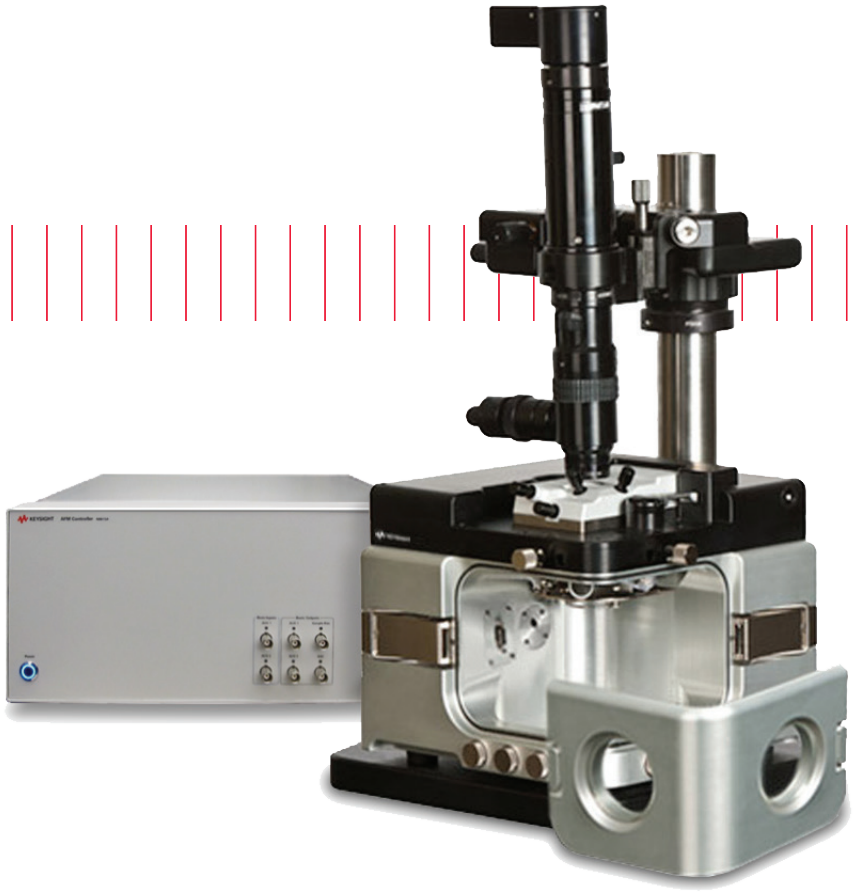
Keysight Technologies
9500 AFM

Data Sheet



KEYSIGHT TECHNOLOGIES

System Overview

The Keysight Technologies, Inc. 9500 AFM seamlessly integrates revolutionary new software, a new high-bandwidth digital controller, and a state-of-the-art mechanical design to provide unrivaled scan rates and truly astonishing ease of use. In addition to completely redefining the user experience for atomic force microscopes, this intelligently conceived system delivers the superior performance and flexible functionality that scientists and engineers have come to expect from Keysight Technologies.

We are confident that users of the 9500 AFM will immediately be impressed by Keysight's new NanoNavigator software, whose workflow-based graphical user interface (GUI) makes the system noticeably easy to use. The new software's Auto Drive feature, for example, automatically and optimally sets all parameters within seconds. NanoNavigator also enables the optionally available Quick Scan, a new technology for ultrafast scanning up to 2 sec/frame (200 x 200 pixels). There's even a handy mobile app to allow monitoring of the system via smart phone or tablet during AFM operation.

The Keysight 9500 system offers a large, closed-loop AFM scanner with atomic resolution, industry-leading environmental control, ultra-high-precision temperature control, and much more. A new high-bandwidth, FPGA-based digital controller ensures high-speed operating precision and eliminates the requirement for additional external control boxes.

The clever, compact mechanical design of the 9500 affords researchers quick and convenient access to their samples. More than a half-dozen of the most commonly used AFM imaging modes are supported by the system's standard nose cone, which can easily be interchanged with specialized nose cones as needed, extending the 9500's capabilities effortlessly.

