DriveAFM

Performance without compromise

Wiley Analytical Science Award Winner

nanosurf

Performance without compromise

CleanDrive photothermal excitation • Ultra-low noise • Fully motorized system

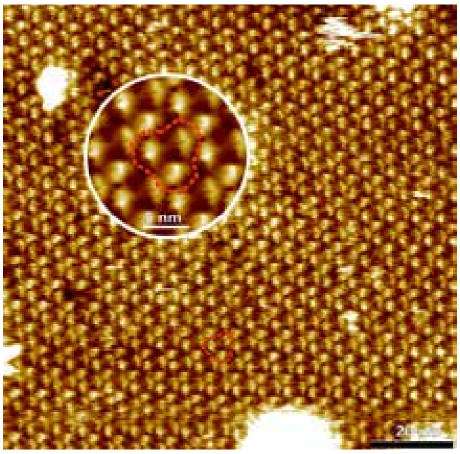
Performance

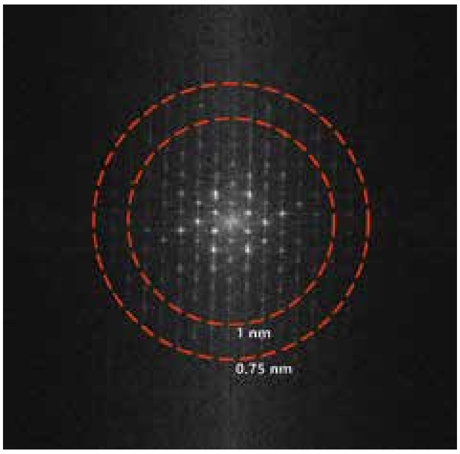
The Nanosurf DriveAFM is the award-winning next generation AFM. It was designed as a system to not only fulfill the demands of today's research but to also serve future needs.

The ultra-low noise of both the deflection detection system and the CX controller in combination with a direct-drive flexure scanner are the basis for **high-resolution imaging** - both in air and liquid environments.

CleanDrive photothermal cantilever excitation, WaveMode and the full motorization and automated laser alignment provide **ultimate operational stability** and **ease of use**.

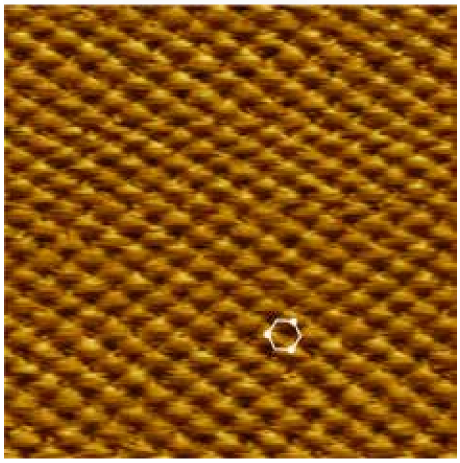
The capability to efficiently use small cantilevers along with the fast control electronics and the high-resonance frequency scanner enables **fast scanning**. Images can now be acquired in seconds instead of minutes.





Left: high-resolution topography image of the cytoplasmic surface of purple membrane from *Halobacterium salinarum*. The topography clearly resolves the trimeric arrangement of bacteriorhodopsin (BR) proteins and substructures within the BR molecules. **Inset:** correlation average of BR trimers. The red dashed lines indicate a BR trimer.

Right: 2D FFT spectrum of the image in the left. The dashed circles indicate resolution of 1 nm and 0.75 nm. The spectrum reveals diffraction peaks beyond the outer circle indicating a resolution better than 0.75 nm.



HOPG's atomic lattice. Image width: 4 nm
Z-range 0.4 nm
Distance between visible atoms: 0.246 nm
No Fourier or Gaussian filtering applied.

No compromise

The DriveAFM is the first fully motorized AFM that can be operated as a **stand-alone** system or be integrated with an **inverted optical microscope**. Switching between setups is just a matter of minutes.

Atomic lattice resolution or large cell imaging? The DriveAFM operates stably in air and liquid environments and spans orders of magnitude in **scan range** up to **100 x 100 x 20 µm³** (xyz) with its large-range high-resonance frequency flexure scanner.

The tip-scanning design of the DriveAFM provides **maximal sample flexibility** while maintaining scanning performance. In contrast to sample-scanning systems, the sample weight has no influence on the DriveAFM's performance. This allows for the design of stable and reliable sample holders for various applications and even integration of a digital inverted microscope underneath the scan head.

Top: DriveAFM mounted on a motorized sample translation stage integrated with an inverted optical microscope.
Bottom: DriveAFM in a stand-alone configuration mounted on a motorized sample translation stage and an Isostage 300 active vibration isolation.

Just press PLAY - with Nanosurf Studio

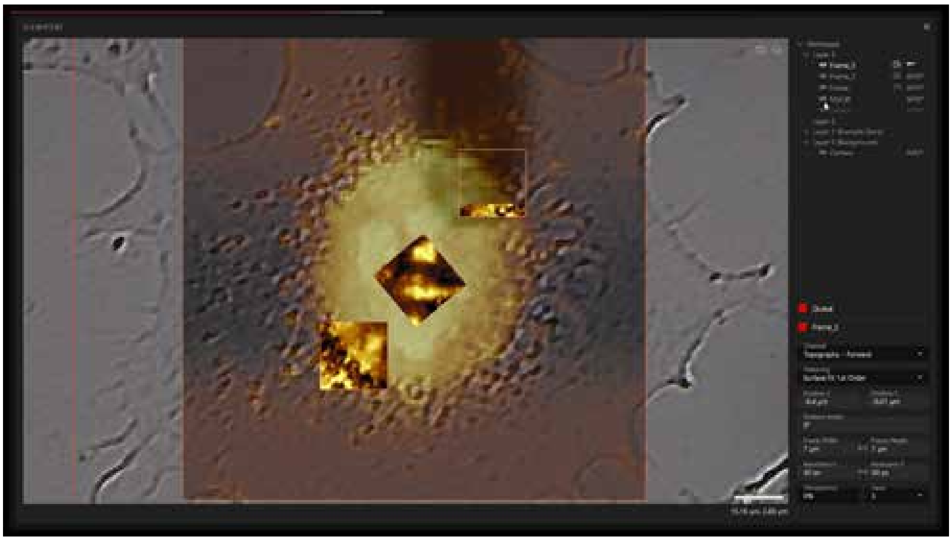
Intuitive & easy • Integrated & automated • Configurable • Quarterly updates

Intuitive operation

Nanosurf Studio is Nanosurf's new AFM control software. It takes full advantage of the DriveAFM's technical features and thus convinces with its **intuitive** and **easy operation**.

The system setup including alignment of the optical deflection detection system and the excitation light source as well as the calibration of the cantilever are fully automated. Various imaging modes are just one click away which allows quick switching between different imaging modes.

Nanosurf Studio software with the setup dialog with the auto setup button, the motorized laser and approach motor control widget, the thermal tune-based cantilever calibration widget and the camera widget showing readout and excitation light spots after automatic alignment.



ViewPort widget with live optical image and superimposed overview and detail topography images.

