Park SYSTEMS

Data Sheet

XE–100™ Product Datasheet

Next Generation AFM/SPM for Small Samples

With the arrival of the XE-100, our first product in the XE-series product line, non-contact AFM has become the most feasible and practical way to scan your small samples with ultimate AFM resolution and reliability. Gone are the days of the tube scanner-based AFM. With a trend-setting design engineered for product quality, user convenience, and customer support, the XE-100 is the ultimate AFM/SPM solution for the True Non Contact nanoscale metrology of small samples in data storage, semiconductors, nanoscience, materials science, polymers, and electrochemistry. The versatile platform of the XE-series has been meticulously designed to meet the diverse functional needs of today's SPM users.

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Figure 1. The XE-100 is the ultimate AFM/SPM solution for the True Non-Contact nanoscale metrology of small samples in data storage, semiconductors, nanoscience, materials science, polymers, and electrochemistry.

True Non-Contact Mode Means the Ultimate in AFM Resolution

When Non-Contact AFM (NC-AFM) is operated with a very small tip-sample distance, even a slight deviation of tip-sample inter action force from the set point can be fatal, unlike in contact mode. This is why the tip has to be significantly far from the sample surface in conventional NC-AFM, resulting in poor resolution. It is a technically challenging task to implement NC mode with a very small tip-sample distance. Tapping mode was initially used to avoid the difficulty of precise tip-sample spacing control. Once correctly engineered, however, NC-AFM provides the ultimate resolution of ambient AFM, far surpassing the capabilities of both Contact and Tapping mode. (See page 2 for details on "True Non-Contact Mode vs. Tapping Mode")

Introduced by the original innovators and pioneers of Scanning Probe Microscope (SPM) technology after 4 years of intensive product development, the XE-series represents breakthroughs in every aspect of SPM technology. The XE-series is the first and only AFM/SPM in the market that realizes True Non-Contact mode in every specification, not just in principle but in practice. True Non-Contact Mode achieves an unprecedented tip-sample distance, combined with superb tip and sample preservation. The advantages of True Non-Contact mode enable the ultimate resolution of AFM and measurement accuracy which are without peer in the AFM/SPM industry. (See page 3 for details on "What is the ultimate resolution of AFM?")

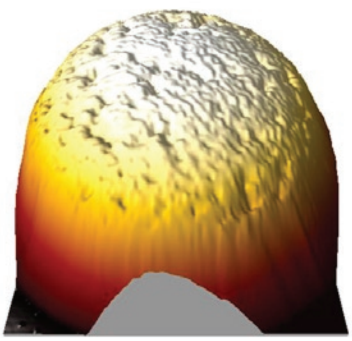

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Figure 2. True Non-Contact AFM image of a polymer sphere taken with an XE-100 (6 × 6 μm). It is not possible to image this sphere in tapping or contact mode. Only True Non-Contact mode from the XE-series with high Z-servo performance can accurately image the steep variations of such soft materials.

XE Scan System

The XE scan system is a core feature that gives the competitive edge to the XE-series over other AFM/SPMs. Park Systems's innovative scanner design separates the Z-scanner from the XY, enabling exceptional Z-servo performance and scan accuracy, unmatched by other AFM/SPMs. Both the XY and Z-scanner are designed to have great versatility.

Separation of XY & Z-scanner

The Z-scanner, which controls the vertical movement of the AFM tip, is completely separated from the XY-scanner which moves sample in XY horizontal directions. This structural change provides the user with significant operational advantages enabling True Non-Contact AFM.

Physical separation of the XY-scanner from the Z-scanner completely removes background curvature from the fundamental level, and effectively eliminates the cross-talk and non-linearity problems that are intrinsic to conventional piezoelectric tube based AFM systems. This uniquely designed XE scan system not only increases the data collecting speed by at least 10 times compared to a conventional piezoelectric tube type scanner, but also improves the error due to the inherent non-linearity of the scanner itself.

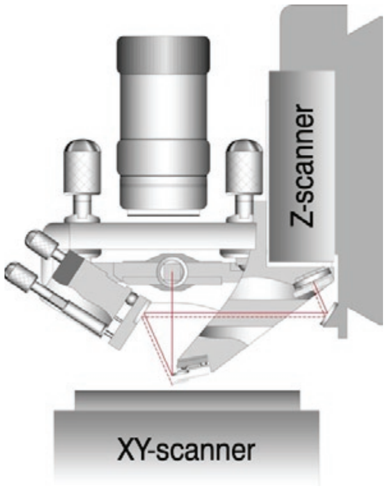

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Figure 3. XE Scan System separates the Z-scanner from the XY, enabling exceptional Z-Servo performance and scan accuracy. The innovative optical design allows for direct on-axis optical view of a sample from the top, the first and only AFM/SPM system to do so in the industry.

