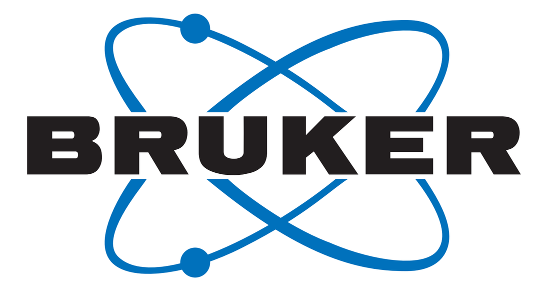
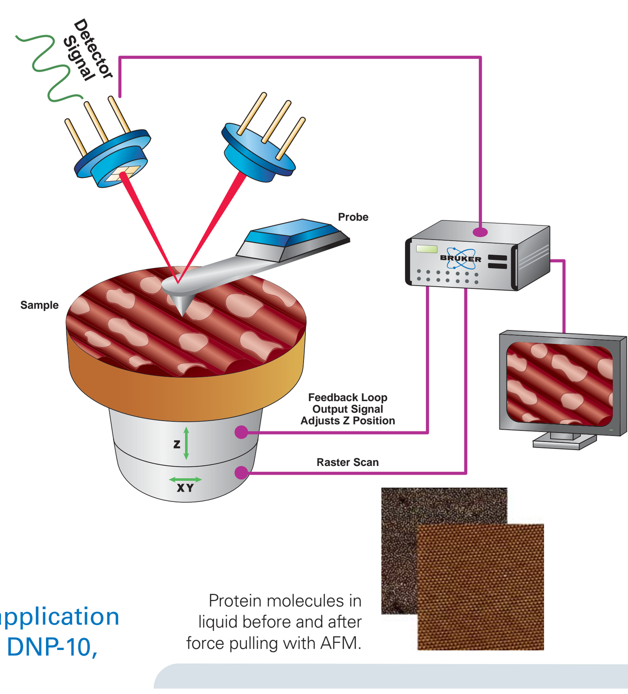
Scanning Probe Microscopy



SPM Operation

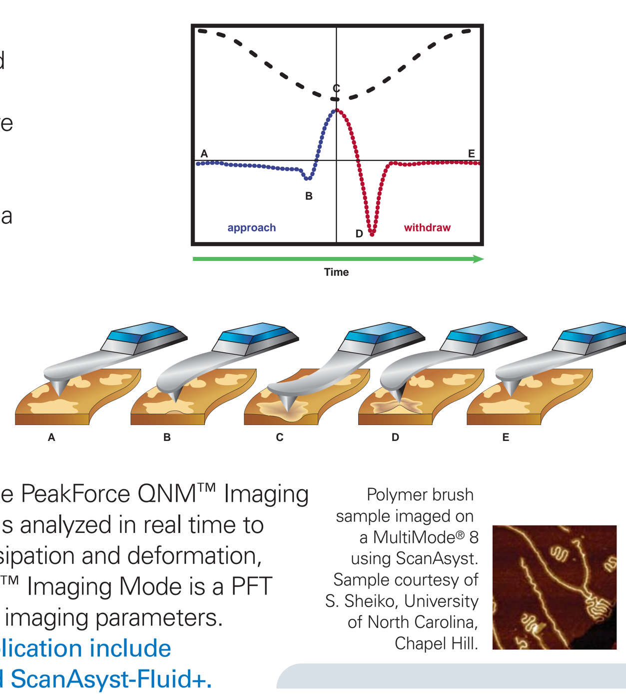
Scanning Probe Microscopy (SPM) is a technique to provide spatially localized three-dimensional information by raster scanning a sharp probe across a surface of interest while monitoring the cantilever deflection from the probe sample interaction. Depending on the interaction, in addition to topographic information, a variety of surface properties can be measured (such as electrical, magnetic, and mechanical). The main SPM scan modes are contact mode, TappingMode™, and PeakForce Tapping™, and these build the foundation of all advanced scanning techniques. Preferred Bruker probes for this application include TESP, RTESP, ESP, SNL-10, DNP-10, MLCT, and MSNL-10.



