bonds, hydrogen content, density), mechanical properties (hardness, elastic modulus), and performance in hard disk drives.

3. PROPOSED METHODOLOGY

To achieve our main objective of reducing the magnetic spacing by reducing the thickness of the overcoats, we propose to take up two approaches as described below.

3.1 FIRST APPROACH – To reduce magnetic spacing by reducing the overcoat thicknesses
In a present day hard disk drive, the magnetic media is protected against corrosion and wear by a ~2 - 3 nm carbon overcoat with ~1 - 2 nm thick lubricant layer on the top to provide extra protection against wear. These layers contribute to the magnetic spacing, which is defined as the distance between the bottom of read/write element of a flying head and the top of magnetic media has to be reduced significantly for which the thicknesses of the overcoats
have also to be reduced. A head-media spacing (magnetic spacing) of about 4 nm would be required to achieve densities beyond 1.5 Tbit/in², as compared to a magnetic spacing of 6.5 nm in 1 Tbit/in² disk drives of today. To achieve this, the thickness of the overcoat layers on the head and magnetic media have to be reduced significantly to a thickness value of ≤ 1 nm each.

Thus, in this approach we propose to use the FCVA technique to modify the magnetic media surface because of its ability
- to implant ions under controlled ion energy conditions [Robertson (2001)],
- to produce the highest fraction of tetrahedral (sp³) carbon hybridization resulting in enhanced mechanical strength [Pharr et al. (1996)] and
- to produce films with high density

3.1.1 PRELIMINARY RESULTS
Through our initial experiments we have established a very novel method of an overcoat free surface modification technique using the filtered cathodic vacuum arc (FCVA) process whereby the media surface is bombarded by high energetic C⁺ ions at specific ion energy. The modified surface exhibited excellent tribological properties, improved scratch resistance and good anti-oxidation properties, which are all needed for the media disk to survive long lives. The modified surface showed excellent compatibility with the perfluoropolyether (PFPE) lubricant layer as well. However, the developed method is to be further evaluated for its direct application in the surface modification of magnetic media [Abdul Samad et al (2011), Abdul Samad et al. (2011).]
3.2 SECOND APPROACH – To use alternative materials to modify the magnetic media surface

In conventional hard disk drives, amorphous carbon films are used as protective coatings on magnetic media/head to protect them from wear and abrasion caused by the read/write head during hard disk drive start-up and operation. Amorphous carbon is relatively cheap and mechanically advantageous and is used in the industry for this coating. However, researchers have found that the carbon overcoat degrades at higher temperatures posing a big question on its suitability to be used effectively for HAMR applications.

Thus in this approach we propose to use the FCVA technique to investigate the feasibility of using alternative materials for the protective films, such as

- nitrides and carbides of boron and
- nitrides and carbides of silicon

These materials are known to have good thermal, structural and tribological properties. The developed protective films will be evaluated at higher temperatures for their applicability in HAMR applications and in a real hard disk drive.

3.3 SPECIFIC TASKS

- Developing of novel surface modification techniques: New surface modification techniques will be developed to produce ultrathin coatings.

- Evaluating the developed surface modification technique: The developed technique will be evaluated for its –

  1. Mechanical properties: As mentioned earlier, the mechanical properties such as hardness, toughness etc govern the performance of the developed surface modification in actual operating conditions of the hard disk drive. Thus the main goal of this task would be to evaluate and understand the relationship between the produced chemical structure (sp³ content, density, carbide formation) and the mechanical properties (hardness, toughness) and to use the knowledge in controlling the depositional parameters.

  2. Anti-corrosion properties: The developed surface modification technique will be evaluated for its anti-corrosion properties by conducting some galvanic corrosion experiments.

  3. Thermal stability for HAMR: Thermal degradation of carbon overcoats is posing a great challenge to researchers and raising concerns on its applicability in heat assisted magnetic recording (HAMR). Thus, the major goal of this task would be to evaluate the thermal stability of the developed surface modification technique for its direct application in HAMR.

  4. Tribological properties: In this task, wear tests will be conducted to evaluate the tribological properties (wear resistance and coefficient of friction) of the developed surface modification technique.

  5. Surface characterizations: Surface energy and surface roughness play a very important role in controlling the properties at the head/media interface. Thus the
The major aim of this task would be to characterize the developed surface modification technique in terms of its surface energy and roughness.

6. **Evaluating the magnetic properties:** The main objective of this task would be to study the effect of the developed surface modification techniques on the magnetic properties of the media as this is of prime importance for the better performance of the hard disk drive.