Designed with scientific and industrial R&D users in mind, the Keysight 9500 is the ideal system for an expansive range of advanced AFM applications associated with materials science, life science, polymer science, electrical characterization, and electrochemistry.

For electrochemistry applications, NanoNavigator provides control of potentials and cyclic voltammetry. To facilitate the investigation of surface reactivity and interfacial processes, the new software supports Keysight's powerful AFM-SECM (scanning electrochemical microscopy) technique.

For electrical characterization applications, the 9500 has Scanning Microwave Microscopy mode (SMM) and for materials applications, Quick Sense permits quantitative mapping of nanomechanical properties by acquiring topography, adhesion, stiffness & elasticity data simultaneously. For life sciences applications, TREC molecular recognition capabilities have been added.

Features and Benefits

- New NanoNavigator software:
  - Workflow-based GUI makes system noticeably easy to use
  - Quick Scan for ultrafast scanning up to 2 sec/frame (200 x 200 pixels)
  - Auto Drive automatically and optimally sets all parameters within seconds
  - Mobile app allows remote monitoring of system operation
  - Provides control of potentials as well as cyclic voltammetry for electrochemistry studies
  - Supports AFM-SECM technique for studying surface reactivity and interfacial processes
  - Enables Quick Sense imaging mode for quantitative mapping of nanomechanical properties
  - Scanning Microwave Microscopy mode for calibrated electrical characterization
  - Supports TREC molecular recognition mode
- New high-bandwidth, FPGA-based digital controller ensures high-speed precision
- 90 µm closed-loop scanner delivers atomic resolution
- Industry-leading environmental and temperature control
- Superior scanning in fluids, gases, and ambient conditions
- STM scanner for studies of conducting materials

Additional Capabilities

- Materials science
- Life science
- Polymer science
- Electrical characterization
- Electrochemistry

New NanoNavigator Software

The 9500 system utilizes NanoNavigator, a revolutionary new imaging and analysis software package that draws upon the vast knowledge and expertise accumulated by Keysight over the course of two full decades spent creating leading-edge AFM instruments and supporting users in the field.

NanoNavigator greatly simplifies the complete control of all scanning parameters and provides the flexibility required for more complex experiments. The new software's optionally available Quick Scan technology enables unprecedented AFM scan speeds – up to 2 sec/frame (200 x 200 pixels).

Even true novices will find it easy to operate the 9500 AFM thanks to NanoNavigator. After loading a cantilever, the user simply enters the cantilever type into the software and the Auto Drive feature does the rest, automatically and optimally setting all parameters, including I and P gains, within a matter of seconds.

If a particular experiment requires the use of non-default settings, NanoNavigator is still exceptionally helpful. AFM beginners and experts alike will appreciate the new software's workflow-based GUI, as it guides users step-by-step through system setup and operation via intuitive and attractive visuals. For ultimate convenience, the NanoNavigator mobile app for smart phones and tablets allows remote monitoring of AFM experiments while they are being performed by the 9500.

NanoNavigator software supports volume spectroscopy and FlexGrid spectroscopy, as well as math plug-ins to facilitate quantitative analysis. Additional and extensive interactive post-processing capabilities are provided by Keysight's easy-to-use Pico Image, an imaging and analysis software package built into NanoNavigator. Pico Image provides all of the features and functions required to build a surface analysis report on multi-layer measurement data.