Protein molecules in liquid before and after force pulling with AFM.

PeakForce Tapping

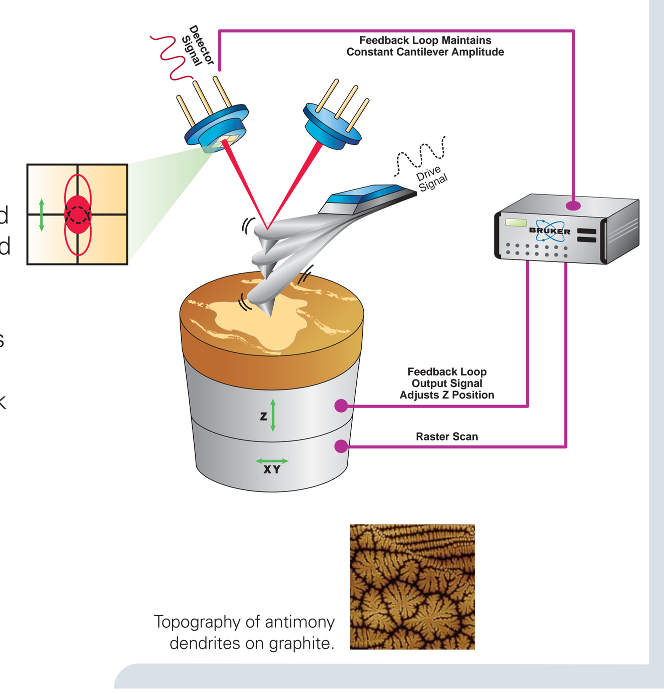
PeakForce Tapping™ (PFT) is a Bruker-exclusive AFM mode optimized to achieve simultaneous high-resolution images and quantitative mechanical measurements. During operation, the cantilever is brought in and out of contact with the surface in a non-resonant cycle, where the PFT algorithms directly control the instantaneous force interaction. Because the entire cycle is monitored and recorded, PFT provides force spectroscopy information at each pixel. In the feedback mode, the instantaneous peak force is limited; potentially down to the pN level. In the PeakForce QNM™ Imaging Mode, the spectroscopic information is analyzed in real time to report modulus, adhesion, energy dissipation and deformation, along with topography. The ScanAsyst™ Imaging Mode is a PFT variant that automatically optimizes all imaging parameters. Preferred Bruker probes for this application include ScanAsyst-Air, ScanAsyst-Fluid, and ScanAsyst-Fluid+.



Polymer brush sample imaged on a MultiMode® 8 using ScanAsyst. Sample courtesy of S. Sheiko, University of North Carolina, Chapel Hill.

TappingMode

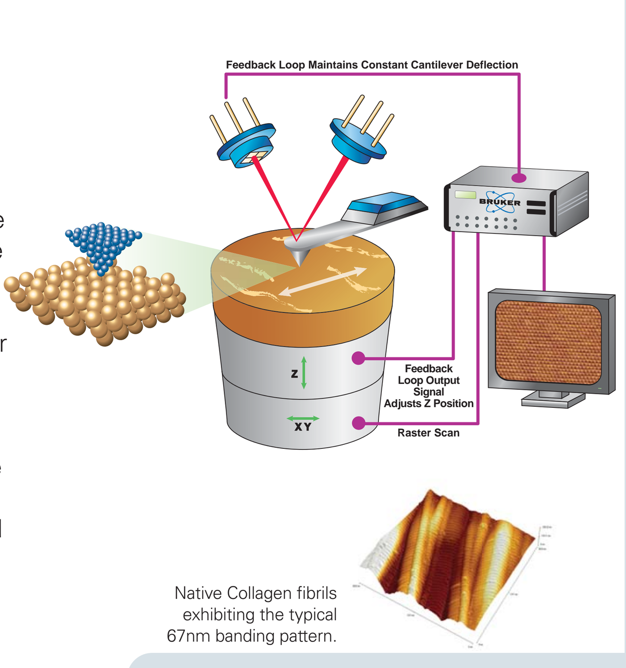
TappingMode™ is a primary SPM mode. During operation, a "tapping piezo" mechanically oscillates the probe at or near its fundamental resonance frequency. The oscillating probe is brought into intermittent contact with the sample to be imaged until the "tapping" between the tip and the sample reduces the cantilever oscillation to a predetermined level. The controller records the cantilever's oscillation amplitude and its phase relative to the drive signal. A feedback loop is employed to adjust the Z position of the sample to maintain a constant tapping amplitude. TappingMode enables numerous secondary modes, including PhaseImaging™, EFM, MFM, and KPFM. Preferred Bruker probes for this application include SNL-10, DNP-10, MLCT, and MSNL-10.



