RADIANT TECHNOLOGIES, INC.

Precision Nano Displacement System (PNDS)

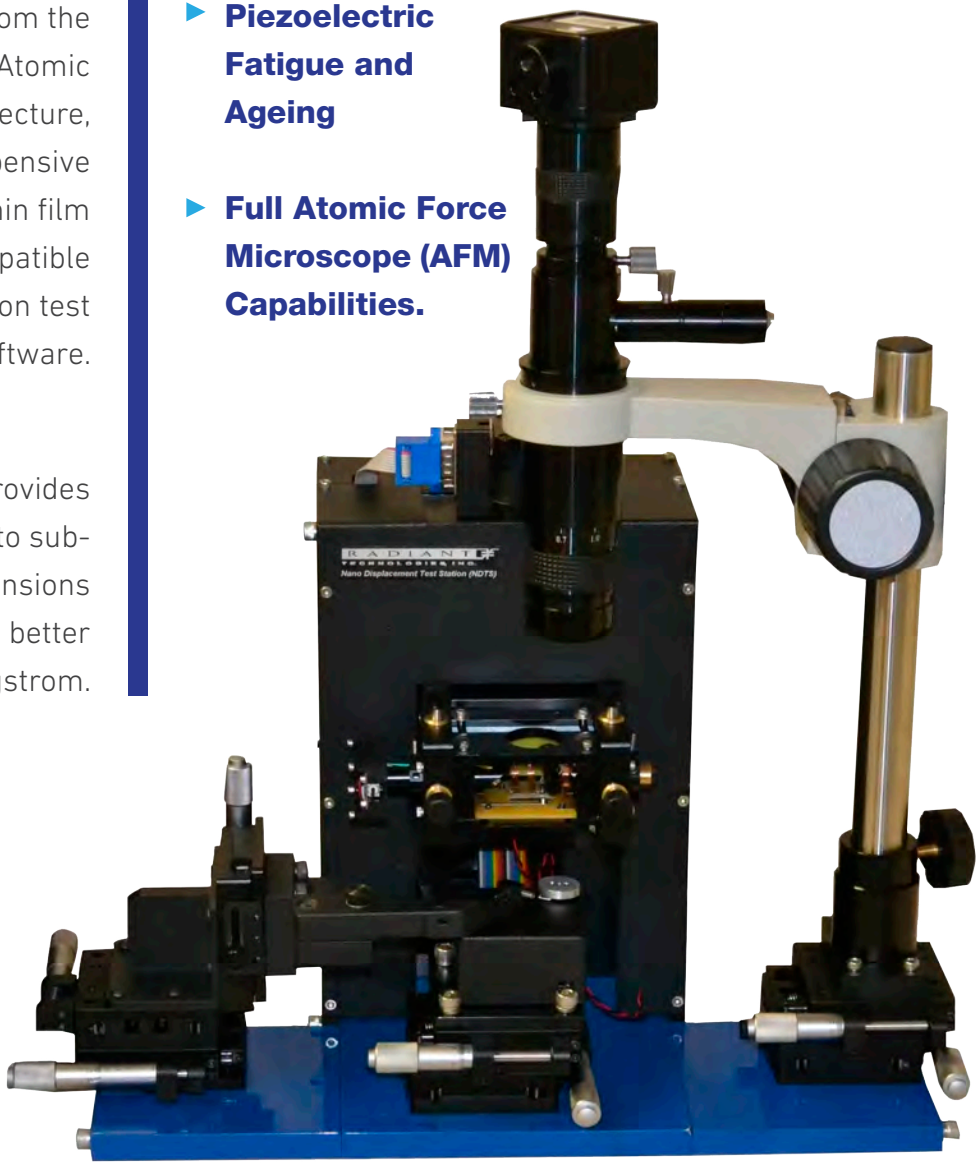
Available in 3 models:

- **A** Displacement only with manual X:Y
- **B** Displacement plus contact-mode X:Y scanning for submicron electrode search.
- **C** Full AFM capability including non-contact X:Y scanning.

