HR-2D AFM

THE **HR-2D** IS AN AFFORDABLE, ROBUST, AND POWERFUL ATOMIC FORCE MICROSCOPE DESIGNED SPECIFICALLY FOR IMAGING ATOMICALLY SMOOTH SURFACES.

FOR

- **Researchers**

  Who need a small-footprint, high-resolution AFM for investigating atomic scale surface features

- **Companies**

  That develop and manufacture ultra smooth materials and need an AFM for nano-metrology

The **HR-2D** is a complete AFM system that includes the microscope stage with linearized XYZ scanner, video optical microscope, Z approach mechanism, and XY micrometer-driven sample positioning stage. The control station includes a state-of-the-art computer with the latest version of Windows software, and control electronics with AFMWorkshop's proprietary 28 bit XY scanning.

SAMPLE SIZES

1" x 1" x ½"

STANDARD SCANNING MODES

Vibrating(tapping), Non-Vibrating(contact), Phase, Lateral Force, Force/Distance

VIDEO OPTICAL MICROSCOPES

1 mm x 1 mm FOV, 2 micron resolution

STAGE DIMENSIONS

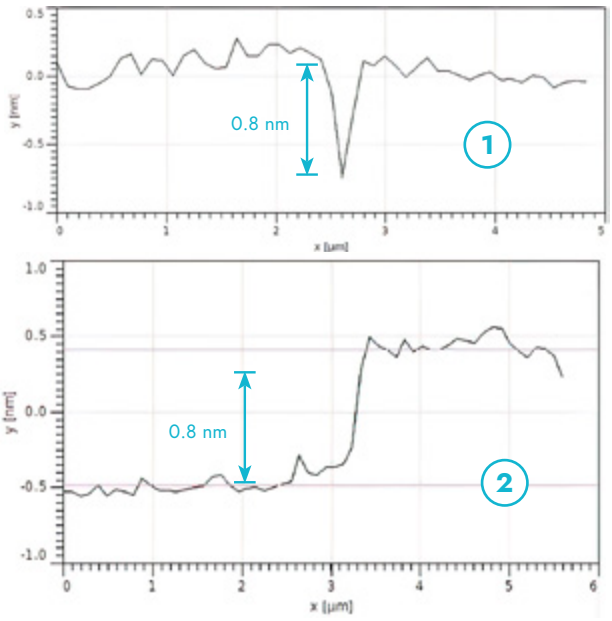
7" wide x 7" deep x 11" high

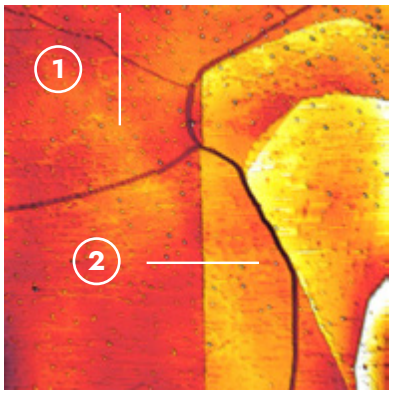
SCANNERS

15 x 15 x 7 µm, 50 x 50 x 7 µm, 100 x 100 x 17 µm

NOISE FLOOR

< 30 picometers in a normal laboratory environment





*Color scale image of NiI² measured in a glove box. Image illustrates both cracks and steps in the sample surface. Image is 23 x 23 microns**

* Q. Song, C.A. Occhialini, E. Ergeçen, B. Ilyas, D. Amoroso, P. Barone, J. Kapeghian, K. Watanabe, T. Taniguchi, A.S. Botana, S. Picozzi, N. Gedik & R. Comin (2022). "Evidence for a single-layer van der Waals multiferroic." Nature 602: 601–605

STAGE

The **HR-2D** Stage has a kinematic design that assures great thermal and mechanical stability. It is optimized for scanning atomically smooth surfaces.

SMALL FOOTPRINT
With a footprint of 7" x 7", the HR-2D AFM requires minimal laboratory space and can fit easily into a glove box.