Topography of antimony dendrites on graphite.

Contact Mode

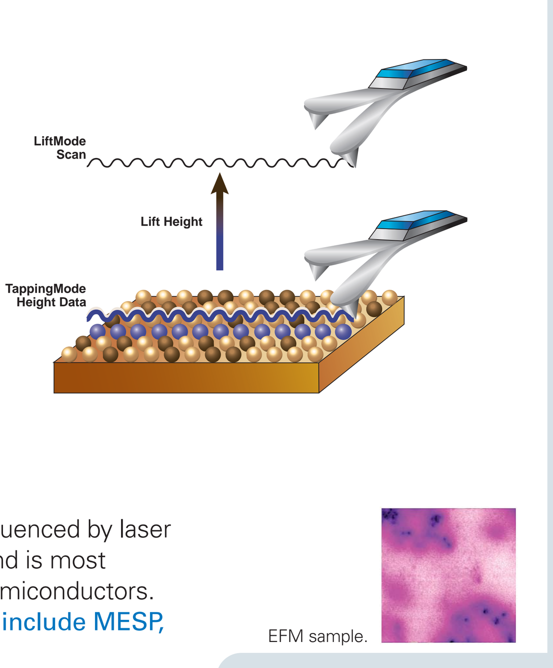
Contact Mode is the original SPM mode, and while not as popular as intermittent contact modes for imaging, it remains in regular use. In contact mode, the tip and sample are in direct contact throughout the raster-scan. The detector measures the deflection of the cantilever in response to the sample topography. During imaging, the sample is either held at a fixed height (Constant Height Mode) or modulated via a feedback loop to adjust the position of the sample to hold the cantilever deflection constant (Constant Force Mode). Contact Mode enables numerous secondary modes, such as LFM, SCM, SSRM, TUNA, and CAFM. Preferred Bruker probes for this application include ESP, MPP-31100-10, SNL-10, DNP-10, MLCT, and MSNL-10.



Native Collagen fibrils exhibiting the typical 67nm banding pattern.

LiftMode

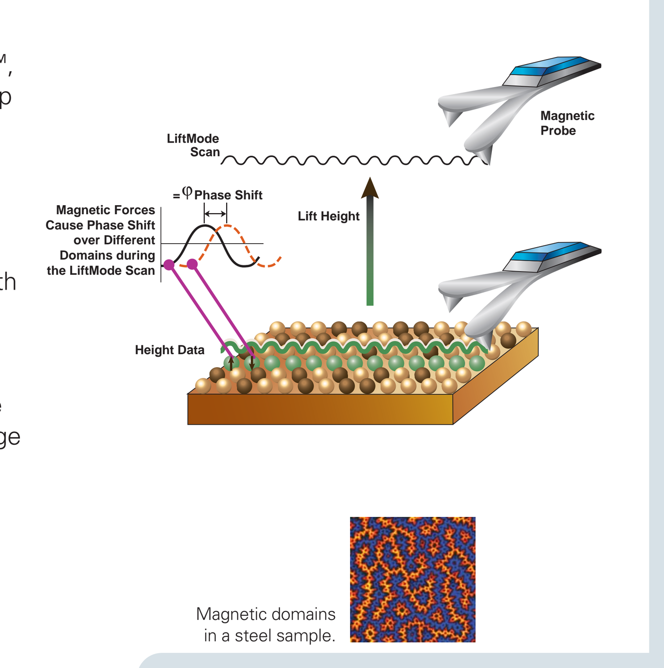
LiftMode™ is not an imaging mode, but rather a technique that enables other modes such as MFM, EFM, and SCM. In LiftMode, the topography of the sample is first recorded in a regular topographic mode such as Contact Mode, TappingMode™ or PeakForce Tapping™. The following line, the "lift line," re-traces the previously acquired topography with an added Z-offset, allowing the desired contrast mechanism to be separated from the topography. Since the sample topography has already been recorded, the feedback laser is not strictly necessary during the lift line, and it can be turned off where experiments would be influenced by laser light. This variation is called "DarkLift Mode" and is most commonly used in electrical applications on semiconductors. Preferred Bruker probes for this application include MESP, SCM-PIT, and SCM-PIC.



