APPLICATION NOTE

# Magnetic Force Microscopy with the Nano-R™:

***Brook Hamilton, Natalia Starostina and Brandon Weeks***

Previously, among the various existing methods of magnetic imaging, high resolution was only achievable using electron microscope based techniques. Magnetic imaging using the electron microscope however, often required that the sample be thinned or, in the case of recording media, have the protective coating removed. Additionally, electron microscope based techniques are capable of only two-dimensional images. Since magnetic force microscopy (MFM) development in 1987(1,2), it has emerged as a powerful tool for studying a wide variety of local magnetic phenomena in 3 dimensions. MFM is able to reveal magnetic processes with unprecedented clarity, resolution and ease. It allows the direct visualization of magnetic domains and has been used as the experimental basis for theoretical modeling.

The principle of MFM is to measure the change of the interaction force between a magnetized probe and the local stray magnetic field from the sample as the probe is scanned across the surface. The probe is typically a cantilever made from silicon or silicon nitride, with a ferromagnetic coating. The inherent resolution depends upon the confinement of the interaction at the end of the probe and sensitivity depends upon the ratio of the cantilever spring constant and the magnetic moment. At present, commercial MFM probes resolve about 10-100 nm features a force constant of about 0.01- 3.0 N/m. Typical standard samples for use in MFM include: magnetic tapes, hard disks, magneto-optical disks and magnetotactic bacteria.

One standard method of obtaining a MFM image is to operate the AFM in close-contact mode with a magnetic cantilever that detects a force gradient, (F) that contains information from both the surface structure and the local magnetic field (3). collect a topography image close to the surface and then 'raise' the cantilever some height above the surface (~100 nm) where the magnetic forces dominate on the reverse scan.

$$F_{total} = F_{surface} + F_{magnetic}$$

Signals from surface topography dominate at close distances to the surface while, at greater distances from the surface (typically beyond 100 nm), the magnetic signal dominates. Consequently, depending on the distance between the surface and the tip, normal MFM images may contain a combination of topography and magnetic signals.

Despite the impressive performance and widespread use of the MFM, there are important probe-related limitations that need to be overcome to realize its full potential. First of these is the enhancement of resolution and sensitivity. As is well known from microscopy, in order to measure something at a given scale it is necessary to have a probe whose fundamental size is well below the size of the object to be measured. In the case of magnetic force microscopy the force between the probe and the sample is carried by the magnetic field. Obviously, the smaller the magnetically active area of the probe, the less it will be affected by areas from far away since the dipole nature of the field causes it to diminish rapidly with distance. Therefore, in order to make a high resolution MFM it would be necessary to create an extremely small magnetic probe. The smaller volume of the magnetic probe, on the other hand, will result in a lower magnetic moment and a smaller interaction volume and thus a weaker force. Hence, the lateral resolution of the MFM probe will also be limited by its sensitivity (e.g. the spring constant of the cantilever). The improvement in resolution would have to be complemented with an enhancement of the probe sensitivity.

The Nano-R™ is capable of collecting the topography and magnetic force image simultaneously by using Labview although this is not necessary except for extremely rough samples. For flat samples (thin films, data storage, etc.) the following methodology can be followed to collect MFM images with the Nano-R™.

## Materials:

1. MFMR Magnetic Force Microscopy Sensors - NanoWorld probes at: (www.probestore.com)
2. Small permanent magnet: (www.kdsmagnets.com)

## Procedure:

1. Magnetize the MFMR Tip by placing the permanent magnet in close proximity (mm).

2. Insert MFMR cantilever and sample into standard positions (the magnetic tip holder and sample holder will not significantly affect the image quality).

