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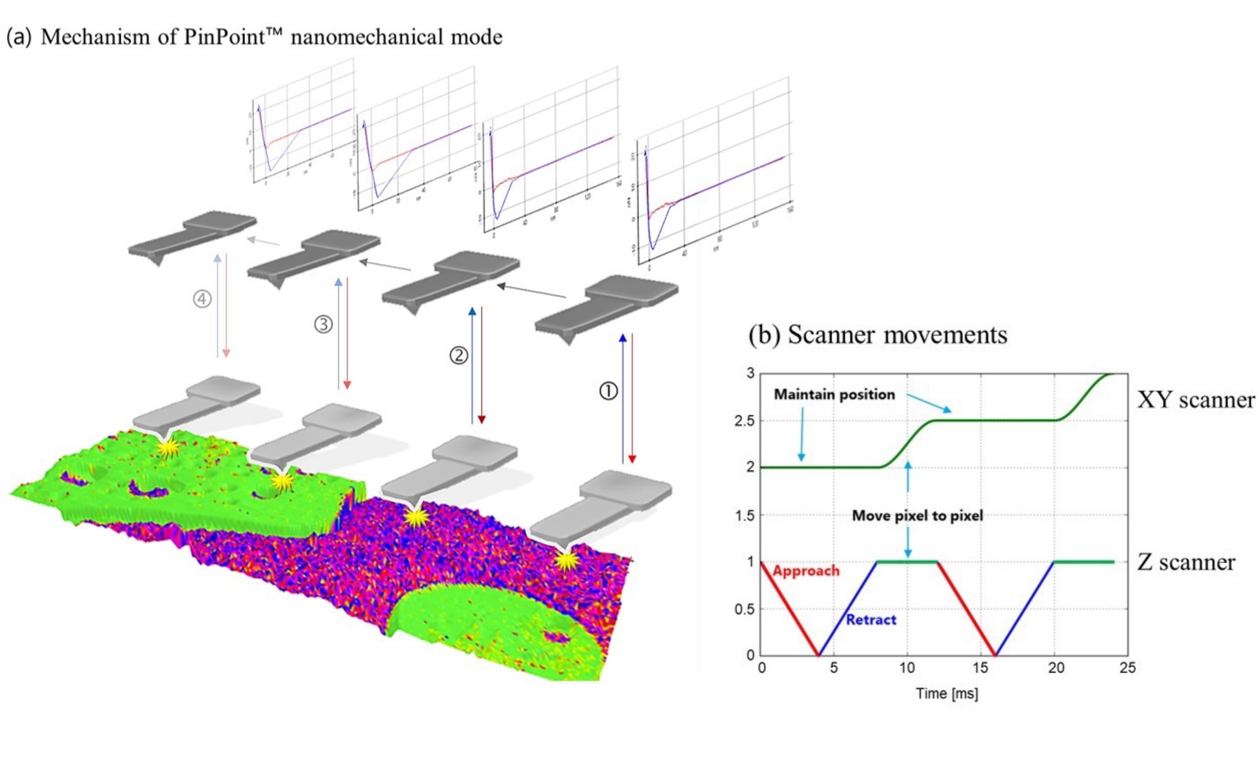
Mode Notes

PinPoint™ Nanomechanical Mode

Atomic force microscopy (AFM) has become a fundamental tool for studying nanomechanical properties such as Young's modulus and adhesion force on a nanometer scale for a variety of samples like polymers, 2D materials, or living cells. Traditionally, force-volume mapping is used to measure quantitative mechanical properties. For that, isolated force-distance measurements are conducted at a defined number of pixels. The cantilever is pressed onto a surface, until a previously defined threshold, the setpoint-force, is reached. Both during the approach and retraction, the cantilever deflection is measured as a function of the z height. Subsequently, the cantilever is moved to the next pixel where another force-distance curve is measured (see Figure 1(a)). Conventionally, it takes at least a few hundred milliseconds to collect a single force-distance curve, which scales up to several hours when recording whole images with thousands of pixels.