ViewPort - the navigation center

ViewPort is the central navigation tool of Nanosurf Studio. **Integrating** the DriveAFM top view camera or an inverted microscope camera, ViewPort is the new control and navigation center. Navigate on live camera or imported images and superimpose AFM and optical images while scanning.

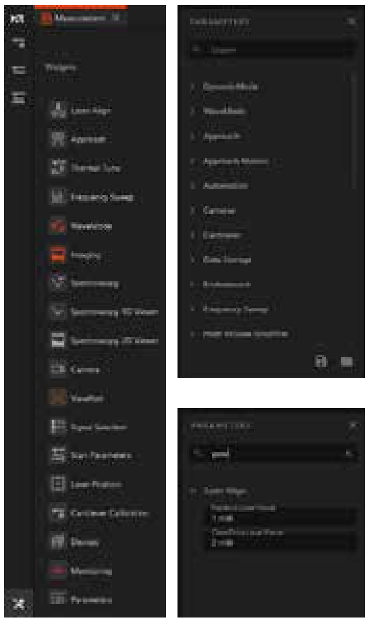
Define multiple areas of interest directly on the optical image or a previously acquired AFM image and effortlessly add them to a queue for an **automated measurement sequence**.

Configurable user interface - meets the needs of every operator

Nanosurf Studio, with its intuitive user interface, is highly **flexible**. Minimalistic views, showing only the essential information and parameters as well as guided and automated system setup features provide ease of use. On the other hand, Nanosurf Studio can be **individually configured** to meet the needs of expert power users.

- Additional widgets provide detailed information and allow full control of the DriveAFM.
- The user interface allows to freely arrange all widgets on the screen.
- The searchable parameters widget grants full access to all parameters available in the Nanosurf Studio software.
- Full Python scripting capability facilitates seamless automation, data analysis and custom mode development projects.

Discover something new in Nanosurf Studio every three months!



Additional widgets that can be displayed and arranged by the user (left).
Searchable Parameters widget (right).

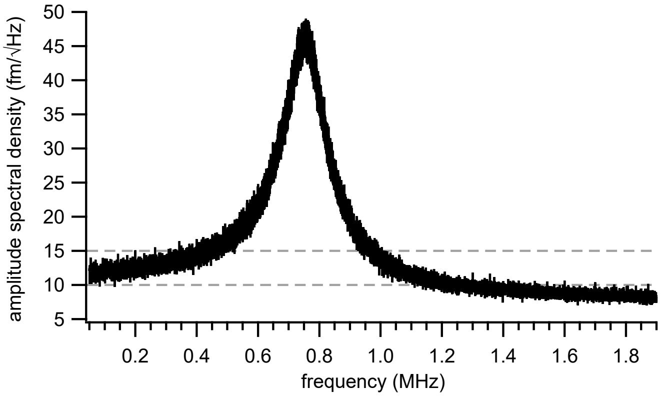
Technology inside the DriveAFM

Low-noise electronics • Direct drive scanner • Tip-scanning design

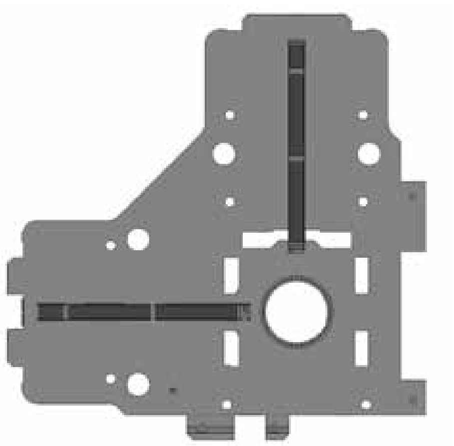
The DriveAFM, Nanosurf's flagship instrument, utilizes the latest technology to deliver stable, high-end performance across all areas of applications from materials science to life science. It was designed to fulfill the needs of top-notch researchers, today and in the future.

Ultra-low noise floor

The DriveAFM has a very low overall noise floor, which is achieved through a combination of an optimized deflection detection system that integrates a low-noise, low-coherence superluminescent diode and a low-noise, high-bandwidth photodetector, and the low-noise/high-bandwidth CX Controller. This low noise floor allows detecting minute changes in the cantilever's deflection. Moreover, the small laser spot size in combintaion with the low-coherence superluminescent light source help preventing interference phenomena caused by light reflected at the sample surface. Together, this is the basis for the stable, sensitive, and high-resolution imaging and force spectroscopy capabilities of the DriveAFM.



Thermal noise spectrum of a USC-F1.2-k7.3 cantilever in buffer solution. The thermal noise spectrum reveals the broad resonance peak of the cantilever at approximately 750 kHz. The noise floor of the system can be clearly identified to be below 15 fm/√Hz, even before the resonance peak. At higher frequencies, the noise floor drops below 10 fm/√Hz.



Schematic of the direct drive actuation scheme with large piezo elements (dark grey) that directly actuate the flexure scanner structure.

Direct drive scanner

The DriveAFM exploits the power of direct drive piezo actuation. The 1:1, non-amplified actuation scheme of the DriveAFM's flexure scanner provides more force and can drive stiffer scanners. The resulting higher resonance frequency of the scanner components allows for a higher available actuation bandwidth than with amplified actuators of the same scan size. Direct drive scanner actuation in combination with the low-noise 28-bit DAC outputs of the CX Controller enable both imaging at large scales and at high resolution with the same scanner. The DriveAFM is the perfect solution for high-resolution imaging of demanding samples such as nanostructures, proteins (e.g. membrane proteins), or polymeric structures (e.g. DNA or synthetic polymers), and even 2D-materials (atomic lattice resolution of HOPG), but also for larger, micrometer-sized structures.

Tip-scanning: No compromise

The DriveAFM with its tip-scanning technology excels in several ways over sample-scanning AFMs. With all the essential components of an AFM system incorporated into a single unit, it is a truly portable and configurable multifunctional device. It can be operated as a benchtop system with a small footprint for opaque samples or easily transferred to an inverted optical microscope within minutes to allow for simultaneous AFM and unperturbed optical observation, thanks to a stationary sample.

Furthermore, the DriveAFM's scanner performance is independent of the mass of the sample or sample holder, because the mass attached to the scanner always remains constant. This enables the DriveAFM to readily investigate large and heavy samples. Similarly, sample holders such as the Variable Magnetic Field Generator, the Heater/Cooler sample holder or the Electrochemical (EC) sample holder, as well as accessories for the DriveAFM are designed to maximize system stability and robustness. These advantages combined with the large clearance below the scanner of the DriveAFM also allow for tailor-made solutions for customer-specific applications or samples.

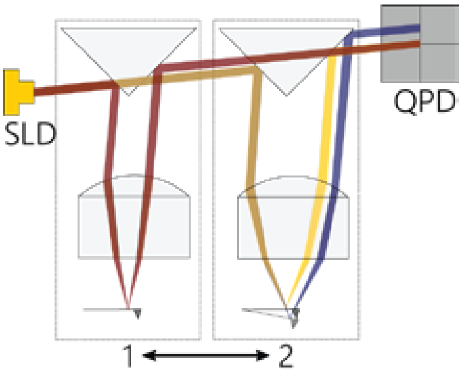
Variable Magnetic Field Generator enabled by the DriveAFM's tip-scanning design.

