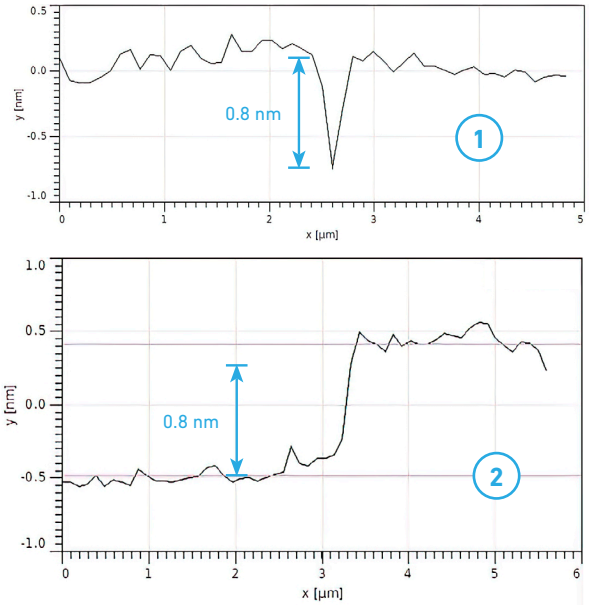
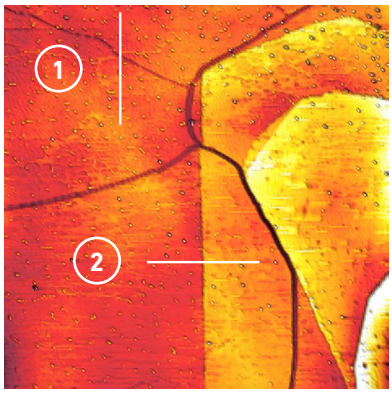
HR-2D AFM

The **HR-2D** is an affordable, robust, and powerful atomic force microscope designed specifically for imaging 2-D material. With a small footprint, it is ideal for use in a glove box.

FOR

- **Researchers**
  Who need a small-footprint, high-resolution AFM for investigating 2-D materials
- **Companies**
  That develop and manufacture 2-D materials and need an AFM for nano-metrology





*Color scale image of Nil[2] 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

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
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

STAGE

The **HR-2D** Stage has a kinematic design that assures great thermal and mechanical stability.

It is optimized for scanning single monolayers of 2-D materials.

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

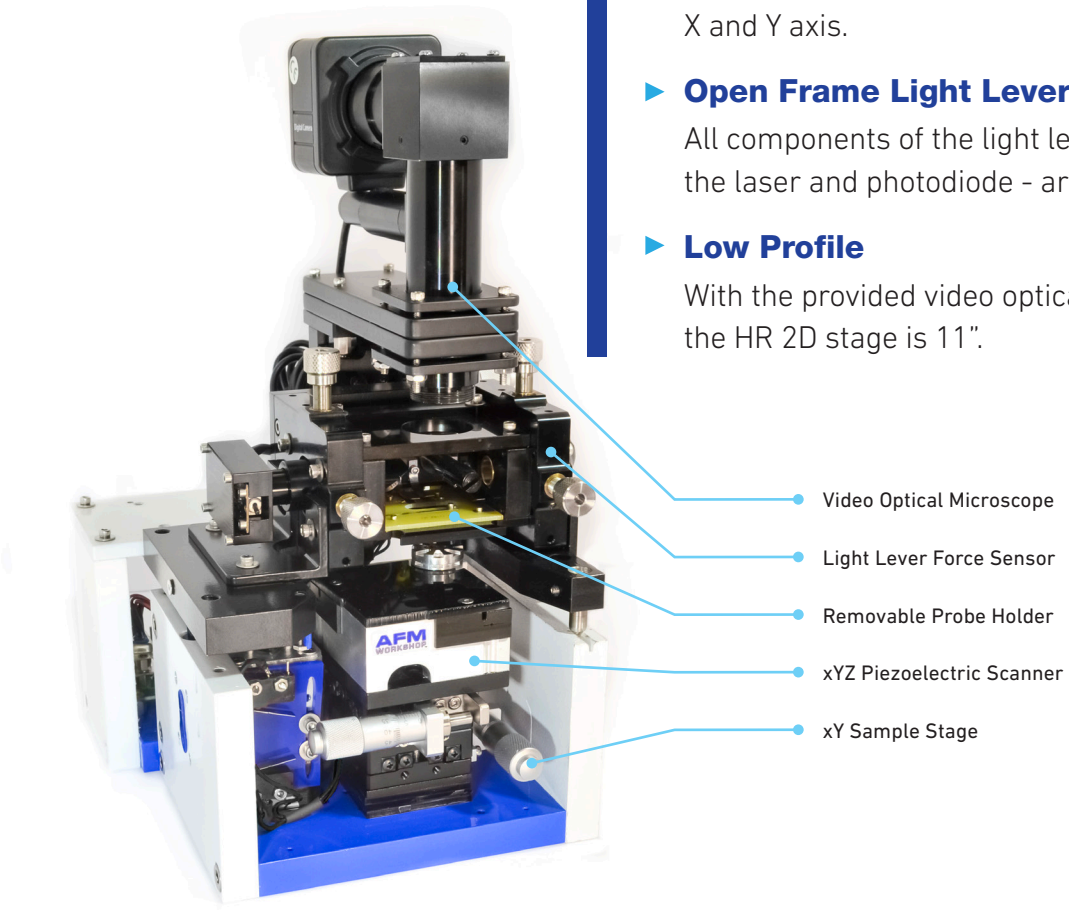
Temperature compensated strain gauges are used to linearize the motion of the XY piezoelectric ceramics in the X and Y axis.

