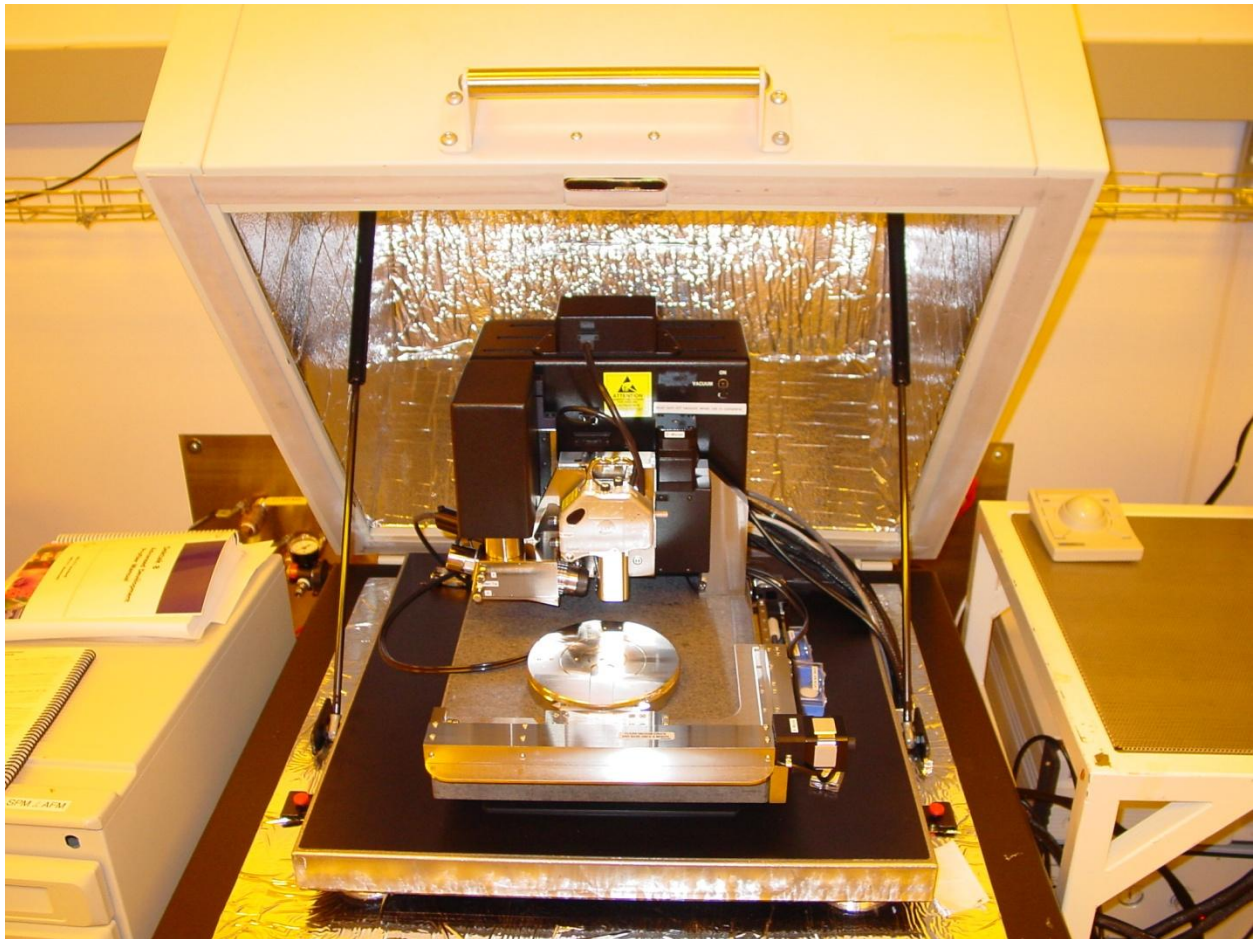


Magnetic Force Microscopy

Operating Procedure

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10/30/2009



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Clean Room Labs

DOCUMENT TITLE: Magnetic Force Microscopy Operating Procedure
DOCUMENT NUMBER: FA2009-CR-002

10/30/2009
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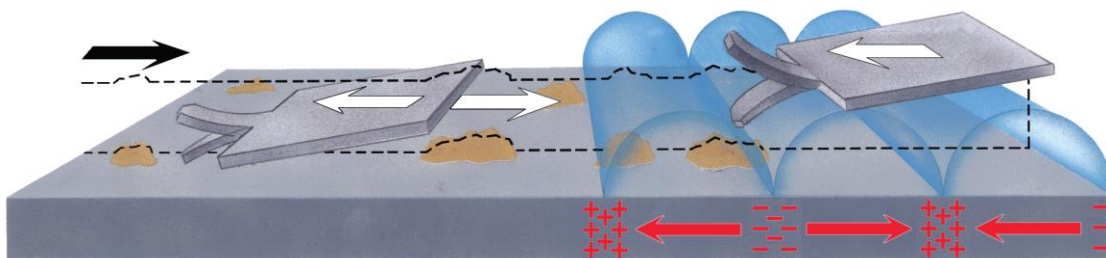
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Purpose

