# The Atomic Force Microscope

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*Revised March 2005*

## Objectives

The Atomic Force Microscope (AFM) is one of the most powerful tools for characterization and measurement at the nanometer scale. With the advent of AFM, the ability of observing and manipulating samples and features with ultra-small dimensions has been greatly enhanced. AFM provides a wonderful platform for identifying the properties of materials, and for understanding interesting physical phenomena at micro/nano-scale. It is playing a very important role in the fields of nanoscale science and technology. This lab is design for undergraduate student in Mechanical Engineering to be involved in an exciting experience with state-of-the-art of the AFM technology.

The major objectives are:

(1) Understand the basic principles of the AFM
(2) Understand the dynamics of AFM cantilever and have a good command of the mechanical parameters of the AFM, and their importance for the functions of the AFM
(3) Characterize the dynamic properties of the current AFM
(4) Image the surface of some commercially available standard samples

## Equipment

The available AFM system, named Pscan2 Controller, is manufactured by Pacific Scaning Corporation (now Pacific Nanotechnology Inc. http://www.pacificnanotech.com). It is a general purpose AFM for making routine images on structures with sub-micron to nanometer sized features.

## Mechanics Dynamics of an Atomic Force Microscope

1. Before turning on the PSCAN controller, check to make sure that the orange Ethernet cable is connecting the PSCAN controller to the computer processor nearby.
2. Turn on the PSCAN controller using the toggle switch on its back. You will hear an initial beep. When the controller is ready, it will produce 3 consecutive beeps. Do not open the software until you hear these 3 beeps.
3. Start the controlling software “MI Metrology Series 2000 AFM System” on the computer (shortcut on the desktop).
4. Laser alignment

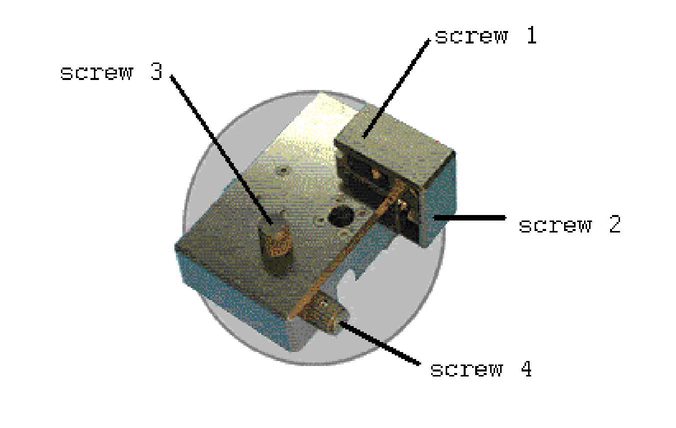
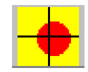



Fig. 1. Position of the different adjustment screws on the AFM head.
Screws 1 and 2 control the laser, and are covered on this picture.
Screws 3 and 4 control the detector.

As shown in Fig. 1, on the scanner assembly, there are two adjustment screws for the laser and two for the detector. To access screws 1 and 2, the cover must be lifted and rotated. There is a label on the cover to assist you. Screw 1 moves the laser along the cantilever direction. Turning it counterclockwise moves the laser spot towards the end of the tip. Screw 2 moves the laser perpendicular to the cantilever*.
* Note that due to a poor quality of the adjustments devices and to the way we attach the tip to the metallic strip, the turning of one or the other screw does not result in a motion perfectly perpendicular or parallel to the cantilever. This must be considered when one of those motions is desired.

