HR-AFM

The **HR-AFM** is an advanced, yet affordable AFM for researchers that need the **highest resolution scanning capabilities**.

The HR is ideal for researchers that want to visualize and measure sub-nanometer surface features

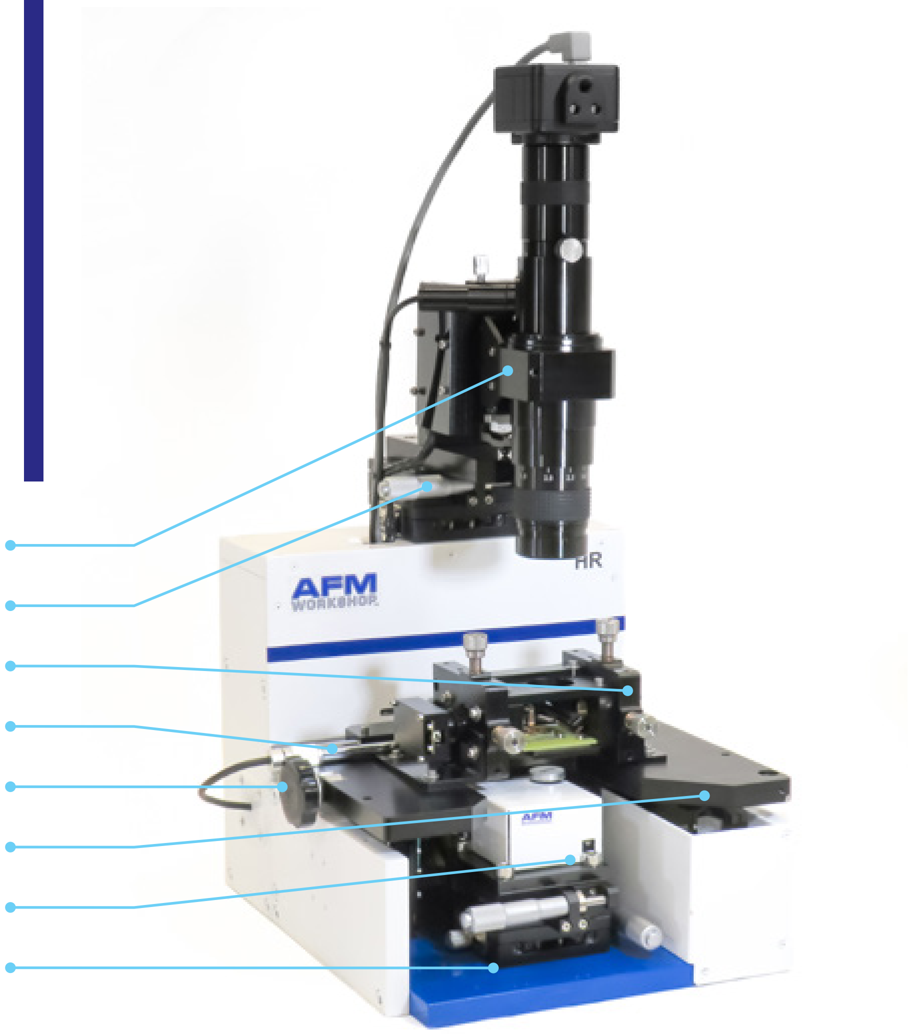
ADVANCED FEATURES

- **Less than 35 picometers of Z noise**
  Measure images of sub-nanometer surface features
- **Top-view and side-view video optics**
  Facilitate locating features and probe approach
- **Choice of three interchangeable scanners**
  Select a scanner for your specific application
- **28 bit XY scanning**
  Maximal dynamic range with highest resolution

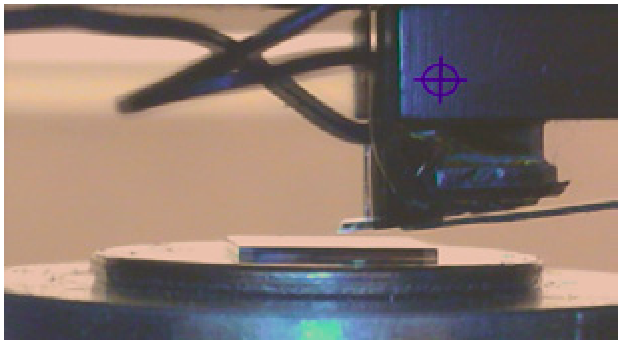
Sample Sizes	Up to 1” 1 × 1” × ½”
Standard Scanning Modes	Vibrating (tapping), Non-vibrating (contact), Phase, LFM
Additional Scanning Modes	Magnetic force microscopy, Electrical force microscopy, advanced force-distance, conducting AFM, scanning tunneling microscopy, liquid scanning
Video Optical Microscopes	Research grade top-view for locating features Side-view for facilitating probe approach
Stage Configurations	2 stage configurations available(1 motor and 4 motor)
Data Station	Core i7 PC with dual 24” monitors
AFM Control Software	LabView environment with advanced features

STAGE

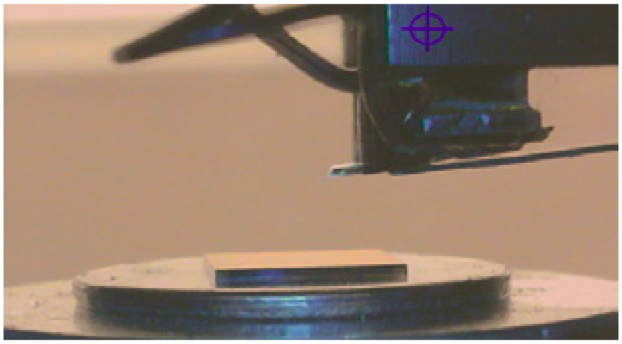
The **HR-AFM** stage uses an advanced three point kinematic design; a motor is used for probe approach, and two micrometers are used for changing the tip-sample distance.