This document describes how to capture an image of the magnetic field just above the surface of a sample using the UTD Cleanroom's Atomic Force Microscope (AFM). This is an advanced imaging technique and requires the prerequisite skill of AFM training and operation experience.

Principles of Magnetic Force AFM Microscopy

The basic principal of how an atomic force microscope obtains an image of the magnetic field above the surface of a sample is as follows: 1) a special magnetized AFM tip is first used in tapping mode to profile the topography of the physical surface of the sample, 2) the AFM is set to "Lift Mode" to enable the tip to re-trace the memorized profile of the surface from a set distance above the surface, and 3) the resulting interaction between the surface magnetic field and the magnetized AFM tip produces an image of the magnetic field gradient, independent of the surface topography. This is visualized in Figure 1.



5. Lifted cantilever - topography while responding to magnetic influences (second retrace).
4. Lifted cantilever profiles topography while responding to magnetic influences (second trace).
3. Cantilever ascends to Lift scan height.
2. Cantilever retraces surface topography on first retrace.
1. Cantilever traces surface topography on first trace.

Figure 1. Principles of Magnetic Force Microscopy depicting the Lift Mode methodology.

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Force Gradient Detection Details

In the standard tapping mode of AFM operation, the probe cantilever is set to oscillating at its resonance frequency, f_0 , by a piezo actuator with a driving frequency, f . As the probe sweeps across the surface, it “feels” the surface by lightly tapping the surface to produce an AFM image of the physical surface. On the return trip across the surface in the same track as before, the tool is set to its “Lift Mode” operation, so that the probe tip travels above the surface by a set distance, following the height topography from memory of the just measured physical profile. When the magnetized probe tip “feels” a change in the magnetic field strength rising from the surface, the cantilever oscillation frequency shifts a small amount, perhaps 1 – 50 Hz in magnitude. These frequency shifts can be detected in three ways: 1) phase detection which measures the cantilever’s phase of oscillation relative to the piezo drive frequency; 2) amplitude detection which tracks variations in the oscillation amplitude; and 3) a frequency modulation technique which shifts the driving frequency in order to maintain the cantilever frequency at f_0 . This active driving frequency, $f(x,y)$, required to maintain the constant cantilever frequency is then plotted as the image.

In general the amplitude detection technique has largely been superseded by the frequency modulation and phase detection methods, since they both offer greater ease of use, better signal-to-noise ratios, and reduce artifact content as compared to amplitude detection. We will specifically describe only the phase detection technique here.

Basic Magnetic Force Microscope (MFM) Operation

This section provides instructions for the Cleanroom’s VEECO Dimension V Atomic Probe Microscope, using the Lift Mode of Interleave Scanning to obtain Phase Shift images depicting a magnetic field profile. We usually refer to this tool as our “AFM”.

The Lift Mode allows the imaging of relatively weak but long-range magnetic interactions while minimizing the influence of topography. Measurements are taken in two passes across each scan line (Interleave Mode); each pass consists of one trace and one retrace. In the first pass, topographical data is collected in the Tapping Mode. The tip is then raised to the lift scan height and a second trace and retrace cycle is performed while maintaining a constant separation between the tip and the local surface topography. Magnetic interactions are detected during this second pass. Since the surface profile data is not included in the frequency signal, the topography is virtually absent from the MFM image.

The first requirement for MFM imaging is a cantilever with a tip that is magnetized so that it can interact with the sample magnetic field. The AFM tip we have that meets that criterion is the MESP tip from VEECO. It has a cantilever of 225 micron length with a resonant frequency f_0 , of between 60 and 100 kHz. The tip is a conducting antimony doped Silicon coated with Chrome and Cobalt and then magnetized to a Coercivity of ~400 Oersteds. The spring constant is on the order of 1 – 5 N/m.