Ingenious optics design • Small cantilevers • Automated laser & detector alignment

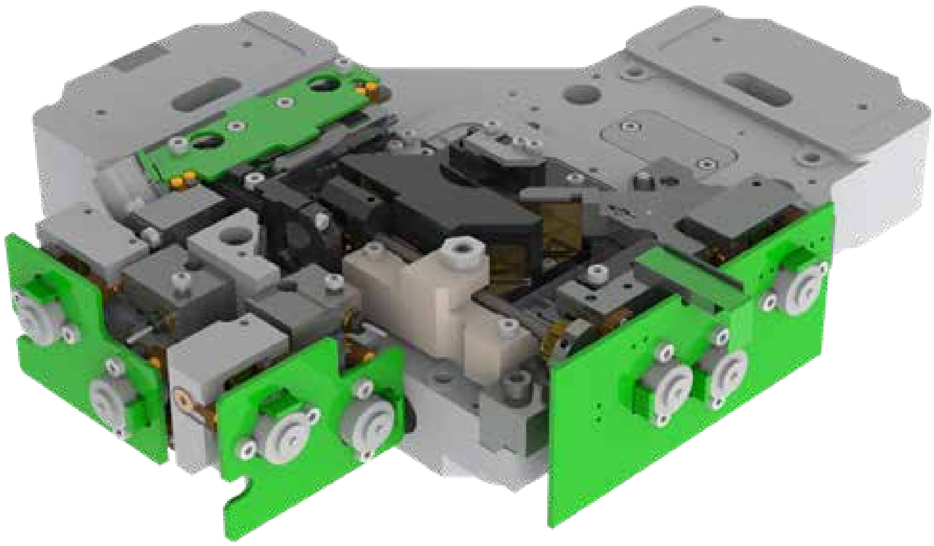
The DriveAFM is the first fully motorized AFM system that can be integrated with an inverted optical microscope. Besides the motorized parallel approach, the DriveAFM features fully motorized and software-controlled automatic adjustment of the whole cantilever deflection detection system (beam positioning and detector alignment) as well as the CleanDrive photothermal excitation laser beam position. For optimal performance, the DriveAFM can also adapt the laser focus to the needs of different environments. This full motorization not only contributes to the ease of use but also allows new possibilities for automated measurements.

New optics design for tip-scanning AFM

The DriveAFM, based on a tip-scanning architecture, introduces a new optics design to track the cantilever's scanning motion with the light beam of the deflection detection system. This ingenious concept avoids mounting a heavy deflection detection unit onto the scanner that negatively impacts its performance, only using light-weight passive components on the scanner. This new, patented beam tracking design is a key technology of the DriveAFM. It allows placing the photodetector and light source off of the scanning unit and even permits adding a second light source for CleanDrive photothermal excitation to the system that can be individually positioned. Importantly, if further enables robust motorization to all components of the optical unit.



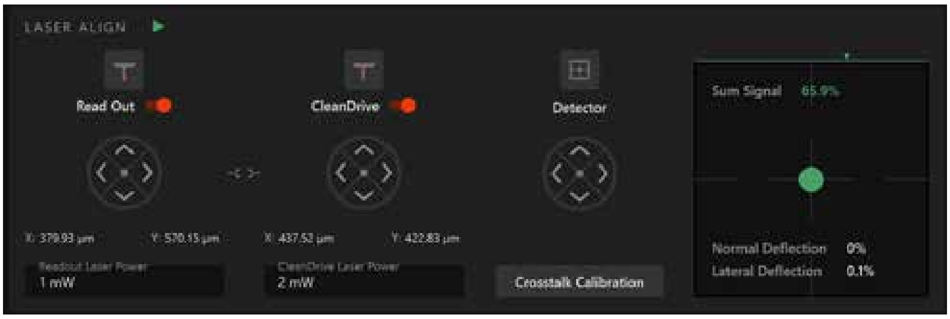
Schematic illustration of the new optical beam tracking concept. The scanner (dashed box), equipped with a mirror and a focus lens, is moved along the axis between positions 1 and 2. The physical arrangement of the light source (SLD) and the photodetector (QPD), along with the layout of the mirrors, maintains the end position of the outgoing light beam on the photodetector regardless of the position of the scanner (positions 1 and 2, red and yellow light paths). Only when the cantilever is deflected, a signal is measured at the photodiode (blue light path). This principle, illustrated in one axis, is extended in two axes to provide XY scan motion optical tracking.



All adjustments of lasers and photodetector are fully motorized

Auto laser alignment

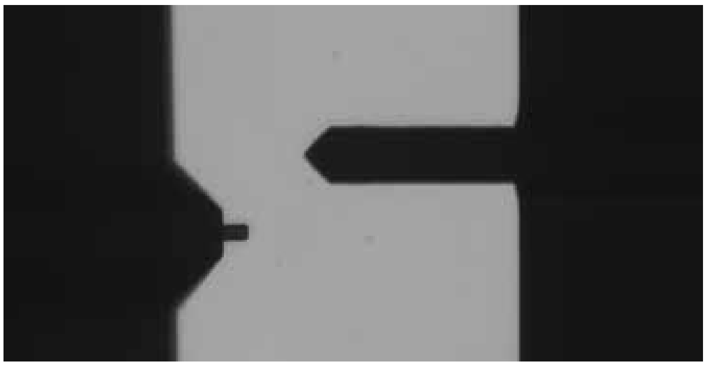
The full motorization of the Drive AFM enables automation of tedious processes like laser alignment. Nanosurf Studio takes full advantage of the motorization and enables a one-click auto setup of the system including alignment of readout and photothermal laser spots and cantilever calibration.



The laser alignment dialog allows fully automatic of the whole optical system or its components as well as providing manual control over all components.