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".



EBOX

Electronics in the **HR-2D** 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 the user access to all of the primary electronic signals without having to open it.

Status Lights

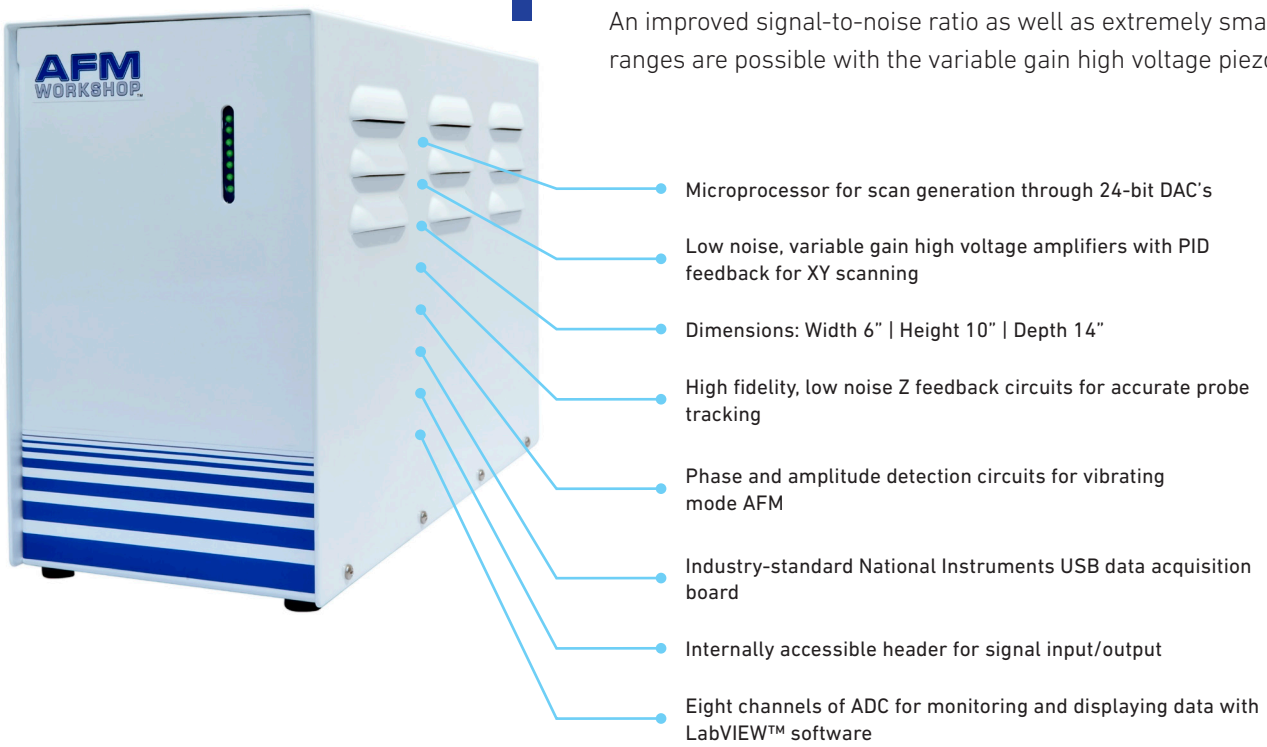
At the front of the Ebox is a light panel that has seven lights. In the unlikely event of a circuit failure, these lights are used for determining the status of Ebox power supplies.