EFM sample.

Magnetic Force

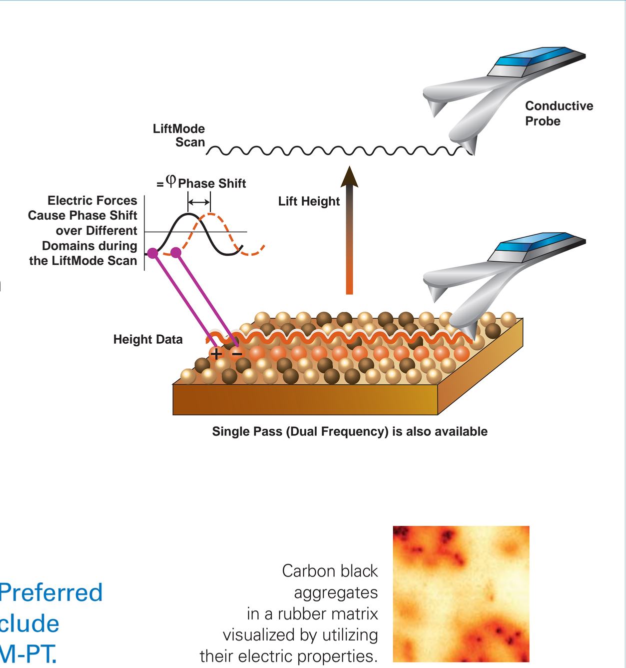
Magnetic Force Microscopy (MFM) uses a combination of TappingMode™, LiftMode™ and a properly prepared tip to gather information about the magnetic field above a sample. Each line of the sample is first scanned in TappingMode to obtain the sample topography. The topographic information is stored and retraced with a user-selectable height offset in LiftMode. During the lift-trace, the magnetic data is collected by measuring the variations in the phase signal. Typical lift heights in MFM range from 20-100 nm. Preferred Bruker probes for this application include MESP, MESP-HM, MESP-LM, and MESP-RC.



Magnetic domains in a steel sample.

Electrostatic Force

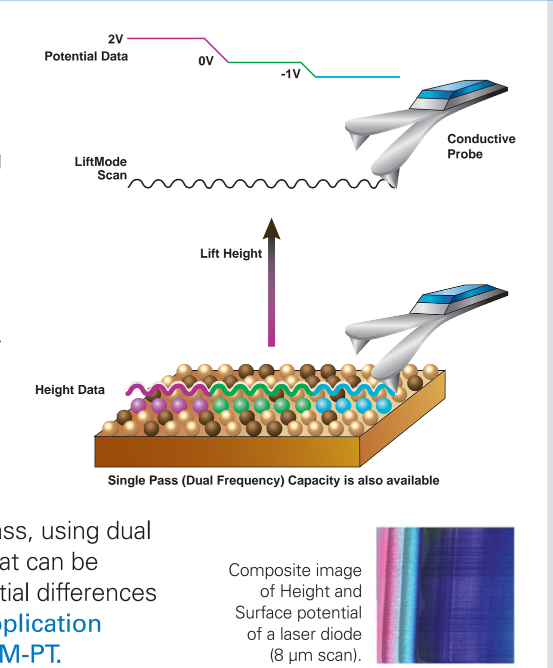
Electrostatic Force Microscopy (EFM) uses a combination of TappingMode™, LiftMode™ and a conductive tip to gather information about the electric field above a sample. Each line of the sample is first scanned in TappingMode to obtain the sample topography. The topographic information is stored and retraced with a user-selectable height offset in LiftMode. During the lift-trace, the electrostatic force data is collected by measuring the variations in the phase signal. Alternatively, phase shift can be used as a feedback signal moving the imaging contrast to frequency shift; making this mode useful for quantitative interpretations. Typical lift heights in EFM range from 20-80 nm. Preferred Bruker probes for this application include SCM-PIT, MESP, MESP-RC, and OSCM-PT.



