The Mechanisms of Friction and Were of an Ion Beam Textured and a-CNx Coated Slider in Sliding against a Hard Disk for Magnetic Storage(イオンビームテクスチャーされa-CNx膜をコーティングされた磁気記憶装置用ヘッドスライダーとハードディスクの摩擦摩耗機構)

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論文内容要旨

Chapter 1 Introduction

Hard disk technology is the key technology of the development of modern computer. It is a successful application of microtribology in the modern magnetic storage system. In the four decades of the development of the hard disk technology, areal recording density has been improved by about one million times. The present technology is far from being sufficient as the requirement of large capacity and small size of hard disk drives continues.

The stiction between head slider and disk is the most important tribological problem in the hard disk technology. Strong stiction consumes more motor power and can even prevent the spinning up of the disks. It has been common practice to apply a surface texture to disks in order to minimize the stiction force. However the head slider surfaces are not textured, despite the fact that the advantage of textured head sliders has been theoretically proved. The traditional texturing methods used for disk surfaces are not valid for slider surface texturing, because the materials used in the head sliders are not uniform. Compared with the effort put into the research on disk surface coating, the research of coatings on head slider surface is still lacking.

The purpose of the present research is to propose a technique to texture the surface of the head slider and to deposit high wear resistant coating on it in order to obtain a head/disk interface with low friction and low wear, and clarify the friction and wear mechanism of textured and coated sliders against disks.

Chapter 2 The Ion Beam Texturing Technique for Head Slider

In chapter 2, a novel texturing technique based on ion beam etching for head sliders is proposed. When a beam of energetic ions bombards a solid surface, the atoms on the surface will be sputtered away. It is usually called dry etching. The material of a head slider consists of several different phases. These different phases have different etching rates under the same beam of energetic ions. The phase that has a lower etching rate than the others will stick out from the surface to form some islands after etching. Therefore, an island-type texture is possible to be made on head slider surfaces by ion beam etching. (Fig.1)

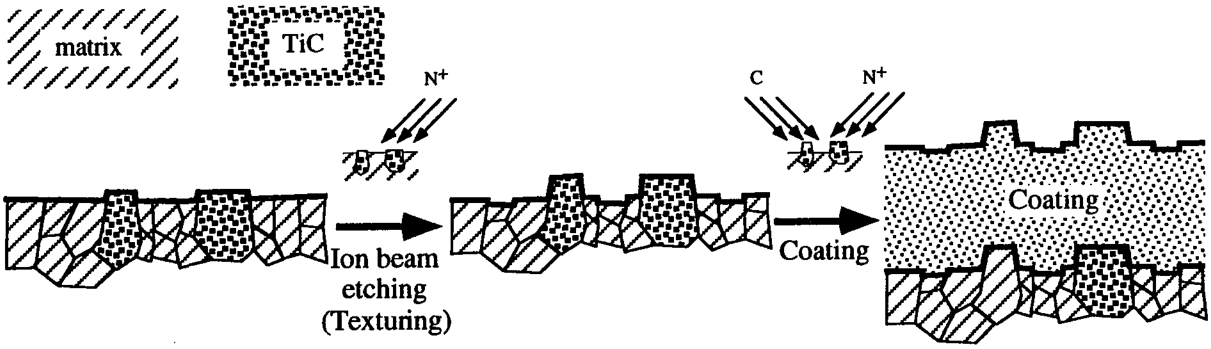

Fig.1 The schematic of ion beam texturing

The results show that an island-type texture with diameter of a 0.3-4 μm can be made on hard disk head slider surfaces by ion beam texturing. Changing the etching dose can control the height of the islands on head slider surfaces from 3~20nm within an accuracy of ±1nm. The island area on slider surfaces can be controlled by changing the TiC percentage in the slider material and the size of the slider air-bearing surface.

Chapter 3 The Evaluation of Wear Resistant Coating Materials for Textured Head Sliders

The texture on head slider surfaces reduce the contact area between the slider and disk, at the meantime, the contact pressure between the slider and disk increases. As the result, the wear of textured sliders becomes another problem that must be solved.

Diamond-like-carbon is the commonly used wear resistant coating material on hard disk surfaces due to its low friction and high hardness. According to theoretical prediction, crystalline carbon nitride (β-C_3N_4) can even be harder than diamond. Based on this prediction, a newly developed coating material, amorphous carbon nitride (hereafter referred to as a-CNx) has become a hot research point. The a-CNx has become a strong competitor for DLC as wear resistant coating material.