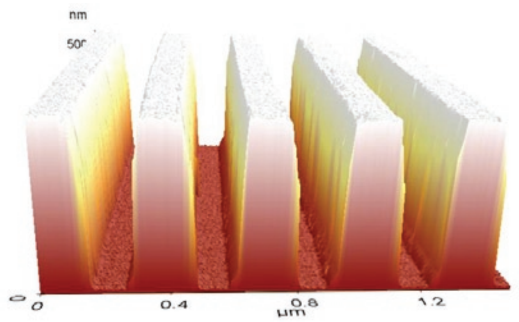

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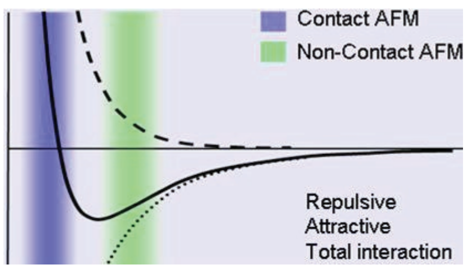
Figure 4. NC-AFM image taken with an XE-100 of 0.16 μm wide, 0.55 μm deep trenches shown in 1:1 aspect ratio 3D rendering (1.5 × 1.5 μm). It is not possible to image such narrow and deep trenches in conventional AFMs. Only True Non-Contact mode from the XE-Series with high Z-servo performance can accurately trace the steep walls of the trenches.

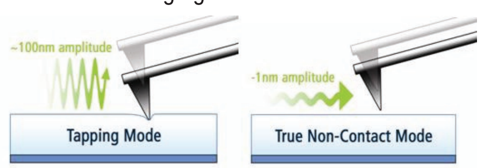
High Performance Z-servo

The Z-scanner, being separate from the XY-scanner, is designed to have a higher resonant frequency than conventional piezoelectric tube scanners. For this reason, a stacked piezo actuator is used for the Z-scanner, and it has a very fast response speed, at least 5 kHz, with a high push-pull force when appropriately pre-loaded. Since

True Non-Contact Mode vs. Tapping Mode



The first Non-Contact mode AFM (NC-AFM) was developed by Martin et al in 1987 (*J. Appl. Phys.* **61**, 4723, 1987). In NC-AFM, a cantilever is deliberately vibrated by a piezoelectric modulator with very small amplitude at a fixed frequency near the intrinsic resonance of the cantilever. As the tip approaches a sample, the van der Waals attractive force between the tip and the sample acts upon the cantilever and causes changes in both the amplitude and the phase of the cantilever vibration. These changes are monitored by a Z-Servo system feedback loop to control the tip-sample distance. If the Z-Servo performance is not sufficiently high, the tip will regularly stick to a sample due to meniscus forces. This stops the non-contact oscillation. In such cases, a Z-Scanner must retract the cantilever far enough to detach the tip from the sample surface. This process generates glitches on AFM images. One quick remedy is to increase the tip sample spacing, but this will result in a significant loss of lateral resolution. In order to solve this problem, Zhong et al. (*Surf. Sci. Lett.* **290**, L688, 1993) introduced a 'tapping' mode in which a tip strikes against the surface on each oscillation cycle and detaches from the sample surface by using a large vibration amplitude. The resolution of tapping mode, however, is not as high as that of NC-AFM since the very sharp end of a tip is extremely fragile and becomes blunt instantaneously when it makes violent contact with the sample. It must be noted that the tip-sample impact force in tapping mode is so great that it is destructive. Tapping mode may eliminate the lateral frictional force, but the tip-sample impact force is greater than in typical contact mode AFM. This force results in significant tip wear, which is bound to limit spatial resolution, and even worse, the sample can be irreparably damaged. This is even more so a problem in the case of imaging soft materials. On the other hand, a constant tip-sample distance is maintained in non-contact mode without damaging the tip or sample. With proper Z-Servo performance, the ultimate resolution of AFM can be achieved in True Non-Contact mode by keeping a constant tip-sample distance of a few nanometers.



the Z-servo response of the XE scan system is very accurate, the probe can precisely follow the steep curvature of a sample without crashing or sticking to the surface. This enables more than 10 times faster scan rates than is possible with a conventional piezoelectric tube type scanner, increasing the speed of the measurements, and protects the tip, resulting in the ability to acquire clear images for an extended period of time. A very high performance Z-servo system is required for NC-AFM. The mechanical response of the Z-scanner has to be extremely fast, a requirement met only by the XE scan system.