- **Large Signal Displacement vs Hysteresis**
- **Small Signal Displacement vs Capacitance**
- **Remanent Displacement**
- **Piezoelectric Fatigue and Ageing**
- **Full Atomic Force Microscope (AFM) Capabilities.**

Radiant's Precision Nano Displacement Sensor is a cost effective, compact, tabletop displacement sensor capable of measuring the surface displacements of piezoelectric thin films and the actuator displacements of piezoelectric MEMs. Derived from the extremely sensitive Atomic Force Microscope architecture, the PNDS is the inexpensive solution for measuring thin film properties. It is fully compatible with Radiant's Vision test execution software.

The PNDS provides measurement capability to sub-micron electrode dimensions with vertical resolution better than an Angstrom.



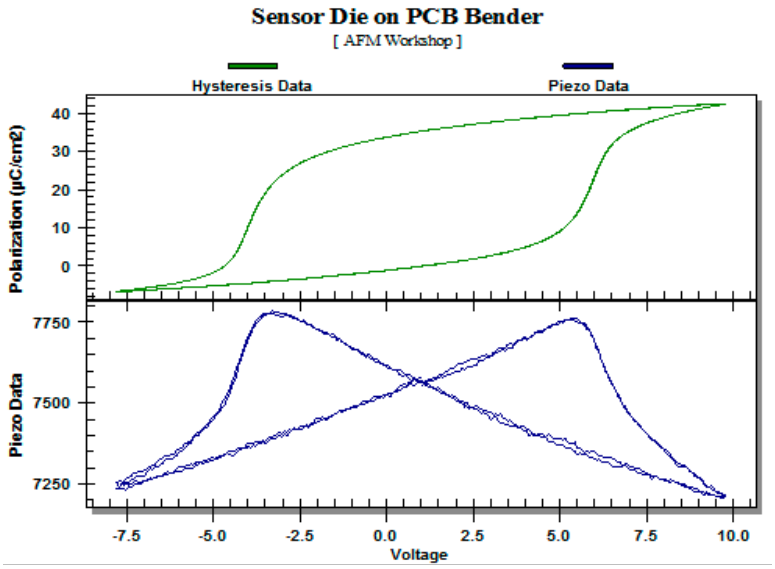
FEATURES OF PIEZO TASK SOFTWARE

Radiant's Advanced Piezo Task Software is bundled with the Precision Nano Displacement System (PNDS) to measure large signal displacement vs. polarization as the sample is stimulated by tester. The Advanced Piezo Task will acquire multiple loops under automated control, remove vertical chuck drift from the measurements, average the loops, and smooth the results.

The PNDS is designed specifically for use with piezoelectric thin films and provides the capability to measure displacement even on simple capacitors with shadow-masked electrodes!

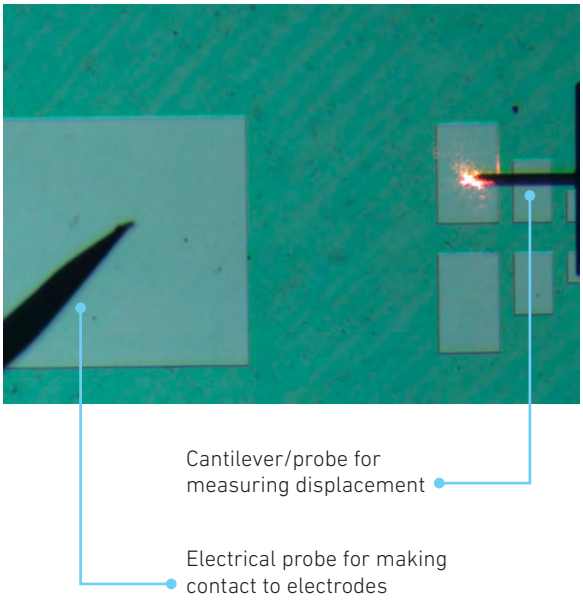
PNDS Output

The PNDS output is connected to the sensor input at the rear of the Precision tester. The following measurement was taken on a Radiant Sensor Die mounted as a bender using the PNDS and a Precision Multiferroic Test System. The Y-axis is in Ångstroms.



Electrical Probe

The PNDS includes an electrical probe that is used as a secondary contact for energizing specimens held in the PNDS. The electrical probe includes micrometer positioning accuracies in the X, Y, and Z axis.



