The Nanosurf Naio Scanning Tunneling Microscope (STM)

The NaioSTM brings together both a scan head and controller in a single instrument for even simpler installation, maximized ease of use, and straightforward transportability. The setup is robust against vibrations and can be used to achieve atomic resolution on HOPG in standard classroom situations. With its 204 × 204 mm footprint, it hardly takes up any workbench space.

Figure 1 – the STM Apparatus

Smart design

The smart and purposeful design is perfectly suited to the needs of educational institutions: the system integrates scan head, controller, air-flow shielding with a magnifying glass to aid the initial approach, and vibration isolation on a heavy stone table. The very small mechanical loop of < 10 mm provides the stability to achieve atomic resolution on a coffee table or in a class room. The additional passive vibration isolation feet further protect measurements against disturbances, making the system very robust during operation. The system functions without high voltage, making it safe in inexperienced hands.

Ease of use

The smart design does not only provide good performance, but also makes the NaioSTM very easy to use. All that is required in terms of setup is to connect 2 cables: power and USB. It is safe to be handled by students or other users with no prior training, thanks to the lack of high voltage and its general robust design. Scanning tips are simply cut from Pt/lr wire, so no hazardous substances are required to etch the tips. The process from setup up to seeing the first successful images can be achieved within a few minutes. The intuitive software is equipped with helpful wizards to guide you through the measurement process.

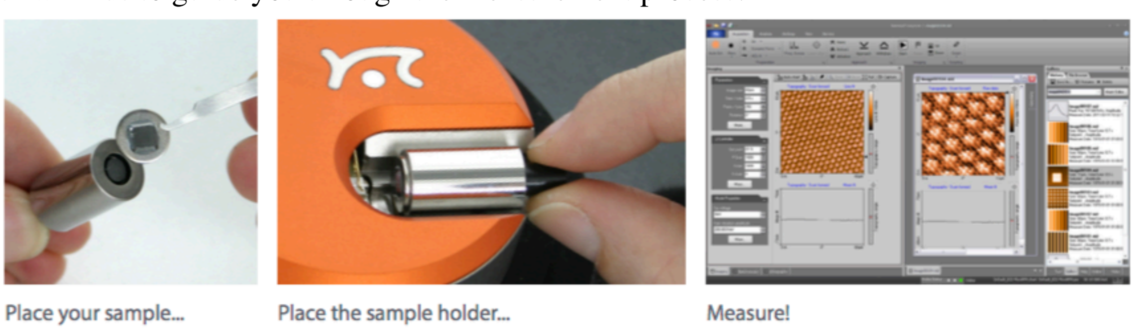


Figure 2 – Placing the sample on the holder, and installing the holder

STM is based on a quantum mechanical phenomenon, called tunneling. In quantum mechanics, small particles like electrons exhibit wave-like properties, which allows them to “penetrate” potential barriers. These waves don’t end abruptly at a wall or barrier, but taper off quickly. If the barrier is thin enough, the probability function may extend into the next region, through the barrier! Because of the small probability of an electron being on the other side of the barrier, given enough electrons, some will indeed move through and appear on the other side. When an electron moves through the barrier in this fashion, it is called tunneling.

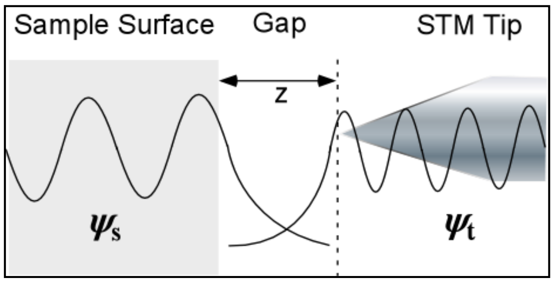


Figure 3 – Waves from the tip and sample in the gap

Quantum mechanics tells us that electrons have both wave and particle-like properties. Tunneling is an effect of the wavelike nature. The distance “z” needs to be extremely small for tunneling to occur, at around 1 nm = 10 angstroms or less.

In general, STM involves a very sharp conductive tip that is brought within tunneling distance (sub-nanometer) of a conductive sample surface, thereby creating a metal-insulator-metal (MIM) configuration, where the Gap in the diagram above is the insulator. The closer the tip gets to the sample, the higher the tunneling current.