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.



AFM CONTROL SOFTWARE

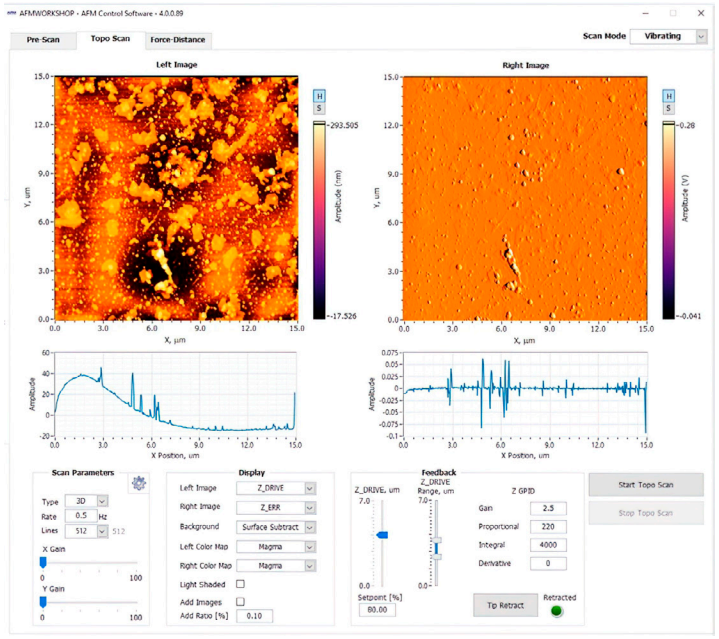
Software for acquiring images is designed with the industry standard LabVIEW™ programming visual interface instrument design environment. There are many standard functions, including setting scanning parameters, probe approach, frequency tuning, and displaying images in real time. LabVIEW™ facilitates rapid development for those users seeking to enhance the software with additional special features. LabVIEW™ also enables the **HR-2D** 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.

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

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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 with the presence of specific molecules, or mechanical properties.