STAGE

The PNDS stage has excellent thermal and mechanical stability required for high resolution AFM scanning. Additionally, its open design facilitates user modification.

- **Rigid Frame Design**
  The crossed beam design for the stage support is extremely rigid so the AFM is less susceptible to external vibrations.
- **Light Lever AFM Displacement Sensor**
  Light lever Displacement Sensor are used in almost all atomic force microscopes and permit many types of experiments.
- **Integrated Probe Holder/Probe Exchanger**
  A unique probe holder and clipping mechanism allows quick and easy probe exchange.
- **Direct Drive Z stage**
  A linear motion stage is used to move the probe in a perpendicular motion to the sample. Probe/sample angle alignment is not required, facilitating a much faster probe approach.
- **Small Footprint**
  The stage dimensions of 7.5 X 12" 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 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 PNDS.
- **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 zoom into a feature visualized in an image.
- **Laser/Detector Alignment**
  Both the light lever laser and the photo detector adjustment mechanism may be directly viewed. This feature simplifies the laser/detector alignment.
- **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.

EBOX

Electronics in the PNDS 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. 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.

24 bit scan DAC
Scanning waveforms for generating precision motion in the X-Y axis with the piezo scanners are created with 24 bit DACS driven by a 32 bit micro controller. With 24 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 be configured to feed back on either phase or amplitude 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 7 lights. In the unlikely event of a circuit failure, these lights are used for determining the status of the 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 the 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

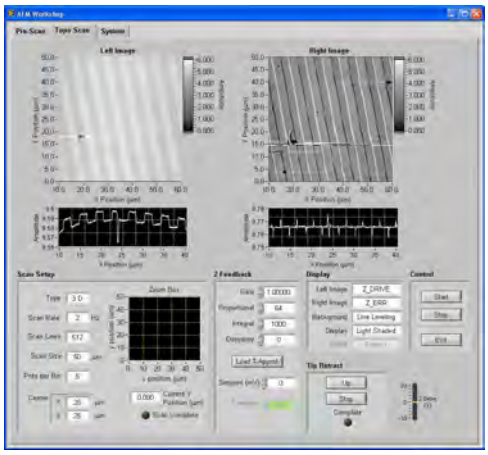
SOFTWARE

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 PNDS to be readily combined with any other instrument using LabView VI.

Pre-scan Window

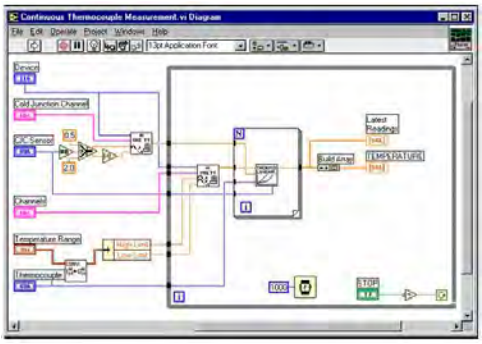
A pre-scan window includes all of the functions that are required before a scan is started. The functions are presented in a logical sequence on the screen.

Scan Window



Once all of the steps in the pre-scan window are completed, the scan window is used for measuring images. Scan parameter, Z feedback parameters, and image view functions may be changed with dialogs on this screen.

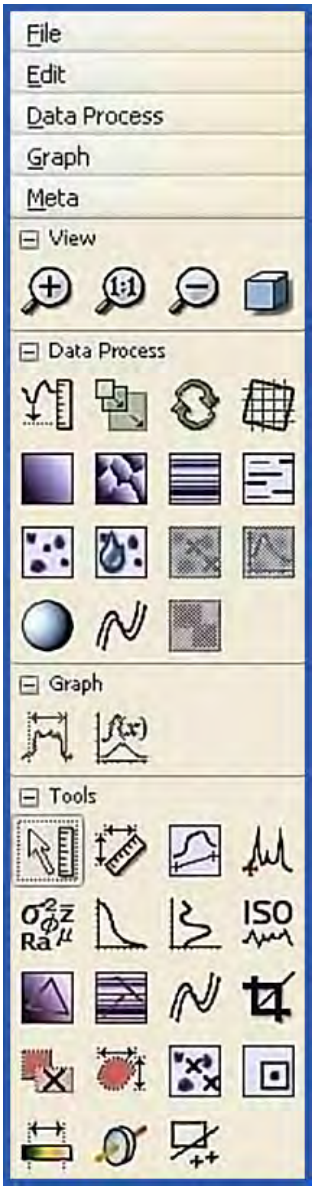
LabVIEW Window



Industry standard programming environment. Readily customized and modified for specialized applications. Instrumentation already using Labview can be added to the PNDS to create new capabilities.

