

1. Contact Mode

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1.1. Preparation

1.1.1. Cantilever Selection

Any standard contact cantilever will work in this mode. A list of contact cantilevers we offer can be found here: [Contact Cantilevers](#).

1.1.2. Preparation and Tutorial

Contact Mode imaging is sufficiently commonplace that a tutorial has been developed for it. If you own an MFP-3D family AFM, please follow *MFP-3D User Guide, Chapter: Tutorial: Contact Mode Imaging in Air*. If you own a Cypher AFM, please follow *Cypher User Guide, Chapter: Tutorial: Contact Mode in Air*. This will familiarize you with the basics of loading the cantilever, sample, and such. Once everything is adjusted and the cantilever is ready to engage above the sample surface, you can switch over to the sections that follow here in order to create high quality images by adjusting parameters in the software. Software differences among the instruments will be covered as necessary.

1.2. Parameter Selection

Based on the previous section, it is assumed that:

- The cantilever is close enough to the surface that the Z piezo actuator can bring the tip and the sample into contact.
- The laser is aligned on the cantilever and the photodetector difference (deflection) signal has been zeroed.

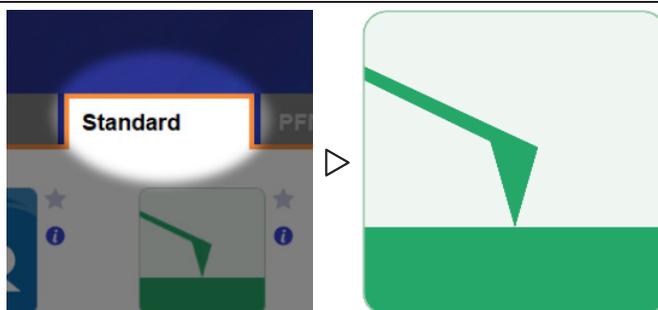
1.

The Mode Master window:

- The software should now be showing the mode master window.
- If not, click the Mode Master button at the bottom of the screen: .



2.

**Select Mode:**

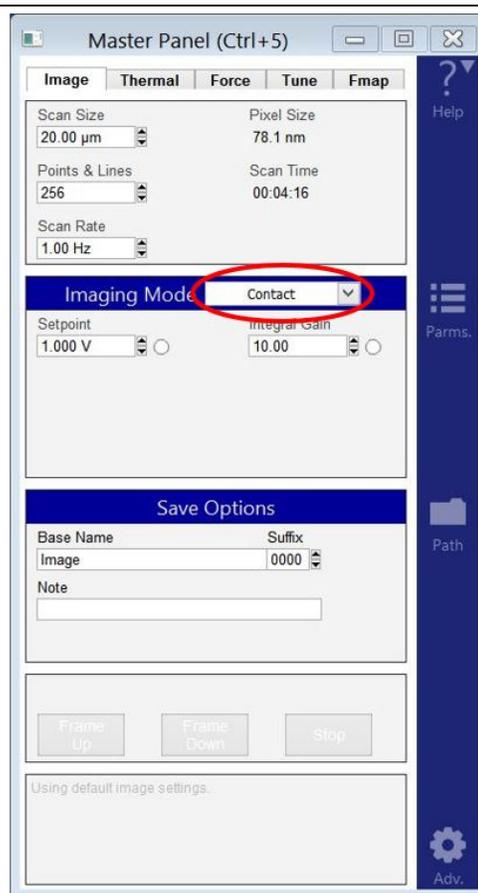
- Select *Standard tab* ▷ *Contact Mode Topography*
- The screen will now re-arrange and present all the controls necessary for this type of AFM imaging.

3.