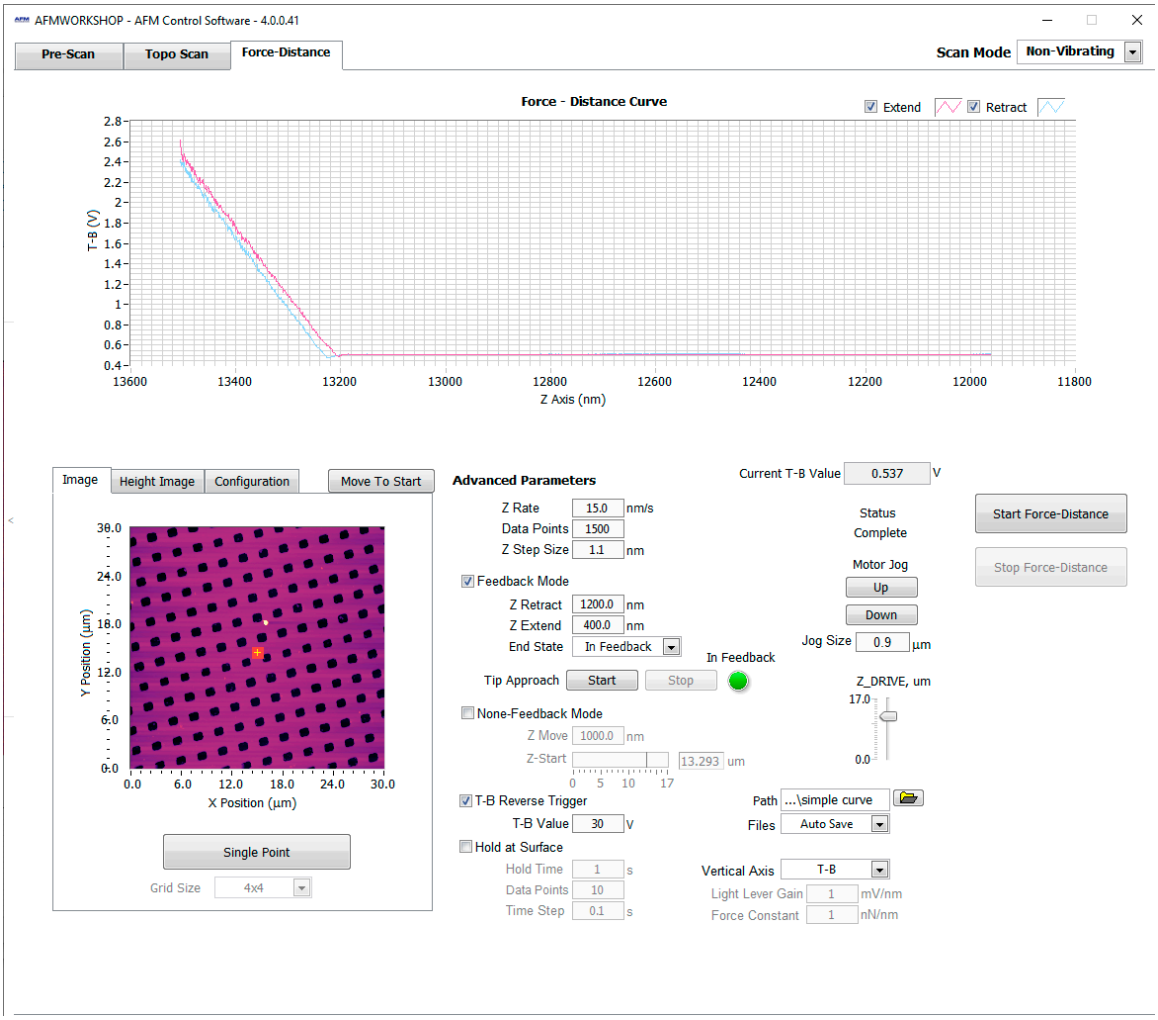
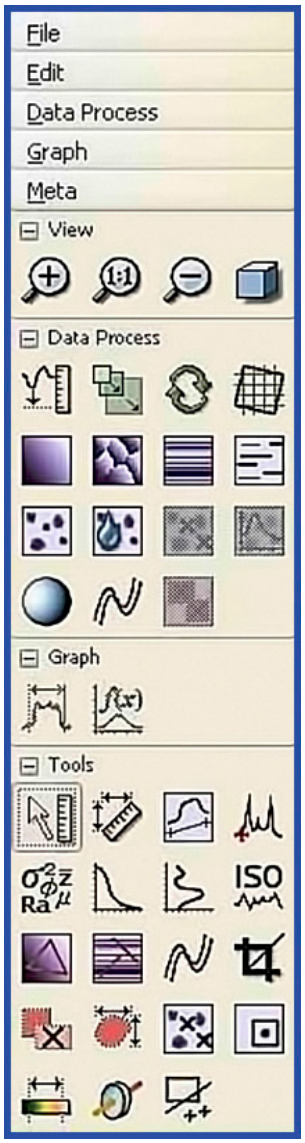


IMAGE ANALYSIS SOFTWARE

Included with the **HR-2D** 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.