RIGID DESIGN
A box structured stage superstructure with a kinematic mount is used to assure great thermal and structural stability.

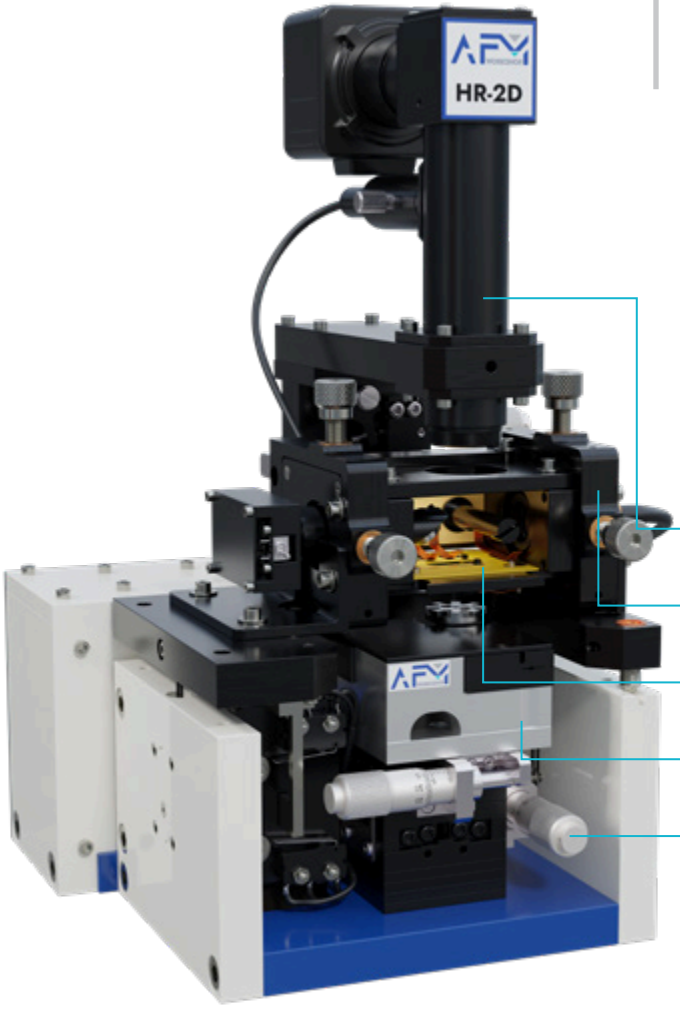
UNIVERSAL PROBE HOLDER
A removable probe holder accommodates probes from all AFM probe manufacturers, providing maximum flexibility.

PRECISE XY SAMPLE STAGE
Micrometers with 1µm accuracy move the sample in the X and Y axis relative to the probe.

XYZ PRECISION PIEZO SCANNERS
Temperature compensated strain gauges are used to linearize the motion of the XY piezoelectric ceramics in the X and Y axis.

OPEN FRAME LIGHT LEVER
All components of the light lever force sensor - including the laser and photodiode - are directly visible.

LOW PROFILE
With the provided video optical microscope, the height of the HR-2D stage is 11".



Video Optical Microscope

Light Lever Force Sensor

Removable Probe Holder

XYZ Piezoelectric Scanner

XY Sample Stage

EBOX

Electronics in the **HR-2D AFM** are constructed around industry standard USB data acquisition electronics. The critical functions, such as XY scanning, are optimized with a 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 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 enable determination of Ebox power supply status.

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.

FEATURES:

- Microprocessor for scan generation through 24-bit DACs
- 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.