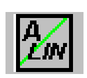
- Flip over the scanner assembly by gently pulling up the stepper motor (instructions on apparatus). Using tweezers, place a cantilever on the cantilever holder. You do this by placing the metallic strip (cantilever up) on the molded rectangular space. It will magnetically hold there.
- Turn screw 1 so that the laser is just over the end of the tip. This can be achieved that by looking at the laser spot on a screen (for that, you can hold the AFM head in vertical position such that the laser beam is horizontal and look at the laser spot on a sheet of paper) and starting with the laser spot on the tip, turning the screw 1 counterclockwise until you can see the laser spot with maximum intensity.
- Turn screw 2 such that the laser beam moves along the edge of the tip, through the center of it. You should be able to see the laser spot with maximum intensity on your sheet at all time. At one point, the laser beam will hit something and a shadow will appear in the laser spot on the sheet, this is the cantilever.
- Turn the screw 2 back and forth and place the shadow in the middle of the laser spot. The laser beam is now centered on the cantilever.
- Now that the laser is reflecting off of the cantilever, the reflection must be centered on the photodiodes used as detectors. To do this, again flip over the scanner

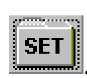
assembly (cantilever facing up) and look at the laser reflection. You should notice a green detector with a cross on it near the reflected beam. The beam should be reflected on the middle of that cross. If it is not, move the detector with the uncovered screws (designated 3 and 4 on figure 1, and labeled "detector horiz" and "detector vertical" on the device) until it is centered.

- Note that since the tips are all mounted differently on the metallic strips, when changing tips, it is normal that the detector position changes a lot. In some case, you may even not be able to center the reflected beam due to an improperly mounted tip on the strip. In that case, the best solution is to use another strip-tip montage.
- In **MI Metrology Series 2000 AFM System**, click on the red dot icon  to open Red Dot Alignment window. The red dot shows the position of the laser spot on the detector. The red bar on the right side is the sum signal from the detector. You should have a signal somewhat over the minimum.
- For oscillating mode: make sure the spot is at the center of the cross. It is more important to have it centered up and down than it is right to left. To center it, again use screws 3 and 4.
- Remember that the turning of one or the other screw does not result in a perfect motion along the cross hair. Also, if the laser is totally out of the detector, the computer will show a quasi-perfectly centered laser with a zero sum signal, so don't be fooled by this and always verify that you laser is effectively reflected on the detector, with a signal greater than the minimum.

5. Obtain a curve of the oscillation amplitude as a function of the frequency

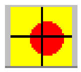
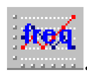
- Click on Open Configuration File icon. 

Select the oscillating mode configuration file (C://ProgramFiles/MI_Metrology/ConfigFiles/Me96/Close-contact.cfg). This establishes the basic settings.
- Press A/LIN icon 

and then click Yes to run auto linearization. This must be run 3 to 4 times before the program converges and returns consistent calibrations. This has to be repeated both to warm up the piezos and because their behavior is somewhat history dependent. Therefore starting from different values will result in a different finishing point. The x and y offset values (in mV) are "consistent" when within a few tens. Values varying by 100s are significant, and the process should be continued.
- Check a few initial parameters in Settings 

. It is VERY important that you click "apply" after changing EACH of the settings below. Otherwise the program will ignore the changes you've made when you switch pages within the window, or close the window.

a. In "Scan Image Setup" folder, set Resolution to 256, Scan Rate to 1, Channels to 4.
b. In "X-Y Control", set Zoom to 15.
c. In "Input Selects to ADC", select Channel 1: Z (HGT) (topography), Channel 2: Z(ERR) (amplitude), Channel 3: Z (DEM) (phase), and Channel 4: Z (SEN) for a 3-axis system.
d. In "Z feedback", set Setpoint Value to 0.