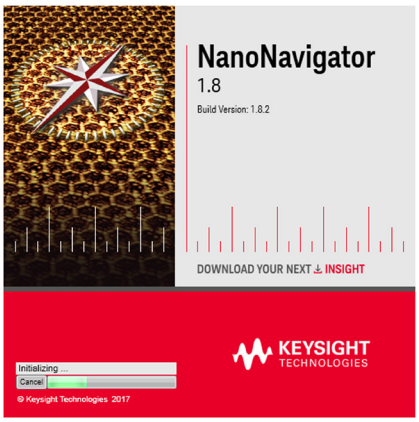


Figure 1. NanoNavigator 1.8.2 launching window

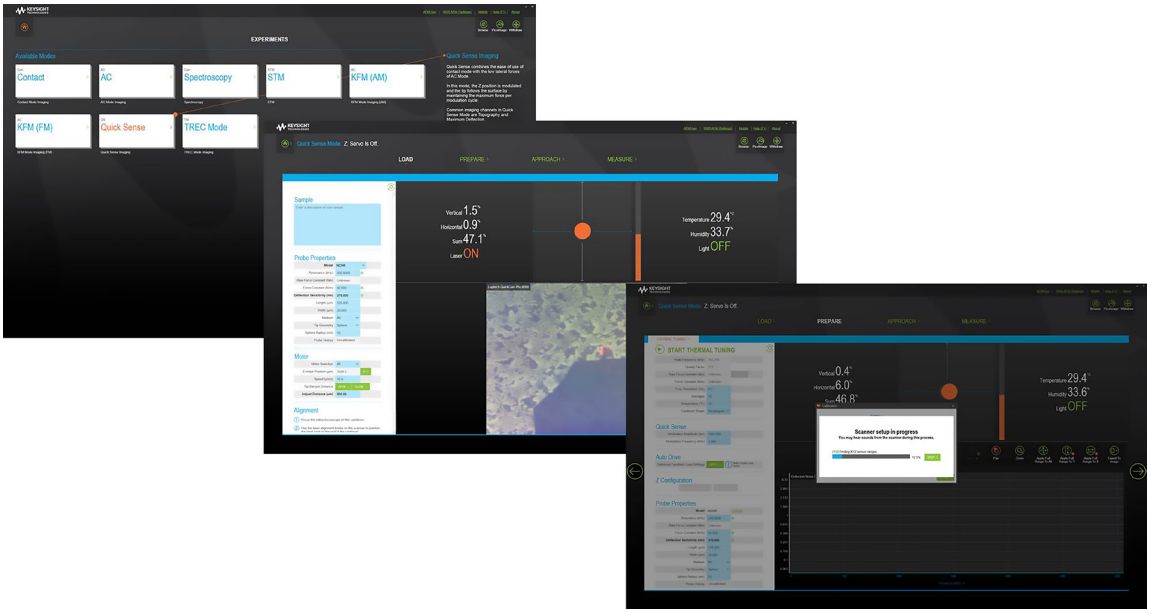


Figure 2. Available modes in NanoNavigator 1.8.2 and automatic parameter setup

Electrochemistry

For electrochemistry applications, NanoNavigator provides control of potentials and cyclic voltammetry, affording researchers a tremendously useful complement to the 9500's comprehensive in situ imaging capabilities. The new software also supports SECM (scanning electrochemical microscopy), a powerful Keysight scanning probe technique suitable for investigating surface reactivity and studying processes at the solid/liquid as well as the liquid/liquid interface. Redox reactions and their kinetics involving active species are of fundamental importance in emerging research areas ranging from the analysis of biochemical signaling processes (e.g., in live cells and tissues) to addressing materials science questions associated with such fields as fuel cell technology, catalysis, sensing, and environmental chemistry.

Quick Sense

NanoNavigator enables Quick Sense, a new Keysight imaging mode that permits quantitative mapping of nanomechanical properties on a wide range of samples. Via NanoNavigator's simple GUI, Quick Sense lets users quickly and easily set modulation amplitudes and frequencies, acquire individual force-distance curves, and measure adhesion, stiffness and elasticity. All of the data is collected whilst the 9500 AFM simultaneously images the sample's topography, resulting in precise and accurate characterization of local mechanical property variations at the nanoscale.

