In-Situ and Ex-Situ Testing of Hard Disk Drives

Nanomechanical test techniques such as nanoindentation and nanoscratch, which have long been used in academic research, are now more commonly finding use in industrial settings both as research and development tools and for quality control. While ex-situ testing can provide the volume of data necessary for statistical analysis, questions regarding the specific failure mechanisms involved can be left unanswered. In some cases, the combination of ex-situ and in-situ studies gives the most comprehensive picture of mechanical behavior. In this study, a Hysitron **PI 95 TEM PicoIndenter®** was used to complement data obtained using a Hysitron **TI 950 TriboIndenter®**. The pairing of these two systems provides a detailed look at the mechanical behavior of a multilayer hard disk film stack.

Hard Disk Films

Evaluating the mechanical integrity of the multilayer films used in hard disk drives is a critical step in their design. Drive failure often occurs due to permanent deformation caused when the read head crashes into the hard disk platter. Knowledge of where and how the deformation occurs within the stack can be particularly useful in drive design. Since film thicknesses are often on the order of a few nanometers, nanomechanical test methods are ideally suited for characterization.

Sample Preparation

The multilayer film stack consisted of a polished glass substrate, seed and orientation layers, a magnetic oxide layer, a perpendicular Pt-X magnet, and a diamond-like carbon (DLC) overcoat. In order to facilitate testing in both test systems, samples were prepared by co-depositing the films onto two different substrate geometries. Samples to be tested ex-situ were deposited on a wafer (Figure 1A), while samples to be tested in-situ were deposited on a wedge-shaped substrate to allow for simultaneous viewing in the transmission electron microscope (TEM) without having to perform laborious FIB milling and lift-out (Figure 1B).

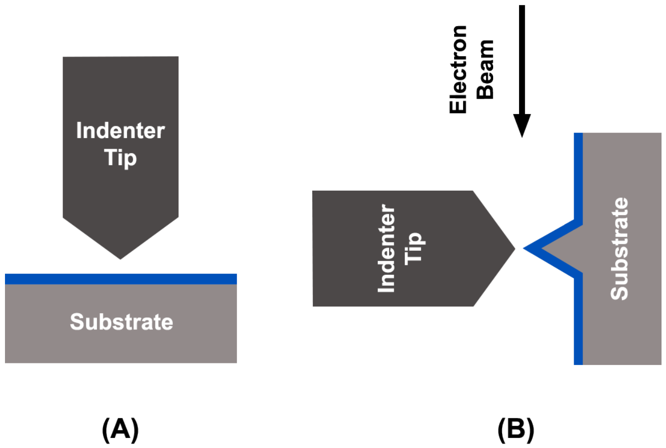

Figure 1: Schematic of sample geometry for ex-situ testing (A) and in-situ testing (B). Film stack layers are shown in blue.

Ex-Situ Sample Testing

The as-deposited wafer was tested using a TI 950 TriboIndenter. The tests utilized Hysitron's **xProbe**, a MEMS-based transducer, which exhibits a noise floor similar to that of contact mode AFM. A series of indents were performed in load-controlled mode, with loads ranging from 5 to 80mN, as shown in Figure 2. The slope of the loading curve indicates a variation in sample properties as a function of depth as the indenter tip progresses through the film stack. Ex-situ testing can be used to acquire a large quantity of data quickly at higher loads than those

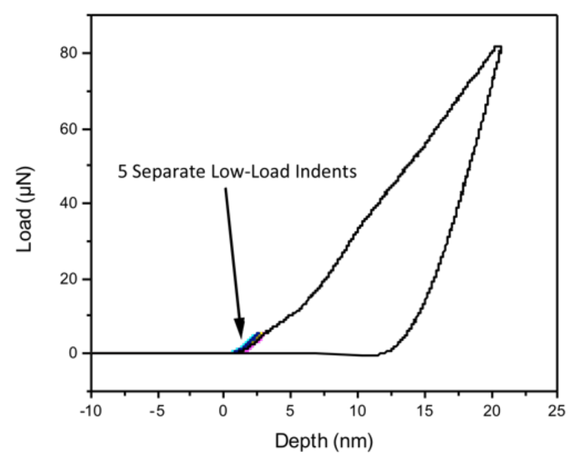

Figure 2: A series of Load-Depth curves acquired during ex-situ testing.

available with in-situ techniques, making it particularly well suited for analysis of materials properties through a range of sample depths. Figure 3 shows the evolution of elastic modulus as a function of contact depth for the film stack, as calculated using data acquired during ex-situ testing. Modulus values at shallow depths are shown to be elevated, presumably due to the thin DLC overcoat. The values then decrease significantly as the probe accesses the underlying magnetic and seed layers.