Magnetic Force Microscopy Procedure

1. Install a magnetized MESP probe into the holder and load it onto the AFM head.
2. Open the AFM software and align the tip as in basic AFM operation procedures.
 - a. Align the laser red spot to the center cross of the alignment graph.
3. Load the sample onto the mechanical stage and lower the probe to the pre-engage position as usual for a normal AFM tapping mode image (~1 mm above the surface).
4. Set the probe drive frequency with the Auto Tune function. (Click on the blue Tuning fork icon in the left screen center of upper icon bar.) Set the frequency range between 60 and 100 kHz, and the probe oscillation amplitude to 500 mV. Click on the Auto Tune button. The tuning function then measures the phase difference between the drive voltage to the cantilever piezo and the cantilever frequency response as measured by the laser sensor signal. When the probe moves through magnetic fields, the ensuing magnetic force placed on the cantilever causes a shift in the cantilever resonance frequency which also gives rise to a phase shift between the two signals corresponding to the magnetic force gradients from the sample.
5. Engage the tip with the sample and adjust parameters to obtain a good tapping mode image – then withdraw.
6. Setup parameters for Lift Mode operation:
 - a. Open the Scan Parameter List window. (Click on the Scan parameter command under the Acquire menu at the upper left of the left screen.)
 - b. Right-Click on the Scan parameter menu title bar and request the 2nd parameter list menu to appear in the box along with the standard parameter menu.

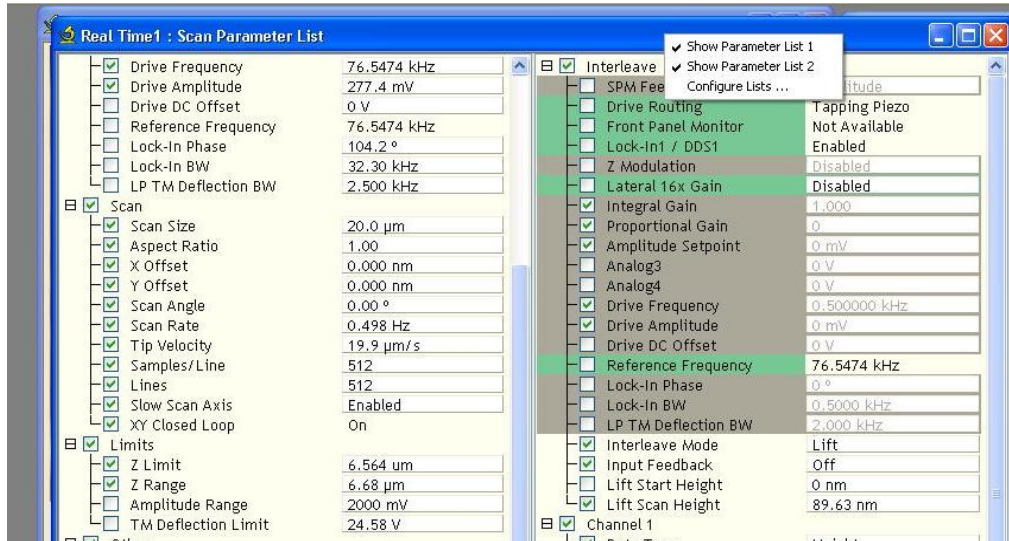


Figure 2. Source of data items to change to make your picture. Expand the parameter list under Interleave by clicking on the box with a + inside.

- c. Under the Interleave controls, set the Lift Start Height to 0 nm, and Lift Scan Height to ~100 nm. (The Lift Height can be optimized later.)
- d. Set the following interleave parameters to the Main values by setting the flags at the left of the interleave column to OFF:
 - i. Amplitude Setpoint
 - ii. Drive Amplitude
 - iii. Drive Frequency
 - iv. Integral Gain
 - v. Proportional Gain