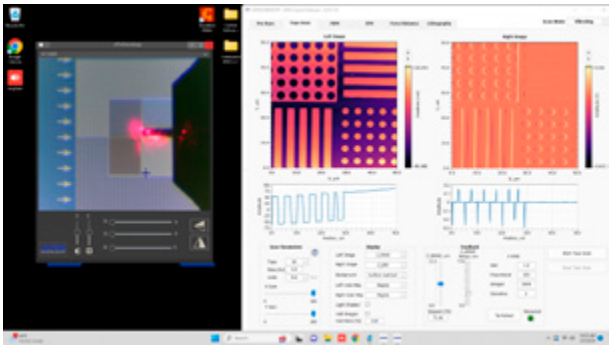
LabVIEW™ facilitates rapid development for those users seeking to enhance the software with additional special features. LabVIEW also enables the **HR-2D AFM** to be readily combined with any other instrument using LabVIEW.

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 PLD 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.



AFM CONTROL SOFTWARE CONTINUED...

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.

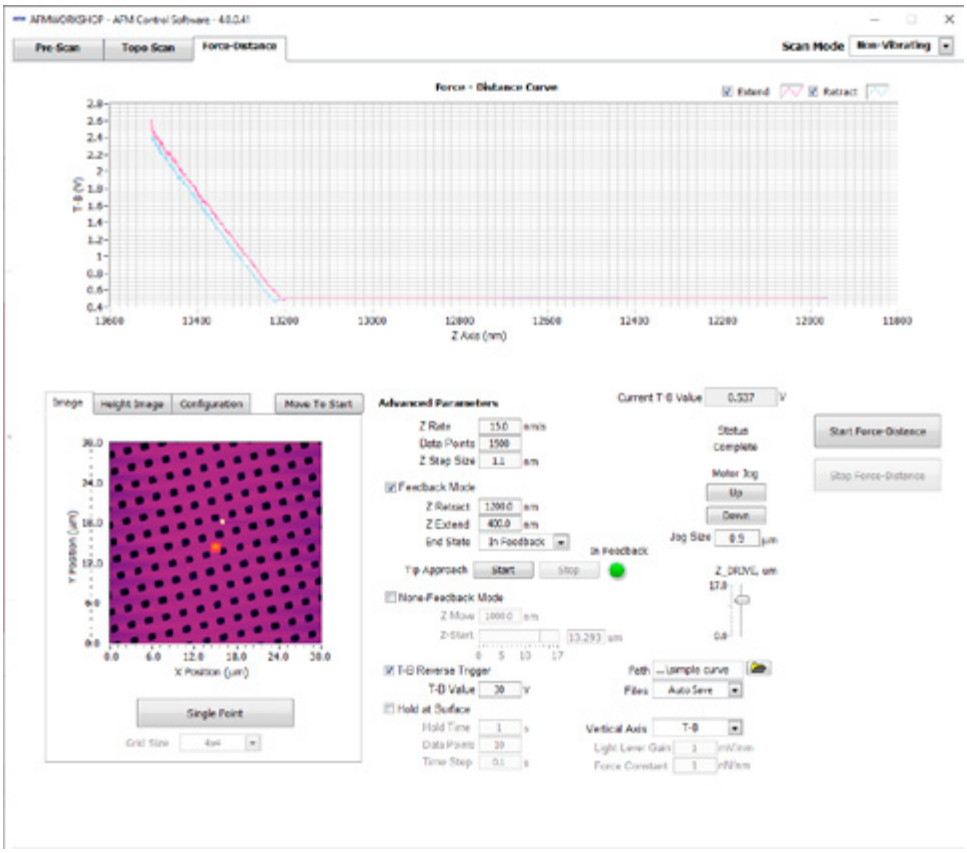
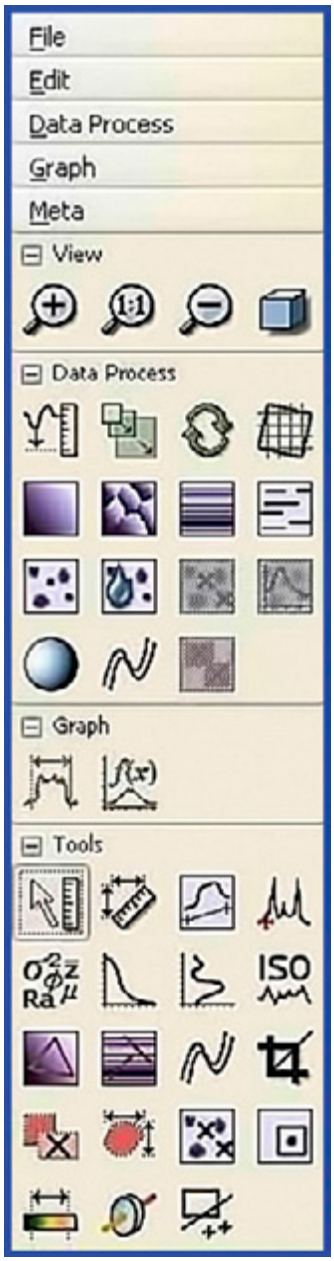


