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Conductive Atomic Force Microscopy Characterization of Ultra-Thin Diamond-Like Carbon Films on Magnetic Recording Heads.

Shirley Mejia[1], Sean P. Leary[1], Guilherme P. Souza[1], and Kurt C. Ruthe[1]

[1.] Western Digital Corporation, Magnetic Heads Operations, Metrology & Materials Characterization, Ayutthaya, Thailand, 13160

Tetrahedral amorphous diamond-like carbon (DLC) has enjoyed a long tenure in the technology evolution of magnetic recording in rotating hard disk drives, where it serves dual functions as a barrier to corrosion of the ferrous recording elements and an interface for tribological wear resistance [1]. Incremental advances in areal storage density continue to rely in great part to decreasing the spacing between the recording head and media, both of which use some form of DLC which in turn can consume as much as 40% of the total spacing budget allowed by design. Thus, commensurate downward scaling of these overcoats is a critical technology enabler. With that scaling, the efficacy of the films to meet their core functional requirements as diffusion barriers and tribological wear protection becomes challenged as the overcoat thickness approaches the scale of the surface topography [2]. In this work, we discuss the application of conductive atomic force microscopy [3] (CAFM) for the characterization of DLC films in the 10-60 Å thickness regime and new insights gained into the robustness of films to meet functional requirements as scaling progresses into the sub-20Å regime.

A conventional filtered cathodic arc (FCA) process [4] was used to deposit DLC films in the 10-60 Å thickness range on magnetic recording heads, and all films included a Si-N adhesion layer on the order of 10 Å deposited in situ under vacuum in the same deposition system used for the DLC films. Prior to deposition, samples received mechanical lapping, chemical cleaning, and an in situ sputter pre-etch. The nominal film thicknesses were controlled in situ by spectroscopic ellipsometer and verified by TEM. Surface topography and conductivity were measured simultaneously with a commercially available CAFM system. A variable gain current amplifier capable of 10^3-10^9 V/A provided probe current sensitivity in the 10-10^4 pA range. I-V curves of the films at various thicknesses were used to identify the optimal sample bias for high SNR below the noise and breakdown voltage thresholds of the films, but a fixed sample bias of 0.5 V, optimized for 20 Å nominal films, was used throughout the studies. Subsequent TEM imaging and EELS were performed using a Schottky field emission gun TEM operating at 200 kV, and a post-column spectrometer with a ~50 mrad collection angle and energy resolution ~1.2 eV. TEM samples were prepared with a Cr_2O_3 capping layer to preserve the DLC integrity prior to FIB cross-sectioning.

The RMS current detected as a function of DLC thickness, shown in Fig. 1, is observed to increase in the thickness range 10-20 Å where is reaches a maximum and then rapidly decays as the thickness increases to 60 Å. Additionally, the sample-to-sample dispersion in the measurements also scales inversely with the film thickness as a second-order quadratic. This behavior suggests two regimes can be defined, and it is proposed that the sub-20 Å regime is dominated by oxide formed with the Si-based adhesion layer due to poor coverage and permeability of the DLC film, while the thick film regime (>20 Å) is dominated by the resistance of the DLC film itself. This hypothesis was tested by partitioning the head fabrication process with CAFM. Fig. 2 shows that no significant current is detected from the surface after cleaning, etching, and deposition of the DLC adhesion seed layer, respectively, consistent with oxidation of the surface occurring between the processing and measurements. Conversely, a 20 Å

DLC film on a clean NiFe surface yields a strong response, but the inclusion of the seed layer in the same film weakens the response, consistent with the hypothesis that the seed layer plays a role. However, the sample-to-sample dispersion suggests that the variation may be dominated by seed-carbon inter-diffusion and oxidation rather than oxidation alone. EELS elemental profiles of full films including seed and DLC shown in Fig. 3 show that at 20 Å DLC thickness oxidation of the seed layer begins to occur, and below 20 Å Si diffuses into the DLC and oxidizes more fully, indicating that the effectiveness of the DLC as a diffusion barrier is compromised.