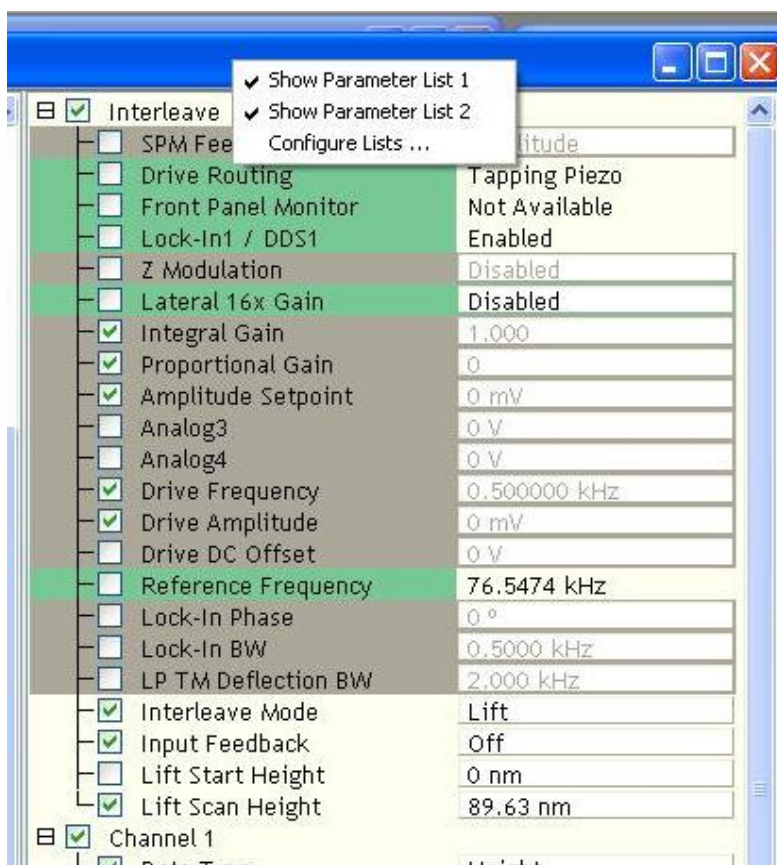


Figure 3. Interleave mode parameter list. (Click the right mouse button while the cursor is in the blue header bar to evoke the command box allowing us to check Show Parameter List 2).

- e. Set the Channel 1 Data Type to Height
- f. Set the Data scale to whatever worked in the initial tapping mode image.
- g. Set the line direction to Retrace.
- h. For Phase Detection mode set the Channel 2
 - i. Data Type to Phase

- ii. Z-Range to 3 deg
 - iii. Line Direction to Re-Trace
 - i. Set the Interleave Mode to Lift.
 - j. Set Interleave to Enable.
 - k. Set Scan Line to Interleave.
7. For phase imaging to obtain the magnetic force image, set the following parameters.
- a. Set channel 2 image data type to Phase.
 - b. Set channel 2 Phase Z range to ~3 degrees.
 - c. Set line Direction to Retrace for both the main and interleave scans.

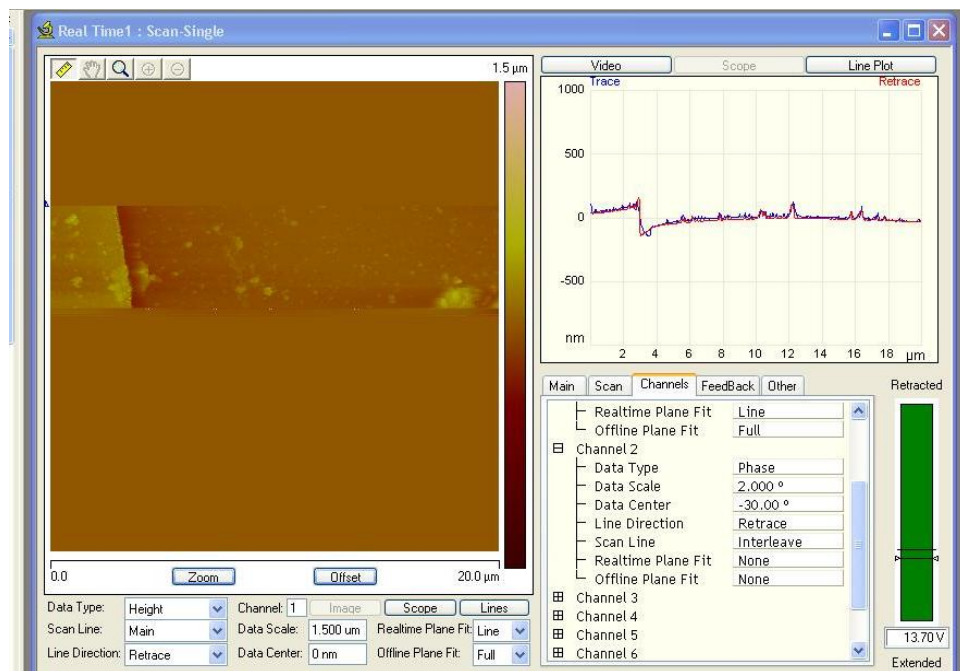


Figure 4. Channel 2 can be set from the Single Scan window.

8. Engage the probe again and obtain the tapping mode topographic image at the same time as the phase information is being plotted. The magnetic gradient data will be produced by the phase plot in Channel 2.

Parameter Adjustment Advice

The above settings merely set the machine up to make magnetic field images. The quality of the images relies on the operator to fine adjust the magnitude of key parameters to reduce noise and obtain a high resolution image. The following comments should help guide the new user to make good images. As experience increases, this adjustment procedure will advance in creativity and speed.