- Press Red Dot icon  and make sure the spot is at the center of the cross. It is more important to have it centered up and down than it is right to left.
- **If the tip goes into feedback runaway (you will hear a strident loud vibrating noise) double click "PID off" in the settings menu under PID on/off.** Anytime the tip goes through runaway, check out the alignment again.
- Press Frequency Sweep icon 

. Make sure Z(ERR) is selected. Type in values for start and end, taking into account your expected resonant frequency (for example, if you expect the tip to have a resonant frequency of 300 kHz, it is a good idea to start at 200 kHz and end at 400 kHz). Click on the Auto checkbox to set the voltage range (y axis). Remember that the setpoint for the first sweep is set at 0.
  a. Press Start Sweep. A sharp inverted peak should appear. This is in fact a voltage which is in a sort of way proportional to the amplitude of oscillation of the cantilever as a function of the frequency. Don't forget to put the vertical axis scale on auto to see the entire curve.
  b. To reduce the sweep range, left click on the left side of the peak and drag the mouse to the right side. Release the left mouse and right click on the shadow area. Press Yes, and start sweep again. Select your area in a way that you can well see all the component of the resonance curve.
  c. To save the data of your curve, go in the menu File, Frequency Sweep, in ASCII Format. You may then save the numerical values of your curve.
- You may want to take several curves with different driving amplitude, to do so, just change the modulation amplitude in the frequency sweep window and redo a frequency sweep. Remember to auto scale your vertical axis.

6. Analysis

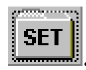
Now that you have your curves in numerical format, you may process them with the software of your choice. Use your results to extract the resonant frequency and the Q-factor. You may also want to know if the model of a forced harmonic oscillator is consistent with the physics of the present cantilever. Now remember that the amplitude of the resonant curve is given in mV, but that you can assume a linear relationship between this voltage and the real amplitude.

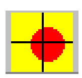
Compare your results with the values given by the tip manufacturer (you will find these values on the pack of the tips box). Test at least three different AFM tips (for each tip start the alignment procedure all over again.

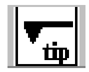
## AFM Imaging of Standard Samples

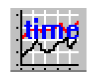
In this section we assume that you just did the first part of this lab. If you are using a new cantilever tip, repeat the "Laser alignment" procedure from the precedent section before continuing on.

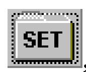
1. Click on Open Configuration File icon, 

. Select the contact mode configuration file (C://ProgramFiles/MIMetrology2000/ConfigFiles/Me96/Contact.cfg).
2. Check a few initial parameters in Settings, 

. It is VERY important that you click "apply" after changing EACH of the settings below. Otherwise the program will ignore the changes you've made when you switch pages within the window, or close the window.
    a. In "Scan Image Setup" folder, set Resolution to 256, Scan Rate to 1, Channels to 4.
    b. In "X-Y Control", set Zoom to 12 (this gives about a 10 $\mu m^2$ image).
    c. In "Input Selects to ADC", select Channel 1: Z (HGT) (topography), Channel 2: Z(ERR) (deflection), Channel 3: Z (L-R) (friction), and Channel 4: Z (SEN) (height measured by Z sensor) for a 3-axis system with a Z sensor.
3. Press Red Dot icon  and make sure the spot is in the green area. The green area will be below the crosshairs for contact mode. The cross hairs are not very relevant for contact mode; the green area is what matters. If the spot in not in the area, move screws 3 and 4 until it is.
4. **If the tip goes into feedback runaway (you will hear a strident loud vibrating noise) double click "PID off" in the settings menu under PID on/off. If the tip goes into feedback runaway while on the surface, RAISE THE TIP**. Anytime the tip goes through runaway, check out the alignment again.
5. Choose a sample chip to scan (it could be one from the TGX set, or one of the TGZ/TGT/TGG set. We suggest that you image at least one from each set). Load your sample onto the black block (this elevates the sample, and also allows you to more easily position it below the cantilever). Make sure it is securely fastened to the double sided tape on the top of the black block.
6. Loosen the back screw (labeled on apparatus).