Set up Master Panel:

- In the Main tab of the Master Panel, select *Contact* from the *Imaging Mode* pull-down menu.
- Setpoint: 1.0 V.
- Integral gain (I):
 - MFP-3D: 8 - 10
 - MFP-3D Extended Z: 2-3
 - Cypher: 30
- Scan rate: 1 Hz; for softer samples, choose a slower scan rate, perhaps 0.5 or 0.2 Hz.
- Scan angle, resolution (scan points & lines), and image size is up to you. These are found in the *Parms.* tab to the right of the Master Panel.

Note Parameters highlighted in orange will be mainly used to fine tune imaging parameters when scanning.

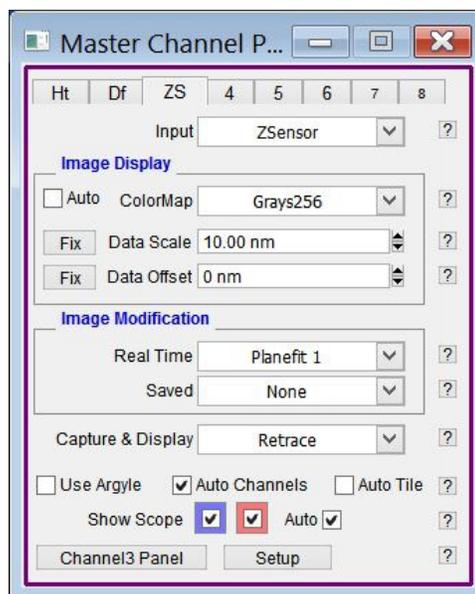


4.

Image channel selection:

- Go to the Master Channel panel.
- Select the leftmost tab and select *Height* under the *Input* pull-down menu. Also set the *Saved* pull-down to *None*.
- For the next two tabs do the same for *Zsensor* and *Deflection*.

Note The *Real Time* and *Saved* pull-downs should be examined before scanning commences. It is important that no effect is applied to the saved data in order to preserve at least one unaltered copy of original data. An effect may be selected for scanning, but this setting could also cause image artifacts depending on the topography.



A brief summary of these data channels:

Height: The voltage applied to the Z piezo to maintain defined positive deflection per X,Y scan point. This signal is a linear approximation to a non-linear signal, meaning it is inaccurate at larger scales; for larger scales, you should use the Z sensor. The advantage of the height channel is that it has less noise than the Z sensor channel.

Deflection: The error signal of the feedback loop used to maintain the user setpoint deflection.

Z sensor: The movement of the optical lever detection assembly as monitored by a closed loop sensor. It is recommended to always activate the Z sensor channel when imaging, especially when sample features are larger than a few tens of nanometers; the Z LVDT sensors are more linear than the piezos, and thus give a more precise Z measurement.

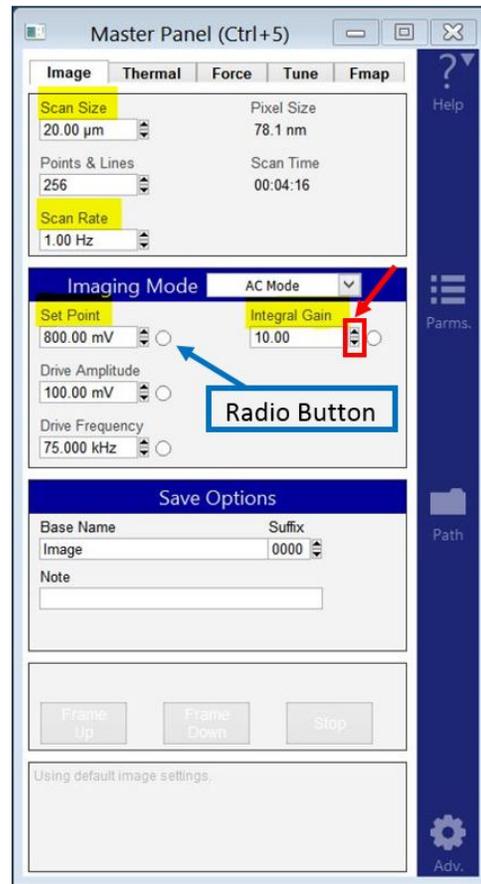
Mode Master: Most of what was described in this section is automatically set by the Mode Master when *Contact Mode* is selected from the standard modes.