The rapid approach control allows moving the probe from within a few tens of microns from the surface to a mm away in less than a second. Below is a side-view video optical microscope view of the rapid approach control in the "stage down" and "stage up" positions.



Stage down position



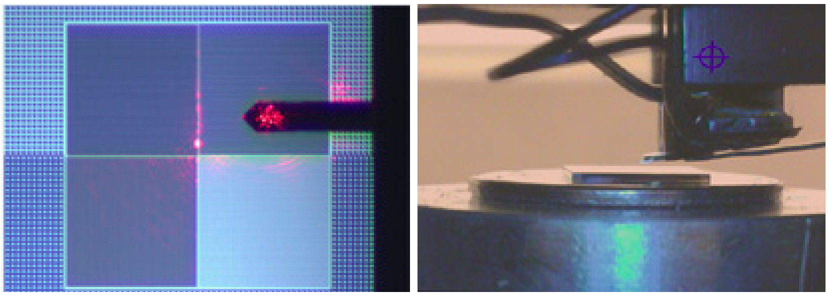
Stage up position

STAGE CONTINUED...

Rigid Kinematic Design:	The kinematic design for the stage support of the light lever force sensor is extremely rigid so the AFM is less susceptible to external vibrations.
Light Lever AFM Force Sensor:	Light lever force sensors are used in almost all AFM instruments and permit the widest range of experiments.
Probe Approach:	The HR-AFM can be upgraded to a 4 motor design for direct probe approach.
Small Footprint:	The stage dimensions of 10” × 10” require little space and fit easily on a tabletop.
Precision XY Stage with Micrometer:	The sample is moved relative to the probe with a precision XY micrometer stage. Thus, the sample can be moved precisely without touching it.
Modes Electric Plug:	A six pole electrical plug is located at the back of the stage to expand the capabilities of the HR-AFM.
XYZ Precision Piezo Scanner:	The modified tripod design utilizes temperature compensated strain gauges which assure accurate measurements from images. Also, with this design it is possible to rapidly and accurately zoom into features.
Laser/Detector Alignment:	Both the light lever laser and the photo detector adjustment mechanism may be directly viewed. This feature greatly simplifies the laser/detector alignment compared to other commercial AFMs.
Adaptable Sample Holder:	At the top of the XYZ scanner is a removable cap that holds the sample. The cap can be modified - or a new cap can be designed – to hold many types of samples.
Signals I/O	The rear of the electronics box allows access to all the signals in the HR-AFM.

VIDEO OPTICAL MICROSCOPES

From the top the **HR-AFM** has research grade optics with a 5 MP video camera and a 7:1 mechanical zoom optic. This top view optic is helpful for aligning the light lever laser, locating surface features for scanning, and probe approach. The resolution of the top view optic is <2 microns.



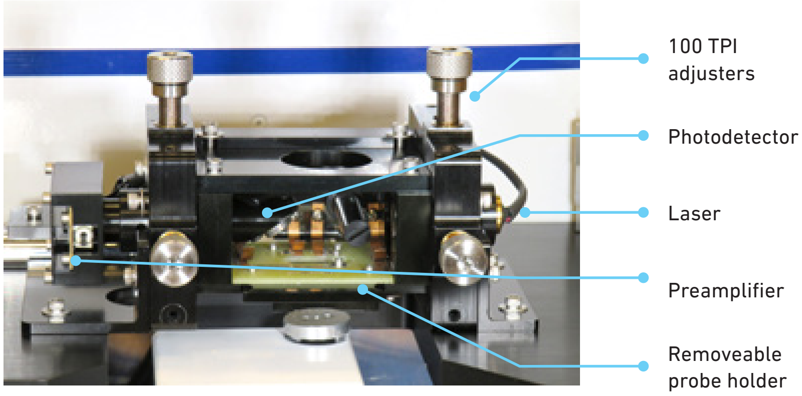
Top-view optic

Side-view optic

Side view optics are used for monitoring the tip sample angle, and facilitating probe approach. These optics are helpful with transparent samples, highly reflective samples, and samples that do not reflect light.