In adjusting parameters to improve image quality, the INTEGRAL GAIN needs to be increased until amplifier oscillations raise the noise level noticeably in the scope trace. The correction procedure

is to then reduce the INTEGRAL GAIN to a level which minimizes the noise. If you are also interested in the phase image, as we are here in the MFM mode, you will have to further reduce the INTEGRAL GAIN to reduce the noise in the phase image. However, to complicate this simple adjustment, the quality of the image (TRACE overlapping RETRACE), also depends interactively on the tip scanning speed. If the tip is scanning fast, and the gain is reduced, the tip cannot climb the walls of a hill fast enough or fall down the other side quick enough to actually follow the terrain. If this is the condition, the speed must also be reduced until the TRACE and RETRACE lines in the scope presentation overlap.

In the MFM process, the scanning mode is set to interleave with the tip lifted for the second pass across the first pass track. For this mode, the topography information from the first pass should not appear in the lifted second pass data. But if the phase image has features like the topography image, then the tip could be hitting the surface during the lifted second pass. If this is the case, then the SCAN LIFT HEIGHT parameter will need to be increased. If the features go away after this adjustment, then the tip is confirmed as hitting the surface at the lesser lift height and all is better now that the topography has been removed.

During MFM imaging, often the phase signal has a baseline offset that causes the image to go all white or all dark. To fix this condition, increase the data scale (graph scale) to a big number like 40 degrees or more and find the offset voltage of the phase baseline. If the offset is positive, put in a positive number equal to the estimated offset voltage of the baseline. This should bring the baseline close to the center of the graph. Then increase the sensitivity of the Y-axis of the phase graph and fine-adjust the baseline offset by adding a delta offset to the previous adjustment.

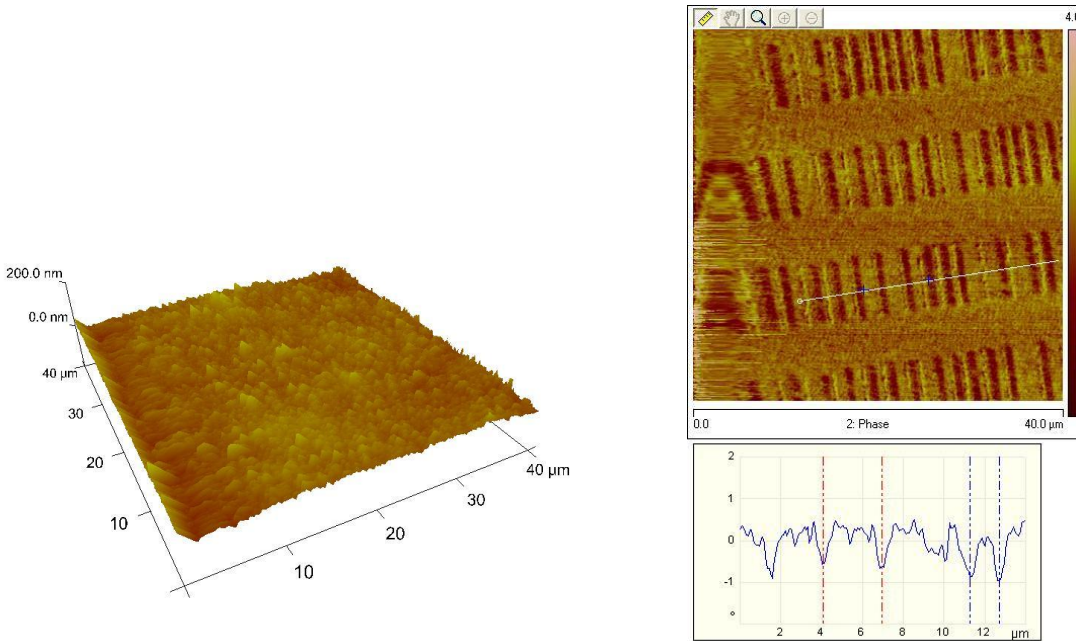


Figure 5. Example of topography image (left) and magnetic image (right) taken with the AFM tip lifted just above the surface depicted in the left image. The dark lines in the right image represent magnetic field corresponding to binary bit numbers (0 or 1)'s. This is the surface of an old ZIP drive disc with data – note the magnetic field image shows no trace of topology.

Conclusion

This instruction document has described the special application procedure for detecting magnetic field patterns on a generic sample consisting of a section of a “ZIP” disc with digital data recorded on it. The data received from this procedure shows relative contrast between the various magnetic fields encountered as the probe tip travels along the surface. There is no absolute magnetic field strength associated with this particular procedure.

The intent of this document is to record procedure details for reference, but you must be trained on this procedure by an appropriate clean room staff member before actually attempting it.