2D Flexure XY-scanner

In the XE scan system, the XY-scanner is a Body Guided Flexure scanner, which is used to scan a sample in the XY direction only. The flexure hinge structure of the XY-scanner guarantees highly orthogonal 2D movement with minimum out of plane motion. The 2D flexure stage of the XE scan system has only 1-2 nm of out-of-plane motion for the scan range of 50 µm, compared to 80 nm by the tube scanner of conventional AFMs over the same scan range. Due to the Parallel Kinematics design, the XY scanner also has low inertia and axis-independent performance.

The symmetrical flexure scanner design also makes it possible to place much larger samples on the sample stage than could normally be accommodated by a piezoelectric tube type scanner. Furthermore, since the flexure scanner only moves in the XY direction it can be scanned at much higher rates (10 Hz~50 Hz) than would be possible with a standard AFM.

Direct On-Axis View

What is the Ultimate Resolution of AFM?

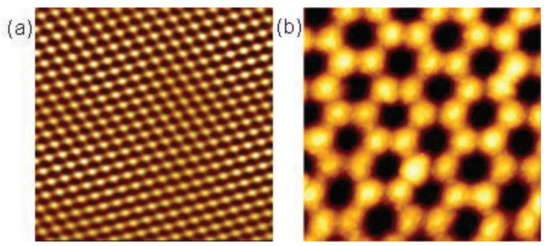
In order to address this issue, the subject of probe tip radius and the term "atomic resolution images" must be addressed. The radius of an AFM probe tip is a few nm at best and this radius is the limiting factor in AFM resolution. It is widely known that "atomic resolution AFM images" such as that of graphite and mica are images that reflect the average spacing of atoms on the sample surface and not the individual atoms (H.A. Mizes et al., *Phys. Rev. B* **36**, 4491, 1987, and T.R. Albrecht et al., *Appl. Phys. Lett.* **52**, 362, 1988). Therefore, we should use the term atomic lattice, rather than atomic resolution since it is unreasonable to expect imaging of individual atoms by AFM.

Atomic Lattice Imaging at the Cost of Ultimate AFM Resolution and Performance

One may still argue that atomic lattice images are an indicator for the stability of an AFM system, however, they are not an accurate test of the performance on every sample since the mechanical design and signal access of such systems are deliberately engineered for and prohibitively limited to a very small scan range of a specific sample. Note that small range scanners with open loop feedback, are required for atomic lattice images, and these scanners have no practical use otherwise. It is no exaggeration that such AFM systems are solely designed for the 1 µm × 1 µm scan of a graphite or mica sample. Consequently, it is not surprising if such AFM systems are fundamentally unable to image the key features of actual samples other than graphite or mica. Making matters worse, although the ultimate resolution of AFM imaging of a user's sample is influenced by the mechanical design and signal access, it critically depends on tip and sample preservation.

How Can I Achieve the Ultimate Resolution of AFM?

As mentioned earlier, the radius of the AFM probe tip is a few nm at best, therefore, the ultimate resolution of AFM is critically defined and scaled by the radius of the AFM tip, which is about 2 nm ~5 nm. Unfortunately, the sharpest part of the tip is very fragile. Once the tip touches the sample surface, no matter how soft the contact or gentle the touch, the tip becomes blunt instantly. Therefore, it is not possible to achieve the ultimate resolution with contact mode or tapping mode AFM. The ultimate resolution can be achieved only in True Non-Contact mode AFM that preserves both tip and sample with a small tip-sample distance.



(a) AFM image of HOPG taken with XE-100 (5 µm scan size). This image shows atomic lattice, not individual atoms.
(b) AFM image of anodically patterned nanostructures on aluminum surface taken with XE-100 (500 nm scan size). The fine details on this image demonstrate about 2 nm resolution.