IMAGE ANALYSIS SOFTWARE

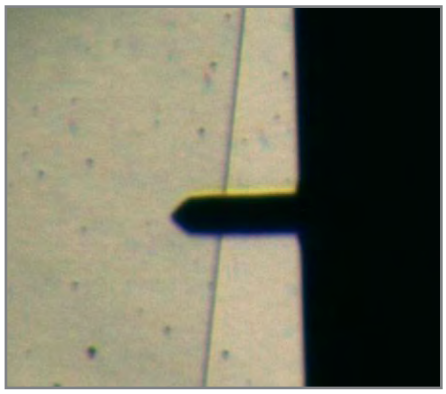
Included with the PNDS is the Gwyddion open source SPM image analysis software. This complete image analysis package has all the software functions necessary to process, analyze and display SPM images.



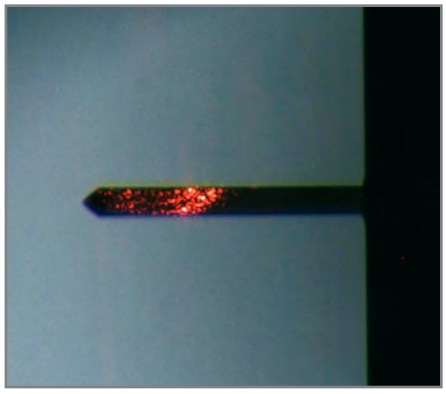
- visualization: false color representation with different types of mapping
- shaded, logarithmic, gradient- and edge-detected, local contrast representation, Canny lines
- OpenGL 3D data display: false color or material representation
- easily editable color maps and OpenGL materials
- basic operations: rotation, flipping, inversion, data arithmetic, crop, resampling
- leveling: plane leveling, profiles leveling, three-point leveling, facet leveling, polynomial background removal, leveling along user-defined lines
- value reading, distance and angle measurement
- profiles: profile extraction, measuring distances in profile graph, profile export
- filtering: mean, median, conservative denoise, Kuwahara, minimum, maximum, 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, 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, watershed marking
- grain statistics: overall and distributions of size, height, area, volume, boundary length, bounding dimensions
- integral transforms: 2D FFT, 2D continuous wavelet transform (CWT), 2D discrete wavelet transform (DWT), wavelet anisotropy detection
- fractal dimension analysis
- data correction: spot remove, outlier marking, scar marking, 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, shrinking
- simple graph function fitting, critical dimension determination
- force-distance curve fitting
- axes scale calibration
- merging and immersion of images
- tip modeling, blind estimation, dilation and erosion

VIDEO MICROSCOPE

A video optical microscope in an AFM serves three functions: aligning the laser onto the cantilever in the light lever AFM, locating surface features for scanning, and facilitating probe approach. The PNDS includes a high performance video optical microscope along with a 3 mega pixel ccd camera, light source, microscope stand, and Windows software for displaying images.



Video microscope used to locate surface features for scanning. The Vibrating Mode Cantilever is 125 µ long.

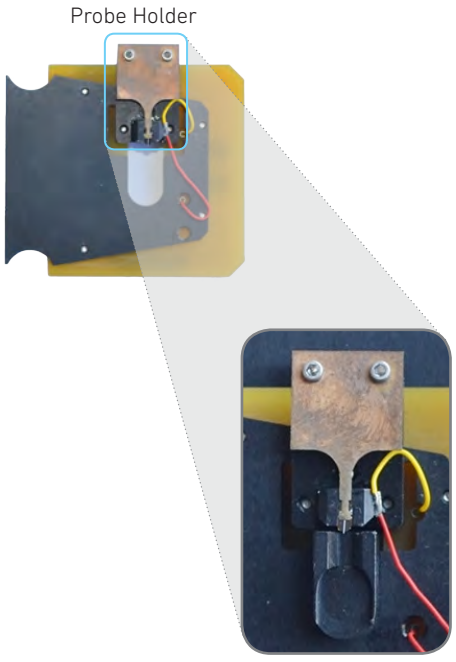


Laser alignment is greatly facilitated with the video optical microscope. This non-vibrating cantilever is 450 µ long. The red spot is from the laser reflecting off the cantilever.

