Imaging Magnetic Materials using Magnetic Force Microscopy

Magnetic Force Microscopy (MFM) is a powerful scanning probe microscopy technique that is used to study magnetic properties or investigate features such as magnetic domains in a wide variety of sample types. Rewritable or re-recordable storage media are excellent examples of magnetic material applications, and characterizing storage medium magnetic surfaces has always been a strong demand. With the ability to resolve features down to tens of nanometer level, MFM stands at the forefront of magnetic domain imaging and characterization. In this application note, a magnetic tape storage medium is analyzed using single-pass MFM.

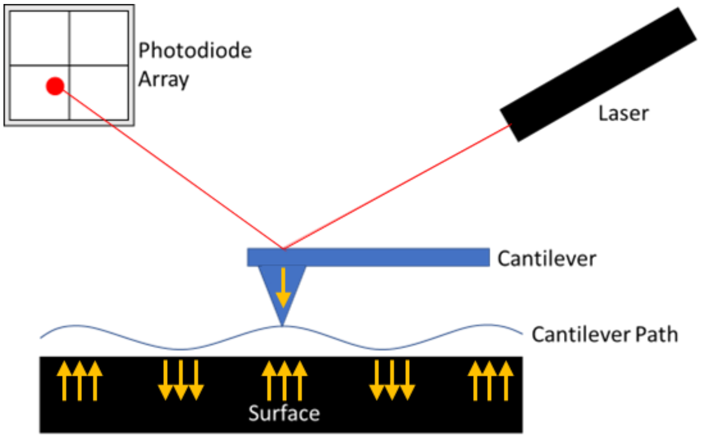

Figure 1. General principles of MFM showing how the tip path is affected by attractive and repulsive magnetic interactions.

In a standard MFM scan, magnetic repulsions or attractions between a magnetic surface and a magnetic tip are measured, as shown schematically in Figure 1. During the scan, the tip is lifted off the surface to sense the long-range magnetic interactions and to eliminate any tip deflection resulting from atomic repulsion or other short-range forces. By operating in oscillation mode, magnetic interactions between the sample and the tip manifest as changes in the phase lag: attractive and repulsive forces shift the phase lag in opposite directions, resulting in bright and dark areas on an MFM image. An MFM scan is analogous to a standard Atomic Force Microscopy (AFM) scan; however, some important distinctions are worth mentioning. Rather than using a standard AFM tip, a soft or hard magnetic tip is used for MFM. Additionally, rather than being in contact with the sample surface during the scan, the tip scans the sample at a fixed height above the sample surface plane in a single-pass MFM or at a fixed height above the sample

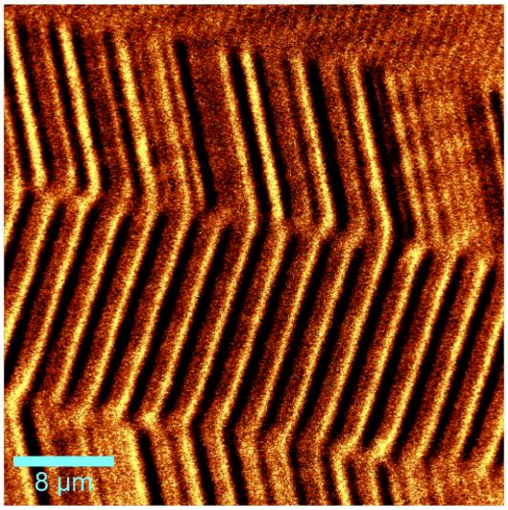

Figure 2. MFM scan of data stored on a video recording tape.

surface features in a dual-pass MFM to further remove topographical influence on the magnetic measurement results.

Many recording devices, such as hard drive disks or video camera film, use magnetic domains to record data. Because these domains can be turned “on” and “off”, data can be rewritten into the media. Video camera film, as characterized here, has a flat surface suggesting a rather featureless material. However, the phase image obtained during the MFM scan shows anything but a featureless material. The scan data is shown in Figure 2. The bright images correspond to areas in which the tip-surface interaction is attractive, and the dark areas correspond to areas in which the interaction is repulsive. Each one of these bright or dark areas represents one bit of data stored on the media. Because it is an MFM scan, the distance between attractive domains can be calculated by profiling a cross-sectional line across the image. The data obtained from such a line is shown in Figure 3. From the cross-section profile, it is observed that the attractive domains are approximately 2.6 μm from one another.

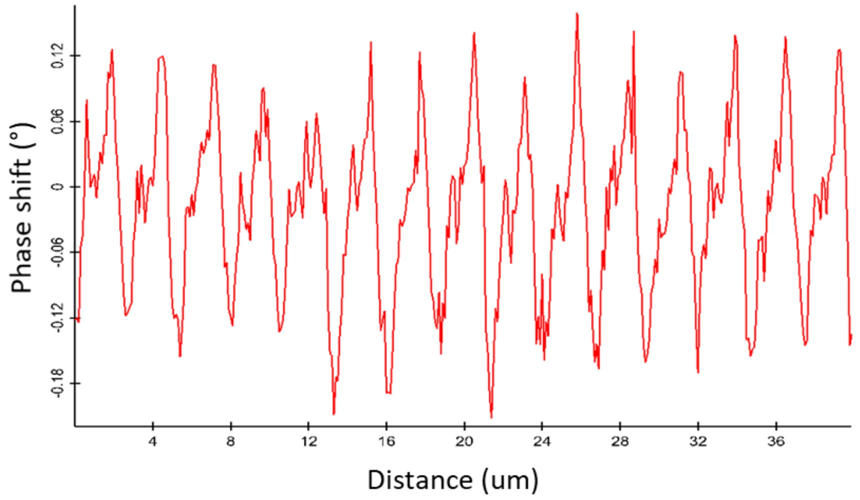

Figure 3. A cross-section profile of the MFM phase signal taken perpendicular to the vertical magnetic domains.

The MFM at Ebatco is capable of scanning areas approximately 200 μm^2 and is currently outfitted with both soft and hard magnetic tips. With this setup, the instrument can characterize the magnetic domain morphology of metals, hard disks, magnetic nanoparticles, hard disk reconstruction, magnetic domain imaging, and magnetic materials in liquids. With such a powerful ability to obtain magnetic information about materials, MFM has found applications from biochemistry (magnetic nanoparticles used for targeted drug delivery, magneto-thermal therapy, and *in-vivo* imaging) to the electronics industry (quality control, process optimization, and R&D for magnetic storage media) and a variety of fields in between.