PeakForce Tapping

- How AFM Should Be

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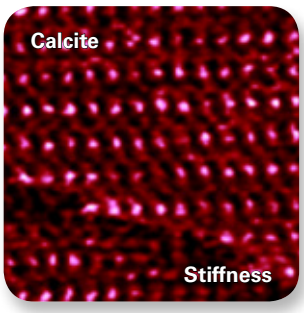
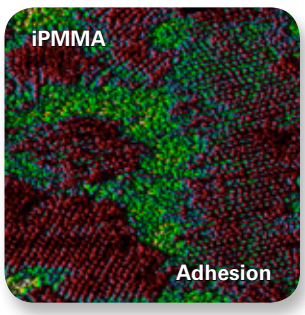
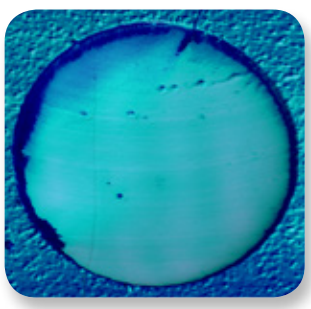
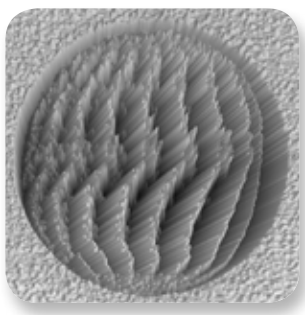
Bruker's exclusive PeakForce Tapping® is the most significant scientific breakthrough in atomic force microscope (AFM) technology since the introduction of TappingMode™. It provides unprecedented high-resolution imaging, extends AFM measurements into a range of samples not previously accessed and uniquely enables simultaneous nanoscale property mapping.





Point defect resolution stiffness on calcite (15 nm image) and submolecular resolution adhesion on iPMMA (100 nm image). Sample courtesy of Prof. Dr. Thurn-Albrecht, Martin-Luther-Universitaet Halle-Wittenberg.





Suspended graphene membrane imaged clearly in PeakForce Tapping (blue, adhesion on height), where TappingMode fails (grey). See N. Clark et al., *Physica Status Solidi* (B), 2013, doi:10/1002/pssb.201300137.

Highest resolution imaging

PeakForce Tapping enables the researcher to precisely control probe-to-sample interaction enabling the lowest available imaging forces. This superior force control results in the most consistent, highest resolution AFM imaging for the widest range of sample types, from the softest biological samples to very hard materials.

Unique, quantitative results, whatever you measure

PeakForce Tapping's piconewton (pN) force sensitivity simultaneously and uniquely combines the highest resolution AFM imaging with quantitative, nanoscale electrical, mechanical, biological, and chemical property mapping, enabling researchers of all experience levels to make new discoveries.

Easy to use, making every user an AFM expert

PeakForce Tapping's direct and linear force control provides the user with unmatched AFM ease of use with ScanAsyst® image optimization software, and the low forces preserve the probe shape for longer life and more consistent imaging.

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"PeakForce Tapping provided my lab with the force control and resolution necessary to produce ground-breaking ligand-receptor interaction maps using functionalized probes on live cells in a very time efficient and controlled way."

– Daniel Müller, ETH Zürich, Switzerland

Enabling New Discoveries

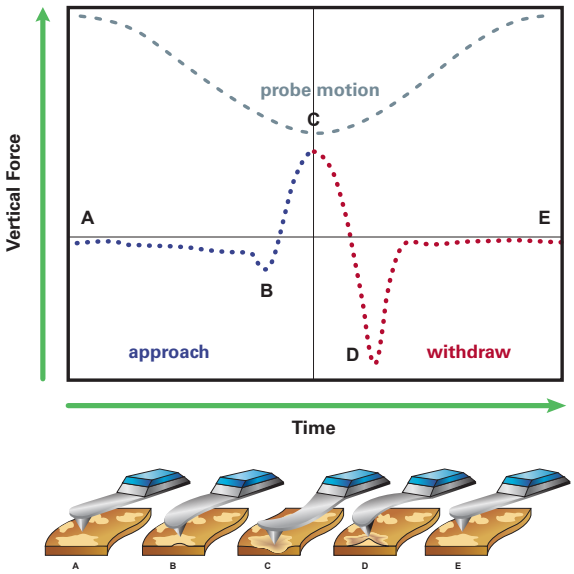
In PeakForce Tapping, the probe periodically taps the sample and the pN-level interaction force is measured directly by the deflection of the cantilever. A real feedback loop (not force trigger) keeps the peak force down to 10 pN at actuation rates up to 8 kHz, in air and fluid.