PROBE HOLDER/ EXCHANGE

The PNDS utilizes a unique probe holder/exchange mechanism. Probes are held in place with a spring device that mates with a probe exchange tool. With the probe exchange tool, changing probes takes only a few minutes.

Probe Exchange Tool



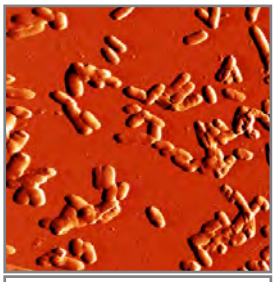
Probe Inserted in Clip

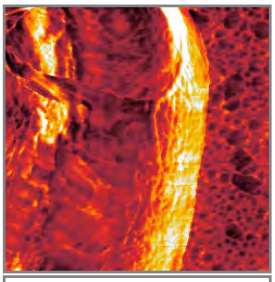
PNDS IMAGES

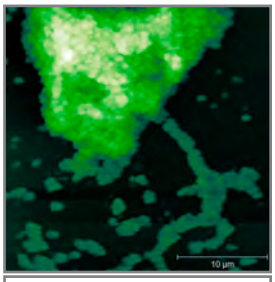
With a vertical noise floor of 0.1 nm and a horizontal resolution of 2 nm, most types of samples may be imaged with the PNDS. These include hard as well as soft samples.

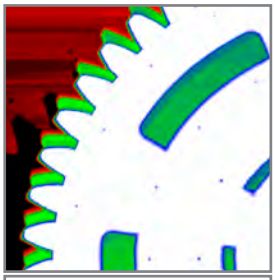
OPEN DESIGN

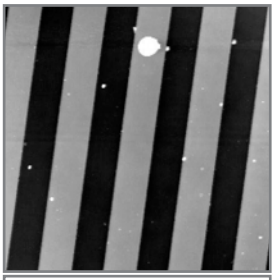
An open design is at the core of all products offered by the Radiant Technologies. New types of experiments are more readily designed and implemented through the use of Lab View software. All the mechanical drawings for the PNDS are available in the documentation package option. Finally, the company's website offers a Users Forum to directly share specialized designs developed for the PNDS. For specialized applications, other types of scanners such as flexure and tubes can be easily added to the microscope stage.