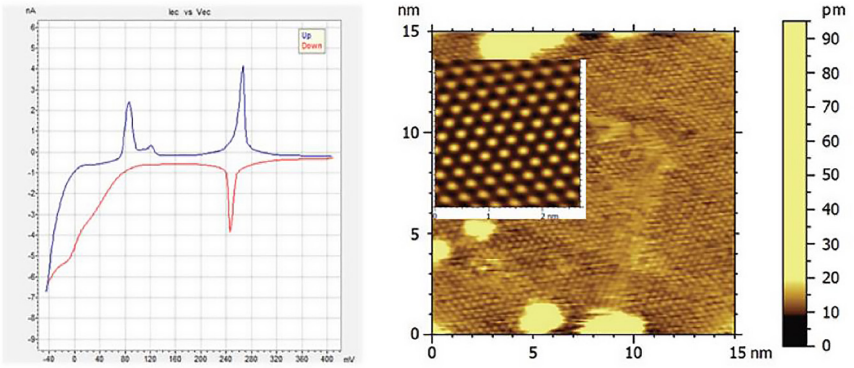


Figure 3. High resolution EC-STM image revealing the overlayer structure formed by Cu UPD on Au(111) surface. This honeycomb structure exists over the entire potential range between the two voltammetric peaks on the CV.

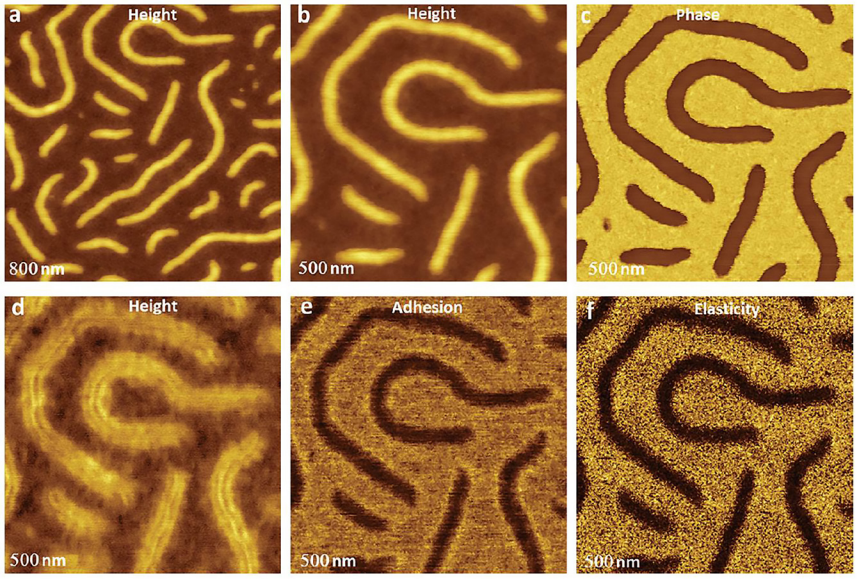


Figure 5. AFM images of brush-like macromolecules of poly(n-butyl acrylate) on mica, which were obtained in amplitude modulation mode (a-c) and Quick Sense mode (d-f). In both experiments silicon probe with spring constant of 2 N/m was applied. The Quick Sense measurements were performed with 4 nN force.

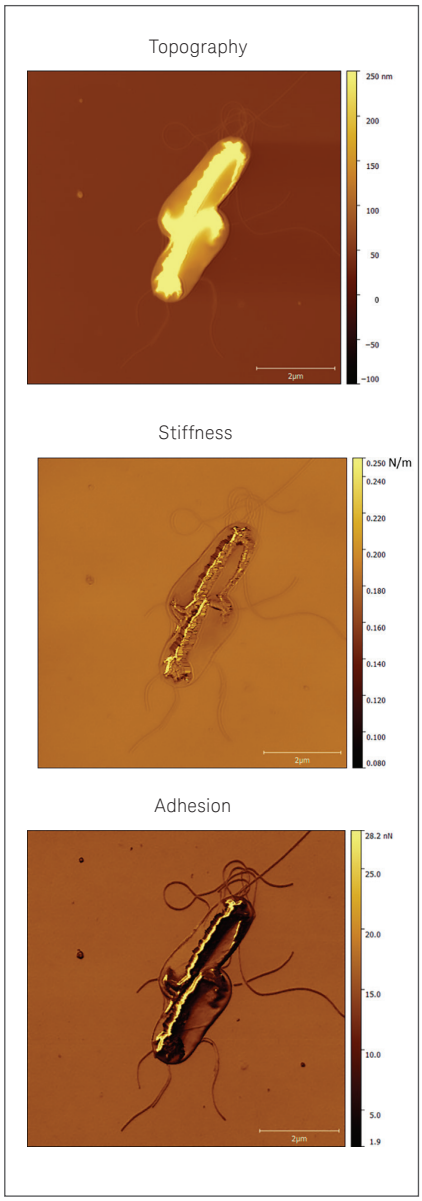


Figure 4. E-coli imaged with Quick Sense. Topography, stiffness and adhesion images were simultaneously acquired in real time.