Carbon black aggregates in a rubber matrix visualized by utilizing their electric properties.

Surface Potential

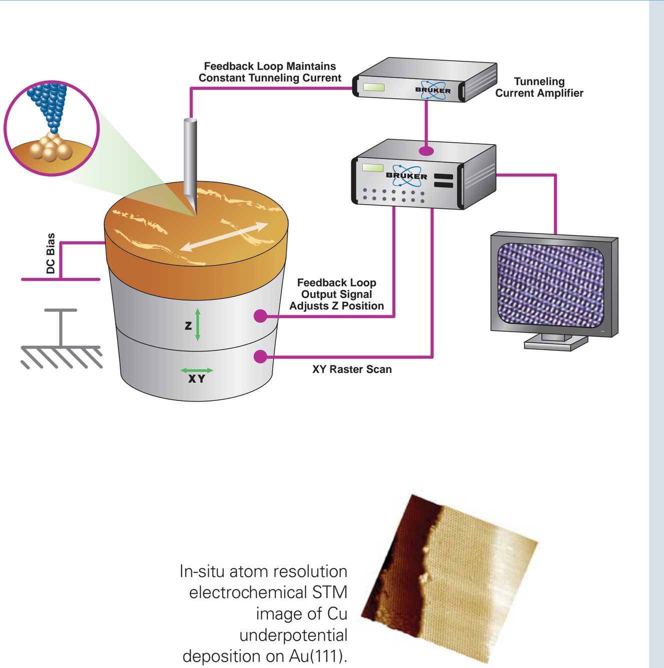
Surface Potential Imaging (often called Kelvin Probe Force Microscopy or KPFM) uses a conductive probe to image work function differences between the tip and the sample. KPFM is accomplished in LiftMode by applying an AC and DC bias to the probe. The AC bias is applied at the probe's fundamental resonance frequency. The DC bias is adjusted through a feedback loop such that no mechanical oscillation is induced from the AC bias. This null condition occurs when the DC bias exactly offsets the work function difference. Using LiftMode achieves the highest sensitivity for the smallest potential differences by eliminating any mechanical disturbance and utilizing resonant enhancement. Alternatively, surface potential can be obtained in a single-pass, using dual frequency, to eliminate topographic artifacts that can be caused by electrostatic forces when the potential differences are large. Preferred Bruker probes for this application include SCM-PIT, MESP, MESP-RC, and OSCM-PT.



Composite image of Height and Surface potential of a laser diode (8 µm scan).