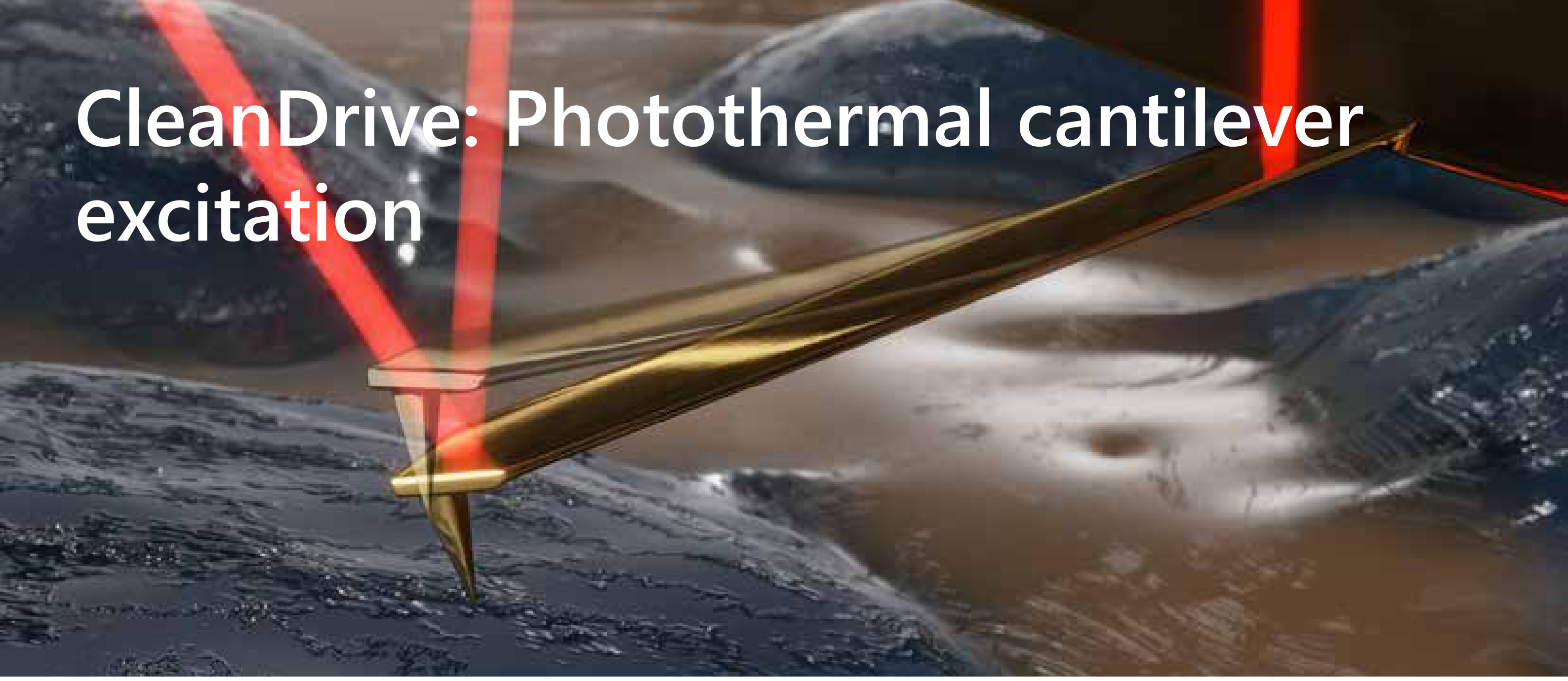
Small cantilevers: Pure performance

The DriveAFM, with its small laser spots, is compatible with small cantilevers, which have several advantages that make them superior in performance. While they have the same spring constant as a conventional cantilever, small cantilevers show a significantly higher resonance frequency and operational bandwidth which is a critical prerequisite for fast AFM imaging. Due to the small dimensions, the sensitivity is increased, and hydrodynamic drag is decreased. All of this results in lower-noise measurements and better imaging performance.



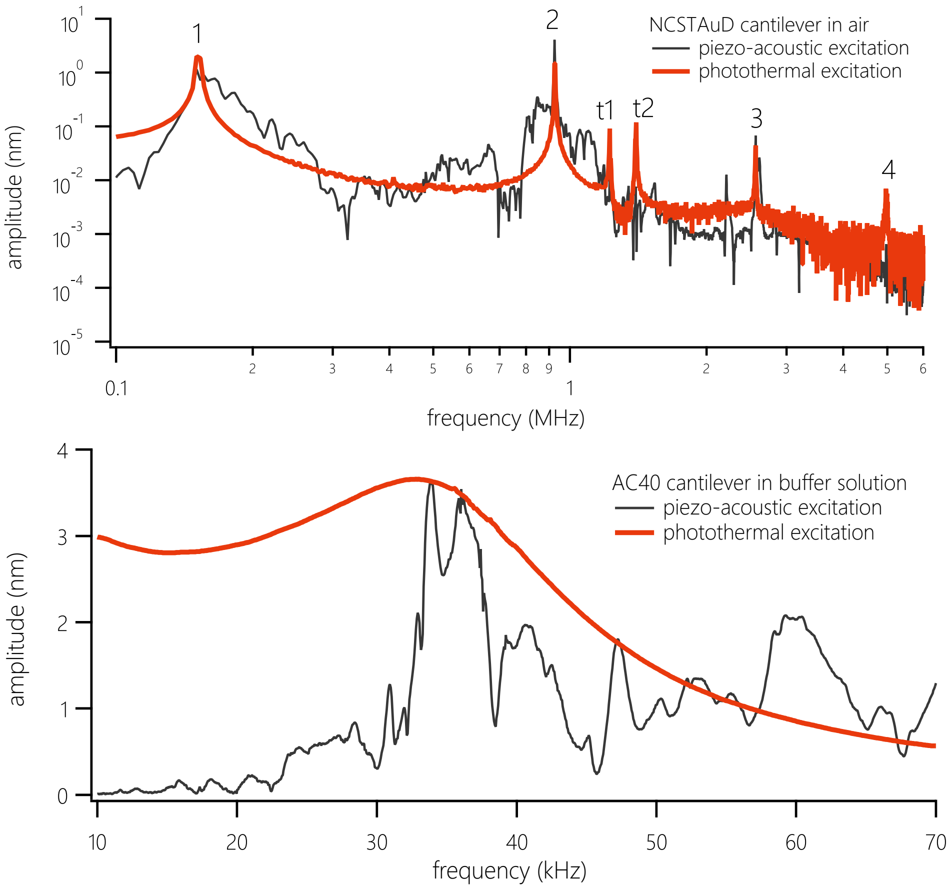
Comparison of a small and a conventional AFM cantilever. The small and regular cantilevers have tip view dimensions of 10 µm x 20 µm (w x l) and 27 µm x 150 µm (w x l), respectively.

CleanDrive: Photothermal cantilever excitation

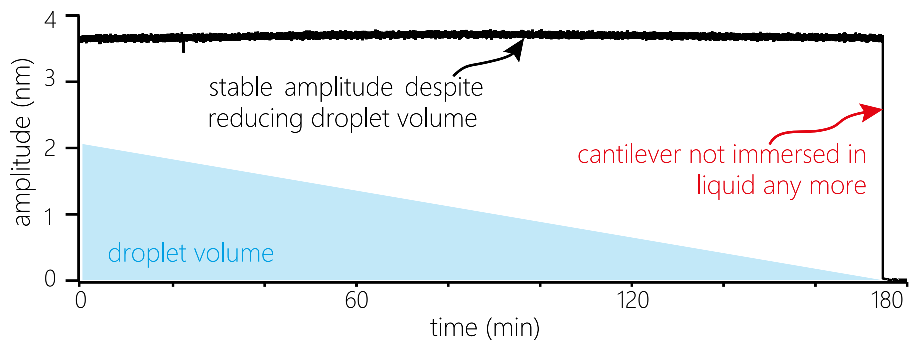


Excitation stability at its best

Photothermal excitation of the cantilever provides unparalleled stability and a high excitation bandwidth in air and liquid environments. Together with the cleanliness of the excitation these benefits allow measurements at multiple frequencies and high-speed applications. Moreover, CleanDrive opens up avenues towards new transformational measurement modes (e.g. PicoBalance and WaveMode). CleanDrive's advantages are amplified in liquids since only the cantilever beam is excited through local heating and the liquid environment remains largely unaffected. The result: unperturbed resonance peaks instead of the "forest of peaks" commonly seen with piezo-acoustic excitation. Furthermore, this method of exciting the cantilever is insensitive to changes in the environment and distance to the sample, making the whole measurement system much more stable, reliable, and easier to work with.