To overcome the time-consuming limitations of force-volume mapping, Park Systems developed the PinPoint nanomechanical mode, where the Z scanner approach and retraction are accelerated by a factor of ten compared to conventional force-volume mapping while maintaining high precision

Figure 1. (a) Schematic diagram of Park Systems' PinPoint nanomechanical mode: the tip approaches the sample and retracts at each pixel before moving to the next pixel. The resulting force curves and their automated analysis allow real-time visualization of nanomechanical properties. (b) Positions of XY and Z scanners during PinPoint nanomechanical mode scanning.



and accuracy. Similar to regular AFM scanning mode, a customizable channel selection allows obtaining various quantitative mechanical data in combination with high-resolution topography, as well as functional electrical data like conductivity, capacitance, etc. The automated analysis of the force-distance curves via Park Systems' SmartScan™ software allows for a real space visualization of nanomechanical data during the scan.

As depicted in Figure 1(b), decoupled XY and Z scanners enable precise movements during PinPoint nanomechanical measurements with minimized crosstalk between lateral and horizontal movements. Thus, in contrast to traditional contact mode, PinPoint nanomechanical mode eliminates lateral shear forces which drastically reduces damage to the tip or surface, while establishing a defined physical contact, that enables precise nanomechanical measurements. Accordingly, users can simultaneously image surface topography as well as mechanical properties such as modulus, deformation, adhesion, energy dissipation, and stiffness. Table 1 (next page) summarizes all selectable channels that can be recorded using PinPoint nanomechanical mode.

Figure 2. Mechanical properties derived from the force-separation curve: stiffness are determined from the sample indentation, the adhesion force and energy are calculated from the retraction curve and the energy dissipation is given by the hysteresis between approach and retraction.