"Thanks to PeakForce QNM, we were able to rapidly obtain pertinent information on the mechanical properties of very soft and sticky polymer materials, such as bioadhesives or adaptive hydrogels, that other classical SPM techniques were not able to provide."

– Philipe Leclère et al, University of Mons (UMONS) Belgium

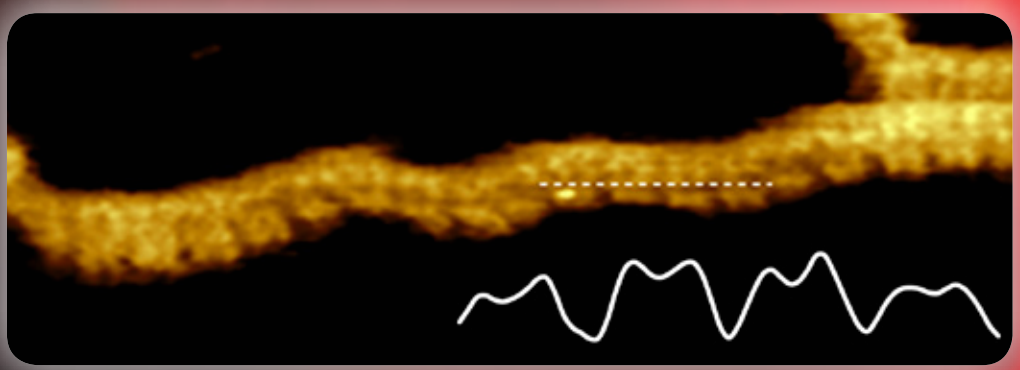
In addition to material research, PeakForce Tapping is ideal for measurement of biological samples due to its unprecedented low imaging forces and ease of use. No cantilever tuning is necessary. Routine measurements of live-cell mechanical properties are now available with PeakForce Tapping technology.

The superior force control maintains tip and sample integrity, leading to consistently accurate and high-resolution measurements of even the smallest biological structures, such as double helix DNA.



Utilizing five separate patents, PeakForce Tapping has led to over 1,000 peer-reviewed publications in the first five years since its release, generating nearly 3,000 citations. This adoption rate has surpassed even that of TappingMode.

The greatest power of PeakForce Tapping technology, however, comes from its ability to simultaneously enable and enhance other correlative and quantitative mapping techniques, delivering new possibilities in an ever expanding set of topographical, mechanical, biological, electrical, and chemical applications at the nanoscale.



Submolecular resolution of the major and minor grooves of the DNA double helix. Image obtained with BioScope Resolve on an inverted microscope. Image size 15 nm x 43 nm.

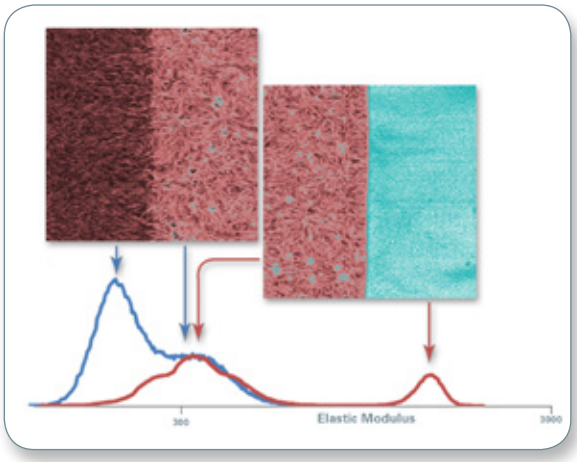
Perfecting Nanomechanics on Materials

Quantitative at Highest Resolution

Utilizing PeakForce Tapping technology, PeakForce QNM® maps and distinguishes between nanomechanical properties—including modulus, adhesion, dissipation, and deformation—while simultaneously imaging sample topography at atomic scale resolution. Because it directly controls the peak normal force and minimizes lateral force on the probe, it is non-destructive to both tip and sample. Since force distance data is analyzed directly, there is no ambiguity regarding the source of image contrast, as often occurs in other techniques. The quantitative data produced can help identify components and their mixing at interfaces, as well as map mechanical properties at previously unattainable resolution.