Scanning Tunneling

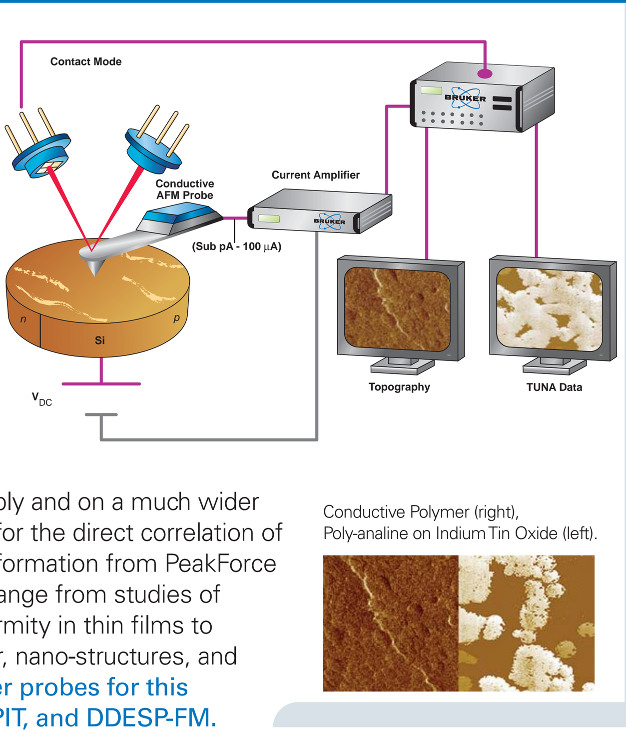
STM is the original embodiment of the SPM and it remains one of the primary modes. In STM, the probe is not a cantilever, but a metal needle, held perpendicular to the sample. The contrast mechanism is the tunneling current between the tip and sample when an electrical bias is applied. In feedback mode, the tip-sample tunneling gap is adjusted in order to maintain a predetermined constant current. Preferred Bruker probes for this application include TT10, PT10, STM, CLST-PTBO, DPT10, DTT10, PT-ECM10, and TT-ECM10.



In-situ atom resolution electrochemical STM image of Cu underpotential deposition on Au(111).

TUNA & Conductive

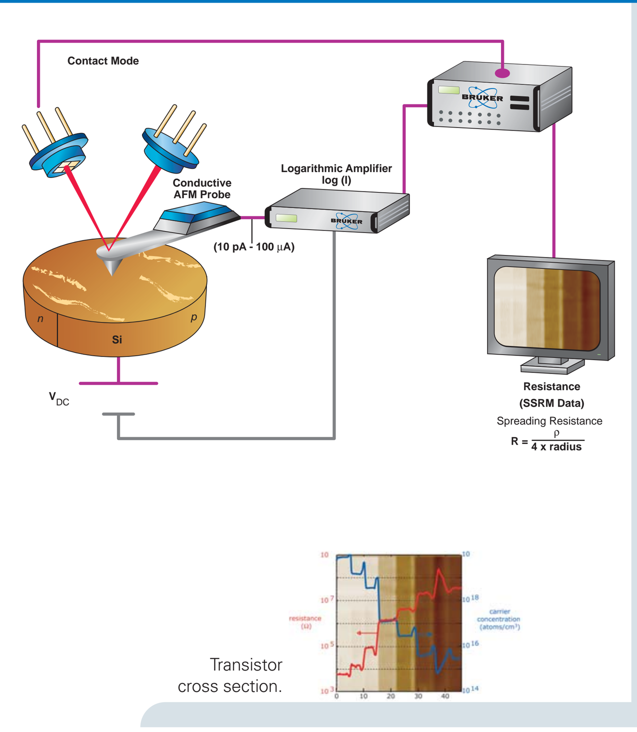
Tunneling AFM (TUNA) and Conductive AFM traditionally operate in contact mode using a conductive probe. The imaging signal is the electric current between tip and sample for an applied DC bias. In the feedback mode, rather than letting the current vary over the sample, the DC bias is dynamically adjusted to maintain a constant tip-sample current. The operational current ranges is from fA (TUNA) to µA (CAFM). More recently, CAFM and TUNA have been utilized with PeakForce Tapping™, enabling these measurements to be taken more reliably and on a much wider range of samples, as well as allowing for the direct correlation of electrical data with nanomechanical information from PeakForce QNM™ measurements. Applications range from studies of dielectric strength and thickness uniformity in thin films to electronic properties of electronic nano-structures, and conductive polymers. Preferred Bruker probes for this application include SCM-PIC, SCM-PIT, and DDESP-FM.



Conductive Polymer (right), Poly-analine on Indium Tin Oxide (left).

