ARX004:
Analysis of Magnetic Recording Media

Thermo ARL (formerly Scintag) powder diffractometer

Application Note

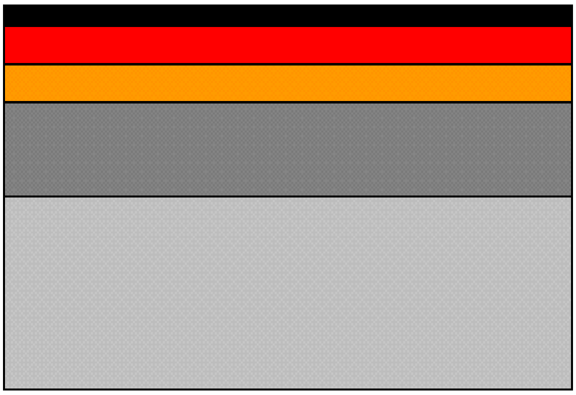

Figure 1 - Schematic of hard disk drive (layer thicknesses not to scale)

Introduction

The production of magnetic recording media, for example, the hard drives on all of our computers, is a multibillion-dollar industry. Tremendous pressure to increase information storage capacity of this media is being exerted as computers have gotten faster and computer programs have gotten larger and more complex. Routine storage of pictures and sounds in multimedia applications has greatly increased the need for more data storage. The magnetic properties of a disk drive, like the storage density, are strongly related to the texture and lattice parameters of the thin films making up the hard drive. So, it is natural for disk drive manufacturers to be interested in using x-ray diffraction as a tool for designing new disk drives with higher data storage capacity.

Figure 1 shows a schematic of a typical hard disk drive platter. It consists of 5 layers. The aluminum alloy substrate (light gray) is coated with a several micron thick buffer layer (dark gray) of a NiP glass. The purpose of this buffer layer is to prevent the crystallographic structure and orientation of the aluminum from affecting the orientation of any of the other thin film layers. On top of the NiP is the so-called seed layer (orange). This is usually a chromium alloy of some kind. While the buffer layer prevents the crystallography and orientation of the substrate from affecting thin film growth of subsequent layers, the seed layer is designed to affect the growth and orientation of the magnetic layer. The magnetic layer (red), usually an alloy of cobalt and chromium is on top of the seed layer. This is the layer where data storage occurs and is the most critical in the design of newer, higher density media. Designers try to get the best match possible between the magnetic layer c-axis and the a and b-axes of the seed layer. There is great interest in reducing the thickness of both the seed and magnetic layers of hard disks. Both are typically in the 300-500 angstrom thickness range. Finally, a top layer (black) of approximately 50 angstroms of carbon is added. The purpose of this layer is for protection of the magnetic layer in the event of a physical crash of the read-write head onto the disk drive.

Drive manufacturers are primarily interested in two pieces of information that may be obtained using x-ray diffraction: 1) the texture, including the degree of anisotropy, of the magnetic and seed layers, particularly those diffraction planes that are parallel to the sample surface and 2) the quality of lattice matching between the seed a and b-axes and the magnetic layer c-axis.

There are several challenges that must be overcome in order to obtain this information. First, the amount of material in the seed and magnetic layers is minuscule compared to the substrate and buffer layers. This means that diffraction intensities from the seed and magnetic layers are very weak. Long data acquisition times, highly sensitive x-ray detectors like the Thermo ARL Peltier-cooled solid state detector or high power rotating anode x-ray sources may be necessary in order to differentiate the seed and magnetic layer intensities from background due to the substrate and buffer layer. To make matters worse, the crystal structure of the aluminum alloy substrate is similar to that of the seed layer so that most of the seed layer diffraction peaks overlap with much higher intensity aluminum diffraction peaks.

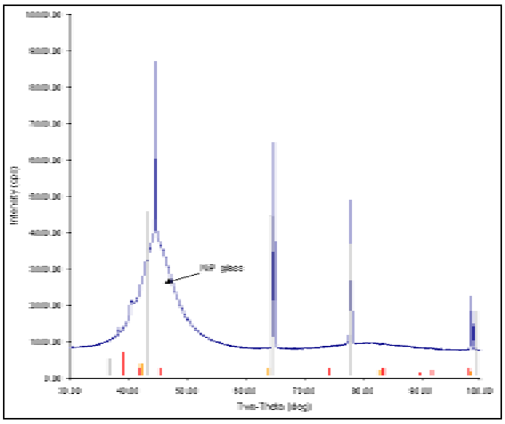

Figure 2 - *Normal diffraction scan from hard disk drive using a Peltier-cooled solid state detector. Stick pattern colors correspond to the layers shown in figure 1.*

Standard Diffraction

Figure 2 shows a normal diffraction scan of a typical hard disk drive taken using a Thermo ARL Peltier-cooled solid state detector. Expected heights of diffraction peaks of the various layers are shown to illustrate the difficulties in this type of analysis. This scan took almost six hours to complete and would have taken much longer had the traditional scintillation detector/graphite monochromator been used. This amount of time was required to differentiate the strongest of the magnetic layer peaks from the buffer layer background and is why high power rotating anode x-ray generators are often used in this application.