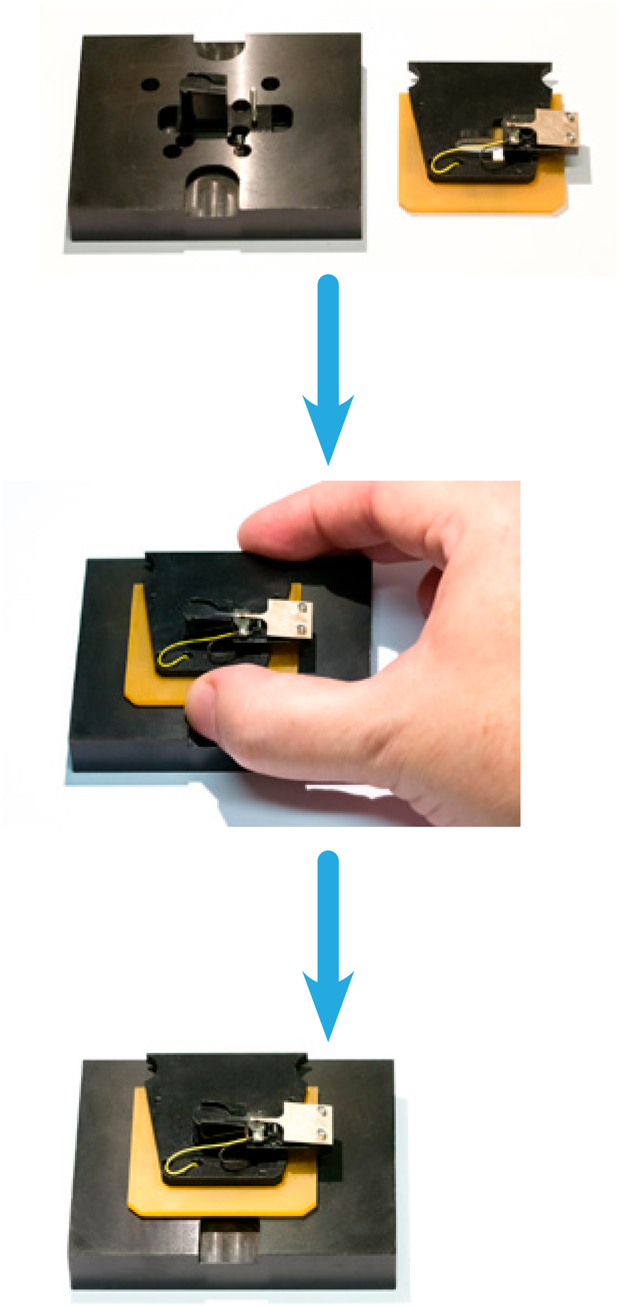
HR-AFM LIGHT LEVER FORCE SENSOR

The **HR-AFM** uses the industry standard light lever force sensor. In the light lever, a laser beam is focused on the back side of a microscopic cantilever, the light is then reflected from cantilever onto a 4 quadrant photodiode.



Two 100 thread per inch adjustment knobs are used for adjusting both the laser and the photodetector +/-1.5mm. This large adjustment range give maximum flexibility so that a large range of cantilevers can be used. The probe is held with a removable holder, so that changing a probe requires less than a minute. With AFMWorkshop's proprietary probe holder design, after changing the probe, only minor adjustments are required.

PROBE EXCHANGE



One of the key design features of the HR-AFM is a unique probe exchange tool. With the tool, changing probes can take less than a minute. The steps for changing a probe are:

① Remove the probe holder from the light lever

② Place the probe holder on the exchange tool

③ Insert the probe

④ Place the probe holder in the light lever

Because of the unique design, when the probe is replaced, there is almost no need for further adjustment of the light lever……it's that easy.

EBOX

Electronics in the **HR-AFM** are constructed around industry standard USB data acquisition electronics. The critical functions, such as XY scanning, are optimized with 24 bit digital to analog converter combined with 4 bits of gain. With the analog Z feedback loop, the highest fidelity scanning is possible. Vibrating mode scanning is possible with both phase and amplitude feedback using the high sensitivity phase detection electronics.

28-bit Scanning

With 28-bit scanning, the highest resolution AFM images may be measured. Feedback control using the XY strain gauges assures accurate tracking of the probe over the surface.

Phase and Amplitude Detector Circuit

Phase and amplitude in the Ebox are measured with highly stable phase and amplitude chips. The system can display phase data while using amplitude for feedback when scanning in vibrating mode.

Signal Accessible

At the rear of the Ebox is a 50 pin ribbon cable that gives access to all of the primary electronic signals without having to open the Ebox.

Status Lights

At the front of the Ebox is a light panel that has seven lights. In the unlikely event of a circuit failure, these lights are used for determining the status of Ebox power supplies.

Precision Analog Feedback

Feedback from the light lever force sensor to the Z piezoceramic is made using a precision analog feedback circuit. The position of the probe may be fixed in a vertical direction with a sample-and-hold circuit.

Variable Gain High Voltage Piezo Drivers

An improved signal to noise ratio as well as extremely small scan ranges are possible with the variable gain high voltage piezo drivers.

Microprocessor for scan generation through 24-bit DAC's

Low noise, variable gain high voltage amplifiers with PID feedback for XY scanning

Dimensions: Width 6" | Height 10" | Depth 14"

High fidelity, low noise Z feedback circuits for accurate probe tracking

Phase and amplitude detection circuits for vibrating mode AFM

Industry-standard National Instruments USB data acquisition board

Internally accessible header for signal input/output

Eight channels of ADC for monitoring and displaying data with LabVIEW™ software

AFM CONTROL SOFTWARE

Software for acquiring images is designed with the industry standard LabVIEW™ programming visual interface instrument design environment. There are many standard functions, including setting scanning parameters, probe approach, frequency tuning, and displaying images in real time.

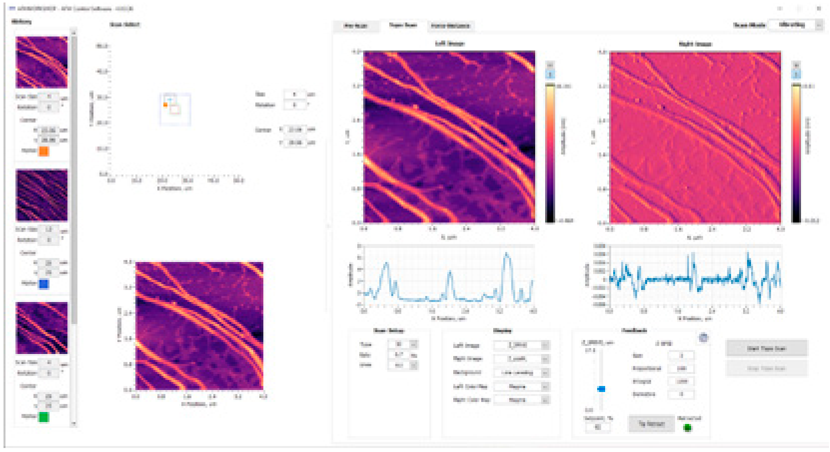
LabVIEW™ facilitates rapid development for those users seeking to enhance the software with additional special features. LabVIEW also enables the **HR-AFM** to be readily combined with any other instrument using LabVIEW.