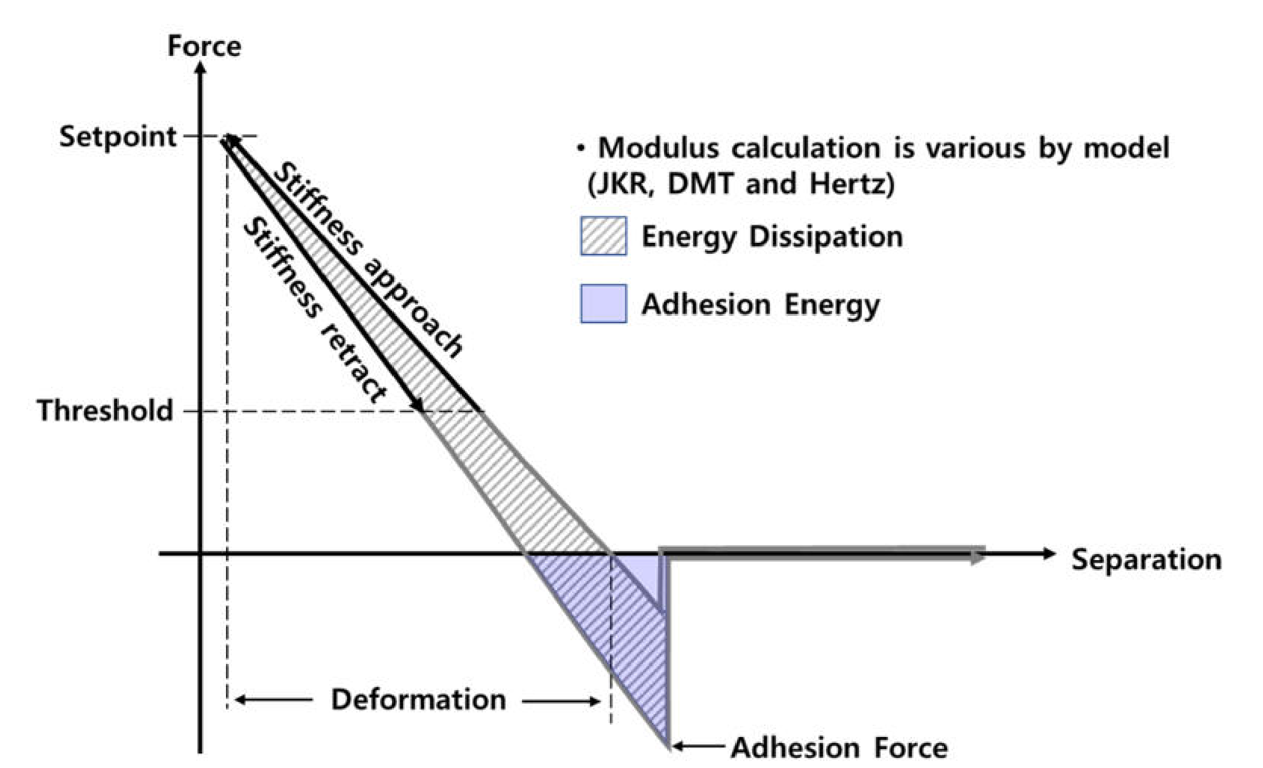


Table 1. Channels information of the PinPoint™ nanomechanical mode.

Channel name	Unit	Description
Modulus	Pa	Young's Modulus is calculated from the slope of the retraction curve; different calculation models can be applied.
Deformation	nm	Deformation is derived from the distance in x between the point of maximum force and zero force.
Adhesion force	nN	The Y value of the minimum point of the retraction curve displays the adhesion force.
Adhesion energy	fJ	The work of the adhesion force is displayed by the total area below the retraction curve after it passed the point of zero force.
Energy dissipation	fJ	The area between the approach and retraction curve is used to calculate the dissipated energy when the tip presses onto the surface.
Stiffness approach	V	The slope of the approach curve between the peak point and threshold point selected by user of the force is used to calculate the local stiffness.
Stiffness retraction	V	The slope of the retraction curve between the peak point and threshold point selected by user of the force is used to calculate the local stiffness.

Figure 3. Comparison of the three modulus models offered for the modulus calculation in the SmartScan^{TM} software and an actua force-distance curve.

Korayem, M. & Rastegar, Zahra & Taheri, Marzie. (2012). Sensitivity Analysis of Nano-contact Mechanics Models in Manipulation of Biological Cell. Nanoscience and Nanotechnology. 2. 49-56. 10.5923/j.nn.20120203.02.

Hertzian model (Non-adhesive elastic contact): elastic deformation without adhesion.

DMT model (Adhesive elastic contact): elastic deformation with adhesion in retraction.

JKR model (Adhesive elastic contact): elastic deformation with adhesion in retraction.