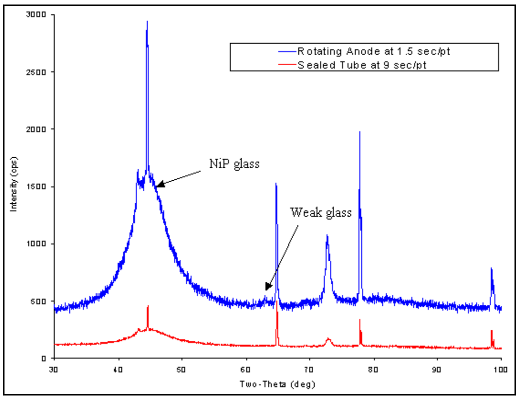

Figure 3 - *Comparison of sealed tube and Rotating Anode diffraction data*

Figure 3 demonstrates this difference on another disk drive sample. The red curve is data collected with a sealed x-ray tube while the blue curve is collected with a 18kW rotating anode generator mounted on a Theta:Theta diffractometer. Both data sets were collected with solid state detectors so the factor of six or so difference in intensity is due only to differences in generator power and diffractometer optics. The rotating anode data is beginning to detect the weak seed layer (200) diffraction peak near 63 degrees two-theta even though the data collection time is four times faster. If rapid data collection is required, then the rotating anode source is the way to go!

Of course, the list price for a rotating anode generator is more than US$100,000 so the search continues for ways to maximize the performance from sealed tube sources. One clever idea is to switch to copper K-beta radiation. The copper K-beta has only about 15% of the copper K-alpha intensity, but K-beta radiation is strongly absorbed by nickel in the NiP glass. This means that very little K-beta radiation will penetrate the NiP layer and, as a result, very little diffraction will be observed from the aluminum alloy substrate.

This idea is very difficult to implement with a scintillation detector and diffracted beam monochromator because of the difficulty in moving the monochromator crystal reproducibly between the two wavelengths. However, this is very easy for a solid state detector and can be done by computer control. Figure 4 shows a normal scan using copper K-beta radiation and a Thermo ARL Peltier-cooled solid state detector. This data is from the same disk drive as used in figure 2.

This data was collected at the same scan speed (15 seconds/pt) as is the data in figure 2. The sharp peaks are due to the aluminum alloy substrate from residual K-alpha x-rays that the solid state detector was not able to discriminate. However, notice that the broad NiP peak is greatly reduced in intensity, which makes the magnetic layer peak near 38 degrees much more obvious. This means that the time per scan could be reduced significantly.

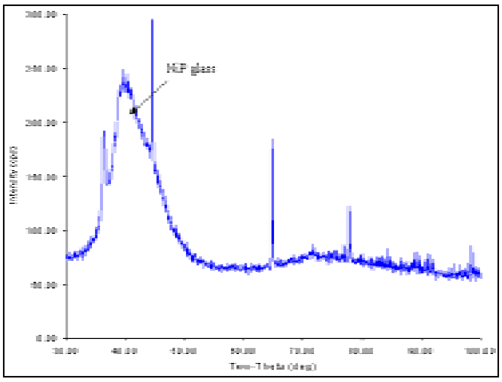

Figure 4 - Normal diffraction of hard disk drive using copper K-beta radiation

Grazing Angle Diffraction

Although the above data may be sufficient to determine the degree of texture in the magnetic or seed layers, it is very difficult to determine the degree of lattice mismatch between the magnetic and seed layers on the basis of only one or two diffraction peaks. For this analysis, another tool must be used; grazing angle diffraction.

The idea behind grazing angle diffraction is to control the penetration of incident x-rays into the sample by fixing the incident angle at some low value, usually less than one degree. The result is that few, if any x-rays penetrate down into the NiP glass buffer layer or to the substrate. This effectively eliminates interference from these layers.