In chapter 3, Ion Beam Assisted Deposition (IBAD) was used to synthesize a-CNx thin films and other thin films (DLC, TiNx and BNx) as protective coating on textured sliders. The friction and wear properties of these head sliders were evaluated by a constant speed drag test against DLC-coated hard disks. The results show that as a wear resistant coating material on the textured slider surface for hard disk systems, a-CNx is better than DLC, BNx and TiNx for its highest wear resistance and lowest friction coefficient. (Fig.2, Fig.3)

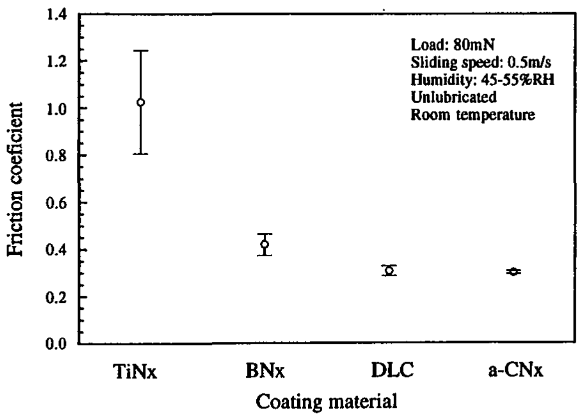

Fig.2 The effect of coating materials on friction coefficient

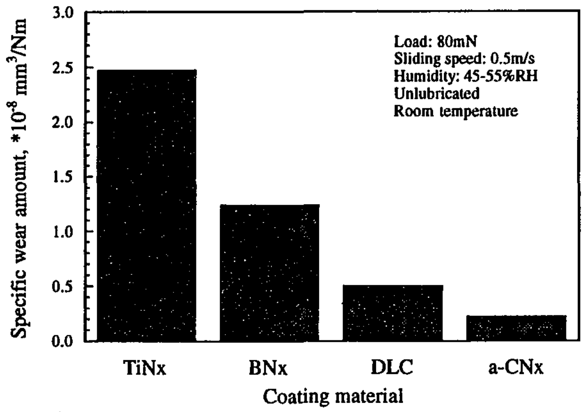

Fig.3 The effect of coating materials on slider wear

Chapter 4 The Effects of Slider Surface Texture and Coating Thickness on Friction and Wear of Slider against Bump-Type Textured Disk

Texture and coating on the head slider surfaces could improve the tribological performance of head/disk interface. High texture and thick protective coating on the head slider surface are advantageous for the tribological performance. However, on the other hand, the texture and coating on the head slider surface increases the spacing between the read/write element to the medium in some degree. In another words, high texture and thick protective coating on the head slider surface are disadvantageous to the high recording density of magnetic storage. Texture area ratio is another factor that affects the tribological performance of head/disk interface. A small texture area ratio tends to have lower friction but a higher wear rate due to higher contact pressure.

It is important to find out the optimum texture area, texture height and coating thickness of sufficient mechanical, or more specifically, tribological reliability of the head/disk interface and sufficiently small spacing for high recording density.

In chapter 4, two kinds of head materials were applied to form texture on the head slider surface with a different texture area ratio. The a-CNx coatings with different thickness were deposited on the head sliders with a different texture height. The tribological properties of these head sliders were evaluated by a constant speed drag test to find out the optimum island area, island height and coating thickness for low friction and sufficient durability. The results show that the island-type texture on head slider surface with heights over 2nm can keep the friction coefficient between head slider and disk at 0.3~0.5 under an unlubricated condition (Fig.4). Coating thicker than 5nm results in almost the same friction between head slider and disk and almost the same wear rate of head slider (Fig.5). The Al_2O_3-TiC head slider has higher friction coefficient and lower wear rate than the ZrO_2-Y_2O_3 head slider against bump-type textured disk due to its higher texture area ratio.