Pre-Scan Tab

All of the functions required before making a scan are on the pre-scan tab. This includes selecting the scan mode, visual laser alignment, frequency scan, and automatic tip approach.

Topo Scan Tab

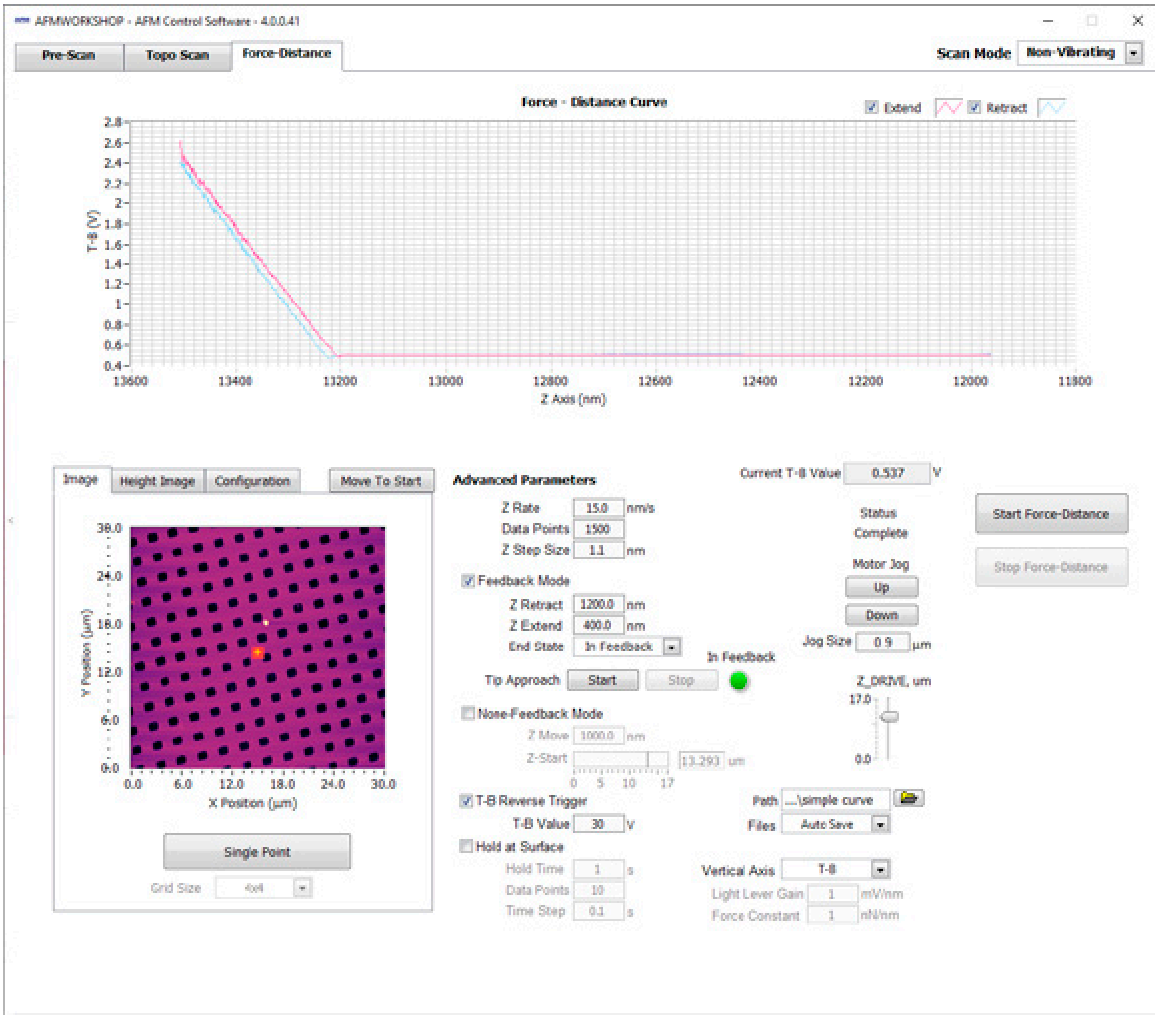
Images are acquired using the Topo Scan tab. Parameters selected on the scanning tab include the scan size, scan rate, GPID parameters, and the color scale used for displaying images. Included with the scanning tab is an image buffer capability that facilitates rapid zooming in and out.



Modes Tabs

Software control for optional modes such as MFM, EFM, and advanced F/D are found in the modes tabs. The example shown here is of the advanced F/D mode tab. This allows fine control of all the parameters controlling acquisition of force-distance curves, as well as acquisition of F-D curve maps.

Mapping of curves in this way allows the user to locate and visualize regions of the sample with differing properties, such as presence of specific molecules, or mechanical properties.



