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An AFM Study of corrosion on rigid magnetic disks

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ABSTRACT

The corrosion susceptibility of a cobalt-based magnetic alloy as a function of overcoat film thickness at 20 °C and 50% relative humidity is investigated using atomic force microscopy. The overcoat films include ion beam-deposited nitrogenated carbon (IBDN), and sputter-deposited silicon carbide (SiC) and silicon nitride (SiN_x). In all cases, corrosion decreases with increasing overcoat film thickness. The critical overcoat film thickness for corrosion inhibition is approximately 25, 25 and 20 Å for IBDN, SiC and SiN_x, respectively. However, larger corrosion particles are found for IBDN and SiC with increasing thickness just below the critical thickness for coverage.

1. Introduction

The thin-film magnetic layers used in rigid computer disks are based on cobalt alloys. In order to prevent their corrosion, a hard-carbon overcoat film is topically deposited. In the last several years, overcoat film thicknesses have been significantly reduced to a mere 30–40 Å in order to meet the magnetic spacing requirements in current hard-disk drives (HDDs). At these reduced film thicknesses, their ability to provide full coverage of the underlying magnetic alloy is severely challenged. Failure to protect against corrosion results in the formation of cobalt-rich particles, primarily as oxides or hydroxides, on the overcoat surface. The surface decoration is attributed to cobalt migration through the overcoat film as shown in the simple schematic below [1] (see Scheme 1).

Corrosion susceptibility in HDDs is therefore quantified by the ability of the overcoat film to prevent the surface decoration of cobalt-rich particles. Denser carbon overcoat films produced by ion beam and/or CVD deposition processes have replaced sputter deposition to allow the reduced thicknesses [1–3]. Further reductions in the overcoat thickness may be realized by utilizing even denser overcoat films based on cathodic arc carbon or silicon-based materials such as silicon nitride. The decreased corrosion susceptibility of these overcoat films has been discussed [2–5].

The corrosion propensity of cobalt-based magnetic alloys is readily understood via a simplified Pourbaix diagram for the Co–H_2O system, Fig. 1 [6]. The redox potential of the solution in equilibrium with oxygen lies above the immunity region for all pH values. Consequently, Co will be oxidized by aerated water with the formation of Co^{2+}. At higher pH and/or potential values, various oxides of cobalt are produced. Many of these oxides have limited or negligible water solubility and could provide passivity [7]. However, rigid magnetic media must demonstrate corrosion resistance under hot, humid conditions using neutral water as partial fulfillment of disk quality assurance. Since cobalt dissolution in the magnetic alloy is assumed to be galvanically coupled to the O_2/OH^- system [1], corrosion is thermodynamically favored. For the interested reader, Pourbaix diagrams for the Co–H_2O system have been recently updated for temperature effects between 20 and 150 °C [8]. Pourbaix diagrams for cobalt alloys are also extant in the literature [7].

The corrosion protection of magnetic films by overcoat films typically decreases with decreasing overcoat film thickness [5]. In today's low-flying hard-disk drives, where pole-tip protrusion renders slider-disk clearances to a mere 2–4 nm, the size of the corrosion particles is expected to be a significant determinant in the reliability of HDDs [9]. For example, a corrosion particle on the overcoat surface that approaches or exceeds current slider-disk clearances will have an increased probability of contact with the low-flying slider, causing unwanted failure of the hard-disk drive. In this report, we investigate by atomic force microscopy (AFM) the size distribution of corrosion particles as a function of overcoat film thickness for the ion beam-deposited amorphous nitrogenated carbon (IBDN), and the sputtered-deposited silicon nitride (SiN_x) and silicon carbide (SiC) overcoat films. The corrosion study is limited to the 20 °C, 50% relative humidity environmental condition. In all cases we observe the expected decrease in surface decoration of corrosion particles with increasing overcoat film thickness.

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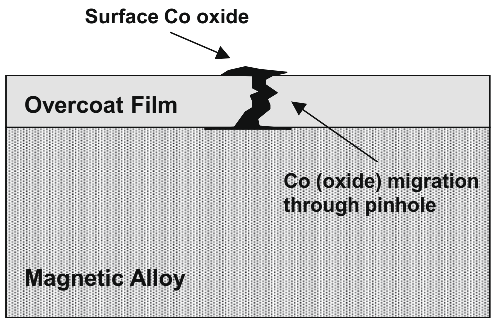

Scheme 1.

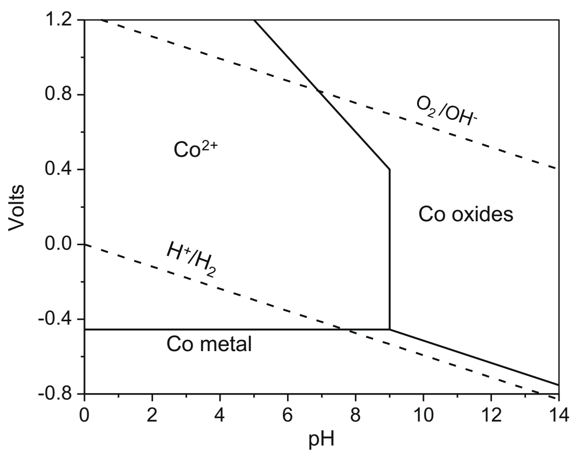

Fig. 1. A simplified Pourbaix diagram for the Co/H_2O system versus the standard hydrogen electrode at 25 °C [6]. A metal ion concentration of 10^{-6} M is assumed.