7. Raise the AFM head with the black turning knob (also labeled) at the back right. Raise it enough to be able to put your sample safely under the tip.
8. Position the black block w/sample under the cantilever, keeping in mind gratings do not cover the entire surface of the chip.
9. Then lower the head with the black knob until the tip is at about 1 mm over the surface of your sample. Use the magnifying lens to get the cantilever as close as possible without risk of conatacting the surface.
10. Tighten the back screw so that the head can no longer be moved manually. The stepper motor will do the approach for the remaining gap.
11. Press Tip Approach/Retract icon, 

which opens the tip Approach/Retract window. Select Z(HGT) in the lower half of the window(tip approach section). Click the tip approach Icon once, to engage the tip. A red LED will flash on the stepper motor, and the window will close automatically when finished.
12. After the stepper motor stops, press Time Mode icon, 

and select Z (HGT) as input.
    a. Click on Full to make the Y-axis to the full scale (-10000 mV to 10000 mV). Usually, Z(HGT) is at 10000 mV right after the motor stops, indicating the tip is not really engaged.
    b. Again click Settings, 

, and go to the “Laser/Motors” tab. To engage the tip, step down (“Fwd”) *50 half-pulses at a time* (be careful, you don’t want to break the tip by pushing it to deep into your sample) until the reading in the Time Mode window is below 10000 mV. This can take up to 100 runs depending on how close you brought the tip to the surface manually, so be patient. Next, reduce to 20 half-pulses, and bring the reading as close to zero as possible—you will probably have to slow to 5 half-pulse steps in order to get accurately close to zero. If the voltage drops under zero, step up using “Rev” until the voltage is as close to zero as possible.

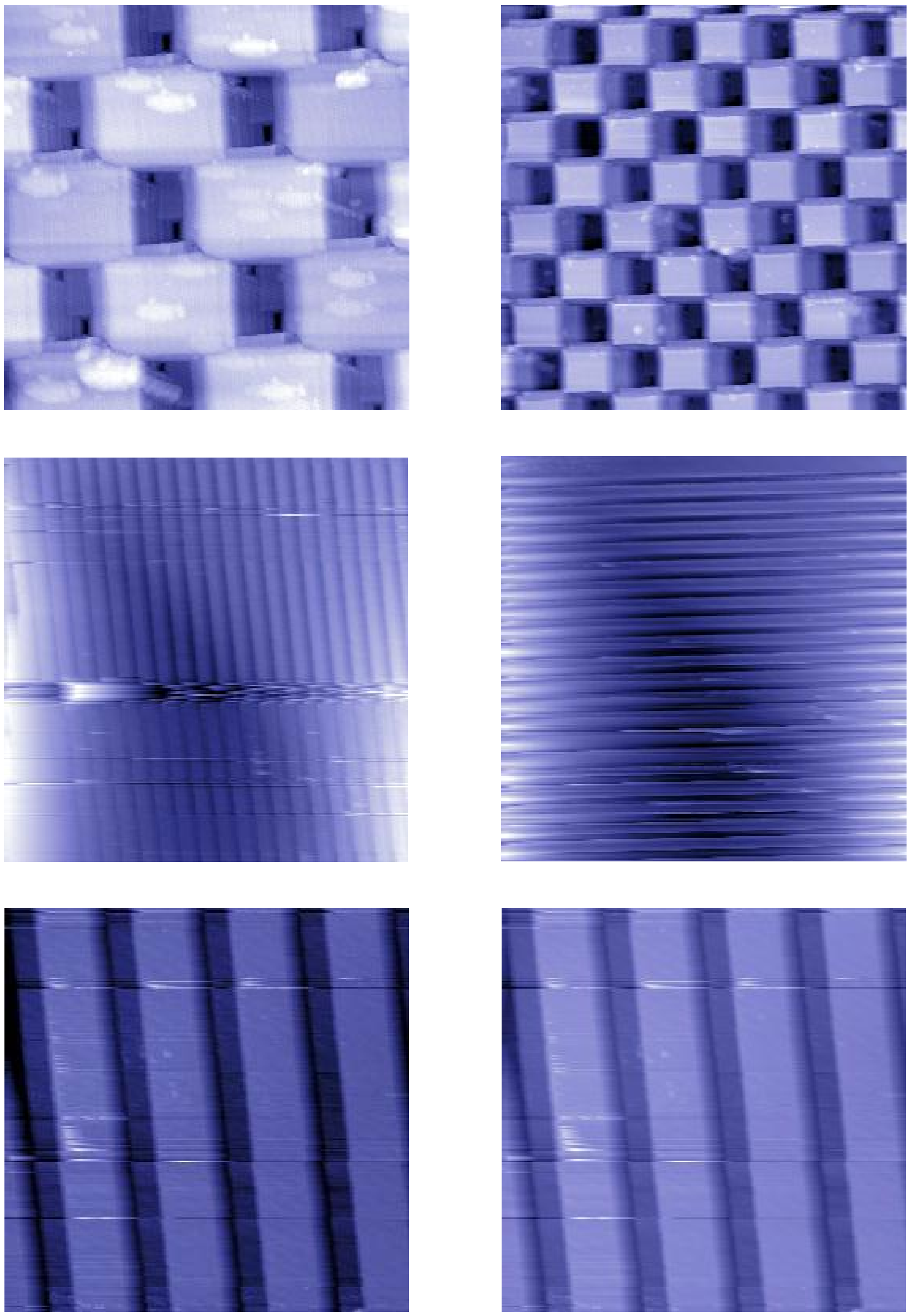
13. Press Image Display icon twice, select Z(HGT), and Z(ERR) as the inputs to two Display Scanned Image windows. Also cool is to display Z(HGT) and Z(ERR) on the Scan Line Cut (hit the Line Mode Icon twice). Usually you will also want the setting folder up in case you need to stop the feedback from running away (PID off). Press Start on the Scan Control Panel window. Now you are getting your first topography, deflection, friction, and Z sensor (3-axis only) images in the contact mode of the grating.
14. To change the image size or location: double click on the display scanned image window. The new window is titled ‘xy offset and zoom.’ This window will allow the image size to be changed (via the zoom setting).