Advanced Parameters

Current T-B Value 0.537 V

Z Rate 15.0 nm/s
Data Points 1500
Z Step Size 1.1 nm

Status
Complete

☑ Feedback Mode
Z Retract 1200.0 nm
Z Extend 400.0 nm
End State In Feedback

Jog Size 0.9 µm

☐ None-Feedback Mode
Z Move 1000.0 nm
Z-Start 13.293 um

☑ T-B Reverse Trigger
T-B Value 30 V

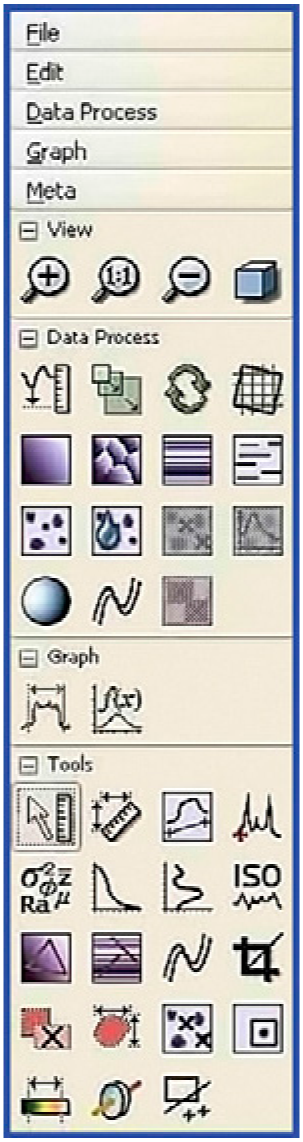
Path ...\simple curve
Files Auto Save

☐ Hold at Surface
Hold Time 1 s
Data Points 10
Time Step 0.1 s

Vertical Axis T-B
Light Lever Gain 1 mV/nm
Force Constant 1 nN/nm

IMAGE ANALYSIS SOFTWARE

Included with the **HR-AFM** is Gwyddion open source SPM image analysis software. This complete image analysis package has all the software functions necessary to process, analyze, and display SPM images.

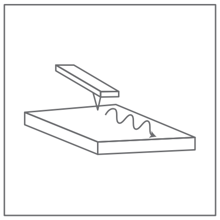


- Visualization: false color representation with different types of mapping
- Shaded, logarithmic, gradient- and edge-detected, local contrast representation, and Canny lines
- OpenGL 3D data display: false color or material representation
- Easily editable color maps and OpenGL materials
- Basic operations: rotation, flipping, inversion, data arithmetic, crop, and resampling
- Leveling: plane leveling, profiles leveling, three-point leveling, facet leveling, polynomial background removal, and leveling along user-defined lines
- Value reading, distance, and angle measurement
- Profiles: profile extraction, measuring distances in profile graph, and profile export
- Filtering: mean, median, conservative denoise, Kuwahara, minimum, maximum, and checker pattern removal
- General convolution filter with user-defined kernel
- Statistical functions: Ra, RMS, projected and surface area, inclination, histograms, 1D and 2D correlation functions, PSDF, 1D and 2D angular distributions, Minkowski functionals, and facet orientation analysis
- Statistical quantities calculated from area under arbitrary mask
- Row/column statistical quantities plots
- ISO roughness parameter evaluation
- Grains: threshold marking and un-marking, and watershed marking
- Grain statistics: overall and distributions of size, height, area, volume, boundary length, and bounding dimensions
- Integral transforms: 2D FFT, 2D continuous wavelet transform (CWT), 2D discrete wavelet transform (DWT), and wavelet anisotropy detection
- Fractal dimension analysis
- Data correction: spot remove, outlier marking, scar marking, and several line correction methods (median, modus)
- Removal of data under arbitrary mask using Laplace or fractal interpolation
- Automatic XY plane rotation correction
- Arbitrary polynomial deformation on XY plane
- 1D and 2D FFT filtering
- Fast scan axis drift correction
- Mask editing: adding, removing or intersecting with rectangles and ellipses, inversion, extraction, expansion, and shrinking
- Simple graph function fitting, and critical dimension determination
- Force-distance curve fitting
- Axes scale calibration
- Merging and immersion of images
- Tip modeling, blind estimation, dilation, and erosion

SCANNING MODES

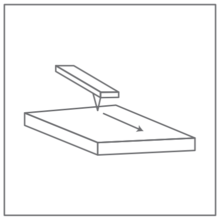
The **HR-AFM** includes the MOST COMMONLY USED AFM MODES. They are:

Vibrating (tapping)



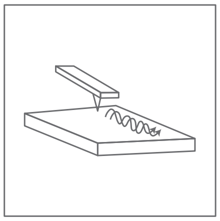
- Vibrating mode imaging is the most commonly used mode for measuring topography images with an AFM. In vibrating mode the vibration amplitude of the probe is held constant during a scan. Adjustable parameters include the vibrating frequency, amplitude of vibration, and the amount of dampening of the vibrating probe.

Non-Vibrating (contact)



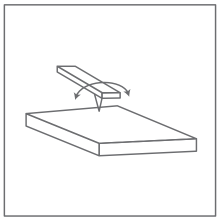
- In non-vibrating mode, commonly called contact mode, the deflection of a cantilever is held constant during scanning. This mode is often used for scanning in liquids and is also used for measuring force-distance curves.

Phase



- Phase mode images are measured in vibrating mode and are useful for identifying different areas of hardness on a surface. The technique operates by measuring the phase change caused by differing materials on a surface while scanning.

Lateral Force



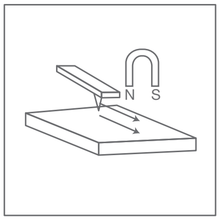
- Lateral force mode measures the local friction a probe senses as it is scanned across a surface. The friction can be caused by surface texture and differing chemical composition.