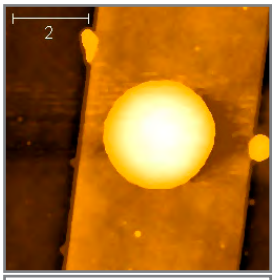

40 X 40 µ - Bacteria


3 X 3 µ – Phase Image


30 X 30 µ Spores

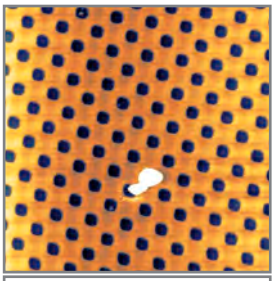

MEMS Multiple Level Gear

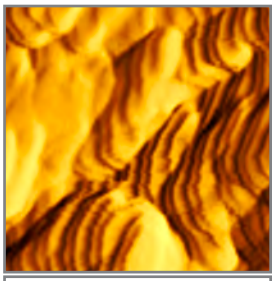

40 X 40 µ – Test Pattern

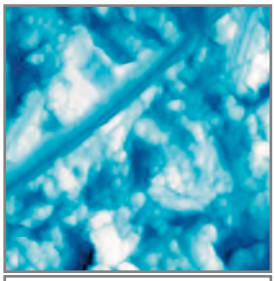


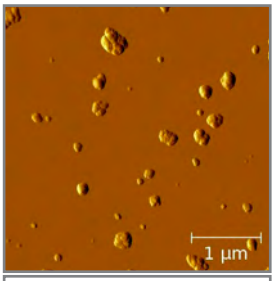
7 X 7 µ - Defect


2 X 2 µ - Si atomic terrace

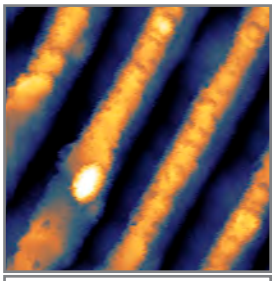

Test Pattern with defect

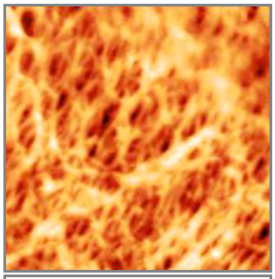

5 X 5 µ - Terraces


10 X 10 µ - Scratch in metal

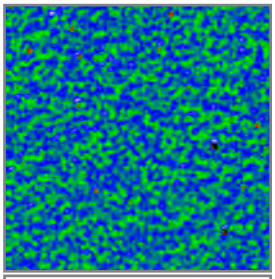


4 X 4 µ -17 nm nanoparticles


1 X 1 µ - 278 nm test pattern


2 X 2 µ - BOPP polymer fiber

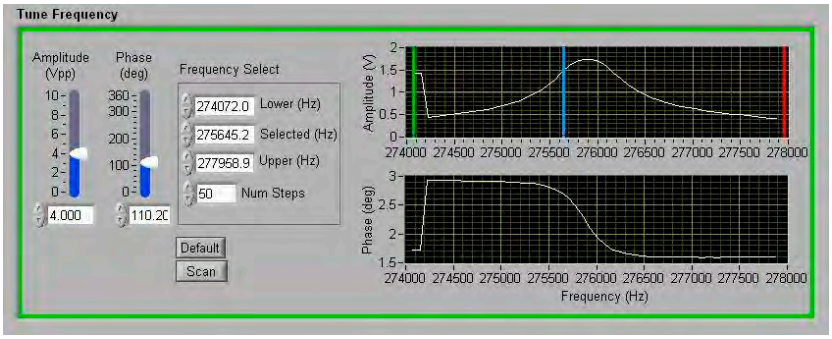
25 X 25 µ - parasites


300 X 300 nm -Phase PMMA

SCANNING MODES

Standard with every PNDS are non-vibrating(NV) mode and vibrating(V) modes for making topography scans. Additional modes included with the product are lateral force imaging as well as phase mode imaging. All of the scanning modes that can be implemented with a light lever AFM are possible with the PNDS.

With the window below, the resonance frequency of a cantilever is readily measured. Additionally, the phase characteristics of the probe sample interaction are captured.



PNDS OPTIONS

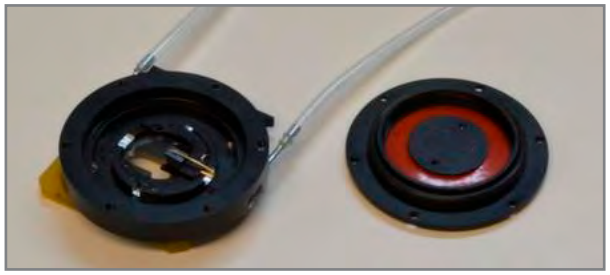
Although the PNDS comes with everything you need to make AFM images, several options are currently available.

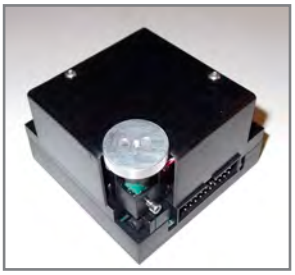
- **Environmental Cell**
  Permits scanning in inert environments or liquids.
- **Scanner Fabrication Tool**
  Facilitates scanner fabrication.
- **High Resolution Scanner**
  Allows a range of 15 X 15 microns in XY and 7 microns in Z.
- **Vibration Cabinet**
  Reduces unwanted acoustic and structural vibrations.
- **Conductive AFM**
  Measures the 2-D conductivity of sample surfaces.

Radiant Technologies regularly develops new Options.

Contact Radiant Technologies for more information on options for the PNDS.