- Before changing the location of the image (you don't have to do this just to change the zoom) use the Laser/Motors tabsheet in the Settings window to lift (motor in reverse direction) the tip or simply the retract tip button on the Tip Approach tabsheet.
- In the 'xy offset and zoom window' the displayed image area may now be moved to the desired location on the sample. Changing the zoom, changes the spatial field-of-view (FOV). As the resolution (in number of pixels) is fixed the spatial resolution is degraded as the FOV is increased.
- Use the "Motors/Lasers" tab in the settings window to bring the tip back into contact with the sample.

15. Try to improve your image quality by playing with the different parameters: the PID values ( to be changed in the Settings window), the scan rate, etc…
16. Analysis

For the TGX grating, the main idea is to determine the x and y size of the square. For the TGZ/TGT/TGG ones, it is mainly the depth of the features that you will want to measure. Compare your results with the values given be MikroMarsh.

## Some Examples of Resulting Images



## Pre-lab Questions

1. Explain how an AFM works.

2. What are the differences between the contact mode and the tapping mode of an AFM? Under what circumstances would we use either of the two modes?

3. You want to purchase an AFM probe to be used in contact mode. Will you choose a probe with a large or small spring constant? Why? What if you will be working in tapping mode?

4. Given a rectangular beam of width $w$, thickness $b$, length $l$ and Young's modulus $E$, calculate the spring constant $k$ of the beam with one end clamped, or pinned, respectively. Apply your appropriate results to an AFM cantilever.

5. What is the Q-factor of a cantilever? What is its physical meaning? How can you determine the Q-factor of a cantilever? Analyze the influence of changing (increasing or decreasing) the Q-factor of the cantilever on the functionality of the AFM.

6. How do you determine the resonant frequency of a rectangular AFM cantilever?

7. What is the expression for the amplitude as a function of the frequency for a forced harmonic oscillator? What is the amplitude at resonant frequency?