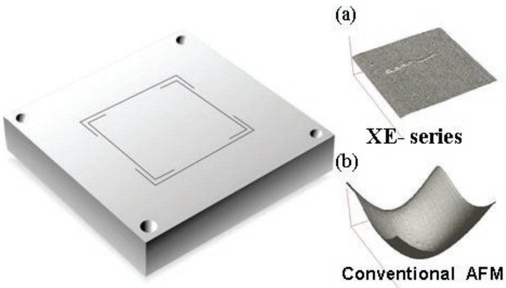


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Figure 5. 2D guided flexure scanner of the XE-100 enables high resolution imaging without background curvature. The raw data images of a bare silicon wafer are compared between (a) the 2D flexure stage and (b) conventional piezoelectric tube scanner.

The optical microscope is used to focus the laser beam onto the cantilever and to locate interesting regions on the sample surface that is to be measured. Since there is suitable clearance above the XE scan head, it is possible to accommodate a direct on-axis optical microscope. The direct on-axis optics is the first in the industry that revolutionizes the way AFM users view their samples by providing the natural on-axis view from the top with unprecedented clarity.

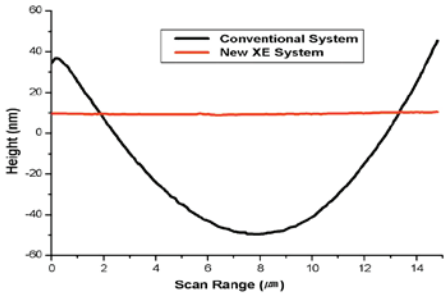

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Figure 6. The outer plane motion of the 2D flexure stage of the XE-series is flat within 1 nm ~2 nm over the range of 15 μm × 15 μm while that of the conventional piezoelectric tube scanner is more than 80 nm.

On-Axis Arrangement of Optical Components

A crucial point of our design is to ensure that the laser beam falls on the same point on the cantilever and the reflected beam hits the same point on the PSPD regardless of the Z-scanner motion, so that only the deflection of the cantilever will be monitored on the PSPD. Moreover, the laser beam path configuration needs to be optimized so as not to interfere with a clear on-axis optical view of the scanning probe and sample surface.

This goal is achieved by casting the laser beam vertically from above and attaching the PSPD to the Z-scanner, while the laser and laser beam aligning mechanism are fixed to the Z-Scanner frame. The laser beam is reflected by a prism, which is mounted on a glass plate. The angle of the glass plate can be adjusted by the two screws on the two diagonal corners of the glass plate holder. Since the laser beam is falling on the cantilever from the vertical direction, the beam always hits the same point on the cantilever regardless of the Z-scanner motion. Therefore, once the laser beam is aligned, there is no need to realign the laser beam, even after the Z-scanner has been moved up and down to change samples. The reflected beam is bounced at the steering mirror and hits the PSPD. The angle of the steering mirror can be slightly adjusted by the two screws on its diagonal edges such that the bounced beam hits the center of the PSPD.

In order to accommodate an on-axis optical microscope, it is desirable to have suitable clearance above the cantilever. For this purpose, the position of the PSPD was lowered and the steering mirror was mounted at a certain angle such that the path of the bounced laser beam became horizontal. The beam then reflects onto the PSPD by another mirror, whose angle is in parallel with the steering mirror. In this configuration, the second mirror exactly compensates for the effect of the first mirror, and therefore the laser beam hits the same point on the PSPD regardless of the Z-Scanner motion. This laser beam/PSPD configuration also improves the response rate in the Z direction by minimizing the weight of the Z-scanner .

Unprecedented Optical Clarity

This design provides clearance above the cantilever and allows for a direct on-axis optical microscope view. The optical path from the sample to the camera is an unobstructed straight line. This configuration provides much higher quality optical views than conventionzal AFMs, where an oblique mirror had to be inserted between the cantilever and the objective lens, introducing significant blur during panning. In the XE-series, the objective lens, tube lens, and CCD camera are rigidly mounted on a single body and move together for panning and focusing to preserve the highest quality optical vision.

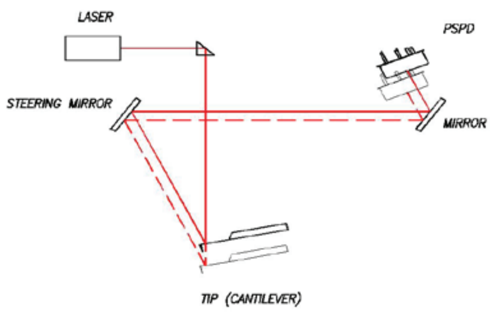

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Figure 7. Cantilever Deflection Measurement Scheme of the XE-series

User Convenience

Every component of the XE-series is engineered for ergonomics, design elegance, and user convenience.