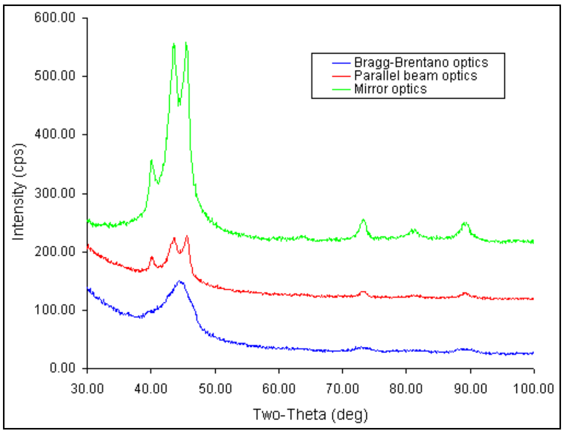

Figure 5 - Grazing angle diffraction at 0.55 degrees. Note: Intensities offset for clarity.

Figure 5 shows grazing angle diffraction data using three different types of optics. All were collected using a 0.55 degree grazing angle. This angle was chosen to eliminate most, if not all background from the NiP buffer layer while maximizing the intensity from the magnetic and seed layers.

The bottom (blue) scan shows the kind of data that you should expect when using standard Bragg-Brentano parafocusing optics. Even though we have removed background interference from the NiP and aluminum alloy substrate, we are unable to resolve the diffraction peaks due to the magnetic layer from those of the seed layer. This is because Bragg-Brentano parafocusing optics only focus when the incident angle is equal to the diffracted beam angle - a condition that is not true in grazing angle diffraction. The result is peak broadening and loss of intensity, especially at higher angle, because of defocusing.

Immediate improvement can be made by switching from Bragg-Brentano parafocusing optics to parallel beam optics. This is done by replacing the diffracted beam slit assembly with a thin film attachment; essentially a long soller slit rotated 90 degrees to the normal soller slit orientation so that it acts like an array of parallel slits. Thermo ARL has made this much easier to do by making available a dual detector bracket. By undoing a couple of thumbscrews, the detector can be moved back and between the thin film attachment and the parallel beam optics. The middle plot in figure 5 shows the results. Now we can clearly see magnetic layer peaks near 40, 46, and 82 degrees and seed layer peaks at 73 and 89 degrees. In addition, the peak at 44 degrees shows directly the degree of mismatch between the magnetic layer (0002) plane and the seed layer (110) plane. A single peak, like the one shown here, is a clear indication of good lattice matching between the two layers.

Both of these first two scans took nearly six hours to acquire. They could have been done faster, but the peak intensities are quite low. This is partly because there is so little material present to diffract and partly because at grazing incidence, the x-ray beam is quite wide. Small divergent beam slits are needed to limit the incident beam to the sample. The result is only a very small solid angle from the x-ray tube actually strikes the sample.

In the past few years, a new approach has been developed to increase the solid angle from the x-ray tube that strikes the sample, and therefore the intensity. This new approach is the parabolic, graded multilayer thin film, incident beam mirror, or mirror for short. The mirror consists of a multilayer chosen for high reflectivity (approximately 70%) for copper radiation. The multilayer is graded, that is, the thickness of each layer changes along the parabolic substrate. The graded multilayer accepts a divergent incident beam and produces a brilliant parallel beam.

The top (green) curve shows the data collected using both a mirror and thin film attachment. The intensity from the same sample is increased by about a factor of 4 at this grazing angle over data collected using just a thin film attachment! The intensity gain is a function of the grazing angle - the lower the grazing angle, the higher the gain. The result is that this data was collected 3 times faster than the other two scans and could have been collected faster still. The development of mirror optics is a great benefit in all thin film applications!

Additional Capabilities

We have not discussed the customer need for measuring the textural anisotropy of these thin films, but this can be done very simply by adding a sample rotation stage. Another capability that is beyond the scope of this applications note is the possibility of depth profiling using variable grazing angle geometry. For example, it is possible to choose a grazing angle that will just penetrate the magnetic layer. This results in a XRD pattern that is only due to the magnetic layer without any contribution from the seed layer.

As film thicknesses decrease, more customers are becoming interested in using x-ray reflectivity to determine layer thickness, roughness and density. This is difficult with hard disk drives because they are traditionally roughened to avoid stiction between the media and read/write heads. However, rough films also limit storage density so the trend is toward smoother films and we believe reflectivity will become a powerful tool in the future. Finally, drive manufacturers have been studying film texture by using subtle increases and decreases in film peak intensity. However, it is also possible to make direct 3D texture measurements using a 4-circle diffractometer with UDC (Universal Diffraction Circle). Of special interest when studying such thin films is the possibility of using mirror optics and collecting grazing angle diffraction pole figure data. This can greatly increase pole figure intensities in the same way as the mirror and grazing angle diffraction increase intensities compared to standard diffraction measurements.

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