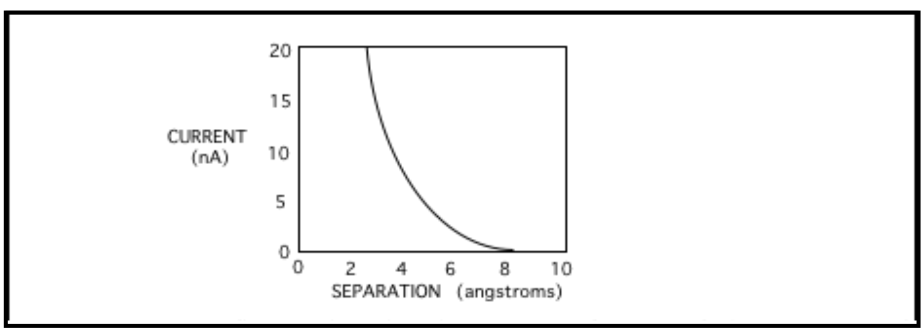


Figure 4 – Dependence of Current and Separation

During an STM scan, the Z-controller Setpoint (in nA) is the tunneling current setting. There is a **Negative Feedback** loop in the electronics that keeps the current constant during a scan. The device that measures the tunneling current is connected to the electronic feedback circuitry that obeys the following rules: *if it senses a decrease in the current, it moves the sample closer to the tip of the probe, and if it senses an increase in current, it moves the sample away from the tip.*

Imagine a sample with some bumps on it, as shown in Figure 5. The microscope is operated by positioning the tip over the sample, then lowering it towards the sample until a tunneling current is detected. The tip is then moved to the right. When the tip approaches a bump, the tunneling current increases. The feedback loop senses this increase and raises the tip to maintain a constant tunneling current. The tip will continue to rise until it is over the top of the bump. As the tip moves farther to the right, the current decreases and the tip must be lowered to maintain a constant tunneling current. By the time the tip has reached the far right, it has traced out a cross section of the topography of the sample.

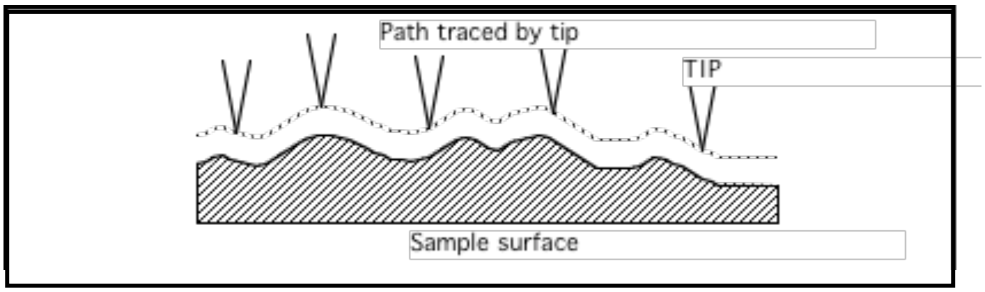


Figure 5 – Tip Path during Constant Current Scan

So, how do we actually move the tip by angstroms at a time? The tip is loaded onto a holder that contains piezoelectric ceramics (PZT). An electric field applied across a piezoelectric ceramic causes expansion in one direction and contraction in another. By having a piezoelectric ceramic in each of the three, the tip can move in very small steps in either the x, y and z direction. The x and y movements are utilized during the scan movement, while the z direction is controlled by the feedback from the changes in current during a scan, in order to keep a constant distance between tip and sample.

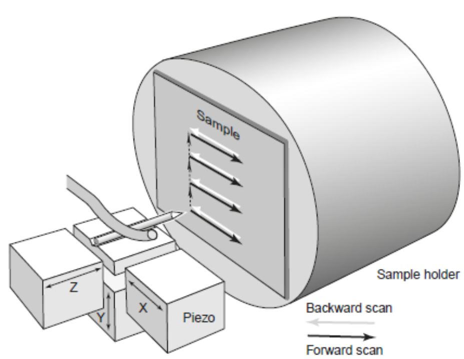
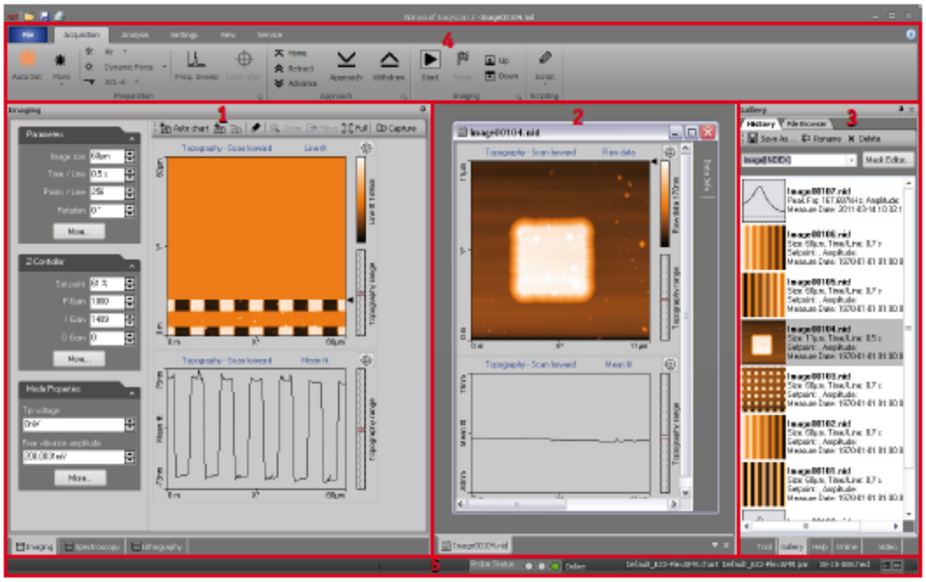