Scanning Spreading Resistance

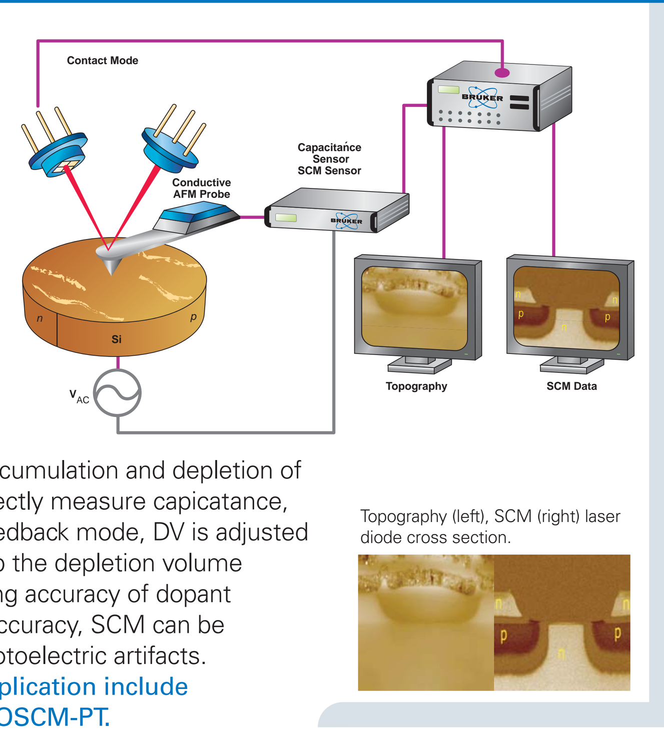
Scanning Spreading Resistance (SSRM) operates in the contact mode using a conductive probe. The imaging signal is the electric current between the tip and sample for an applied DC bias. SSRM is similar to CAFM in that it measures the current by referencing it to an internal resistor. However, unlike CAFM, SSRM uses a logarithmic amplifier to extend the range of measurable local resistance value (at the expense of frequency response). The preferred Bruker probe for this application is DDESP.



Transistor cross section.

Scanning Capacitance

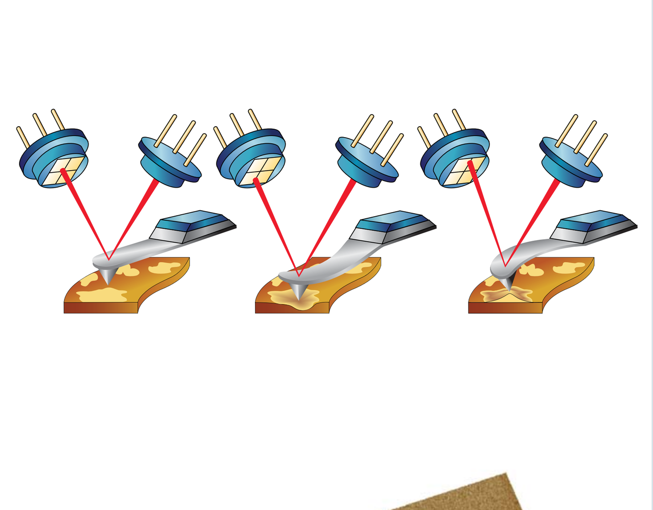
Scanning Capacitance Microscopy (SCM) can be used on flat, well-prepared semiconductor surfaces to map the relative changes of majority carrier concentrations. SCM operates in contact mode by forming a metal-insulator-semiconductor capacitor between the tip and the sample. This capacitor is measured using an ultrahigh-frequency (1 GHz) detector as it is varied with an applied AC + DC bias. The AC (~90 kHz) + DC bias is set to create capacitance variations through the accumulation and depletion of the surface layers. SCM does not directly measure capacitance, but DC/DV. In the Bruker-exclusive feedback mode, DV is adjusted to maintain a constant DC/DV to keep the depletion volume constant, which improves the mapping accuracy of dopant boundaries. To further enhance this accuracy, SCM can be combined with Dark Lift, avoiding photoelectric artifacts. Preferred Bruker probes for this application include SCM-PIC, SCM-PIT, MESP-RC, and OSCM-PT.