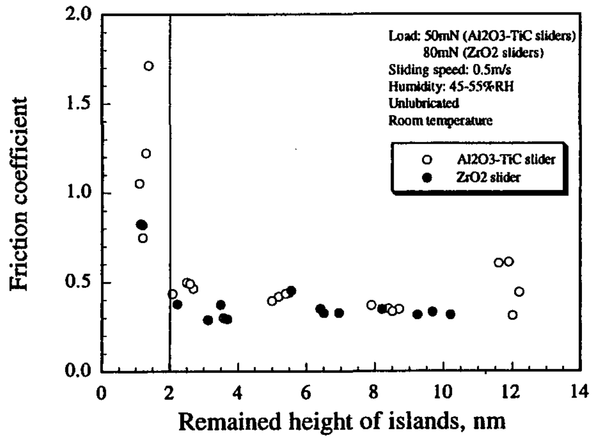

Fig.4 The effect of remained height of islands on friction coefficient

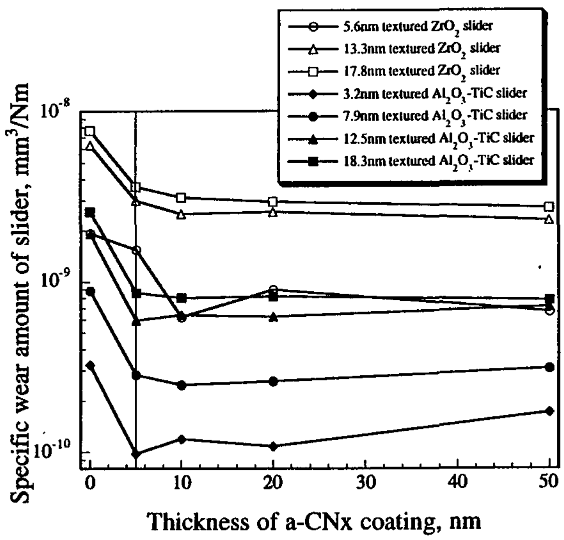

Fig.5 The effect of coating thickness on slider wear

Chapter 5 The Effects of Disk Surface Texture, Lubricant and Coating Material on Friction and Wear of Slider

In chapter 4, sliders with several nanometer high island-type textures and several nanometer thick coatings show low and stable friction coefficients against bump-type textured disks without lubricant. The effects of disk surface properties, such as the style of disk surface texture, the present of lubricant and the material of disk surface coating on the friction against textured sliders with coating and the wear of the sliders are important things to be considered.

In chapter 5, four types of disk surface texture with and without lubricant were applied to test against textured sliders with coating. The a-CNx coating was also deposited on the bump-type textured disk. The wear on slider surface and the friction between slider and disk were measured to show the effect of disk surface properties on the wear of slider and friction. The results show that the bump-type textured disks were a better candidate for textured and coated slider than the random textured disks, the circularly textured disks and the crater-type laser textured disks, due to the lower friction coefficient by 20~30% and lower wear of head slider by 0~40%. The lubricant on the disk surface reduced the wear of the head slider surface more than on order, but did not decrease the friction coefficient by much. The a-CNx coated disk had a lower friction coefficient than the DLC coated disk by about 20%. The a-CNx coating on disk surface doubled the wear of the ZrO_2-Y_2O_3 head slider, but did not change the wear of the Al_2O_3-TiC head slider very much.

Chapter 6 Friction and Wear Mechanism of Textured Hard Disk Head Sliders against Disks

In order to improve new texture pattern and overcoat for sliders, the friction and wear mechanism of textured hard disk sliders for against disks should be elucidated.

In this chapter, the contact condition between textured sliders and textured disks is discussed by the establishment of a contact model. After discussion of the contact condition, the friction and wear mechanism of textured hard disk head sliders against disks are discussed on the basis of the results of the previous chapter.

In brief, the contact between slider and disk are mainly elastic. Plastic deformation only occurs between sub-bumps on the slider and disk surfaces in the initial phase of the drag tests. Friction coefficients between sliders and disks had linear relations with the apparent contact area between slider and disk (Fig.6). The wear of the textured sliders against bump-type textured disks occurs by the plastic deformation of sub-bump on the slider surfaces. The wear particles of nanometer or sub-nanometer size oxidized in oxidative ambiences. The particles agglomerated into some big particles and attached to the taper of the slider surface in non-oxidative ambiences.