Laser Beam Alignment

Since the CCD camera is aligned directly with the cantilever with nothing blocking its view, it is very convenient to focus on or to observe the sample while moving the camera up and down. To align the laser beam, conventional AFMs use additional positioning equipment, the operation of which is often difficult and cumbersome. However, laser beam alignment becomes very easy and convenient with the XE-series. Manageable control knobs on the XE-series head can be adjusted manually with the help of the control software and the video monitor display, making location and movement of the laser beam easy and accurate.

Probe Tip Exchange

Since the tip wears out eventually, it is necessary to replace it after some amount of usage. Probe tip exchange is just a snap with our patented pre-aligned kinematic chip mount that guarantees the same position of a probe tip every time you need to exchange a cantilever. The magnetically coupled kinematic chip mount allows you to exchange a probe tip without the need of tools or head removal.

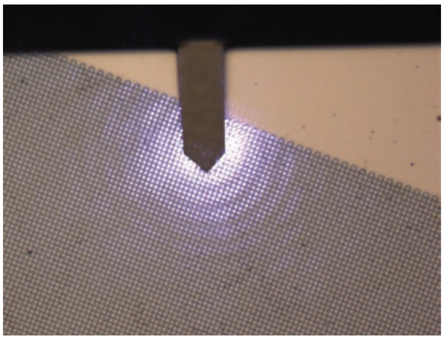

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Figure 8. XE-100's standard 10× objective lens yields about 500 times magnification, while the optional 20 ×, about 1000 times. The figure shows 10 µm grating with a laser spot on a cantilever.

Dovetail Lock Head Mount

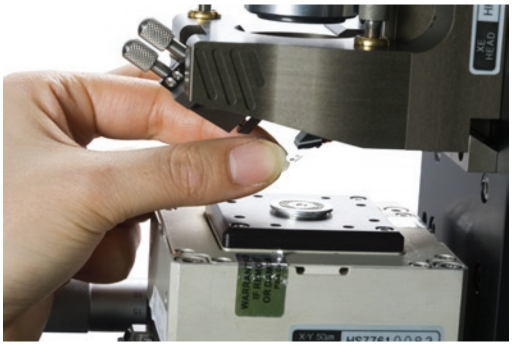
With our patented dovetail lock head mount, AFM head removal is no longer an expert operation. The AFM head, which includes the Z-scanner, is easily inserted or removed by sliding it along a dovetail rail and locking it into place with a convenient turn of two thumb locks. There are no additional knobs or springs to adjust as is common with other AFM designs.

Ball Screw Driven Z-Stage

5-phase stepper motor and backlash-free harmonic gear reduction provides reliable and swift operation. The Z-stage has a step size of 0.1 µm with the maximum speed of 30,000 steps per second.

Acoustic Enclosure

The XE-100 includes a hermetically sealed acoustic enclosure that shows trend-setting high efficiency in blocking external optical and acoustic noise.



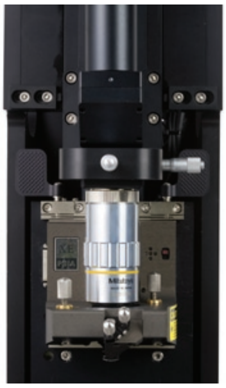


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Figure 9. (Left) Probe tip exchange is just a snap with our patented pre-aligned kinematic chip mount.
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Figure 10. (Right) The XE head can be easily removed by turning the dovetail lock by 90 degrees and sliding the head from the dovetail rail.

Electronics

The XE-series not only achieves a structural design innovation that yields a trend setting AFM performance, but it also brings state-of-the-art improvements to the electronics. The XE Control Electronics incorporates advanced digital circuitry with precision software and hardware components that empowers high speed and high capacity data processing. It has a fast and powerful DSP (Digital Signal Processor), 21 DACs (Digital to Analog Converters), and 20 ADCs (Analog to Digital

Converters). The XE Control Electronics are designed to enable the scanner, the core unit of the AFM, to provide efficient, accurate and fast control, and to facilitate the acquisition of a stable image even beyond a scan speed of 10 Hz. In addition, the controller contains input/output terminals that provide a simple means for users to design advanced experiments that extend far beyond and are much more complicated than obtaining basic images. It is the most advanced AFM/SPM controller with superb features, functionality, flexibility, and expandability.