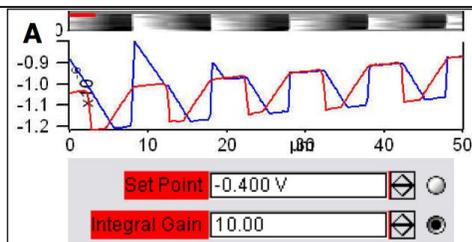
1.3. Optimize Imaging Parameters

1. Click the 'Frame Up' button on the Image Tab. After a brief moment, imaging will begin. Tune the parameters with Set Point, Integral Gain, and Scan Rate. Use the arrow clickers to right of setvar windows to adjust parameters.

2.

- Alternately, you can fine-tune the parameters using the Hamster Wheel on the front of the controller. The Hamster Wheel on the first generation controller, ARC1 black, is permanently attached to the controller whereas on the second generation controller, ARC2 silver, it is detachable.
- Any parameter with a “radio” button next to it can be changed during a scan when it is activated by the Hamster Wheel. The Hamster gives “digital control with analog feel.”
- For the ARC1, there is a toggle switch which allows you to scroll through the parameters. For the ARC2, the outer ring allows you to select the parameter whereas the inner ring changes the value. This is a GREAT feature for tuning on the fly, and eliminates the need for the mouse.





Determining Image Quality:

- 3.
- Image quality can be monitored by image resolution and by the amount of noise in the line traces (located below images).
 - Start the learning process on a sample with a known topography, like an Asylum Research Calibration Grating (basically a matrix of square pits). Then you know immediately if the image looks sub-optimal.
 - Look at the Scope Trace below the image. This graph represents the most recent line of the image. **Blue** indicates the tip moving left to right (**trace**) and **Red** indicates tip returning from right to left (**retrace**).

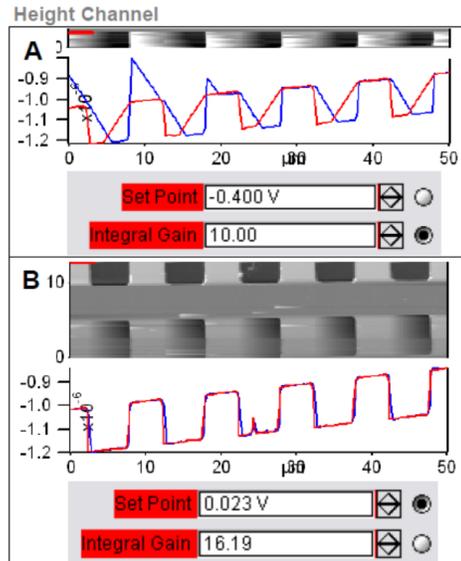
On most samples with relatively slowly changing features, trace and retrace should look the same. In other words, the landscape should look the same if you are flying the exact same route one way or the other. In the image above, the two are quite different; this is an indication that imaging parameters need to be adjusted.

Nomenclature In the previous image the tip is not following the surface. As the blue trace shows (left to right), the tip seems to climb up out of the pits of the calibration grating quite nicely, leaving a sharp edge along the left side of each pit, but then it descends back into the next pit along a relatively gentle slope. During this descent the tip actually flies through the air while it is completely undeflected, a bit like a hang glider running off a cliff. The lateral motion of the tip simply marches on as dictated by the XY scan pattern. The feedback control algorithm is simply not aggressive enough to bring the tip back down to the bottom of the pit. Such behavior is commonly called **parachuting** or **poor tracking**.

4.

- The Setpoint voltage and Integral gain should first be adjusted to achieve good tracking. The picture to the right shows an example of imaging a calibration grid, with corresponding parameters from the Main tab below.
- Panel A) shows the initial tracking of the tip upon engagement with a Setpoint voltage of -0.4V when the free air voltage was about -0.45V .
- Panel B) shows that with an increase in the Setpoint force and a slight increase in the Integral gain, tracking is improved greatly.