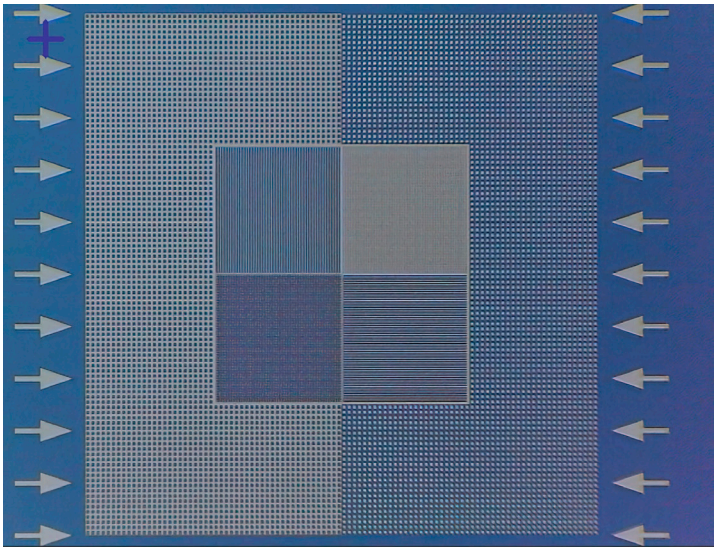


- Visualization: false color representation with different types of mapping
- Shaded, logarithmic, gradient- and edge-detected, local contrast representation, and Canny lines
- OpenGL 3D data display: false color or material representation
- Easily editable color maps and OpenGL materials
- Basic operations: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

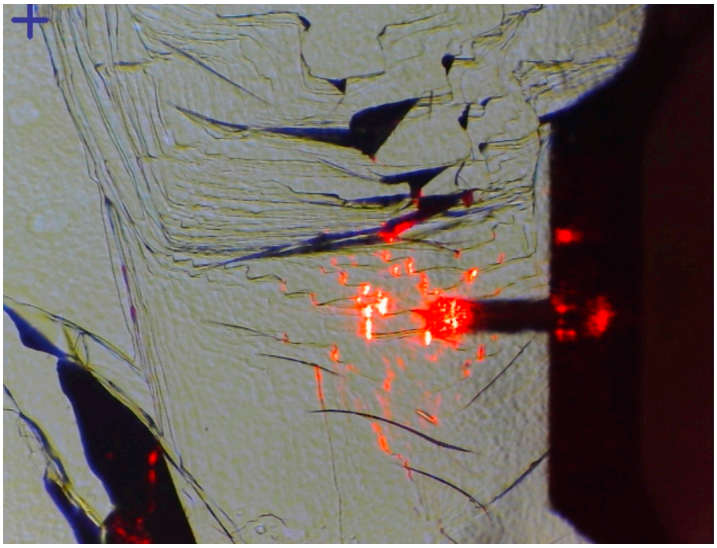
VIDEO OPTICAL MICROSCOPES

Included with the **HR-2D** 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.



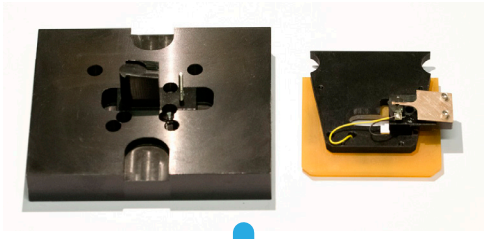
Video microscope image of a Budget Sensors test pattern. The squares in the outer section are 5 microns on a 10 micron pitch, and the features on the inner section are 2.5 microns on a 5 micron pitch.

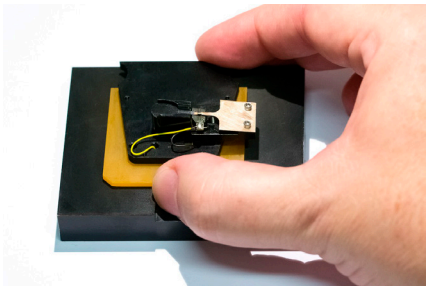


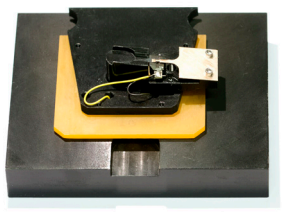
Atomic level terraces are clearly visible in this video microscope image from the HR-2D. The cantilever in this image is 35 microns wide by 125 microns long. The red light is from the laser used to measure the deflection of the cantilever in the light lever force sensor.