PeakForce QNM provides:

- Highest resolution mapping of nanomechanical properties
- High-speed, most quantitative nanomechanical mapping
- Widest operatring range for samples, from extremely soft materials (~1 kPa) to hard metals (100 GPa)



PeakForce QNM images of layered packaging showing fine structure and quantitative modulus values near phase boundaries of ULDPE, LDPE, and PS. Image size 4 µm.

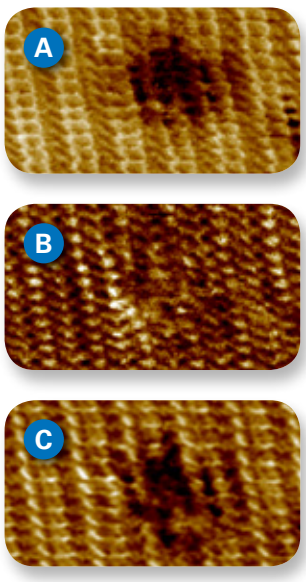
Several hundred publications cite PeakForce QNM data.

High-Sensitivity Nanomechanical Data at Every Pixel

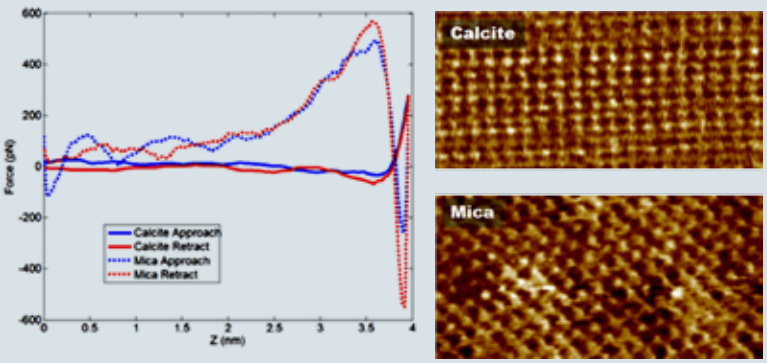
Where PeakForce QNM analyzes each force curve in real time to generate material property maps, PeakForce Capture™ goes beyond the image to provide actual force curves at every pixel, in addition to the calculated property channels. When enabled, force curves from the PeakForce QNM image are saved alongside the standard image file. This allows direct calculations with NanoScope® analysis, as well as simple export to other systems or programs for additional analysis. When paired with PeakForce QNM, it provides the highest resolution mechanical mapping and analysis with standard models for biomechanics.

PeakForce Capture provides:

- Highest resolution force mapping
- Sensitivity to discover unexpected events not captured with other techniques
- User-specific models through data export features



PeakForce QNM reveals a molecular defect on a polydiacetylene crystal, in air. Individual molecules are resolved in height (A) as well as adhesion (B) and stiffness (C) maps, with a notable decrease in stiffness at the defect site. Image size 10 nm.



PeakForce Capture data cubes: Atomic resolution on calcite and mica (10 nm images) and individual force curves for every pixel show differences in tip-sample interaction.

Expanding Life Sciences Research

From Molecular Recognition to Mechanobiology

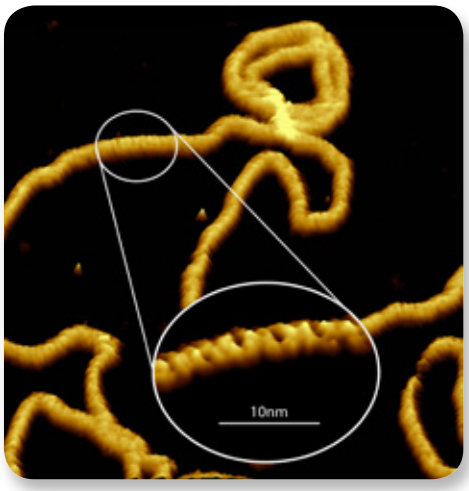
Overcoming limitations of conventional modes, PeakForce Tapping enables new research across a broad range of BioAFM areas, from single molecules to cells and tissues. It combines highest spatial resolution on biological structures with quantitative nanomechanics over the widest available frequency range.

In highest resolution molecular imaging, PeakForce Tapping images of individual biomolecules have revealed variations in the DNA double helix structure. In cell imaging, PeakForce Tapping has enabled the first and only images of microvilli on live cells.