Top: Comparison of frequency sweep in air. Far cleaner peaks over a wide frequency range. **Bottom:** Comparison of frequency sweeps using piezo-acoustic and photothermal excitation (CleanDrive) in liquid. CleanDrive shows textbook-like amplitude response and no "forest of peaks".

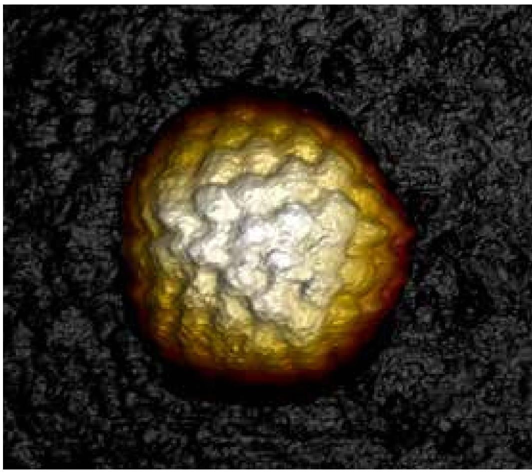


A cantilever immersed in a 100 µl buffer droplet was excited to an amplitude of 3.6 nm. The amplitude of the cantilever was observed while the buffer droplet was allowed to evaporate. Until the cantilever lost contact with the droplet, the amplitude of the cantilever did not change significantly. As the cantilever was released from the liquid, the amplitude suddenly dropped, as expected.

WaveMode: Off-resonance imaging remastered

A new AFM mode

WaveMode is Nanosurf's new off-resonance imaging mode using photothermal excitation. The first implementation of photothermal off-resonance tapping (PORT) was set up by Georg Fantner at the EPFL. Since then, WaveMode was developed in collaboration with researchers from ZHAW Zürich and the EPFL to provide a new, simpler implementation of PORT that does not rely on background subtraction for feedback control but uses the amplitude reduction of the cantilever trajectory when interacting with the sample surface. It is the first commercially available off-resonance imaging mode using CleanDrive photothermal excitation that is itself well-known for its exceptional excitation stability and bandwidth in any environment. Founded on these advantages, WaveMode allows stable and fast operation in all environments and provides additional ease of use for users from all backgrounds.



Herpes simplex virus 1 (HSV-1) capsid imaged in WaveMode at 10 kHz ramp rate resolving individual capsomeres. Image size: 230 x 230 nm^2, z: 60 nm. Sample courtesy: Alex Evilevitch, Lund University.

WaveMode converts the AFM cantilever from a simple detector of tip-sample interactions into a combined detector and actuator. AFM cantilevers are well-know for their capability to serve as fast actuators. Paired with photothermal excitation, the AFM cantilever is used to provide the oscillatory relative motion between AFM cantilever tip and sample surface that is typical for off-resonance modes. The combined high bandwidth of both the cantilever and the photothermal excitation allow overcoming the main speed-limiting factor in conventional off-resonance modes – the z-scanner that is typically used to generate the relative oscillatory motion.

WaveMode allowings tailoring the tip-sample interaction according to the requirements of the sample. Moreover, it significantly reduces lateral forces acting on the sample during imaging. This allows also imaging samples that are otherwise difficult to image due to their displacement during the imaging process.

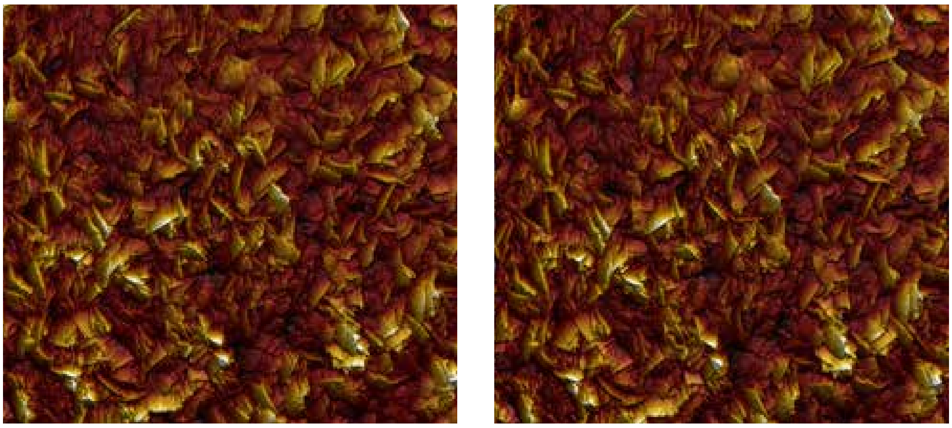
Prof. Georg Fantner, EPFL, about WaveMode

„I expect PORT will become a real game-changer for AFM and I am very happy that Nanosurf has integrated an implementation of PORT on the DriveAFM."*

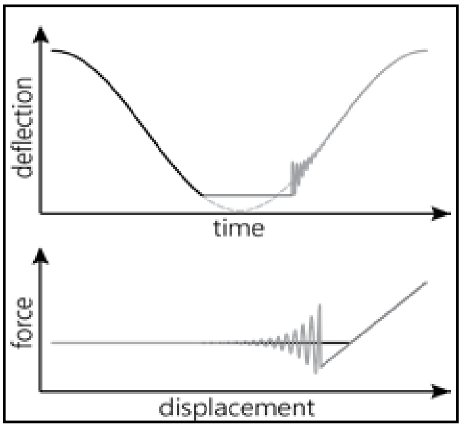
*Photothermal off-resonance tapping

Imaging with precisely controlled tip-sample interaction

During imaging, the cantilever is excited by a laser that is sinusoidally modulated in its intensity, causing a sinusoidal deflection profile of the free cantilever. Once the cantilever interacts with the surface, the tip-surface interaction causes a new, characteristic cantilever deflection profile, flattened where interacting. This results in a profile with reduced amplitude compared to the free oscillation amplitude. In WaveMode, operating below the resonance frequency, this reduction in amplitude can be used for feedback control. Moreover, the amplitude reduction also relates to the interaction force between sample and surface and thus allows maintaining and adjusting the interaction force. The force-distance relationship during an oscillation cycle corresponds to that well-known from force spectroscopy.



TipCheck sample imaged at 4Hz line rate, 2.9 µm frame size, 90 nm color scale. The left and right images are the first and last images in a series of 20 images.



Schematic of tip deflection during a single cycle and the corresponding reconstructed force-distance relationship obtained by post-processing.