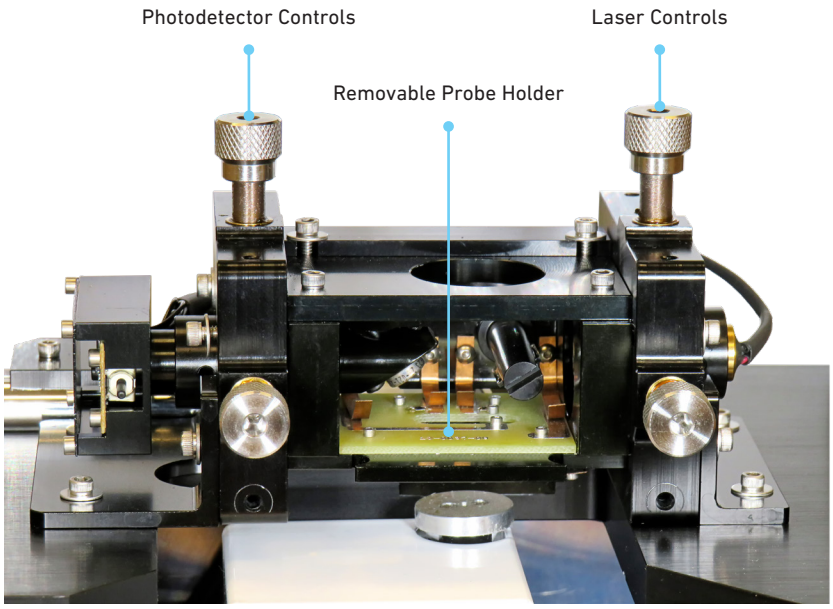
PROBE HOLDER/ EXCHANGE

The **HR-2D** uses a probe holder that is easily removed from the light lever force sensor to exchange probes. Once the probe holder is removed from the light lever, it is placed on top of the probe exchange tool and the probe is readily exchanged. Changing a probe takes less than 2 minutes.









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

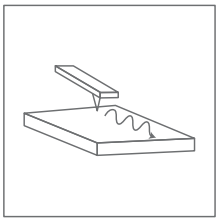
Because of the unique design, when the probe is replaced, there is almost no need for further adjustment of the light lever.....it's that easy.

With AFMWorkshop's universal probe holder, probes from most major manufacturers are accommodated.

SCANNING MODES

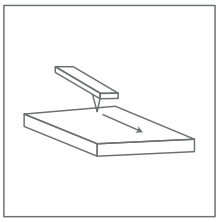
The **HR-2D** includes the most commonly used AFM modes. They are:

Vibrating (tapping)



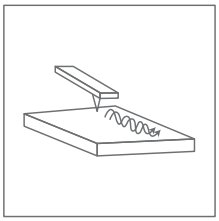
- Vibrating mode imaging (also called 'tapping mode') is the most commonly used mode for measuring topography images with an AFM. In vibrating mode the vibration amplitude of the probe is held constant during a scan. Adjustable parameters include the vibrating frequency, amplitude of vibration, and the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

Non-Vibrating (contact)



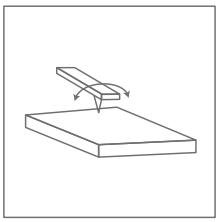
- In non-vibrating mode, commonly called contact mode, the deflection of a cantilever is held constant during scanning. This mode is often used for scanning in liquids and is also used for measuring force-distance curves.

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

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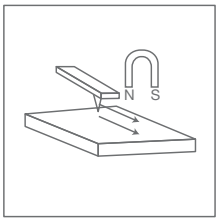
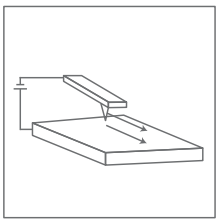
Optional modes that can be purchased with the **HR-2D** include:

Magnetic Force



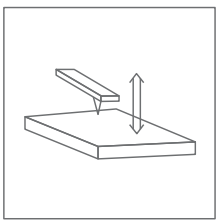
- Magentic Force Microscopy (MFM) measures surface magnetic field by incorporating a magnetic probe into the AFM. MFM is used to generate images of magnetic fields on a surface, and is particularly useful in the development of magnetic recording technology. Magnetic fields associated with individual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

Electric Force



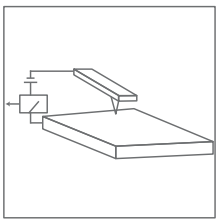
- Electrostatic Force Microscopy (EFM) is a type of dynamic non-contact atomic force microscopy where the electrostatic force is probed. "Dynamic" here means that the cantilever is oscillating and does not make contact with the sample. This force arises due to the attraction or repulsion of separated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