7. **Compatibility with the lubricant:** The compatibility of the developed surface modification technique with the lubricant is of prime importance for the proper functioning of the hard disk drive. Thus, this task will aim to evaluate and improve the bonding between the modified surface and the lubricant to further improve the functioning of the hard disk drives.

8. **Flyability:** The ultimate test for any surface modification done on the media or the head is the flyability test which governs the actual applicability of the technique to the real world hard disk drives. Thus, media with the developed surface modification will be put to the flyability test to evaluate its performance.

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**4. POSSIBLE OUTCOMES**

The ultimate goal of this study is to identify the optimum FCVA process window that would yield ultrathin overcoats on the magnetic media with ultra-smooth topographies with tribological and corrosion properties superior to those of carbon overcoats in current hard disk drives. This will enable a major savings in the spacing budget of 1-2 nm currently used by the carbon overcoat leading to higher areal densities.

The approaches and the tasks defined for this study are catered to reducing the overcoat thickness in the range of $\leq 1$ nm which in turn will help in realizing the goal of ASTC of achieving storage densities of $1.5 - 4$ Tbit/in$^2$. Some of the specific outcomes would be:

- Magnetic media with an ultra-thin functional overcoat of $\leq 1$ nm for achieving storage densities of $1.5 - 4$ Tbit/in$^2$
- Magnetic media with alternative material overcoats ($\leq 1$ nm) such as nitrides/carbides of silicon/boron for superior functionality
- New surface modification techniques for reduced overcoat thicknesses
- Possible alternative materials to be used as protective coatings
- A thorough scientific understanding of the relationships between the depositional parameters and the resulting chemical structures, mechanical, thermal and tribological properties.
- Possible publications in reputed scientific journals and conference proceedings.

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**5. RESOURCES AVAILABLE**

The major part of the proposed research will be carried out at the National University of Singapore (NUS). The team has got access to the latest technological research facilities in terms of equipment and resources at NUS. A specialized lab catering to the data storage
research has been set-up at NUS which is equipped with latest tools having diverse capabilities such as deposition of thin films, characterization of thin films and evaluating the nano-mechanical properties of thin films. The equipment includes the following:

- Filtered cathodic vacuum arc (FCVA) equipment – access with a fee
- AJA Magnetron Sputtering Machine
- E-Beam lithography tool
- TR-Moke
- Laser tool for HAMR studies
- Atomic Layer Depositions tool (ALD)
- Dip coating machine capable of depositing nanoscale lubricant films
- Corrosion measuring setup
- Scanning Probe Microscope (SPM)
- Nano-tribometer
- Optical profiler
- SQUID/MFM
- Contact angle measuring equipment

Besides the above mentioned equipment the team has access to, x-ray photoelectron spectroscopy (XPS), x-ray diffraction (XRD), Raman spectroscopy and scanning electron microscopy (SEM), TEM with EELS capability for additional characterization of the deposited thin films.

6. BUDGET

[6] Resources requested from ASTC and how they will be utilized

a. Funding
   i. Overhead 30%
   ii. Direct project cost 80K/Yr
   iii. Facility use fees: 10K
   iv. Materials 5K
   v. Postdoc 50K
   vi. Travel 15K (3 trips/yr to attend ASTC meeting)

   **NOTE:** If ASTC awards project funding to NUS as an “unrestricted gift” then no overhead is required.

We would also very much like to partner with companies for functional testing such as glide, take-off-height and flyability testing. We will be able to provide a limited number of samples for them to test.
### 7. TIME LINE

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**SUMMARIZING**

[8] Not more than one-half page per contributor: contact information and biographical sketch of researcher.

C. Singh Bhatia worked on magnetic hard disk drives at IBM/HitachiGST for ~30 years and many ideas developed in the lab were commercialized under his management. INSIC presented the 2008 Distinguished Contribution Award to Prof. C. Singh Bhatia in recognition of his dedicated, longterm leadership and outstanding level of contribution to the INSIC EHDR Research Program in advanced hard disk storage technology. Dr. Bhatia is the only individual to have twice been awarded the INSIC Leadership Achievement Award (in 1998 and 2003). He was honored for his recent efforts in leading a working group to define approaches to the head-disk interface for 10 terabit per square inch recording, and for his pioneering efforts to include Singapore in INSIC's research programs. Prof Bhatia joined NUS as Professor in Electrical and Computer Engineering Department, NUS in Aug 2007. Prof. C. Singh Bhatia  
Dept. of Electrical and Computer Engineering  
National University of Singapore  
4 Engineering Drive 3  
Singapore 117576  
Tel: (+65) 6516-7216  
Fax: (+65) 6779-1103  
elbecs@nus.edu.sg
References