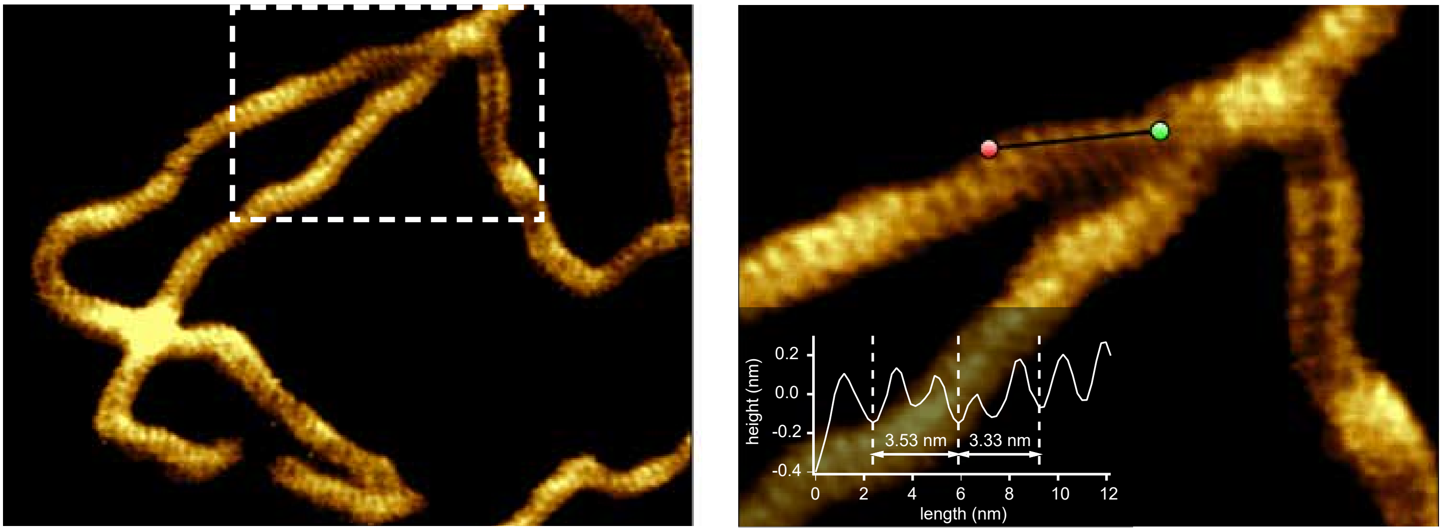
Tip preservation

WaveMode allows gentle imaging conditions, even on challenging samples like the tip checker, a sample known to notoriously blunt the tip with its sharp edges. WaveMode overcomes these problems with its precise interaction control. WaveMode thus not only simplifies the imaging process but also helps to preserve the tip and thus extend its lifetime.

Life science

Stability without compromise

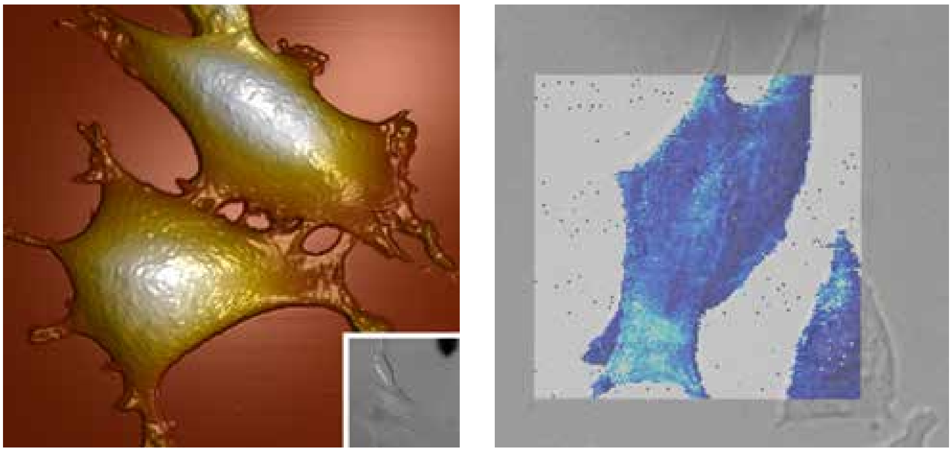
The DriveAFM plays out all its advantages when it comes to biological applications. Automatic alignment of the beam deflection detection system and full motorization allow adjusting the lasers and photodetector and navigating the sample without interfering with a temperature-controlled environment. CleanDrive provides reliable and clean cantilever tuning in liquid environments. The insensitivity of CleanDrive towards environmental changes, the high sensitivity of small cantilevers, the ease-of-use and interaction control of WaveMode facilitate imaging of delicate samples over long periods of time with ease and at high resolution.



Left: high-resolution topography image of double-stranded DNA on mica in buffer solution. Several DNA molecules can be observed. All of them show a characteristic periodic pattern. Image width: 110 nm. **Right**: zoomed-in section of the left area indicated in the left image. The black line indicates the location of the cross section shown in the inset. The average spacing between every second-next groove in the section corresponds to 3.4 nm, the characteristic pitch distance of a helical turn of B-DNA. The valleys in the section correspond to the major and minor grooves found in dsDNA. Image width: 45 nm.

Seamless integration

The DriveAFM integrates with most commonly used inverted optical microscopes to allow transmitted light and fluorescence microscopy to be combined with AFM imaging and force spectroscopy. The wavelengths of the two light sources used (785 nm and 840 nm) were selected to prevent interference with biological samples and the most commonly used fluorescent dyes across the visible spectrum. This way, using optical microscopy, cells or other features to be investigated by AFM imaging or spectroscopy can be selected based on morphology or fluorescent markers. Subsequently, AFM results can be correlated to the optical information. Moreover, with its high-resolution capabilities and the large 100 x 100 x 20 μm^3 scan range, the DriveAFM provides the means to image selected cells or cell assemblies as well as to focus on areas of interest on subsections thereof.



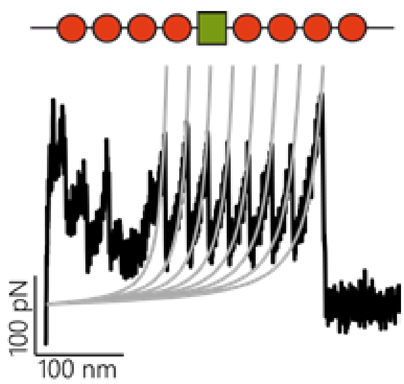
Immortalized mouse embryonic fibroblasts in cell culture medium. **Left:** AFM topography image of two cells. Image size: 70 µm. **Inset:** DIC image of cells in optical microscope. **Right:** Young's modulus map superimposed on optical image

Force spectroscopy from single molecules to cells

With its generous 20 µm z-range and the new 150 µm z-actuator sample holder, the DriveAFM is the solution for all force spectroscopy-based investigations: single-molecule force spectroscopy, mechanical characterization of biomaterials, substrates, cells or tissues, or single-cell force spectroscopy.

Environmental control

The DriveAFM comes with a new line of accessories for biological applications from single-molecule investigations to live cell observations. This includes a new Petri-dish holder and a new 150 µm z-actuator, which is essential for cell adhesion experiments. Both sample holders are designed to maintain biological samples at physiological temperature and to be ultimately converted into a live cell incubator that allows temperature and CO_2 control for optimal cell viability.