Scanning Microwave Microscopy

Scanning microwave microscopy (SMM) mode combines the exceptional electrical measurement capabilities of a vector network analyzer (VNA) with the outstanding spatial resolution of an atomic force microscope (AFM). This unique mode outperforms traditional AFM-based scanning capacitance microscopy techniques, offering far greater application versatility, the ability to acquire calibrated quantitative results, and the highest sensitivity and dynamic range in the industry.

In SMM mode, a VNA sends an incident microwave signal through a diplexer to the sub-7-nm conductive tip of a platinum-iridium cantilever. The signal is reflected from the tip and measured by the VNA. The magnitude and phase of the ratio between the incident and reflected signals are calculated and a model is then applied in order to calculate the electrical properties of the sample. The AFM scans the sample and moves the tip to specific locations to perform point probing. Operation frequencies up to 20 GHz are supported.

SMM mode offers unprecedented utility for a diverse set of applications. SMM mode's ability to provide calibrated, high-sensitivity, compound electrical and spatial measurements is particularly useful for semiconductor test and characterization. In addition to enabling complex impedance (resistance and reactance) measurements, SMM can be used to acquire calibrated capacitance and dopant density measurements when studying sidewall diffusion. SMM mode works on all semiconductors: Si, Ge, III-V (e.g., GaAs, InAs, GaN), and II-VI (e.g., CdTe, ZnSe). Unlike scanning-probe capacitive techniques, SMM mode does not require an oxide layer.

TREC

Keysight's exclusive TREC molecular recognition toolkit is designed for use with AAC mode, preferably with MAC mode using MACLevers modified with specific biochemistries. It provides the ability to detect and map the molecular binding events while simultaneously generating topographic images in real time. With TREC, researchers can quickly distinguish between species that are engaged in molecular binding events and those that are not specific binding, thus eliminating the need to perform slow and tedious force-volume spectroscopy experiments to get the same results.

Scientists can use TREC to explore dynamic properties of biological systems (antibody-antigen, ligand-receptor, drug-receptor, DNA-protein, DNA-DNA, and so forth) by imaging patterns of molecular binding and adhesion on surfaces.

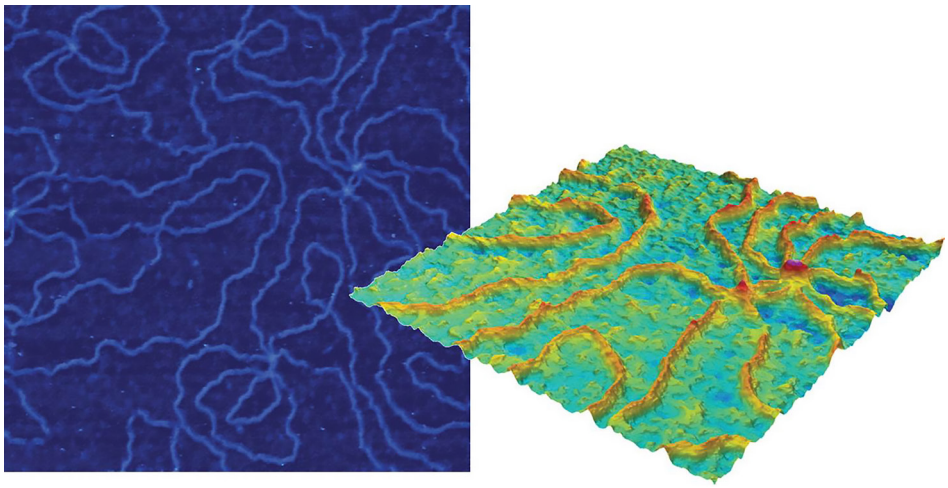


Figure 6. Topography images of lambda DNA on mica imaged with AC mode in HEPES buffer solution. Size: 500 nm x 500 nm (Left) and 200 nm x 200nm (Right, 3D).