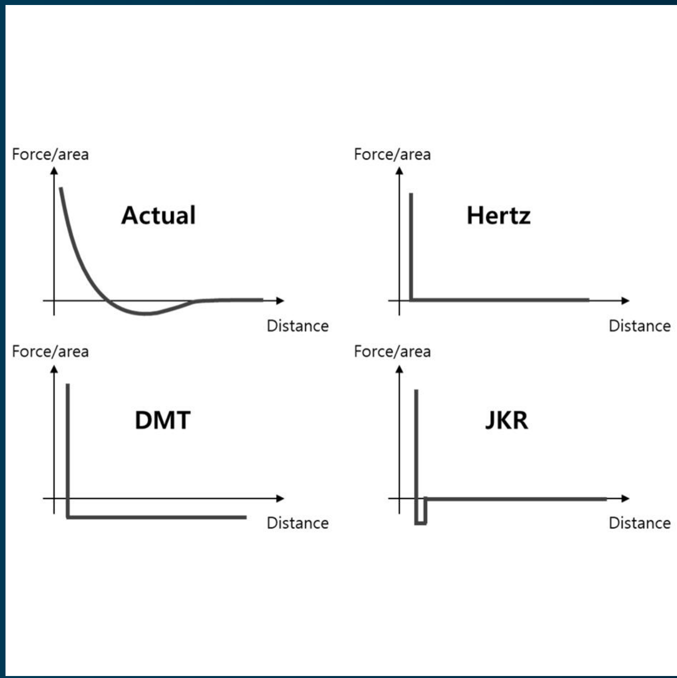
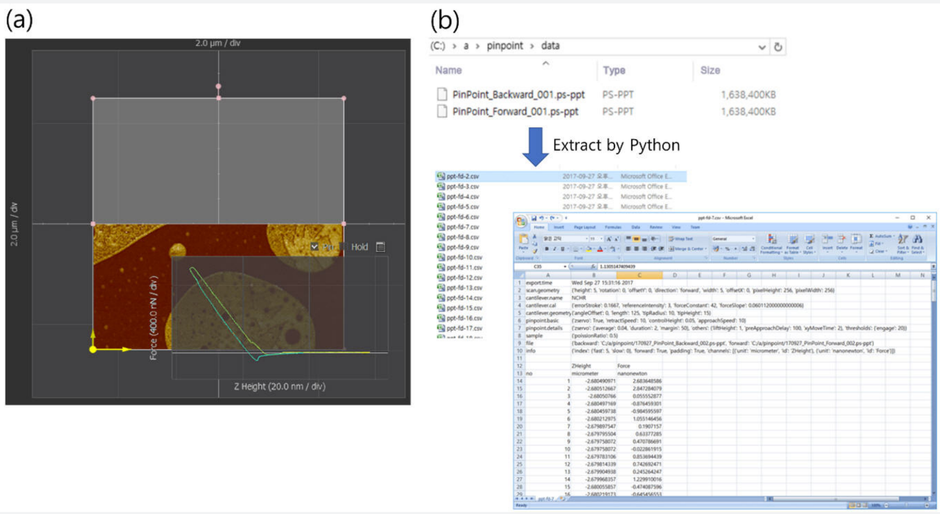
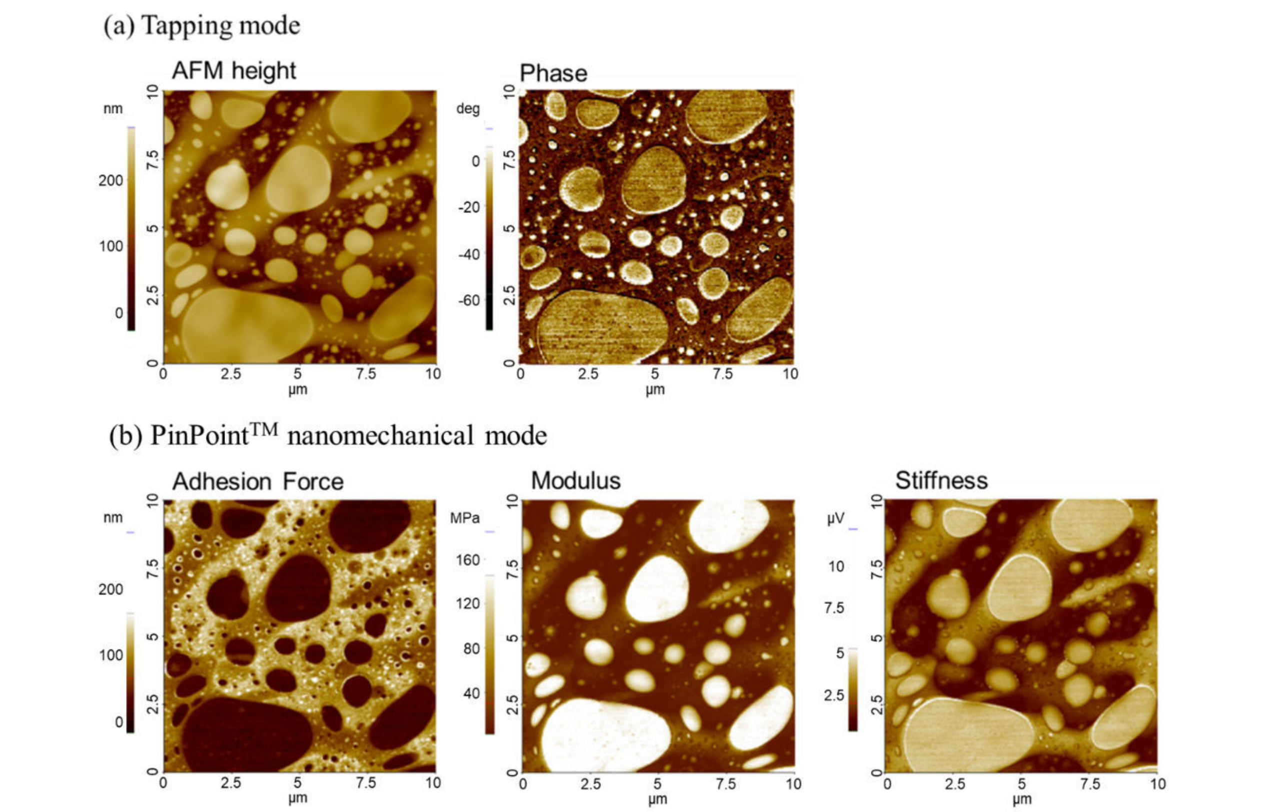