Unfolding of an engineered polyprotein containing Ig27 domains and a sandwiched test protein. The characteristic sawtooth pattern with equally spaced force peaks is visible. Average contour length increase per unfolding event: 28 nm.

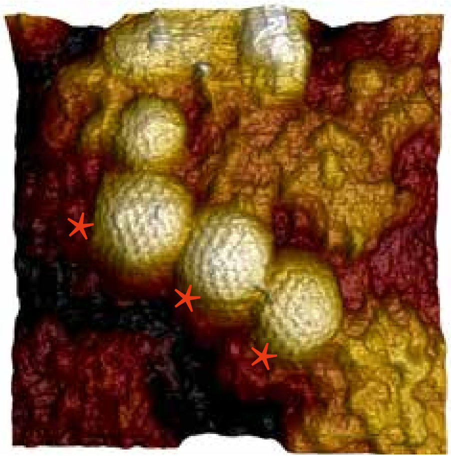
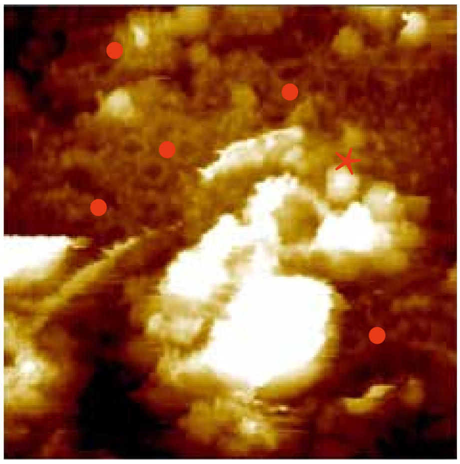
WaveMode for life science research

Imaging performance on soft and fragile samples

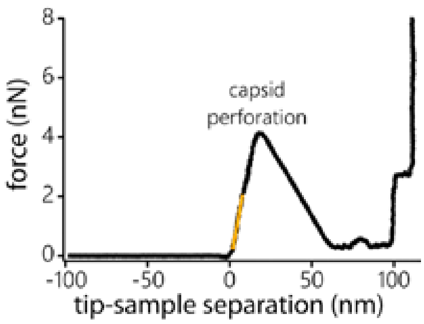
WaveMode imaging excels at imaging fragile biological samples that are otherwise difficult or impossible to assess. It allows applying very low imaging forces in a controlled way and at the same time minimizes lateral forces that may displace or disrupt the sample while not compromising on speed or image quality.

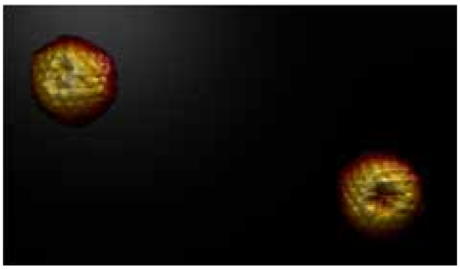
Using the AFM cantilever as an actuator for WaveMode provides the imaging bandwidth required to maintain imaging speed and performance. Actuating only the cantilever also reduces lateral hydrodynamic drag acting on the sample that is created when oscillating the whole sample or cantilever assembly and this way introducing liquid flow across the sample.

WaveMode can be combined with other AFM-based techniques such as force spectroscopy. It can be e.g. used to locate individual virus capsids (~120 nm diameter) that are then subjected to mechanical probing using the same AFM tip to investigate the capsid stiffness and breakdown force, when the structural integrity of the capsid is destroyed. Subsequently, the breakdown can be confirmed by re-imaging the capsid at high resolution, visualizing individual capsomers and the perforated area on the capsid.

HSV-1 capsids (*) imaged bound to and on intact rat liver nuclei resolving individual capsomeres. Nuclear pore complexes (•) residing withing the membrane are well visualized. Sample courtesy: Alex Evilevitch, Lund University.

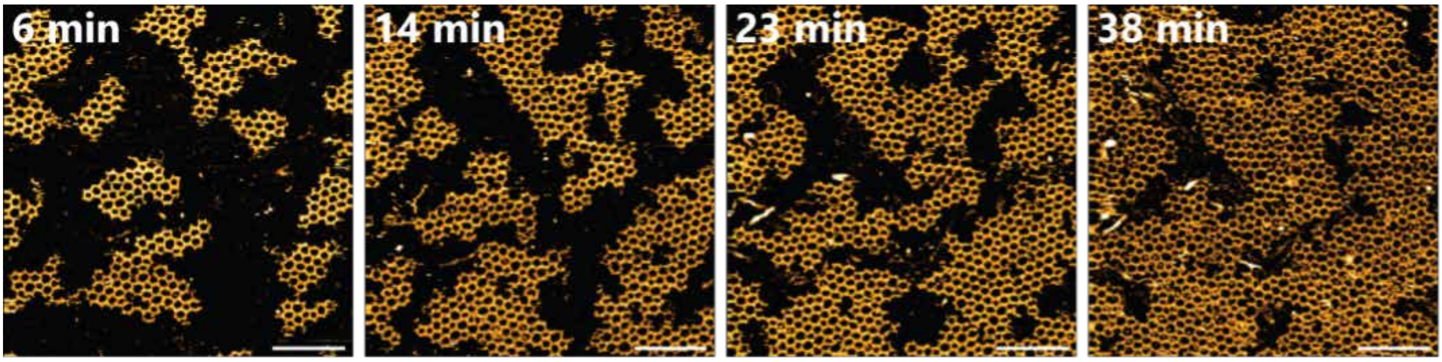




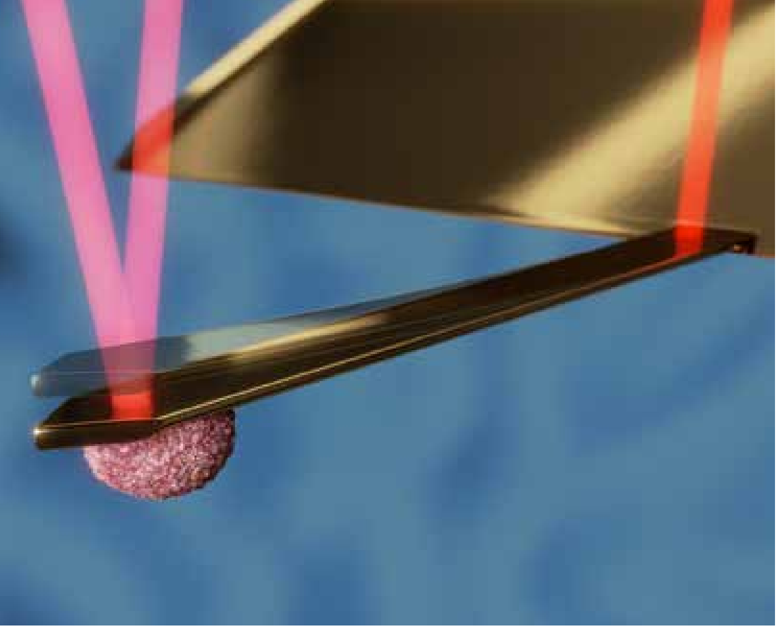
HSV-1 capsid perforation. Capsids were initially located by WaveMode imaging and subsequently individually addressed by force spectroscopy to perforate the capsid. A characteristic force distance curve of such an experiment is shown (left). The orange line indicates the elastic stiffness of the capsid. After proforation, capsids were re-imaged with the same cantilever to verify capsid breakdown. Sample courtesy: Alex Evilevitch, Lund University.