SCANNING MODES

CONTINUED...

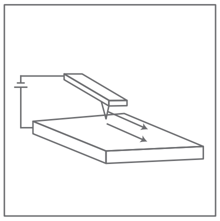
OPTIONAL MODES that can be purchased with the **HR-AFM** include:

Magnetic Force



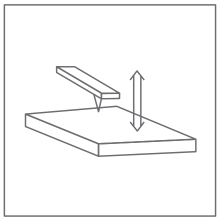
- Measures surface magnetic field by incorporating a magnetic probe into the AFM. MFM is used to generate images of magnetic fields on a surface, and is particularly useful in the development of magnetic recording technology. Magnetic fields associated with individual magnetic nanoparticles can also be revealed through MFM.

Electric Force



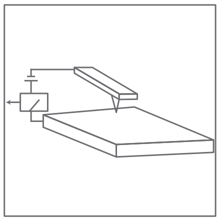
- Electrostatic Force Microscopy (EFM) is a type of dynamic non-contact atomic force microscopy where the electrostatic force is probed. “Dynamic” here means that the cantilever is oscillating and does not make contact with the sample. This force arises due to the attraction or repulsion of separated charges.

Advanced F/D



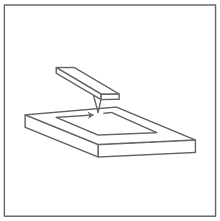
- Force-distance curves measure the deflection of a cantilever as it interacts with a surface. Force-Distance measurements monitor such surface parameters as: adhesion, stiffness, compliance, viscoelasticity, and surface layer thickness. This advanced AFM module is flexible and enables many types of experiments.

Conductive AFM



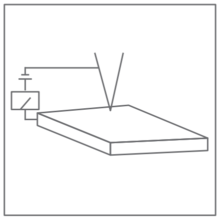
- The C-AFM measures topography and conductivity images simultaneously. This option allows measuring current-voltage (I/V) curves at specific locations on a surface. This can be highly useful in development of microelectronics,

Lithography



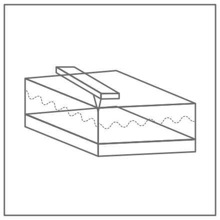
- This NanoLithography software option enables the AFM probe to alter the physical or chemical properties of the surface. Created in LabVIEW and integrated with the AFM Control software. This software allows the customer to design their own nanolithographic patterns to be written to the sample surface. VI's are available to customers who want to modify the software and create new capabilities.

Scanning Tunneling



- In the STM, the current flow between a metal probe and a sample are used to control the distance between the conductive probe and conductive surface. When the probe is scanned across the surface, if the current between the probe and surface are held constant with a feedback control loop driving a piezo ceramic, the topography of the sample's surface in measured. This also allows measurement of localized I/V curves,

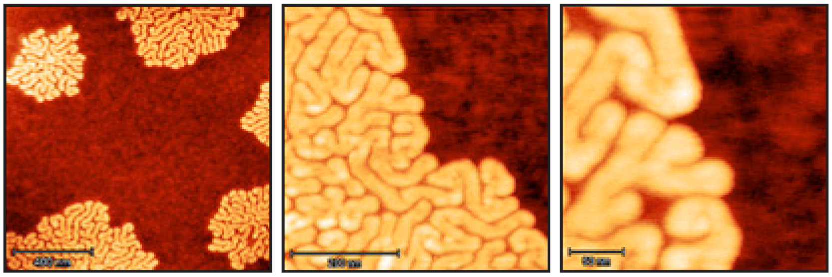
Open Liquid Cell



- This option includes a special probe holder and open liquid cell for scanning samples submerged in liquids. The open liquid cell can directly replace the HR-AFM probe and sample holder.

EXAMPLE IMAGES

The true measure of an AFM is the quality of images it measures. With a noise floor of less than 35 picometers, and 28 bit scanning resolution, the **HR-AFM** is capable of measuring the highest resolution images on many types of samples including: polymers, 2-D samples, crystals, ceramics, biomolecules, biomaterials, and semiconductors.

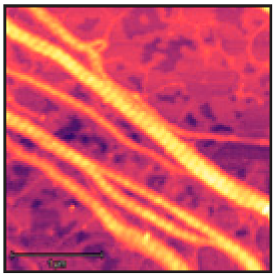


2 x 2 microns

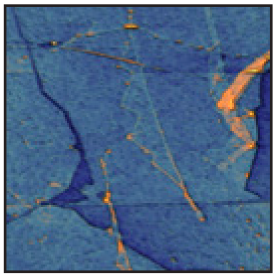
500 x 500 nm

250 x 250 nm

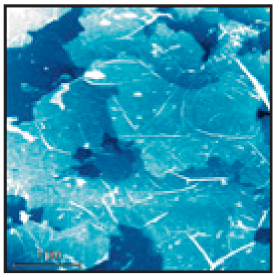
Vibrating mode image of F10H20 measured with a 50 x 50 x 17 micron scanner.