Advanced F/D



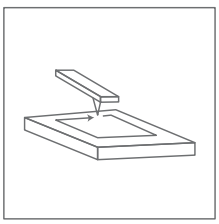
- Force-distance curves measure the deflection of a cantilever as it interacts with a surface. Force-Distance measurements monitor such surface parameters as: adhesion, stiffness, compliance, viscoelasticity, and surface layer thickness. This advanced AFM module is flexible and enables many types of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

Conductive AFM



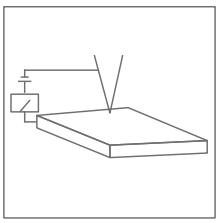
- The Conductive mode C-AFM measures topography and conductivity images simultaneously. This option allows measuring current-voltage (I/V) curves at specific locations on a surface. This can be highly useful in development of microelectronics.

Nanolithography



- 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.

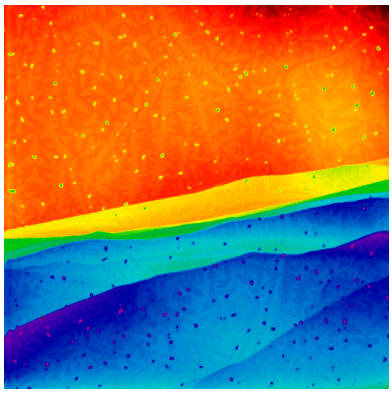
Scanning Tunneling



- During Scanning Tunneling Microscopy (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.

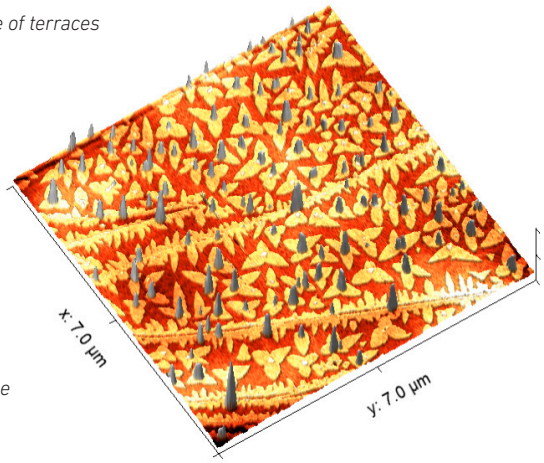
EXAMPLE APPLICATION

With a noise floor of <30 picometers, the **HR-2D AFM** is ideal for scanning all types of 2-D materials. This is an example of using the HR-2D for scanning a sample of $TiSe_2$ grown on HOPG with MBE.

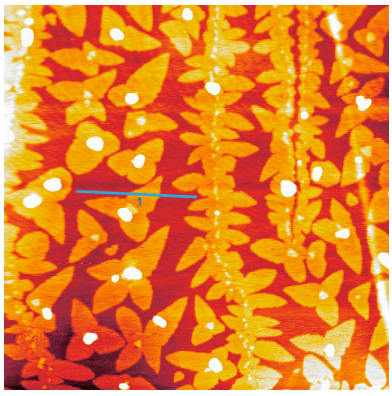


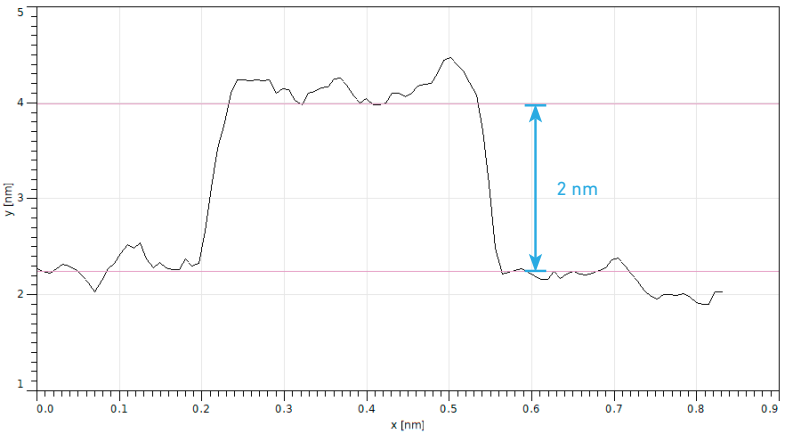
This is an example of using the HR-2D AFM for scanning a sample of $TiSe_2$ deposited on HOPG using MBE.