Topography (left), SCM (right) laser diode cross section.

Piezoresponse

Piezoresponse (Piezoforce) Microscopy (PFM) is a technique based on contact mode that maps out the inverse piezoelectric effect on a sample. The sample is electrically stimulated and the topographic response of the sample is monitored using lock-in techniques. Amplitude and phase channels reveal information about the strength and direction of the polarization on the sample. Preferred Bruker probes for this application include MESP-RC, SCM-PIT, MESP, and DDESP-FM.

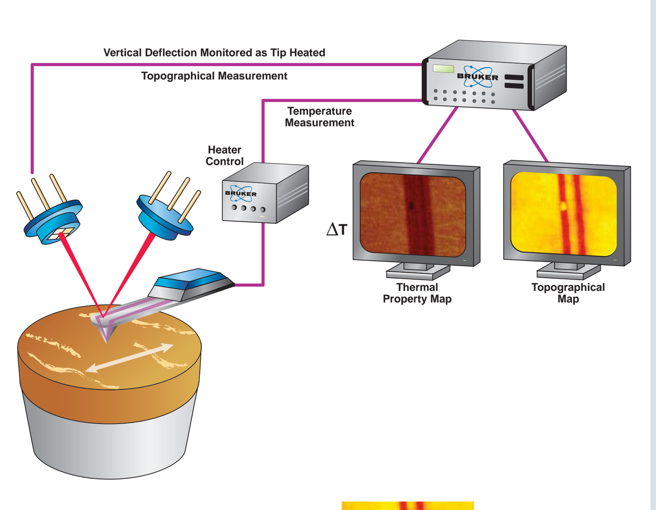


Small defect on the poling boundary of a Lithium niobate film visible in the amplitude signal of a PFM experiment.

Scanning Thermal

In Scanning Thermal Microscopy (SThM) a heated tip is scanned across a sample. Changes in the tip's resistivity reveal either thermal conductivity or thermal gradients on the sample.

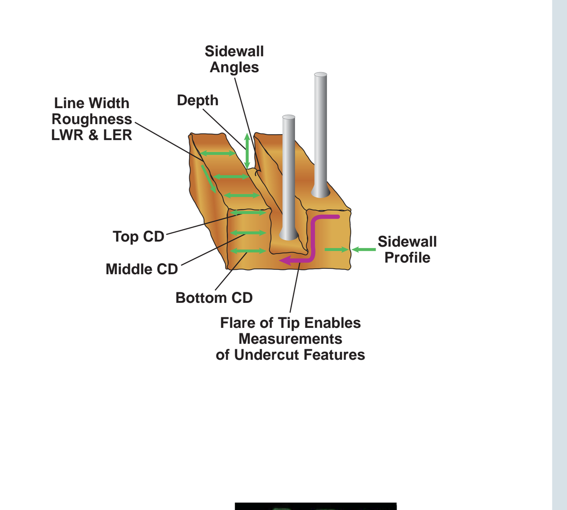
In Nanoscale Analysis (NA) a tip is heated in such a way that it induces a phase transition in the sample. That transition is monitored using the cantilever deflection and is material specific. Preferred Bruker probes for this application include 1610-00, VITA NanoTA Probes, and VITA SThM Probes.



Topography and thermal map of a data storage sample.

Critical Dimension

Critical Dimension Atomic Force Microscopy (CDAFM) is a nondestructive, high-resolution SPM technique that enables accurate measurement of three-dimensional (3D) features. CDAFM is accurate as it provides highly linear measurement over a range of line-widths and is unaffected by feature type, density or material type. Additionally, the technique is able to measure undercut features and can be calibrated using NIST-traceable calibration standards to ensure accuracy of measurements. CDAFM capabilities have enabled its use as a reference metrology tool. Preferred Bruker probes are the 3D Metrology Probes.



Multiple semiconductor trenches.

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