3. Choose close-contact imaging mode.

4. Find the resonant frequency of the cantilever.

5. Reduce the maximum amplitude of the resonant peak to less than 1.5 V.

6. Collect a topography image of the area of interest.

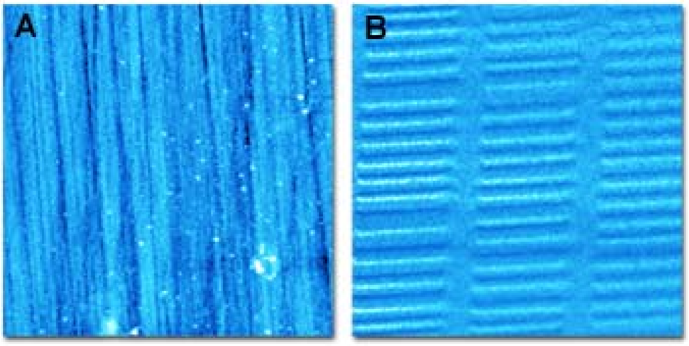
7. To collect an MFM image you will need to raise the tip above the surface of the sample to remove the topography component. The simplest way is to change the set point by increasing the absolute magnitude of the cantilever oscillation.

8. Start collecting an image while slowly increasing the cantilever set point. You will notice the topographic image becoming less sharp until no information is evident.

9. As the topographic image fades away, you should be able to clearly see the magnetic information on a surface by looking at the phase signal.

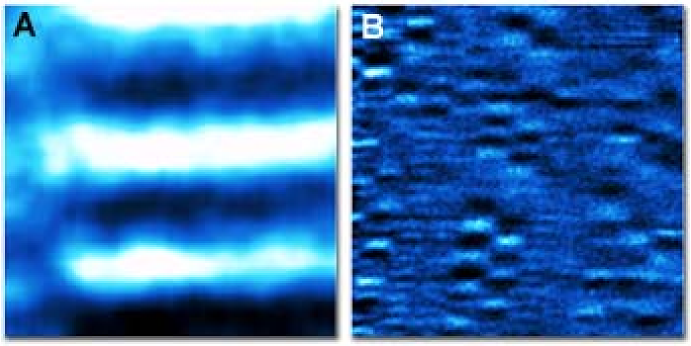
10. As complex as this seems, We were able to collect MFM images of hard disks within 30 minutes of imaging:

### Figure 1



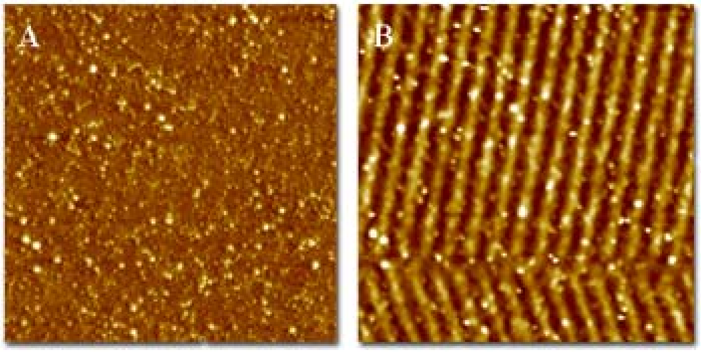

*Magnetic domains on a 5 Gb hard disk: A) Topographic image in close contact mode; B) Phase image after increasing the set point of the same area in A. Both images are 40 x 40 µm.*

### Figure 2




*5x5 µm MFM images of a 5 Gb hard disk (A) and a 70 Gb hard disk (B). The magnetic domains in A are ~ 12 µm in length while the domains in B are on the order of 250 nm. This shows the high resolution capability of the Nano-R™ with MFM.*

### Figure 3




*10x10 µm MFM images of magnetic tape, topography (A) and phase image (B). The magnetic domains are ~ 650 nm in length. Image courtesy of Toyo Corp.*

## References


1: Y. Martin and H. K. Wickramasinghe, Appl. Phys. Lett. 50, 1455 (1987)

2: J. J. Sáenz, N. García, P. Grütter, E. Meyer, H. Heinzelmann, R. Wiesendanger, L. Rosenthaler, H. R. Hidber and H. J. Guntherodt, J. Appl. Phys. 62, 4293 (1987)

3: Q. Zhong, D. Inniss, K. Kjoller, and V.B. Elings, Surf. Sci. Lett. 290, L688 (1993).