Vibration Enclosure


Environmental Cell


15 micron scanner

SPECIFICATIONS

Optional 50 Micron xyz Scanner

Type	Modified tripod
XY Linearity	< 1%
XY Range	> 50 µ
XY resolution	< 10 nm closed loop < 1 nm open loop
XY Actuator type	Piezo
Sensor type	Strain Gauge
Z Range	> 16 µ
Z Linearity	< 5 %
Z sensor noise	< 5 nm
Z feedback noise	< 0.2 nm*
Z Actuator Type	Piezo
Z Sensor type	Strain Gauge

Optional 15 Micron xyz Scanner

Type	Modified tripod
XY Linearity	< 1%
XY Range	> 15 µ
XY resolution	< 3 nm closed loop < 0.3 nm open loop
XY Actuator type	Piezo
Sensor type	Strain Gauge
Z Range	> 7 µ
Z Linearity	< 5 %
Z sensor noise	< 5 nm
Z feedback noise	< 0.1 nm*
Z Actuator Type	Piezo
Z Sensor type	None

Sample Holder

Type	Magnet
Max Lateral Dimensions	1 inch
Max. Height	0.25 inch

Light Lever AFM Force Sensor

Probe Types	Industry standard
Probe insertion	Manual – probe exchange tool
Probe holding mechanism	Clip Vibrating mode piezo Electrical connector to probe
Laser/Detector adjustment range	+/- 1.5 mm
Adjustment resolution	1 micron
Minimum Probe to Objective	25 mm
Laser Type	670 nm diode, < 5 mw
Detector	
Type	4 quadrant
Band Width	> 500 kHz
Signals Transmitted	TL, BL, TR, BR
Gain	Lo, High Settings
Probe sample angle	10 degrees

Standard XY Translator

Range	25.4 mm
Resolution	2 µ
Type	Bearing - spring loaded
Lock Down	Yes

Z Motion

Type	Direct Drive
Range	25 mm
Drive Type	Stepper Motor
Min. Step Size	330 nm
Slew Rate	8 mm/minute
Limit Switch	Top, Bottom
Control	Software – rate, step size

Digital Data Input Output

Connection	USB
Scanning DAC	
Number	2
Bits	24
Frequency	7 kHz
Control DAC	
Number	2
Bits	14
Frequency	2 kHz
ADC	
Number	8
Bits	14
Frequency	48 kHz

Analog Electronics

Vibrating Mode	
Freq Range	2 kHz – 800 kHz
Output Voltage	10 Vpp
Demod. Freq	TBD
Z Feedback	
Type	PID
Bandwidth	> 3 kHz
Sample Hold	Yes
Voltage	0-150 V
XY Scan	
Voltage	0 – 150 V
bandwidth	> 200 Hz
Pan & Zoom	22 Bits
Tip Approach Cutoff	> 20 µ sec.

SPECIFICATIONS *Continued*

Software

» Environment	Lab View
» Operating System	Windows 7
» Image Acquisition	Real Time Display (2 of 8 channels)
» Control Parameters	
PID	Yes
Setpoint	Yes
Range	Yes
Scan Rate	Yes
Image Rotate	0 and 90 degrees
» Laser Align	Yes
» Vibrating Freq. Display	Yes
» Force Distance	Yes
» Tip Approach	Yes
» Oscilloscope	Yes
» Image Store Format	Industry Standard
» Image Pixels	16 X 16 to 1024 X 1024
» H.V. Gain Control	XY and Z
» Real time display	Line Level, Light Shaded, Grey Color Pallet
» Calibration	System Window
» Probe Center	Yes

» Video Microscope

	Minimum Zoom	Maximum Zoom
Field of view	2 X 2 mm	300 X 300 u
Resolution	20 µ	2 µ
Working Distance	114 mm	114 mm
Magnification	45 X	400X

» Computer	Industry Standard Computer

Tests that may be performed on thin films in place

» 1. All ferroelectric tests in Vision
» 2. Piezoelectric displacement
» 3. Device sorting
» 4. pMEMs reliability
» 5. Memory effects in pMEMs
» 6. bulk sample d31

* *Z Noise performance depends greatly on the environment the PNDS is used in. Best Z noise performance is obtained in a vibration free environment.*

** *Every effort is made to present accurate specifications, however, due to circumstances out of the Radiant Technologies control specifications are subject to change.*