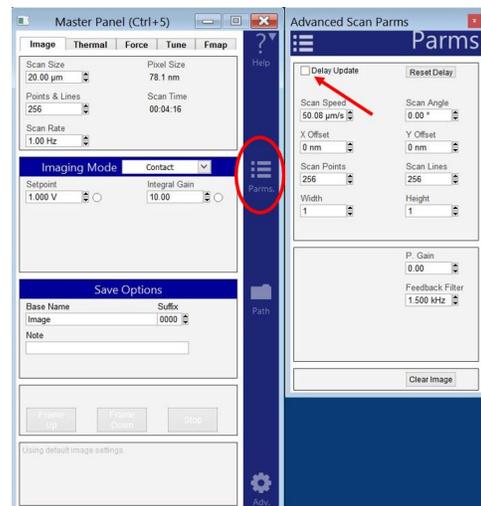
Note Don't be alarmed if you have to crank up the Integral gain when using long floppy cantilevers - the gain is related to the optical lever sensitivity (more gain for less sensitivity).



5. The second parameters to adjust are the Scan Rate and Scan Angle. Having a vague idea of the orientation of the tip on the cantilever can make scanning at 90 degrees more advantageous than 0 degrees because of the shape of the tip at the end of the cantilever. Some cantilever manufacturers compensate for the slight angle the cantilever is mounted relative to the surface by having the front and back angles of the pyramid at different angles.

6.

- The *Delay Update* checkbox allows the user to change the parameters during a scan, which will take effect at the end of that scan.
- During the period before update, the parameters changed will be highlighted in an orange color.
- Notice that there are setvars without radio labels; highlights occur here because these values only take effect when the frame is finished (e.g. scan rate).
- The *Delay Update* checkbox can be found by clicking on the Parm.s. Tab to the right of the Master Panel as shown by the image on the right.



Q When I make changes to scanning parameters, when do those changes take effect in the scanned image?

A Most imaging parameters in the main tab of the main panel (See 3) will update as soon as you make a change. Points, Lines, and Scan Rate do not change mid-image; those parameters will only change at the next frame.

If you check the 'Delay Update' box just above the Setpoint parameter, then any changes you make to parameters above that box will only update when a new image is started. Until the image is complete, the changed variables are highlighted in orange.

You can always force a new image by clicking 'Frame Up' or 'Frame Down'. A nice way to see the effect of changing imaging parameters can be as follows:

- Check the 'Delay Update' box as described above.
- Click 'Frame Up' and collect a dozen scan lines. Observe the image quality
- Make some changes to the scan parameters (number of points, rate, gains, setpoint).
- Click 'Frame Up' again.
- Observe as the exact same scan region is painted over with new data taken with your new parameter choices.

2. Contact Mode Imaging: Scientific Background and Theory

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Contact Mode AFM, also known as Constant Force Mode, is one of the more commonly used imaging modes in AFM. It is often used in imaging hard materials, in some electrical techniques, and in imaging biological materials, such as cells, under low setpoint forces and scan rates (Because cells are big bags of water, they can be easily oscillated if AC Mode is used on them. Contact Mode works better, and the Deflection images shows a great deal of detail). It is also among the simplest methods to explain, and therefore leads the chapters on AFM imaging modes. The typical user will do more AC Mode imaging than Contact Mode imaging (See ?? on page ??), but should know Contact Mode imaging as well.

2.1. Theory and Background

An AFM imaging technique typically requires a method by which the tip can track the topography of the sample. A relatively simple method of doing this is to monitor the cantilever deflection. Please refer to [Figure 2.2 on page 16](#).