IMAGE ANALYSIS SOFTWARE

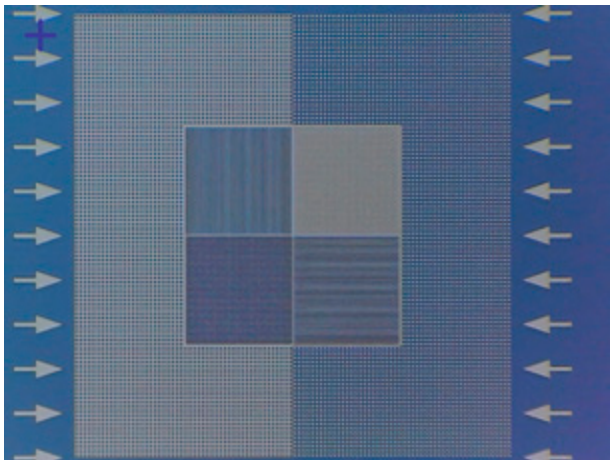
Included with the **HR-2D AFM** is Gwyddion open source SPM image analysis software. This complete image analysis package has all the software functions necessary to process, analyze, and display SPM images.



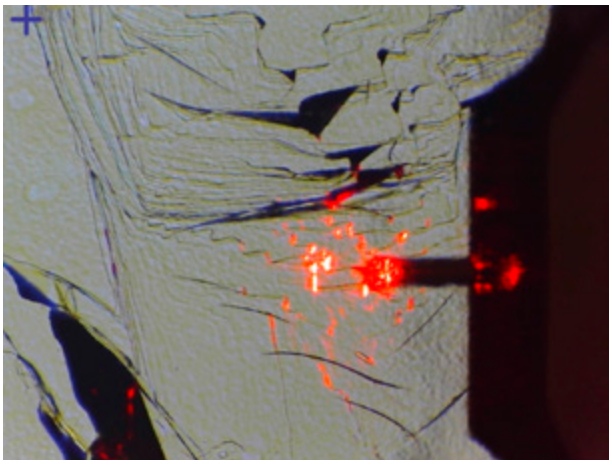
- Visualization: false color representation with different types of mapping
- Shaded, logarithmic, gradient- and edge-detected, local contrast representation, and Canny lines
- OpenGL 3D data display: false color or material representation
- Easily editable color maps and OpenGL materials
- Basic operations: 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

VIDEO OPTICAL MICROSCOPES

Included with the **HR-2D AFM** is a high-resolution video microscope with a 5 MP CMOS camera, and a mechanical XYZ capacity having a 12 x 12 x 12 mm range. The field of view of the video camera is 1 x 1 mm and the resolution is 2 microns. The video microscope includes proprietary software with 16 levels of zoom. Additionally, a software marker is available for marking the location of a probe or a feature on a sample.



Video microscope image of a Budget Sensors test pattern. The squares in the outer section are 5 microns on a 10 micron pitch, and the features on the inner section are 2.5 microns on a 5 micron pitch.