Figure 6 – The Piezoelectric ceramics that allow for angstrom movements in all directions



Power up the STM unit by pressing the power button located in the back of the unit directly above the power cord. A blue light will indicate that the power is on.

OPEN the **Nanosurf Naio** software from the Start Menu. Let the software connect to the controller. We will be scanning four different samples. *The order that they are done is not important*.

1) <u>The Monochromator Grating</u> (we only have one of these, so run once you have this sample)

Use the tweezers to pick up the disk with the sample of interest (the monochromator grating). Do not touch the actual sample! Carefully attach the sample to the sample holder. Then, place the holder onto the STM unit and carefully slide the sample to around a 1 mm distance from the tip. Do Not allow the sample to touch the tip. It will destroy it!

Set up the parameters as follows:

Parameters		**Z-Controller**		**Mode Properties**	
Image Size	490 nm	Setpoint	1 nA	Tip Voltage	50.1 mV
Time/Line	0.4 s	P-Gain	1000		
Points/Line	256	I-Gain	2000		
Rotation	0	D-Gain	0		

ACQUISITION Tab → Click "**Advance**" to move sample towards the tip.

Use magnifier on cover and bring sample close enough so the reflection of the tip is seen close to actual tip (less than 1 mm).

Click "**Auto-Approach**" to bring sample close enough to achieve tunneling current.

Verify that the Probe Status is Green (located at bottom-right of screen). If not, click "Auto-Approach".

The scan will start automatically once tunneling current has been achieved. Once the scan is looking good, click "**Finish**" to capture the image when the scan is done. To change the color of the image, click on the bar to the right of the image, and adjust both the White down-arrow & the Black up-arrow to get the best image.
Right-click on the good image → "Copy". Open MS Word from the task bar at the bottom of screen, open a Blank Document, and "Paste" image onto page.

Cross-Section: Click the **Analysis** Tab, then click on the image, then select "**Create Cross-Section**". Draw a line on the image, and the cross-section will be shown on the far-right Tool Chart. How wide is each grating? How many total individual gratings are there on the 8 mm wide monochromator grating?

To get the cross-section to the Word page, use the "Snipping Tool" from the Start Menu, draw a box around the Cross-Section, then "Copy" the image & "Paste" into the Word document.

REPEAT with a tunneling current of 2 nA and compare.

2) <u>HOPG Sample (Highly Oriented Pyrollytic Graphite)</u>

Use the tweezers to pick up the disk with the sample of interest (the HOPG sample). Place a piece of tape over the sample, push down on sample, then quickly rip the tape away from the sample. This will expose a fresh HOPG layer. Carefully attach the sample to the sample holder. Then, place the holder onto the STM unit and carefully slide the sample to around a 1 mm distance from the tip. Do Not allow the sample to touch the tip. It will destroy it!

Set up the parameters as follows:

Parameters		**Z-Controller**		**Mode Properties**	
Image Size	200 nm	Setpoint	1 nA	Tip Voltage	50 mV
Time/Line	0.07 s	P-Gain	1000		
Points/Line	128	I-Gain	2000		
Rotation	0	D-Gain	0		

ACQUISITION Tab → Click "**Advance**" to move sample towards the tip.

Use magnifier and bring sample close enough so the reflection of the tip is seen close to actual tip.

Click "**Auto-Approach**" to bring sample close enough to achieve tunneling current.

Verify that the Probe Status is Green (located at bottom-right of screen). If not, click "Auto-Approach".