For the purposes of this discussion, we will assume the tip hovers above the sample surface by a few microns with the Z feedback turned off and the Z actuator fully retracted. The lever is now in its relaxed position. The photodetector is aligned so the laser beam is centered and the difference output from the photo detector is zero. Any deflection of the lever away from the relaxed position registers as a non-zero voltage: negative for bending toward the sample and positive for bending away. Next, a setpoint voltage for this output is chosen, corresponding to a certain deflection. Usually the quantity of interest is the force exerted on the sample by the lever. [Chapter 20 on page 278](#) shows how to calibrate detector output voltage in terms of the force on the sample. Once you are familiar with using a particular type of cantilever, you will become accustomed to the forces involved and will probably skip the step of calibrating the force.

To conceptually aid the process of selecting of a setpoint voltage, a qualitative depiction of cantilever deflection vs. Z Sensor is shown in [Figure 2.1 on page 15](#). At the far right of the graph, the tip is above the surface. Further left, the tip is approaching the surface, but since it is not yet touching, the deflection stays the same. At the contact point the tip becomes fixed against the surface, and the deflection voltage starts the increase. The more the Z actuator extends, the more the lever bends, and the bigger the deflection signal gets.

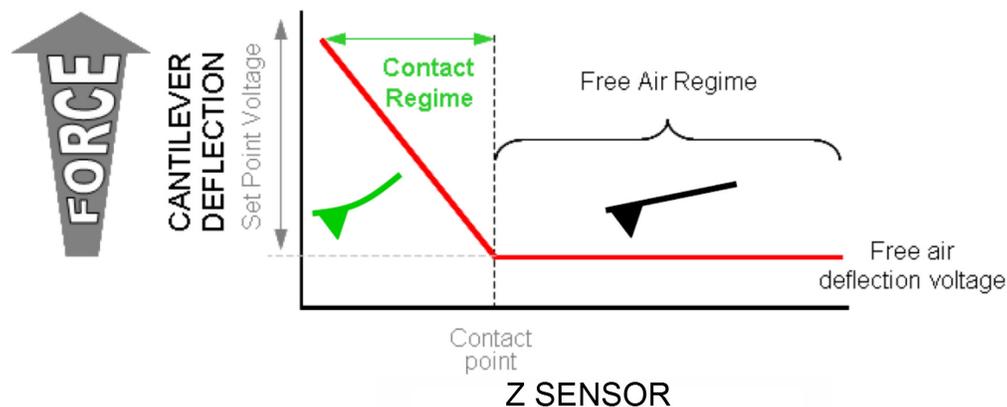


Figure 2.1.: Qualitative depiction of Cantilever Deflection vs. Z Sensor.

The Z feedback loop is what controls the Z actuator. It tries to maintain the specified setpoint voltage (see Figure 2.2 on page 16). If the measured deflection voltage is less than the setpoint voltage it extends the Z actuator. If the measured deflection is greater than the setpoint voltage it retracts the Z actuator. When the Z voltage is railed at 150V it implies that the Z actuator is full extended, and the deflection is still below the required setpoint. What this means is physically the cantilever is not in contact enough or at all with the surface. Likewise when the Z voltage is railed at -10V it means that the Z actuator is fully retracted, yet the cantilever is still so bent against the sample the deflection remains higher than the setpoint.

While the Z feedback keeps the deflection constant, the scanner is rastered in X and Y. As the cantilever goes over the sample, voltage to the Z actuator will change due to the feedback. The Z actuator is made from piezo electric material which is inherently non linear over large distances. Over small ranges it acts very linearly and the voltage sent to the Z actuator is an accurate measurement of the sample topography. In the software this voltage scaled is the *Height* channel. For large ranges, it is more appropriate to use the *Z sensor* channel. The sensor is much more accurate but introduces some noise to the measurement. Over large ranges this noise is negligible compared to the range itself. If your sample features are around 1 μ m or greater it is good idea to use *Z sensor* rather than *Height*.