Unique Design Advantages

The Keysight 9500 offers stable AFM imaging combined with exceptionally flat, easily reproducible displacement over the entire scan range to deliver high resolution and very low distortion. Keysight's patented top-down tip scanner technology is ideal for imaging in fluids and in air as well as under controlled temperature and environmental conditions. The 9500 AFM scanner's standard nose cone enables the use of contact mode, AAC mode, current-sensing AFM (CS-AFM), EFM, KFM, MFM, and MAC Mode in fluids and in air. Easy-to-load nose cones for additional techniques, such as Quick Scan, Top MAC Mode, and DLFM, can be interchanged quickly and conveniently. Standard Keysight nose cones are made from PEEK polymers, have low chemical reactivity, and can be used in a wide range of solvents. The Quick Scan nose cone is titanium. A stainless steel nose cone is available for fluorescence work.

Keysight's patented MAC Mode is a gentle, nondestructive technique optimized for AFM imaging of soft samples in fluids. MAC Mode has allowed researchers to resolve sub-molecular structures that could not be resolved with any other AFM technique. It is particularly useful for imaging delicate samples in application areas that require high resolution and force sensitivity, such as life science, polymer science, and surface science. MAC Mode employs a magnetic field to drive a paramagnetically coated cantilever, enabling precise control over oscillation amplitude (thus providing excellent force regulation). Since only the tip is driven, the signal-to-noise ratio is greatly enhanced, yielding significant improvement while imaging in fluids.

The system's video optics include a color camera and can resolve details to less than 1.7 µm. Open access to the scanner and easy alignment of the optics help simplify use of the 9500. The user-friendly scanner has a built-in detector, no cables to plug-in, and is easy to calibrate. Furthermore, the 9500 utilizes a new high-bandwidth, FPGA-based digital controller that ensures high-speed operating precision and eliminates the requirement for additional external control boxes.

A dedicated STM scanner is also available for use with the 9500 platform. The STM scanner delivers outstanding results on a variety of conducting materials in ambient, controlled gas, and fluid environments. Keysight offers an ILM system as well, letting researchers leverage MAC Mode and other important 9500 AFM capabilities for life science studies whose results depend on the simultaneous acquisition of atomic force and optical (or fluorescence) microscopy data. The Keysight ILM system is compatible with many popular inverted microscope and camera models.

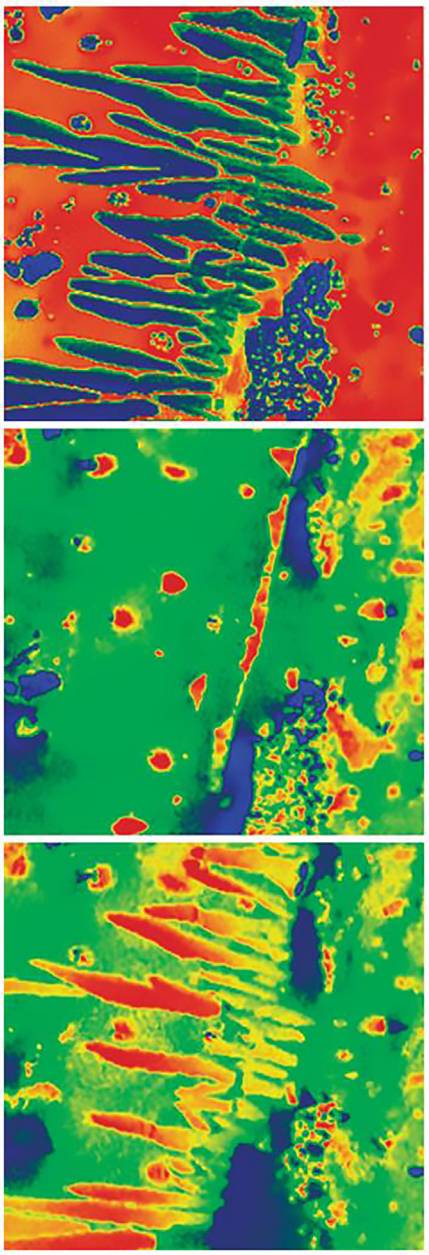


Figure 7. 10 sec/frame scan of phase images of polydiethylsiloxane (PDES) on silicon in Quick Scan mode. The top, middle and bottom images were acquired at 25 °C, 46°C and 28 °C. Scan size: 4 µm.