Run a **200 nm** scan initially. The scan will start automatically once tunneling current has been achieved. Once the scan is looking good, click "Finish" to capture the image when the scan is done. To change the color of the image, click on the bar to the right of the image, and adjust both the White down-arrow & the Black up-arrow to get the best image.

Right-click on the good image → "Copy". Open MS Word from the task bar at the bottom of screen, open a Blank Document, and "Paste" image onto page.

Click on the color map to make it active.

Click "Zoom". Draw a small box inside the smoothest region of scan, around 1/5th the size of the original scan. The "box" will be the area that will be scanned, which should be around **40 nm.** Double-click inside of the box. Verify the axis scales are correct, and verify the "Probe Status" at the bottom is green, indicating tunneling is active. If orange, click once on the "Approach" icon.

Run a scan at this new smaller region by clicking Start.

Click "Zoom". Draw a small box inside the smoothest region of scan, around 1/5th the size of the original scan. The "box" will be the area that will be scanned, which should be around **8 nm**. Double-click inside of the box. The scale of the plot will change to the new values.

Run a scan at this new smaller region by clicking Start.

Click "Zoom". Draw a small box inside the smoothest region of scan, around 1/4th the size of the original scan. The "box" will be the area that will be scanned, which should be around **2 nm**. Double-click inside of the box.

Run a scan at this new smaller region by clicking Start. Once the scan is looking good, click "Finish" to capture the image when the scan is done. To change the color of the image, click on the bar to the right of the image, and adjust both the White down-arrow & the Black up-arrow to get the best image.

Right-click on the good image → "Copy". Open MS Word from the task bar at the bottom of screen, open a Blank Document, and "Paste" image onto page.

Cross-Section: Click the Analysis Tab, then click on the image, then select "Create Cross-Section". Draw a line on the image, and the cross-section will be shown on the far-right Tool Chart. How much distance is there between each carbon atom?

To get the cross-section to the Word page, use the "Snipping Tool" from the Start Menu, draw a box around the Cross-Section, then "Copy" the image & "Paste" into the Word document.

NOTE: This HOPG is the only sample that we zoom-in on to get to atomic level.

3) The Copper Metal Sample

Run this sample exactly as you did for the Grating Sample on page 2.

Parameters		**Z-Controller**		**Mode Properties**	
Image Size	490 nm	Setpoint	1 nA	Tip Voltage	50 mV
Time/Line	0.4 s	P-Gain	1000		
Points/Line	256	I-Gain	2000		
Rotation	0	D-Gain	0		

Cross-Section: Click the **Analysis** Tab, then click on the image, then select "Create Cross-Section". Draw a line on the image, and the cross-section will be shown on the far-right Tool Chart. How smooth is the surface of the copper sample? How much height difference between the high and low points do you observe?

To get the cross-section to the Word page, use the "Snipping Tool" from the Start Menu, draw a box around the Cross-Section, then "Copy" the image & "Paste" into the Word document.

4) The Gold (111) Sample

Do Not touch this sample! Do Not place Tape on this sample!

Parameters		**Z-Controller**		**Mode Properties**	
Image Size	490 nm	Setpoint	1 nA	Tip Voltage	**500 mV**
Time/Line	0.4 s	P-Gain	1000		
Points/Line	256	I-Gain	2000		
Rotation	0	D-Gain	0		

On this sample, very thin films of (111) oriented gold have been prepared using a template-strip method. The images hope to show flat terraces with steps having a height of one monolayer gold.

ACQUISITION Tab → Click "**Advance**" to move sample towards the tip.

Use magnifier and bring sample close enough so the reflection of the tip is seen close to actual tip.

Click "**Auto-Approach**" to bring sample close enough to achieve tunneling current.

Verify that the Probe Status is Green (located at bottom-right of screen). If not, click "Auto-Approach".

The scan will start automatically once tunneling current has been achieved. Once the scan is looking good, click "Finish" to capture the image when the scan is done. To change the color of the image, click on the bar to the right of the image, and adjust both the White down-arrow & the Black up-arrow to get the best image.

Right-click on the good image → "Copy". Open MS Word from the task bar at the bottom of screen, open a Blank Document, and "Paste" image onto page.

Cross-Section: Click the Analysis Tab, then click on the image, then select "Create Cross-Section". Draw a line on the image, and the cross-section will be shown on the far-right Tool Chart. How wide is each "shelf"? How tall is each shelf? Is the height difference on an atomic level?

To get the cross-section to the Word page, use the "Snipping Tool" from the Start Menu, draw a box around the Cross-Section, then "Copy" the image & "Paste" into the Word document.