15 x 15 micron color scale image of terraces on the $TiSe_2$ sample



3D 7 x 7 micron color scale image of a section of a terrace from the $TiSe_2$ sample.





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

HR-2D OPTIONS

Vibration Solutions

An acoustic enclosure to dampen sound vibrations is available for the **HR-2D**. The dimensions of the enclosure are 18 x 18 x 28 inches. For dampening structural vibrations, a Minus-K table, or elastic cords, are available.

Optional Modes

Several modes such as MFM, EFM, C-AFM, Lithography and Advanced F/D are available for the HR-2D AFM. Additional modes are developed at AFMWorkshop and released on a routine basis.

Image Logger

With the image logger, the forward and reverse images are displayed and stored for multiple channels. Additionally, all channels of scanning can be displayed at once. The channels include Z Drive, Z Sense, Z Error, Z Phase, Lateral Force, and Z amplitude. The image logger option includes the hardware and software required for displaying forward and reverse images.

Training Programs

AFMWorkshop offers online as well as on-site installation and training packages. The **ONLINE TRAINING PACKAGES** include three sessions:

- **Session 1:**
  AFM Theory and Design, Changing Probes
- **Session 2:**
  Scanning in Vibrating and non-vibrating modes
- **Session 3:**
  Noise floor and calibration

With on-site installation, a certified engineer travels to the installation site for two days. The schedule for **ON-SITE INSTALLATIONS** is:

- **Morning 1:**
  Set-up AFM, measure noise floor, Theory of AFM presentation
- **Afternoon 1:**
  Training on vibrating and non vibrating mode
- **Morning 2:**
  Customer operates AFM independently
- **Afternoon 2:**
  Calibration, noise floor, and practice scanning.

GLOVE BOX

For customers who need to scan samples in an oxygen-free environment, the HR-2D AFM in a glove box is the ideal product.

This semi-custom product includes:

- Acrylic viewing front
- Latex gloves
- Load lock chamber
- Sealed wire pass through port

Structural vibrations are reduced with an elestic cord suspension system, and foam on the glove box walls filter sound vibrations. This product is made from ¾" HDPE which is both durable and chemically inert.

Note: Customers must provide a gas handling system for the AFM glove box. The AFM glove box must be assembled at the customer site.

SPECIFICATIONS	Glove Box	Base
Width	36"	36"
Depth	24"	24"
Height	40"	23"
Weight	250 lbs	100 lbs

SPECIFICATIONS

Scanner Specifications*

	100 x 100 x 17	50 x 50 x 17	15 x 15 x 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	<.035 nm	<.035 nm	<0.030 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 x 28-bits	24-bit scan DAC, 4-bit gain	192 KHz
» XY Linearization Control	2 x 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 x 16-bits	ADC	50 KHz
» L-R Signal Capture	2 x 16-bits	ADC	50 KHz
» Amplitude Signal Capture	2 x 16-bits	ADC	50 KHz
» Z Error Signal Capture	2 x 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
  - 5 MegaPixel CMOS Camera
  - 60 mm Working Distance
  - On-axis LED Light
  - XY Range - Micrometer ½"
  - Focus Range - Micrometer ½"

	Minimum Zoom
Resolution	2 microns
Field of View	1 mm x 1 mm
Magnification*	400 x
Digital Zoom	16 Levels

**Measured on a 23" monitor*

Stage Specifications:

Sample Holder	Magnetic
Sample Size	1" x 1" x ½"
Sample Translator	
XY Range	½" x ½"
Resolution	1 micron
Actuator	Micrometer
Z Translation	
Stepper	Motor
Minimum Step Size	150 nm
Maximum Range	0.75"

Physical Specifications

Stage	
Weight	10 lbs
Dimensions	7" x 7" x 11"
Ebox	
Weight	5 Lbs
Dimensions	6" x 14" x 10.5"
Power	< 250 W
Voltage	110 V/220V

**All scanner specifications ± 10%*