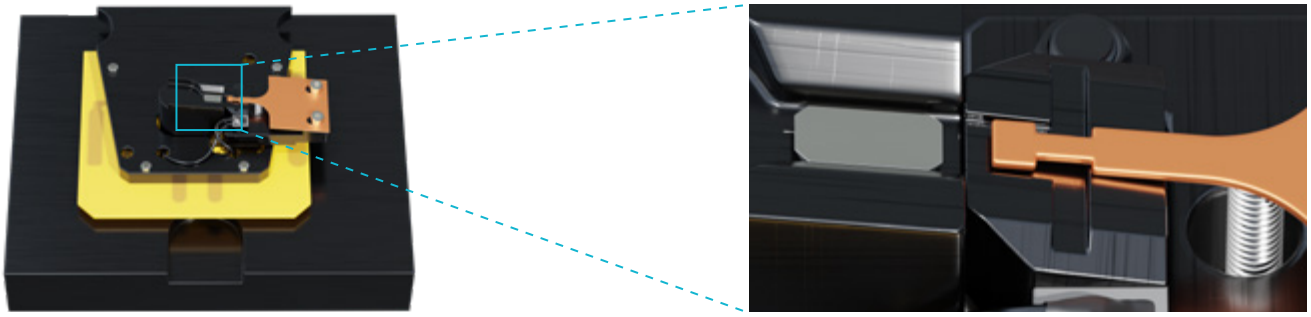
Atomic level terraces are clearly visible in this video microscope image from the HR-2D. The cantilever in this image is 35 microns wide by 125 microns long. The red light is from the laser used to measure the deflection of the cantilever in the light lever force sensor.

PROBE EXCHANGE

One of the key design features of the **HR-2D 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:

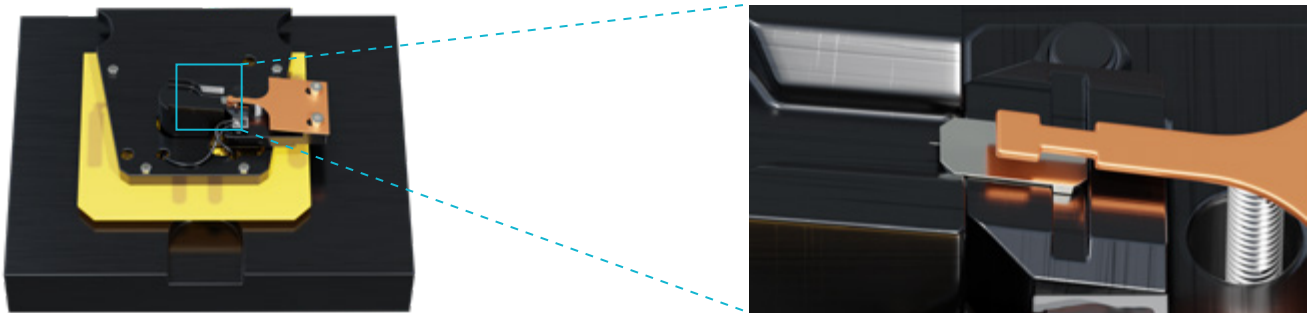
STEP 1

Put probe on exchange tool



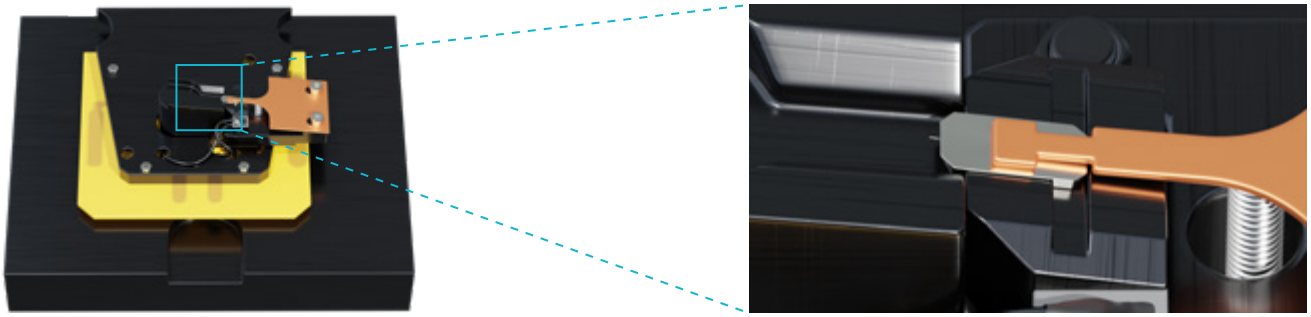
STEP 2

Press down and slide probe into holder



STEP 3

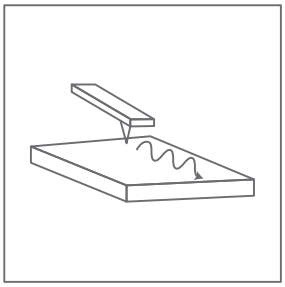
Release spring



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.

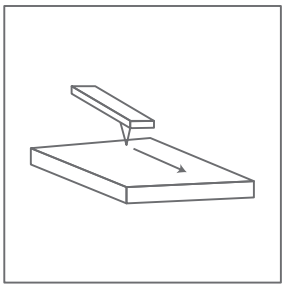
SCANNING MODES

The **HR-2D AFM** includes the MOST COMMONLY USED AFM MODES.
They are:



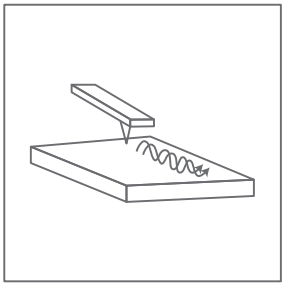
VIBRATING (TAPPING)

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.



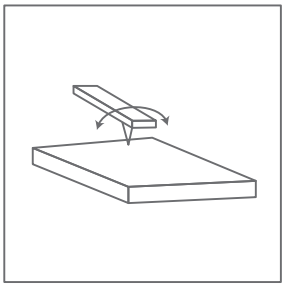
NON-VIBRATING (CONTACT)

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.



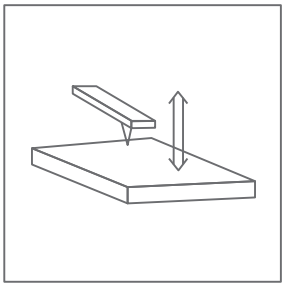
PHASE

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.

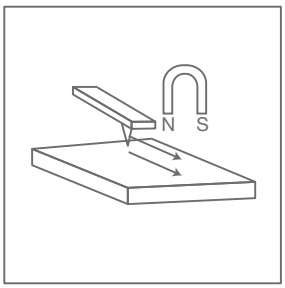


BASIC FORCE/DISTANCE

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, Hardness, and Contaminate Thickness. This simple AFM module allows measurements of force-distance curves. It can be upgraded to the Advanced Force-Distance module (see below).

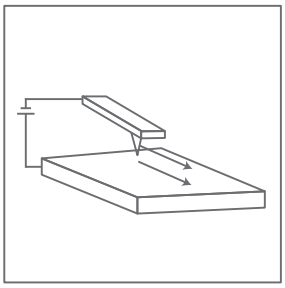
SCANNING MODES CONTINUED...

OPTIONAL MODES that can be purchased with the **HR-2D AFM** include:



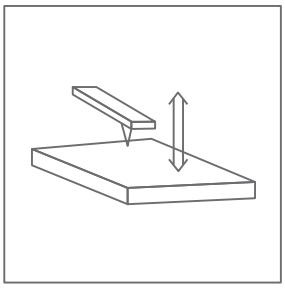
MAGNETIC FORCE

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.



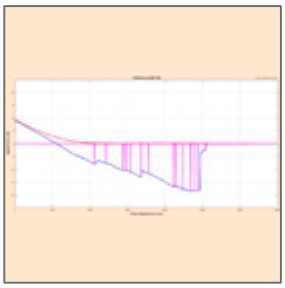
ELECTRIC FORCE

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.