Table 1
Some overcoat film properties.

Overcoat film	Acronym	At.% N, C, Si (Auger, ESCA)	ρ (g/cm^3) (XRR)
Ion beam carbon	IBDN	6% N	2.1
Sputtered SiC	SiC	46% C, 54% Si	2.9
Sputtered SiN_x	SiN_x	50% N, 50% Si	3.2

However, we find the surprising result that, just below the critical thickness for coverage, the corrosion particle size actually increases for the carbon-based IBDN and SiC overcoats. In contrast, the corrosion particle size distribution on the SiN_x overcoat simply decreases with increasing overcoat film thickness. Possible explanations are discussed.

2. Experimental

The substrates used in these studies were 65 mm glass disks nominally of 2 Å RMS roughness and a peak roughness of approximately 11 Å. Roughness measurements were conducted on an AFM Dimension 5000 with a standard AFM tip used in the tapping mode. The typical scan size was 5 μm × 5 μm with a scan rate of 0.5 Hz and 256 lines of resolution. Atop the glass substrates were sputter-deposited a cobalt-based magnetic layer (CoPtCr), and some overcoat films based on carbon and silicon (Table 1). The elemental composition (at.% nitrogen) of the overcoat films were quantified using Auger electron spectroscopy (AES) and/or ESCA as previously described [10]. XPS measurements were made using a Phi Quantum 2000 ESCA system employing Al Kα irradiation. Measurements were conducted at a 75° take-off angle. Auger measurements were made using a PHI Auger 660 (Perkin–Elmer) operated at 3 kV and 200 nA beam current. These data are summarized in Table 1. The thickness of the carbon films used in these studies was quantified by both ellipsometry and X-ray reflectivity (XRR) measurements [10].

Cobalt-rich corrosion particles were produced on the overcoated magnetic disks by exposure to 20 °C and 50% RH (relative humidity). Instead of using accelerated corrosion tests under harsh environmental conditions (high temperature, corrosive environments), we choose to investigate ambient storage conditions. Typically, several weeks to months of storage were required to observe the corrosion particles by AFM. The disk samples shown in Figs. 3, 5 and 6 were therefore interrogated by AFM approximately 4 months after ambient storage to ensure corrosion decoration.

3. Results

We first describe in more detail the AFM sampling methodology used in these studies. Fig. 2 shows representative AFM images for the temporal evolution of corrosion particles on the disk surface for an 18 Å IBDN film. The 18 Å film does not provide sufficient coverage of the underlying magnetic alloy and hence Co corrosion occurs. Initially after overcoat film deposition, no corrosion particles are detected on the disk surface by AFM. After 1 month, corrosion particles (brighter spots) just become detectable by AFM (Fig. 2 middle). After several months, the corrosion particles are plainly evident (Fig. 2 right). AFM analyses indicate that they are on the surface of the IBDN film with particle heights as much as 6–8 nm. The brighter spots in the AFM images were confirmed to be cobalt oxides by ESCA (Co 2p ~ 781 eV), to be detailed below. In the magnetic recording industry, the kinetic aspects of corrosion are often ignored in favor of a "pass/fail" criterion using accelerated tests that are conducted at a higher temperature and relative humidity [11,12]. These accelerated tests are typically completed within ⩽1 week. Since HDD reliability in the field is measured in

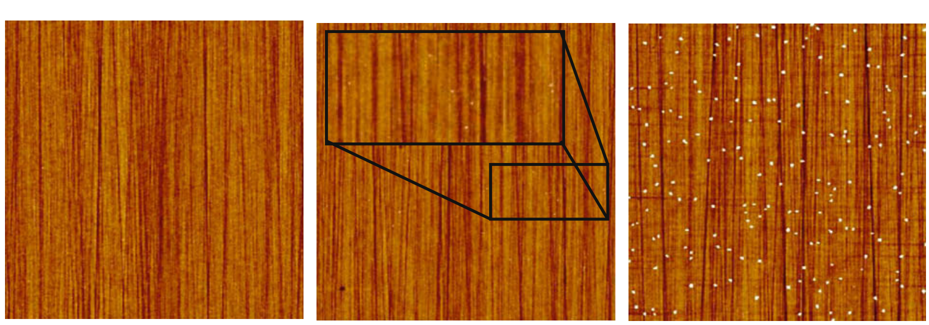

Fig. 2. Corrosion versus time for an 18 Å IBDN film stored at 20 °C and 50% RH after: 0 (left), 27 (middle) and 81 days (right). All AFM images are 5 μm × 5 μm. The middle inset figure shows the magnified image of the rectangle.