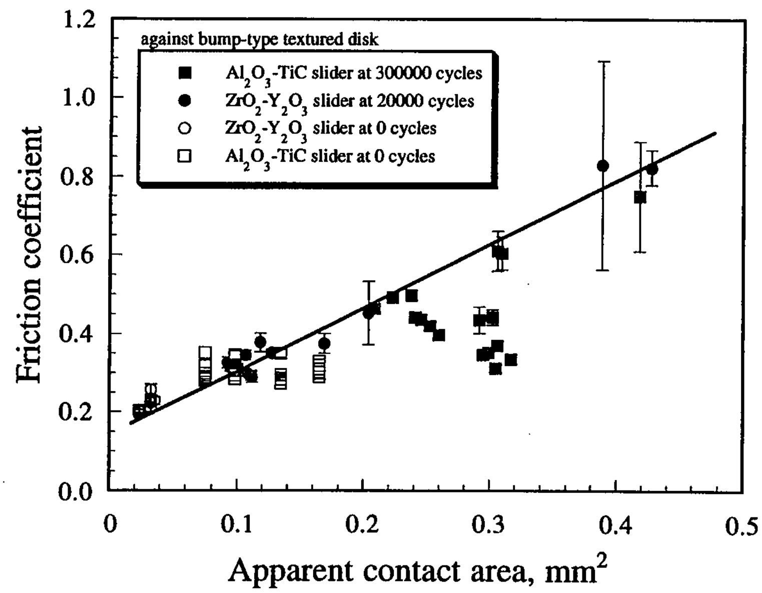

Fig.6 The relation between apparent contact area and friction of the all the tests of in chapter 4

Chapter 7 Conclusions

The present research proposes a technique to texture the surface of head slider by ion beam etching for the first time. The flexibility and accuracy of this new technique is discussed. High wear resistant a-CNx coating is selected to be deposited on textured slider surfaces, and its properties of low friction and low wear against bump-type textured disk is shown. The friction and wear mechanism of textured and coated sliders against hard disks is discussed. This chapter summaries the main conclusions of above chapters.

審査結果の要旨

磁気記録ディスクにおいて$20Gb/in^2$以上の高磁気記録密度化を達成するためには、10nm以下のヘッド浮上量の実現が求められている。この様な低浮上量ヘッドのニアコンタクト方式においては稼働中も間欠的な接触が生じており、現在よりも更に低摩擦低摩耗のヘッドディスクインターフェースが求められている。この問題を解決するためには、スライダーにテクスチャーを施し、保護膜をコーティングする方法が考えられるが、まだその摩擦摩耗機構は明らかではない。

本論文は、イオンビームテクスチャリングによりテクスチャー高さを高精度で制御したスライダーに、将来の保護膜として期待されているa-CNx膜を種々の膜厚でコーティングし、そのディスクに対する摩擦摩耗特性と摩擦摩耗機構を明らかにしたもので、全編７章よりなる。

第１章は、緒論であり、本研究の背景及び目的が述べてある。

第２章では、イオンビームエッチングにより、現在使用されているスライダー表面にnmスケールで高さを制御しながらテクスチャーを形成できることを示している。更に得られたテクスチャーのミクロな形状と分布をアボットの負荷曲線により分類しテクスチャーの性格を明らかにしている。

第３章では、スライダー上にコーティングする保護膜材料として最適な材料を選択するために、４種類の膜材料の摩擦摩耗特性を評価している。その結果、a-CNx膜が最も低摩擦低摩耗であることを示している。これは、実用上重要な知見である。

第４章では、スライダーとディスクの摩擦摩耗特性に及ぼすスライダーのテクスチャー高さとa-CNx膜厚の影響を明らかにしている。その結果、2nm以上のテクスチャ高さ及び5nm以上の膜厚において摩擦摩耗特性が安定でかつ実用可能な値を示すことを明らかにしている。これは重要かつ有効な知見である。

第５章では、テクスチャーとa-CNx膜を有するスライダーに対するディスク表面テクスチャーの影響を調べ、４種類の異なるテクスチャーを有するディスクにおいて、バンプタイプのディスクが最も低摩擦低摩耗を示すことを明らかにしている。

第６章では、イオンビームテクスチャーされa-CNx膜をコーティングされたスライダーとディスクの接触状態を力学的に解析し、得られた実験結果と比較することで、スライダーとディスクの摩耗機構が、スライダー表面にイオンビームテクスチャリングにより形成されたnmスケールのサブバンプの塑性変形によるものであることを明らかにしている。また、スライダーとディスクの摩擦力がみかけの接触面積に比例した事から、摩擦機構がスライダーとディスクの表面間力に依存するものであることを明らかにしている。これらは、テクスチャーされa-CNx膜をコーティングされたスライダーの改良と開発を行うために重要な知見である。

第７章は結論である。

以上要するに本論文は、イオンビームテクスチャーされa-CNx膜をコーティングされた磁気記憶装置用ヘッドスライダーとハードディスクの摩擦摩耗機構を明らかにしたもので、機械工学ならびにトライボロジーの発展に寄与するところが少なくない。

よって、本論文は博士（工学）の学位論文として合格と認める。