Furthermore, the computer is equipped with the latest high power Pentium chip and Windows XP operating system. Dual 19” LCD monitors display crystal clear images using a DVI (Digital Video Interface). All necessary software, including XEP, the Data Acquisition program, and XEI, the Image Processing program, is installed on the computer.

XE Software

XEP is a data acquisition program that communicates with the XE Control Electronics in order to control the XE-series system. The XEP interface allows a user to investigate and analyze a sample surface. That is, XEP controls and operates the XE system to collect sample data. XEP supports all the standard and advanced measurement modes.

XEP has full windows multi-tasking capability with Windows XP based data acquisition and imaging processing programs. It can acquire up to 16 images simultaneously in both forward and reverse scan with real time auto-tilt, auto-contrast and auto-curvature. XEP provides arbitrary data pixel size in both X and Y directions, up to 4096 × 4096. All images are originally in TIFF format, and can be exported as PNG, JPEG and Text files.

XEI is an excellent software program that provides user-friendly and dynamic tools for image processing, quantitative analysis and statistics, and exporting and printing of processed images and measurement results. It is quite important to make good use of the XEI image processing program, just as it is important to collect the best possible data utilizing the XEP data acquisition program. The XEI software maximizes the system’s potential by allowing users to extract more information from the sample surface by utilizing various analysis tools and also by providing the ability to remove certain artifacts from scan data.

XEI supports all the standard imaging processing such as Fourier power spectrum editor, low pass filter and deglitch, and 1st-2nd order polynomial surface fit. Its analysis functions include but are not limited to user selectable Profile Tracer and Region, Line Measurement of Height, Line Profile, Power spectrum, Line Histogram, Region Measurement of Height, Average Roughness, Volume, Surface Area, Histogram, Bearing Ratio, Ry, Rz, Grain Analysis Functions, and many more. If the customer wants to add new functions to XEI, Park Systems will gladly accept customer’s demand. For presentation, user can take advantage of our powerful 3D image rendering and multi-image presentation with user selectable color palette.

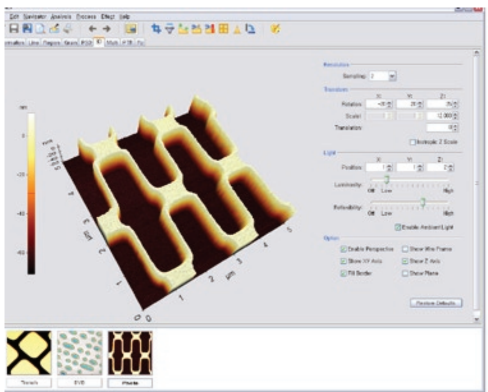

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Figure 11. (Left) XEP is not only the most advanced AFM/SPM control software in the market, but also the most user-friendly.

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Figure 12. (Right) XEI has the most advanced and versatile imaging features, which allow XE users to obtain essential and critical information from their experiments.