If the Z feedback worked perfectly the deflection would never change. In reality the Z feedback is close to maintaining a constant deflection but not perfect. Sudden changes in the sample topography cause the Z feedback to either under or over compensate. The *Deflection* channel is therefore a measurement of the error signal. This channel can be useful for detecting features that don't show up well on the other channels.

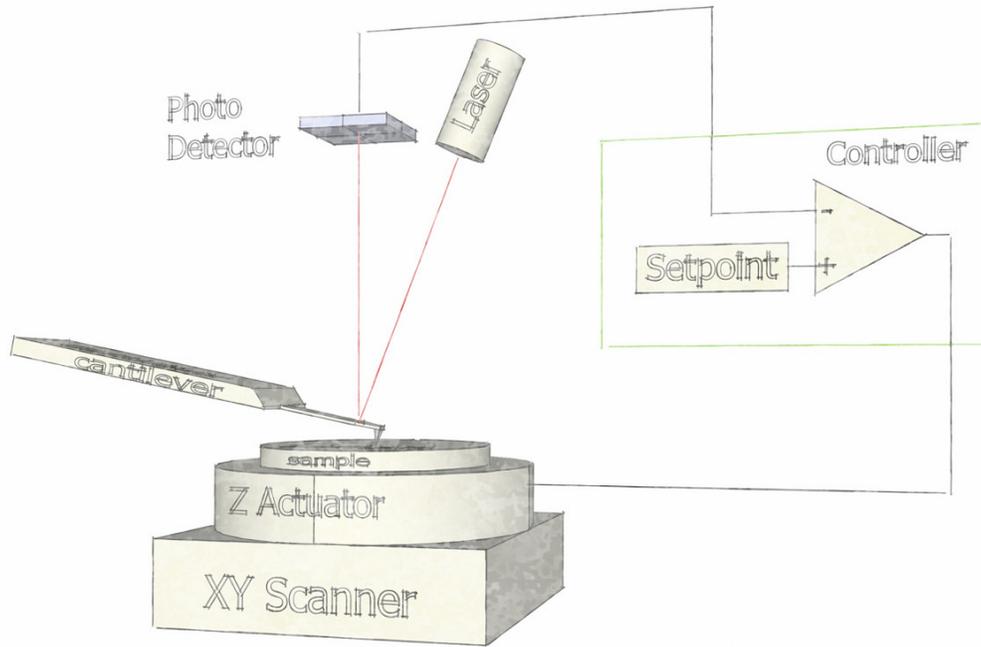


Figure 2.2.: Contact Mode AFM. Z actuator feeds back to keep cantilever deflection at a given setpoint.

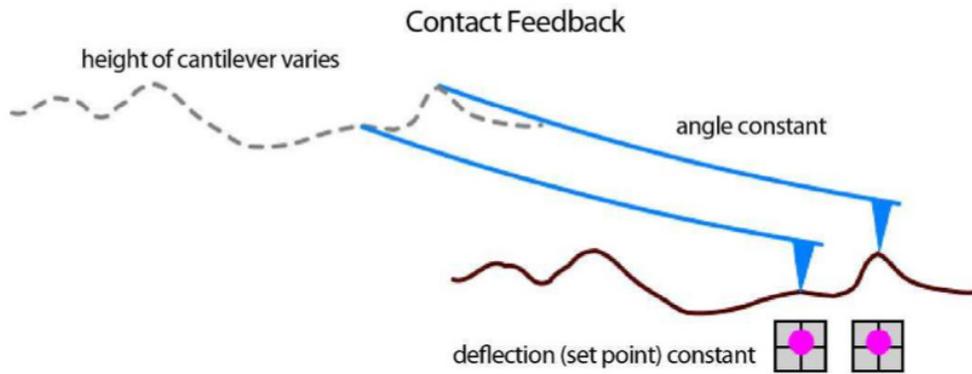


Figure 2.3.: Contact Mode tracking of the surface. Feedback keeps the cantilever deflection constant.