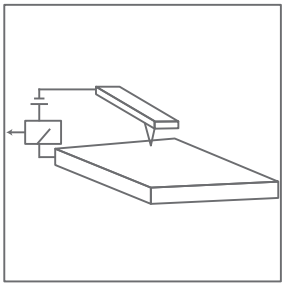
ADVANCED F/D

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.



FORCE DISTANCE CURVE ANALYSIS SOFTWARE

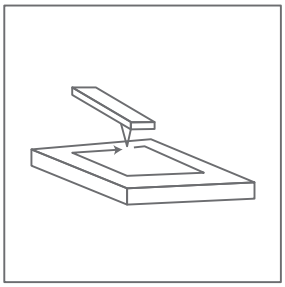
ISFVEM is a fast, intuitive software program for the analysis of a single force distance curve or a grid of curves generated with the AFMWorkshop advanced force distance acquisition software.



CONDUCTIVE AFM

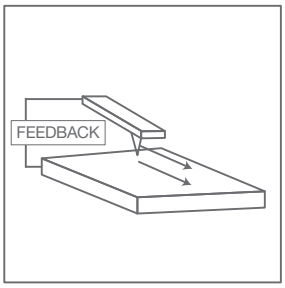
The C-AFM measures topography and conductivity images simultaneously. This option allows measuring current-voltage (I/V) curves at specific locations on a surface. This can be highly useful in development of microelectronics.

SCANNING MODES CONTINUED...



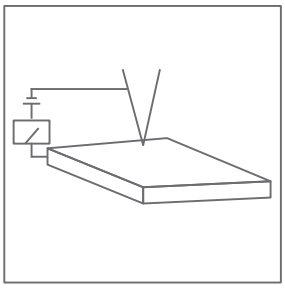
LITHOGRAPHY

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 KELVIN PROBE MICROSCOPY (SKPM)

SKPM measures the potential difference between a conductive probe and a conductive sample. The SKPM measurement is made by monitoring the output of a feedback loop that adjusts the potential on a probe so that the potential difference between the probe and surface is zero.

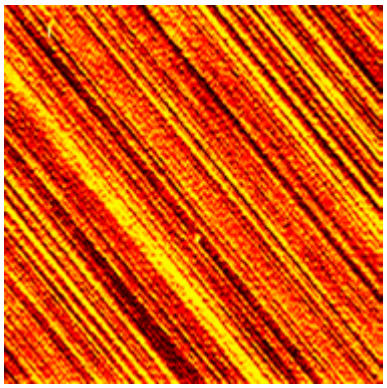


SCANNING TUNNELING

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.

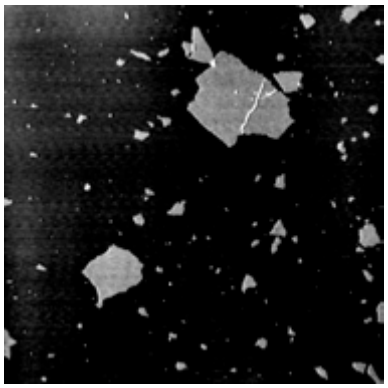
HR-2D APPLICATION

With a noise floor of <30 picometers, the **HR-2D AFM** is ideal for scanning all types of atomically smooth samples. This includes 2-D materials and polished surfaces.