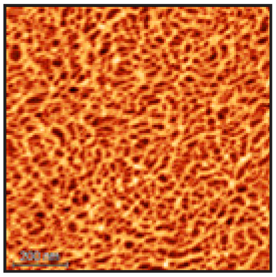
Vibrating mode images of collagen fibrils; 3µm × 3µm × 19.8 nm



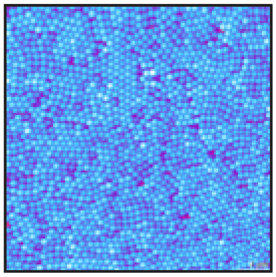
Single layer graphene sheets on silicon wafer



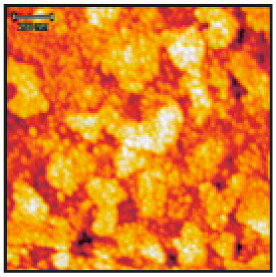
Multilayer graphene on silicon wafer



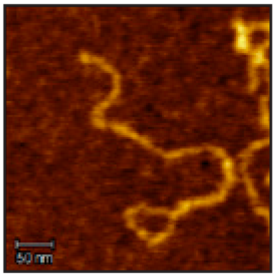
Network of DNA molecules, 1 µm × 1µm × 3.5 nm micron scan



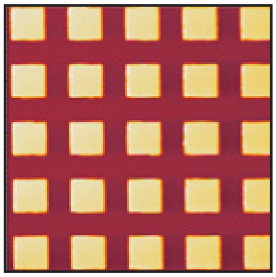
8 × 8 µm image of polymeric nanocapsules



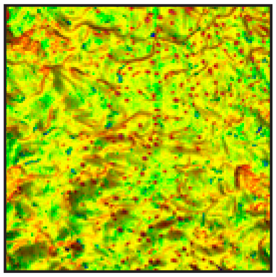
Indium Tin Oxide electrode surface; 1.3 µm × 1.3 × µm × 21 nm



Individual dsDNA molecule; 250 × 250 × 1.2 nm scan



Highly linear scan of silicon reference sample



Phase image of polymer blend showing discrimination of different phases

HR-AFM OPTIONS

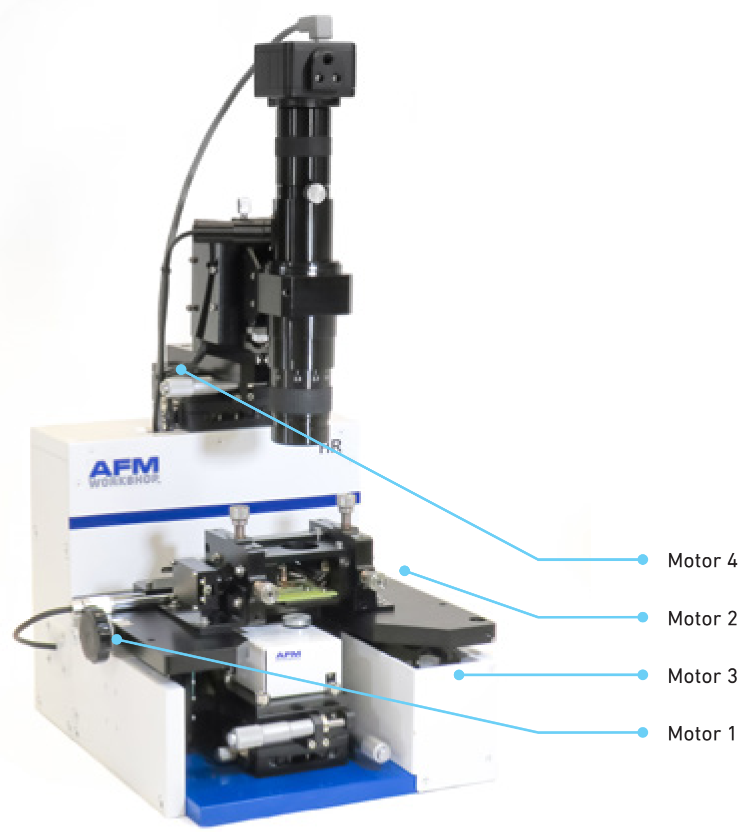
In the **HR-AFM** with direct drive option, three motors are used to translate the plate that supports the light lever force sensor. When the probe approaches the surface, it moves directly onto the features viewed in the tip view optical microscope.

The fourth motor controls the focus of the top view optical microscope. If all four motors are activated at the same time, the top view video optical micrscope will remain focused on the probe as it approaches the surface.

▶ Direct Drive Option

There are several benefits to the the 4 motor option for the HR-AFM. These include:

- Allows direct drive tip approach.
- Motorized control of probe sample angle
- Focusing on the probe during tip approach
- Sample to Probe focus with software control



▶ Q-Box

The AFMWorkshop Q-Box filters both structural and acoustic vibrations and assures the highest resolution images. The Q-Box, constructed from high density polyethylene has high density foam for filtering sound and a floating platform for filtering structural vibrations.

HR-AFM OPTIONS

CONTINUED...

The **HR-AFM** has a number of options to enhance its performance and expand its capabilities. These options may be purchased with a new AFM or at any time after the original purchase.