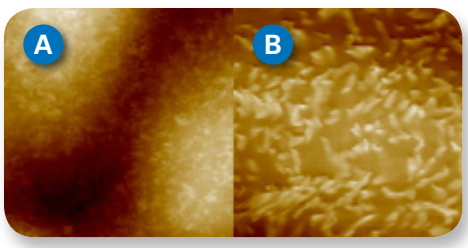
PeakForce QNM has enabled high-impact work in high-resolution nanomechanical mapping on membranes, revealing stiffness variations in submolecular units. On live cells, PeakForce QNM–based recognition mapping has combined high spatial resolution, quantitative data, and optical microscopy to provide detailed insight into cell infection processes.

PeakForce QNM enables:

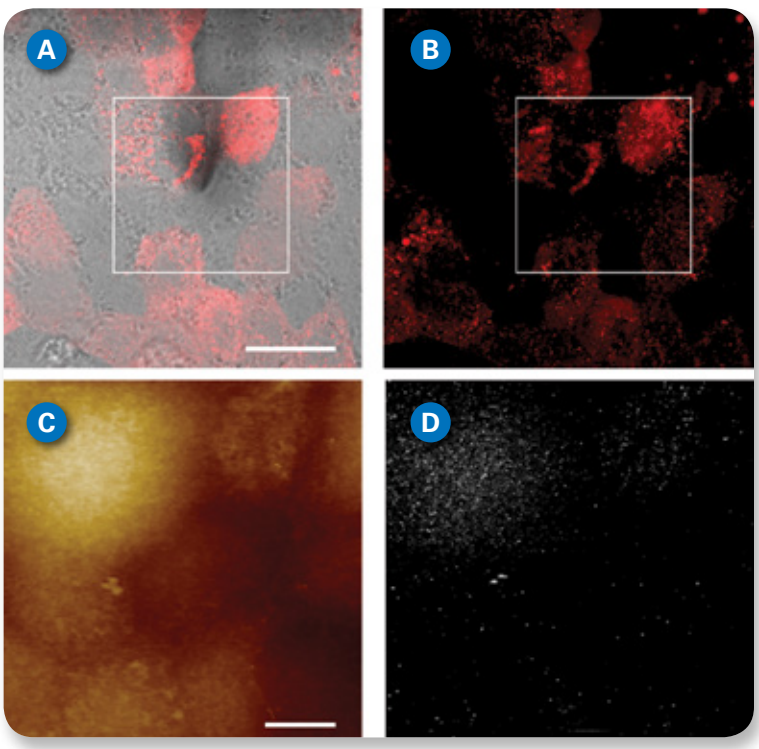
- Submolecular resolution mapping of mechanical, chemical and biological interactions
- High-speed, quantitative mechanical property and adhesion mapping of live cells
- Ease of use, making every user an AFM expert



DNA double helix structure showing major and minor grooves, imaged with PeakForce Tapping.
Courtesy of Dr. Bart Hoogenboom and Alice Pyne, University College London, *Small,* 2014, doi: 10.10002/smll.2012400265).



First and only AFM images resolving individual microvilli on living MDCK cells.
Image size 25 µm (A), 10 µm (B).



PeakForce Tapping maps single virus binding events directly on living MDCK cells: (A) DIC and confocal overlay (25 µm scale); (B) mCherry channel; (C) topography and (D) adhesion PeakForce Tapping images from white inset areas (10 µm scale).
Data courtesy of Alsteens et al., *Nature Nanotechnology*, 2016, doi:10.1038/nnano.2016.228).

"It was previously impossible to resolve the finest structures of a live cell like microvilli, but now with the improved PeakForce Tapping on BioScope Resolve I can image them easily."

– Hermann Schillers,
University of Münster, Germany

Achieving Full Nanoelectrical Characterization

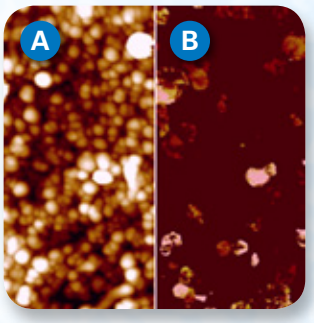
Current Mapping on the Most Fragile Samples

PeakForce TUNA™ is an ideal method for probing conductivity of fragile samples such as organic photovoltaics, conductive nanotubes, and nanoparticles. It overcomes the limitations of traditional contact-mode-based conductive AFM techniques by eliminating lateral forces and avoiding sample damage, thus enabling routine high-resolution current imaging.

Now users can benefit from both the full fA to µA current range and directly correlated PeakForce QNM quantitative nanomechanical property imaging with one module. PeakForce TUNA can also be integrated with environmental control to regulate oxygen and water levels down to ppm for the most sensitive samples.