Figure 4. (a) Real-time FD curve on scan area (b) FD curve extracts for post analysis.



For the internal and automated calculation of Young's modulus, Park Systems offers three optional contact mechanics models as shown in Figure 3. Depending on the sample's elastic and adhesive properties, either the Hertzian-, JKR-, or DMT-model yields the most accurate results. Hard samples that exhibit very little adhesion and deformation with contact force are best fitted with the Hertzian model. In the case of hard samples (modulus is over 1 GPa) with significant surface adhesion, it is recommended to use the DMT model. The JKR model is recommended for soft samples with high surface adhesion. Since PinPoint™ nanomechanical mode enables users to monitor force-distance curves in real-time as demonstrated in Figure 4(a), the choice of contact mechanics model can be optimized during imaging depending on the requirements of the experiment and the respective shape of the force-distance curves. For additional analysis of the force-

Figure 5. (a) Phase imaging in tapping mode and (b) PinPoint™ nanomechanical mode results of polystyrene -polybutadiene block copolymer (PS-PB) in the same measurement area.



distance curves obtained during PinPoint nanomechanical mode, the whole data set can be saved separately. Figure 4 (b) shows an example of curve extraction using python software.

To achieve quantitative nanomechanical data, every cantilever needs to be calibrated in regard to its sensitivity and spring constant prior to the measurements. A reliable sensitivity calibration requires hard reference samples (e.g. sapphire) that will not deform. Furthermore, the force constant of the cantilever needs to be considered (see App note #44: "Proper AFM cantilever selection depends on sample properties"). For quantitative modulus calculation, the cantilever tip must cause sufficient deformation of the sample without applying to high loading forces, while maintaining a high force sensitivity. Accordingly, the force constant of the cantilever needs to match the stiffness of the sample. As a rule of thumb, Park Systems recommends hard cantilevers for hard samples and soft cantilevers for soft samples, as described in Table 2.

Qualitative differences in mechanical properties can also be observed in the phase channel in standard tapping mode. However, phase imaging neither allows distinguishing between differences in local stiffness and adhesion nor offers quantitative modulus data. To illustrate the capabilities of PinPoint compared to phase imaging, Figure 5 presents two data sets on the same polymer blend of polystyrene and polybutadiene: the first data set was collected via phase imaging (Figure 5(a)) and the second was collected in PinPoint nanomechanical mode (Figure 5(b)). Whereas the phase-contrast mainly resolved the material distribution, PinPoint delivered quantitative data on adhesion, modulus and stiffness.

Table 2. Recommended AFM probes for samples with different mechanical properties.

Sample modulus (E)	Probe	Nominal force constant value of the probe
1 MPa < E < 20 MPa	PPP-CONTSCR	0.2 N/m
10 MPa < E < 2000 MPa	PPP-FMR	2.8 N/m
1000 MPa < E < 5000 MPa	OMCL-AC160TS	26 N/m

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