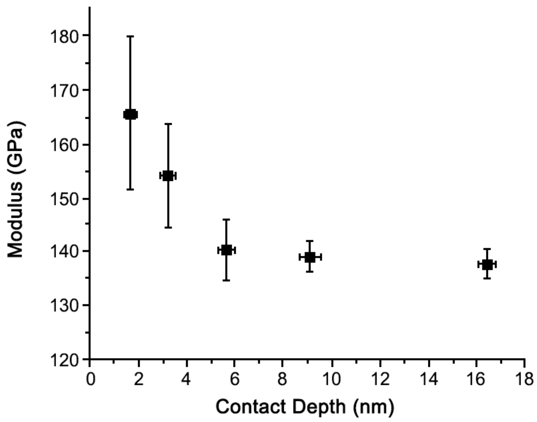

Figure 3: Modulus as a function of contact depth for the film stack.

In-Situ Sample Testing

The wedge-shaped sample was mounted in the PI 95 TEM PicoIndenter such that the electron-transparent region was visible with the electron beam and accessible by the indentation tip (illustrated in Figure 1B). The tests were performed in a TEM operating at 300kV. The PicoIndenter system was equipped with a wedge-shaped conductive-diamond tip with a 50nm radius, which is a good analogy to the read head of an HDD. Testing was performed in displacement-controlled mode so as not to exceed the electron transparent region of the sample. Time-synchronized video was acquired during each test.

TEM micrographs of the sample before and after deformation are shown in Figure 4, along with the load-depth curve. Analysis of the micrographs reveal several interesting results. First, as the probe pushes past the topmost protective layer, the DLC flows away from the tip of the probe and begins to pile up at the contact periphery, which does not match classical deformation behavior of what is normally a brittle solid. Second, deformation in the buried magnetic and seed layers appears to be top-down. This means that even though the region of highest shear stress is located in orientation layers, deformation is still observed in the important data-storage layers. Interestingly, analysis of the video shows that the applied stress appears to cause grain rotation prior to plasticity, which by itself may result in failure of the hard disk drive and ultimately, loss of stored information.

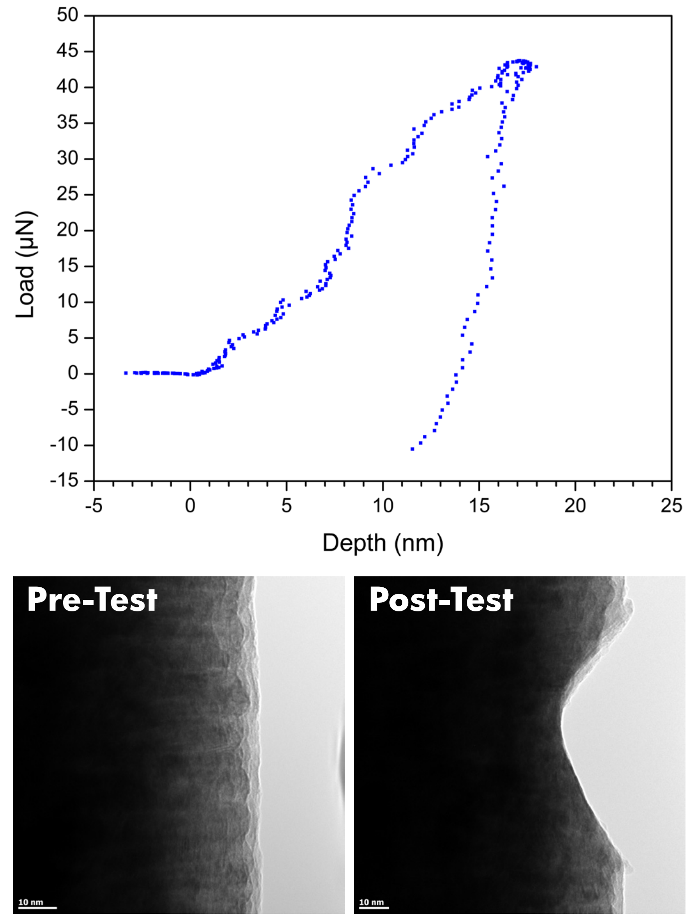

Figure 4: A load-depth plot from the in-situ testing and TEM micrographs of the film stack before and after deformation.

Conclusions

The combination of in-situ and ex-situ test techniques allows for a comprehensive analysis of the mechanical behavior of hard disk drive film stacks. The ex-situ testing performed on the TI 950 TriboIndenter provides high-throughput, repeatable, statistically relevant data for quality control purposes. For research and development, the PI 95 TEM PicoIndenter provides insight into the underlying mechanisms responsible for deformation at the nanoscale by leveraging direct TEM observation. In this case, the protective DLC layer appeared to flow under applied stress. Also, grain rotation was clearly observed in the magnetic layer, which provides new insights into the root cause of mechanically initiated data loss in hard disk drives.

Modern electronics must be engineered to be as small as possible while maintaining structural stability. Nanomechanical testing is a particularly powerful technique for evaluating these devices. In tandem, these two quantitative test techniques can provide a thorough analysis of mechanical performance.

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