Environmental and Temperature Control

The 9500 AFM system includes a built-in environmental chamber engineered to meet the many requirements of intricate, demanding nanoscience applications. The chamber provides an easily accessible, sealed sample compartment that is completely isolated from the rest of the system. Six inlet/outlet ports permit the flow of different gases into or out of the sample area.

The 9500 system's scanner resides outside the environmental chamber, thus it is protected from contamination, harsh gases, solvents, caustic liquids, and other potentially damaging environments. Humidity levels and temperature are automatically monitored by sensors built into the chamber. Oxygen and reactive gases can be introduced into and purged from the sample chamber via six inlet/outlet ports.

Robust, easy-to-handle sample plates designed specifically for use with the 9500 are offered to facilitate studies in air or in fluids. The system's standard sample plate can be utilized for many imaging modes and is configurable with a fluid cell. Special heating and cooling plates offer a total range of -40 °C up to 250 °C. Sample plates for Top MAC Mode are also available.

Keysight's temperature control system employs a patented thermal insulation and compensation design to deliver the industry's most precise temperature control. This highly versatile option allows imaging during temperature changes and is fully compatible with all imaging modes, including those utilized in fluids. The temperature controller's unique design isolates the sample plate from the rest of the system, improving stability and performance. Temperatures can be controlled from -40°C up to 250°C, with suitable resolution and control to match any experimental requirements.