In summary, we have shown CAFM to be a useful technique for characterization of DLC thin films on magnetic recording heads. It can be used to complement established techniques such as TEM as a proxy film thickness metrology; however, the ultra-thin sub-20Å thickness regime reveals a highly variable conductivity mechanism which complicates interpretation of data without additional TEM analysis. These phenomena, resulting from marginality of the film's ability to completely protect the head from oxidation, potentially puts a fundamental physical limit on opportunity for further downward thickness scaling on magnetic recording heads without new process and materials breakthroughs.

References:

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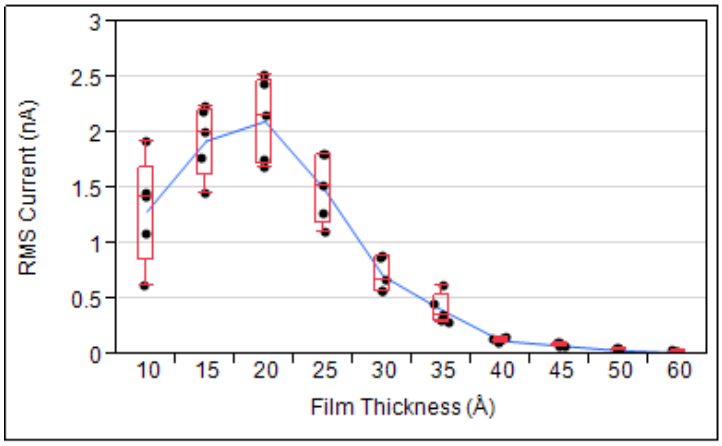

Figure 1. CAFM RMS current measured on NiFe as a function of film thickness.

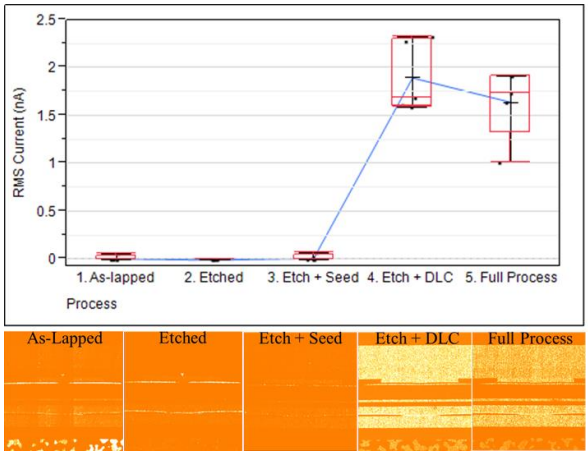

Figure 2. CAFM partitioning of process steps in DLC fabrication.

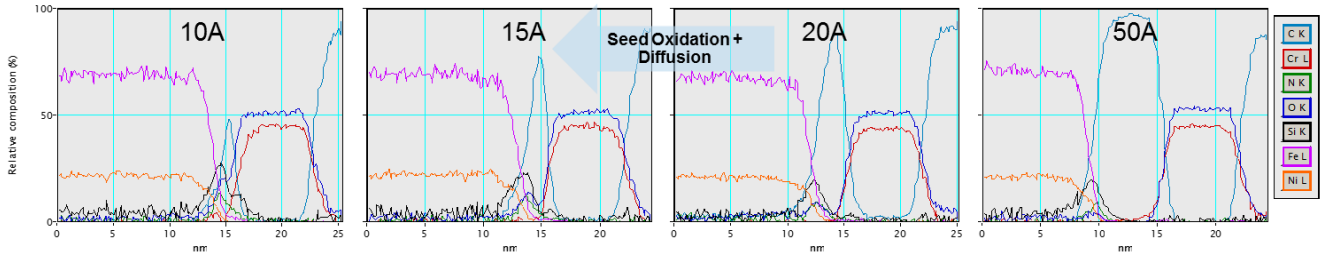

Figure 3. EELS elemental profiles of various DLC thicknesses.