Direct Drive	The 4 motor option allow a direct drive probe approach as well as motorized focus of the top view optical microscope.
Q-Box	An acoustic cabinet is essential for reducing external vibrations that can reduce the resolution of the AFM.
XYZ Piezo Scanners	100 micron XY 17 micron Z 50 micron XY 17 micron Z 15 micron 7 micron Z
50 micron XY 17 micron Z	The stage dimensions of 10" X 10" require little space and fit easily on a tabletop.
15 micron 7 micron Z	The sample is moved relative to the probe with a precision XY micrometer stage. Thus, the sample can be moved precisely without touching it.
Dunk and Scan Probe Holder	Open liquid cell for scanning samples submerged in liquids. Can directly replace the HR-AFM probe holder.
Conductive AFM	Measures the 2D conductivity maps of sample surfaces.
Magnetic Force Microscopy	Measures the surface magnetic field of a sample by incorporating a magnetic probe into the AFM.
Lithography	Uses an AFM probe to alter the physical or chemical property of a sample surface.
Advanced Force Distance Curves	Measures the deflection of a cantilever as it interacts with a surface. Monitors parameters such as: adhesion, stiffness, viscoelasticity, Hardness, and surface layer Thickness. SPIP software is also availble as an option for advanced F-D curve analysis.
Scanning Tunneling Microscope	The current flow between the probe and sample is used to control the feedback loop in the microscope when scanning electrically conductive samples.
Electric Force Microscope	Using two pass scanning, the electric charge at a surface is imaged.
Breakout Box	BNC gives access to most of the signals in the Ebox
Document Package	This option includes all of the mechanical drawings, electronic schematics, and software protocols used in the microscope.
Image Logger	This option allows display of six channels in both the forward and reverse directions. It has a spectrum function as well as a twelve channel image data logger

SPECIFICATIONS

SCANNER SPECIFICATIONS

	100 × 100 × 17	50 × 50 × 17	15 × 15 × 7
Engineering Specifications			
» XY Resolution	0.010 nm	0.005 nm	0.003 nm
» XY Linearity	<0.1%	<0.1%	<0.1%
» Z Resolution	0.003 nm	0.003 nm	0.0015 nm
» Z Linearity	<0.1%	<0.1%	<0.1%
Performance Specializations			
» XY Range	100 µm	50 µm	15 µm
» XY Linearity	<1%	<1%	<1%
» XY Resolution			
• Closed Loop	<6 nm	<3 nm	<1 nm
• Open Loop	<1 nm	<1 nm	<0.3 nm
» Z Range	17 µm	17 µm	7 µm
» Z Linearity			
• Open Loop	<5%	<5%	<5%
• Closed Loop	<1%	<1%	<1%
» Z Sensor Noise	1 nm	1 nm	N.A.
» Z Feedback Noise	<0.15 nm	<0.15 nm	<0.035 nm
Actuator Type	Piezo	Piezo	Piezo
Design	Modified Tripod	Modified Tripod	Modified Tripod
XY Sensor Type	Strain Gauge	Strain Gauge	Strain Gauge
Z Sensor Type	Strain Gauge	Strain Gauge	N.A.

Electronic Control Specifications			
» XY Scan	2 × 28-bits	24-bit scan DAC, 4-bit gain	192 KHz
» XY Linearization Control	2 × 24 bits	24 bit ADC	192 KHz
» Z Axis Control	Analog	4 amplifier – GPID	1 microvolt noise
» Input Signal Bandwith	5 MHz		
» Z axis Signal Capture	20 bits	16-bit ADC, 4-bit gain	50 KHz
» Phase Signal Capture	2 × 16bits	ADC	50 KHz
» L-R Signal Capture	2 × 16 bits	ADC	50 KHz
» Amplitude Signal Capture	2 × 16 bits	ADC	50 KHz
» Z Error Signal Capture	2 × 16 bits	ADC	50 KHz
» Main Controller MPU	80 MHz/105 DMIPS, 32 Bits (5-stage pipeline, Harvard architecture)		
» Excitation/Modulation	Analog PLL	0-800 KHz	
» Communication	USB 2.0		
» Signal capture specified includes the image logger option. Without Image Logger 1 X 16 bits			

Optional Electronics Specifications			
» User Input Signal (1)	32 × 18 bits	ADC	625 KHz
» User Output (1)	32 × 18 bits	DAC	625 KHz
» User Monitor(1)	48 Lines	Digital IO	MHz
» Optional Controller MPU (2)	80 MHz/105 DMIPS, 32 Bits (5-stage pipeline, Harvard architecture)		

(1) Optional User I/O upgrade (2) Used for MFM, PhotoCorrect, EFM

SPECIFICATIONS *CONTINUED...*

Software

Environment	LabVIEW™
Operating System	Windows
Image Acquisition	Real Time Display (2 of 8 channels)

Control Parameters

GPID Z feedback Control	Yes
GPID XY feedback control	Yes
Setpoint	Yes
Scan Range	Yes
Scan Rate	Yes
Image Rotate	0° to 360°
Laser Align T-B, L-R, T+B	Yes
Vibrating Freq. Display	Yes
Force Distance	Yes
Automated Tip Approach	Yes
Oscilloscope, Y-Z	Yes
Image Store Format	Industry Standard
Image Pixels	16 × 16 to 1024 × 1024
H.V. Gain Control	XY and Z
Real Time Display	Line level, histogram, multiple false color palletes
Calibration	System Window
Jog Up - Jog Down	Yes
Image Buffers	12

Video Optical Microscope Specifications

	Minimum Zoom	Maximum Zoom
Resolution	20 microns	2 microns
Field of View	2 × 3 mm	300 × 300 μm
Magnification	45 ×	400 ×

- Top-view Optic:
  - Research Grade
  - Mechanical 7:1 Zoom Ratio
  - 5 MegaPixel CMOS Camera
  - 114 mm Working Distance
  - On-axis LED Light
- Side-view optic:
  - Miniaturized Sensor
  - LED Lighting
  - 2 MegaPixel CMOS camera

Physical Specifications

Stage	
Weight	23 lbs
Dimensions	9" × 11" × 20"
Ebox	
Weight	6 lbs
Dimensions	6" × 14" × 10.5"
Power	< 250 W
Voltage	110 V/220V