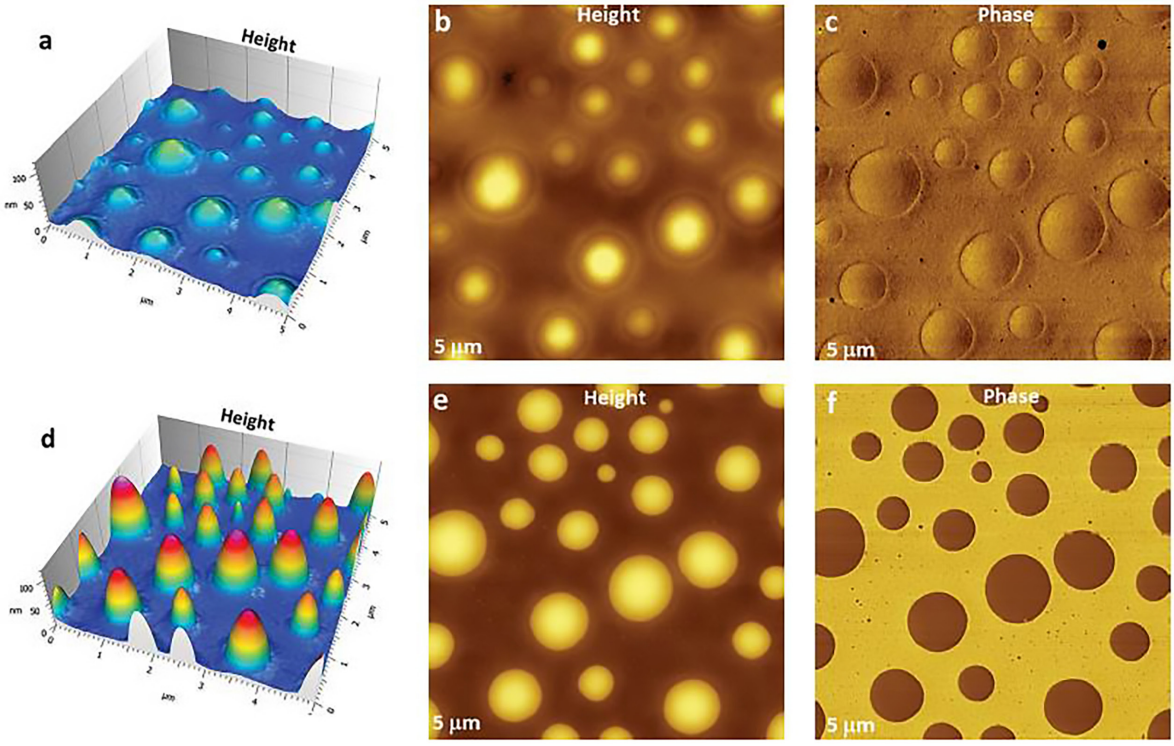


Figure 8. AFM images of PS/PVAC film on glass in amplitude modulation mode, which were obtained in air (a-c) and in methanol vapor (d-f). (a) and (d) -3D representations of surface morphology in air and in methanol atmosphere.

9500 System Specifications

Microscope	
Scanner	
Scan range	90 µm in XY, > 12 µm in Z
X/Y sensor noise	110pm @ 1.5KHz
XY linearity	< 1%
Z sensor noise	60pm @ 1Hz-11KHz
Out of plane travel	< 100 nm over 90 µm
Video microscope	
Top down video microscope	
Manual focus and zoom	
2 M pixel color USB camera	
1.7 µm resolution	
Microscope dimensions	
L x W x H	191 x 191 x 201 mm
Weight	7.5 Kg
Environmental	
Vibration	VC-C or better
Acoustic	< 85 dBC
Isolation chamber	N9445A recommended
Sample size	
Manual X/Y stage	~ 10 mm travel
Motorized Z stage	~ 10 mm travel
Max sample diameter	~ 25 mm
Max sample height	~ 8 mm

System and modes	
System controller	
N9613A	
FPGA @ 200 MHz	
XY PID update rate	1 MHz
Z PID update rate	10 MHz
Inputs Control Loops	
Photodiodes	100 MS/s – 14 bit
XYZ sensors	1 MS/s – 18 bit
Supplemental IO	
AUX in	1 MS/s, 18 bit, 100 KHz, ±10 V
VEC, IEC Itip(fast)	10 MS/s, 16 bit, 2 MHz, ±1 V
Itip(slow)	1 MS/s, 18 bit, 150 KHz, ±1 V
AUX out	1 MS/s, 20 bit, 500 KHz, ±10 V
MAC	100 MS/s, 16 bit, 1 MHz, ±100 mA
AAC	100 MS/s, 16 bit, 12 MHz, ±10 V
Sample bias, Tip bias, Ref set	1 MS/s, 20 bit, 150 KHz, ±10 V
EIS (Sample bias, Tip bias, Ref set)	100 MS/s, 16 bit, 2.1 MHz, ±8 V
High Frequency modulation output for Electrochemical Impedance Spectroscopy(EIS)	

9500 System Specifications *(Continued)*

System and modes *(Continued)*
System controller
PC
Quad core Xeon, 16G ram, 1 TB disk, Win7 x 64, 30" FPD, 2560 x 1600 display
Scan speed
Quick Scan in air > 100 lps (2 seconds/frame @ 200 x 200 pixels)
Standard modes
Contact, LFM, AAC, Phase, Quick Sense, MFM, EFM, KFM, Liftmode, F-d Spectroscopy, F-V Spectroscopy, Flexgrid, Force Plugins, Scripting, Thermal Tuning, PFM, Auto Drive
Optional modes
MAC, STM, CS-AFM, Quick Scan, Electrochemistry, SECM, SMM, TREC
Preamps for CS-STM Applications
0.1 nA/V
1 nA/V
10 nA/V

AFM Instrumentation from Keysight Technologies

Keysight Technologies offers high precision, modular AFM solutions for research, industry, and education. Exceptional worldwide support is provided by experienced application scientists and technical service personnel. Keysight's leading-edge R&D laboratories are dedicated to the timely introduction and optimization of innovative, easy-to-use AFM technologies.

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