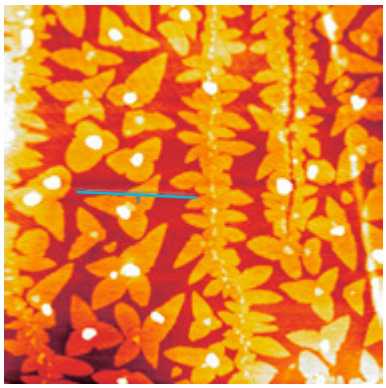
POLISHED DIAMOND SURFACE

15µm x 15µm image of polished diamond surface



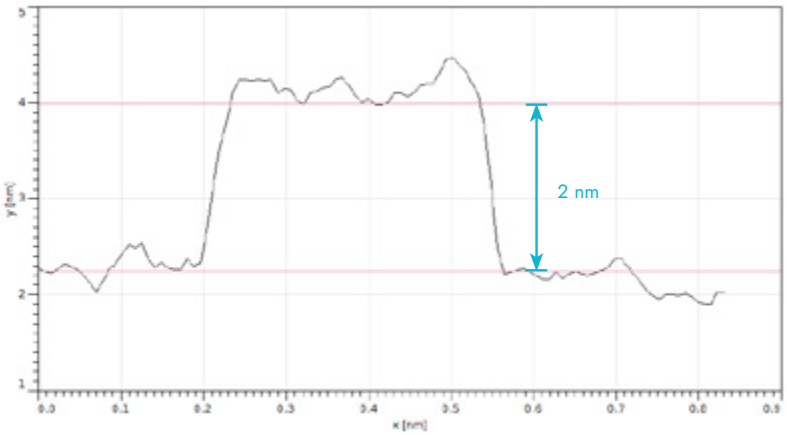
GRAPHENE

This is image of graphene flakes was made on an atomically smooth mica sample



TiSe2

This is an image of TiSe2 prepared on HOPH with MBE



Higher magnification image, color scale, with a line profile across one of the features. The features are 2 nm height.

HR-2D AFM OPTIONS

The **HR-2D 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.

OPTIONAL MODES

Listed on Page 9-11 of this data sheet are the optional-modes available for the HR-2D AFM.

ELECTRICAL MODES

- Conductive AFM (C-AFM)
- Scanning Kelvin Probe (SKPM)
- Electric Force Microscopy (EFM)
- Scanning Tunneling (STM)

OTHER MODES

- Lithography
- Advanced Force/Distance
- Magnetic Force
- Force Distance Curve Analysis Software

OPTIONAL FEATURES

Image Logger

This option allows display of six channels in the forward and reverse direction. It has a spectrum function as well as a six channel data logger.

Break Out Box

BNC gives access to most of the signals in the Ebox.

Scanners

There are three scanners available for the HR-2DAFM. They are:

- 15 x 15 x 7 µm
- 50 x 50 x 17 µm
- 100 x 100 x 17 µm

SQ Box

The SQ Box is a small acoustic isolation box for Atomic Force Microscopes. It is designed to work with several vendors' structural isolation platforms.

- Isolates AFM from sound vibrations
- Compatible with structural vibration isolation platforms
- Fabricated from rugged HDPE

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 Specifications			
◆ 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	<0.035 nm	<0.035 nm	<0.025 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 Linearizion Control	2 × 24 bits	24 bit ADC	192 KHz
◆ Z Axis Control	Analog	4 amplifier - GPID	1 microvolt noise
◆ Input Signal Bandwidth	5 MHz		
◆ Z Axis Signal Capture	20 bits	16-bit ADC, 4-bit gain	50 KHz
◆ Phase Signal Capture	2 × 16 bits	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 Pallets
Calibration	System Window
Jog Up - Jog Down	Yes
Image Buffers	12

VIDEO OPTICAL MICROSCOPE SPECIFICATIONS

- Top-view Optic:
  - Research Grade
  - 6 Levels of Digital Zoom
  - 5 MegaPixel CMOS Camera
  - 114 mm Working Distance
  - On-axis LED Light

HR-2D STAGE SPECIFICATIONS

Light Lever	
PLD Motion	XY ±1.5 mm · Z 2 mm
Detector Motion	XY ±1.5 mm · Z 7 mm
Sample Translator	
XY Range	12 x 13 mm
Resolution	2 microns
Z Approach Translator	
Range	19 mm
Resolution	150 nm
Z Sample Size	
Thickness	12 mm
Probe Accessible Area	25 x 25 mm
Maximum Size	75 x 75 mm

PHYSICAL SPECIFICATIONS

Stage	
Weight	12 lbs
Dimensions	7″ × 7″ × 11″
Ebox	
Weight	6 lbs
Dimensions	6″ × 14″ × 10.5″
Power	< 250 W
Voltage	110 V/220V