XE-150 Features	XE Performance Advantages
Advanced XE Scan System	Separated XY & Z-scanner No coupling between the XY plane and the z-scanner completely removes background curvature from the fundamental level, and effectively eliminates the cross-talk and non-linearity problems that are intrinsic to conventional piezoelectric tube based AFM systems. Ultra High Force Z-Scanner The key innovation that enables True Non-Contact mode in the XE-Series. The ultra high force z-scanner allows a significantly higher resonance frequency than those of conventional piezoelectric tube scanners. Since the Z-servo response of the XE scan system is very accurate, the probe can precisely follow the steep curvature of a sample without crashing or sticking to the surface. This enables more than 10 times faster scan rates than is possible with a conventional piezoelectric tube type scanner. Hardware Closed-loop Feedback Hardware, not software, feedback is used to drive all the AFM signals in order to guarantee distortion free imaging. Hardware closed-loop position control allows for the absolute scaling of AFM measurements.
2D Guided Flexure XY Scanner	High resolution imaging without background curvature. This single module parallel-kinematics XY-scanner has low inertia and minimal runout, providing the best orthogonality, high responsiveness, and axis-independent performance.
Direct On-Axis Top Optical View	The direct on-axis optics is the first in the industry that revolutionizes the way AFM users view their samples by providing the natural on-axis view from the top with unprecedented clarity. The optical path from the sample to the CCD camera is a unobstructed straight line. This configuration provides much higher quality optical views than is possible with conventional AFMs.
EZ Snap Probe Tip Exchange	Probe tip exchange is just a snap with an advanced pre-aligned kinematic chip mount that guarantees the same position of a probe tip without the need of tools or head removal.
Dovetail Lock Head Mount	The AFM head, which includes the Z-scanner, is easily inserted or removed by sliding it along a dovetail rail and locking it into place with a convenient turn of two thumb locks.
Ball Screw Driven Z-Stage	5-phase stepper motor and backlash-free harmonic gear reduction provides reliable and swift operation.
Acoustic Enclosure	The XE-100 system includes a hermetically sealed acoustic enclosure that shows trend-setting high efficiency in blocking external optical and acoustic noise.
Low Noise XE System Controller	The XE-100 system is controlled by a state-of-the art DSP that empowers high speed and high capacity data processing. The low noise performance of the XE controller is unmatched by other AFM/SPM controllers in the market. The resultant Q performance of the XE-series system is exceptionally high – so high that the extra Q-controls offered by other companies become obsolete. Its fast and versatile USB connection adds to user convenience.
XEP - Data Acquisition Software	XEP is not only the most advanced AFM/SPM control software in the market, but also the most user-friendly. The easy user interface and extraordinarily short learning curve of XEP reflects our user-oriented software development that allows our users to focus on their experiments, not programming.
XEI - Image Processing Software	XEI is another trend-setting and market leading innovation from PSIA. XEI has the most advanced and versatile imaging features, which allow XE users to obtain essential and critical information from their experiments. From routine grain size analysis to industry leading high resolution image generation, XEI is an example of XE product quality and customer support.
XE Design Sense	Every component of the XE-100 system, from system software to overall mechanical design, is engineered for user support, customer service, product innovation, and ergonomic elegance.

SPECIFICATIONS

Scanner

Decoupled XY and Z scanner
Single module flexure XY scanner with closed-loop control
Height sensing of Z scanner

Scan range of XY scanners:	5 µm, 50 µm, or 100 µm
Scan range of Z scanners:	12 µm or 25 µm

Stage

Working range of XY stage:	25 mm × 25 mm, manual precision movement
Working range of Z stage:	27.5 mm, motorized movement
Measureable sample size:	80 mm × 80 mm, 20 mm thick, and up to 500 g

Head

Detection of cantilever deflection

Laser Diode:	650 nm
Super Luminescent Diode:	835 nm with low coherency

Optical access availability (optional)

Accessible solid angle:	58 ° of cone angle

Raman spectroscopy on localized region (Raman AFM)

Vision

On-axis vision of sample surface and cantilever

Focus range:	20 mm, motorized
Magnification:	780× (optional 160×, 390×, and 1500×)
Field of view:	480 µm × 360 µm
Optical resolution:	1 µm

Electronics

High performance DSP:	600 MHz with 4800 MIPS
Maximum image size:	16 data channels of 4096 × 4096 pixels
Signal inputs:	20 channels of 16 bit ADC at 500 kHz sampling
Signal outputs:	21 channels of 16 bit DAC at 500 kHz settling
Electric signal noise:	< 10 pA (system default), < 0.1 pA (optional)
Synchronous signal:	End-of-image, end-of-line, and end-of-pixel TTL signals

Active Q control (optional)
Cantilever spring constant calibration (optional)

Software

XEP

Dedicated system control and data acquisition software
Adjusting feedback gain, set point, drive frequency/amplitude/phase in real time
Script-level control through external programs such as LabVIEW (optional)

XEI

AFM data analysis software (running on Windows, MacOS X, and Linux)

Supporting Mode

True Non-Contact Mode
Contact mode
Lateral Force Microscopy
Force – distance spectroscopy
Phase imaging of True Non-Contact, FMM, MFM, EFM, and SCM
Conductive AFM
Scanning Tunneling Microscopy
Magnetic Force Microscopy
Electric Force Microscopy
Scanning Capacitance Microscopy
Scanning Thermal Microscopy
Nanolithography
Nanoindentation

Accessories

Electrochemistry AFM
Liquid cell with heating/cooling stage
Heating/Cooling sample stage

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