PeakForce TUNA offers:

- Highest resolution current mapping on the most fragile samples
- Unmatched repeatability and consistency in nanoelectrical measurements
- Correlated nanomechanical and nanoelectrical properties



PeakForce TUNA height (A) and current (B) maps of vertical carbon nanotubes, impossible with contact mode. Image size 1 µm.

PeakForce TUNA current map reveals current paths in P3HT film. Image size 500 nm. Courtesy of P. Leclere, University of Mons, Belgium.

More than a hundred publications cite PeakForce TUNA data.

"With the combined application of PeakForce QNM and PeakForce TUNA we were uniquely able to determine the nanostructure and ionic conductivity distribution on humidity sensitive ionomers with unprecedented quality and resolution. For us, the versatility and flexibility with these modes opens the path for numerous explorations of materials for electrochemical energy applications."

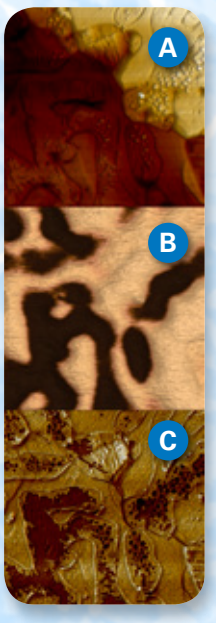
– Dr. Renate Hiesgen, University of Applied Sciences Esslingen, Germany

Accurate, High-Resolution Workfunction Mapping

PeakForce KPFM™ improves measurement performance over traditional Kelvin probe force microscopy techniques by providing the highest spatial resolution and most accurate measurements of surface potential. These improvements have been achieved with the combination of PeakForce Tapping, proprietary scan algorithms, and Bruker's in-house probe developments. Uniquely, PeakForce KPFM provides the most accurate and consistent measurements across different material types. It can be used with PeakForce QNM to deliver simultaneous, correlated topography, as well as electrical and mechanical property mapping on a wide range of samples. It also has overcome the ease-of-use issues of traditional KPFM techniques by operating in ScanAsyst mode, enabling the acquisition of expert-quality data by users of all experience levels.

PeakForce KPFM delivers:

- Most accurate, repeatable, and sensitive work function measurements
- Leading-edge spatial resolution combined with artifact-free potential contrast
- Correlated quantitative nanomechanical property mapping



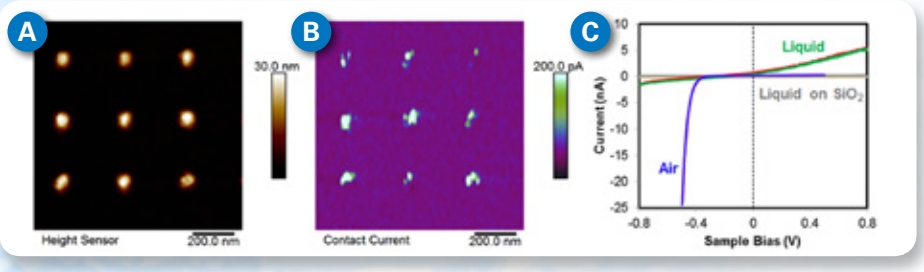
PeakForce KPFM height (A), adhesion (B), and surface potential (C) images of Sn-Pb. The workfunction difference is accurately mapped, while nanoscale phase structure in the adhesion map is simultaneously revealed. Image size 4 µm.

Previously Impossible Measurements of Local Electrochemistry and Conductivity in Liquid

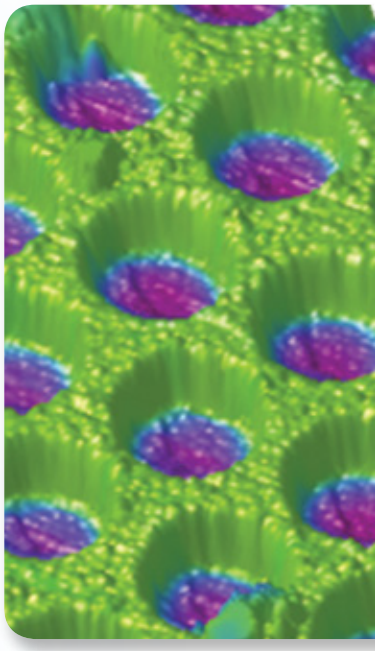
PeakForce SECM enables for the first time measurements of electrochemical activity with sub-100 nm resolution, enabling applications from catalysis and corrosion to solar fuels and battery research. Piconewton force control combined with Bruker's exclusive probe solution make a routine measurement of what was previously impossible. It provides the first and only conductivity measurements in the presence of conducting liquids, as well as nanomechanics, even on the most fragile samples.

PeakForce SECM delivers, for the first time:

- Previously unobtainable electrochemical information with <100 nm spatial resolution
- Simultaneous electrochemical, electrical, and mechanical mapping in liquid
- Reliable, easy-to-use commercially available probes specifically designed for SECM



PeakForce TUNA™ measurement with the SECM probe in liquid on an array of nanoelectrodes (125 nm diameter and 300 nm period): (A) topography; (B) contact current; and (C) current-voltage characteristics of nanoelectrodes in air and in an aqueous solution.



3D topography of a nanomesh electrode (Au-SiO_2) covered by EC current skin. Sample courtesy of C. Stelling and M. Retsch, University of Bayreuth.

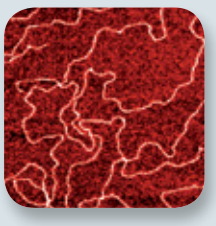
Self-Optimizing AFMs

Intelligent Algorithms for Guaranteed High-Resolution Imaging

ScanAsyst is a PeakForce Tapping–based image optimization technique that enables every user to create the highest resolution AFM images using single-touch scanning. It eliminates the need to navigate complicated AFM interfaces and parameter settings, automating PeakForce Tapping so that extremely high-quality images can be produced by any user, regardless of experience level. "Intelligent" algorithms automatically and continuously monitor image quality and make appropriate parameter adjustments. The user simply selects a scan area and scan size for a sample, in air or fluid, essentially providing a turnkey solution for AFM imaging. ScanAsyst uniquely enables easy imaging of live cells while simultaneously providing high-resolution cellular detail.

ScanAsyst enables:

- Easiest, consistent measurement of a wide range of samples for material research
- Single-button, repeatable roughness measurements for wafer applications
- Easiest, most stable high-resolution imaging of cells and molecules



DNA imaged using ScanAsyst. Image size 1 µm.

Triangle DNA origami structure imaged in fluid with ScanAsyst. Image size 300 nm. Sample courtesy of Prof. M. Endo and Prof. H. Sugiyama, Kyoto University.

PeakForce Tapping Applications

	PeakForce QNM	PeakForce Capture	PeakForce TUNA	PeakForce KPFM	PeakForce SECM	ScanAsyst
Characterization of novel, nanostructured, and 2D materials	●	●	●	●	●	●
Composition mapping and nanomechanics of multiphase polymeric and composite materials	●	●	●	●	●	●
Materials research for energy and devices, including lithium ion batteries, fuel cells, organic photovoltaics	●	●	●	●		●
In situ lithium ion battery anode, cathode, and SEI layer studies				●	●	●
Local electrochemical activity and conductivity in liquid					●	
Molecular bio-imaging, including DNA, proteins, and membranes in liquid	●	●			●	●
In situ live and fixed cell imaging, including recognition mapping and cell mechanics as function of disease states	●	●				●
Semiconductor device characterization and failure analysis	●	●	●			●
Analysis and classification of defects on industrial samples	●	●		●		●
Roughness and deep trench measurements						●

PeakForce Tapping Specifications

Typical imaging force	~10 pN
Minimum force setpoint	<0 pN (below free deflection)
Demonstrated spatial resolution	Atomic defect resolution in topography and stiffness
Actuation rate	125 Hz to 8 kHz, sine wave
Feedback	PI loop (not force trigger)
Force control	Automatically synchronized to peak force, direct, linear
Nanomechanical channels	Modulus (DMT, Sneddon), adhesion, deformation, dissipation, and peak force in real time (PeakForce QNM); Full force curve for each pixel (PeakForce Capture); Hertzian, Sneddon, Cone-Sphere, and JKR models offline
Conductivity measurement	<100 fA noise; >10 kHz bandwidth, no lateral forces (PeakForce TUNA); Current measurement in liquid (PeakForce SECM)
Workfunction mapping	AM-KPFM and FM-KPFM, main or lift line, with nanomechanical channels and ScanAsyst auto-optimization
Self-optimization	Linear feedback control auto-optimization (ScanAsyst), does not require prior sample knowledge

See the Difference Peakforce Tapping Can Make

We welcome you to visit one of our many application labs worldwide to see for yourself how PeakForce Tapping modes work on your samples. Our application scientists will be pleased to work with you to define how best to solve your scientific and applications challenges.

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