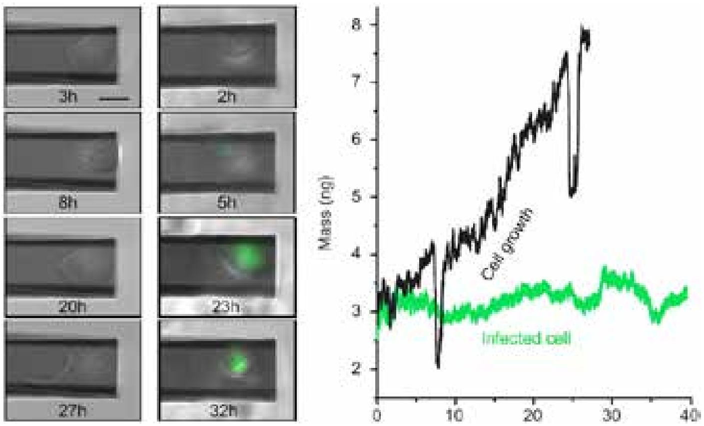
Off-resonance time-lapse imaging

Time-lapse imaging requires temporal resolution that allows observing dynamic processes. In this discipline, WaveMode excels with its superior imaging bandwidth that allows for higher imaging rates than conventional off-resonance imaging. Moreover, it does not disturb the assembly process by introducing unnecessary hydrodynamic drag on the sample. The example below shows time-lapse imaging of DNA tripods assembling into a hexagonal network. Growth nucleates at different sites within the observed area and finally, the different islands fuse into a large network covering almost the whole surface. The assembly process requires low, controlled imaging forces in the order of <50 pN that only WaveMode can deliver. Higher forces would impact the assembly process.



Assembly of DNA tripods structures: time-lapse imaging of DNA tripods assembling into a hexagonal structures. Image size: 250 x 250 px^2, 5 Hz line rate, 50s/frame, image with: 1 µm
Sample courtesy: Cem Tekin, Prof. Maartje Bastings, Programmable Biomaterials Laboratory EPFL.
Image courtesy: Veronika Cencen, Prof. Fantner group, Laboratory for Bio- and Nano-Instrumentation EPFL.





Long-term cultivation and optical/fluorescence/mass monitoring of control (unlabeled; left image column) and virus-infected cells (labeled with eGFP; right image column). While the healthy cell grows in mass and divides (dips in the black curve indicate cell division), the infected cell does not change its mass but engages in production of new virus particles (green fluorescence of GFP-labelled virus proteins).

PicoBalance ready

Mass measurement is a well-accepted method in many fields of science to characterize systems of any kind. Indeed, mass is typically a well-regulated quantity in biological systems, especially at the macroscopic level. However, mass measurements at the microscopic level, e.g. single cells or colloidal particles, were lacking able instrumentation. With the PicoBalance, Nanosurf offers a solution available on the DriveAFM that fills this gap.

PicoBalance non-invasively measures the mass of microscopic systems or their change with picogram mass and millisecond time resolution by observing changes in the resonance frequency of a cantilever-based oscillator. For reliable measurements, a clean and stable oscillation of the cantilever in liquid is mandatory. The DriveAFM with its CleanDrive photothermal excitation is the only AFM that is capable of performing such mass measurements.

The high temporal resolution of the PicoBalance makes it the ideal tool for investigating dynamic processes taking place in cells. It fully integrates with optical microscopy to allow observation of cell morphology or expression of fluorescent markers in parallel to the mass measurement. A different area of application could be the investigation of the dynamic swelling properties of colloidal systems in different solvents.

PicoBalance can be combined with FluidFM technology to make use of the strengths of both technologies.

Key features & benefits

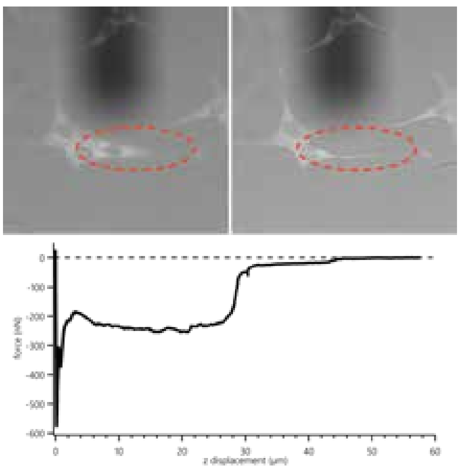
- Direct measurement of the total mass in liquids
- Mass: 5 pg mass resolution, tens of pg to tens of ng range
- Time: 10 ms time resolution, from seconds to days range
- Long-term stability enabling days-long experiments
- Compatible with LiveCell chamber, inverted light microscopy, FluidFM and DriveAFM

FluidFM® ready

FluidFM® probe microscopy (FPM) combines the force sensitivity and positional accuracy of an AFM with FluidFM technology by Cytosurge. The DriveAFM is fully compatible with the FluidFM technology and combined with the new accessories a wide range of exciting experiments from nanoscience to cell biology are possible:

- Single cell force spectroscopy (both in cell-substrate and cell-cell configuration)
- Targeted cell injection
- Material extraction from cells for further analysis (e.g. mass spectrometry, PCR)
- Targeted deposition of substances on cells/tissues
- Substrate patterning or modification

The FluidFM and PicoBalance technologies can be combined for e.g. serial measurement of cell mass, where the reversible attachment of cells to the FluidFM cantilever significantly increases the throughput of the mass measurement.

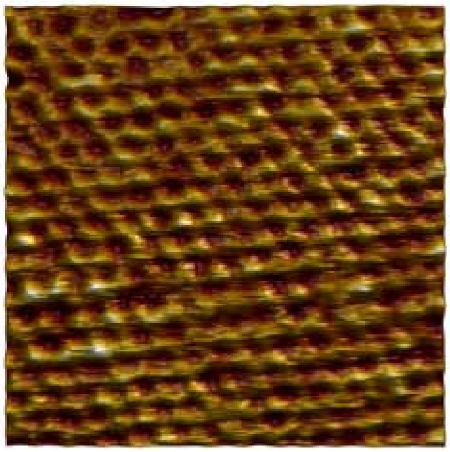


The optical images show the same area before (left) and after (right) a cell adhesion experiment using the 150 µm z-actuator sample holder. Force-distance curve corresponding to the cell detachment process.

Materials science

Versatility without compromise

The DriveAFM with its high-performance tip-scanning design is the ideal solution for materials science research. The combination of its unique direct drive tip-scanner technology paired with CleanDrive photothermal excitation and the fast, high-resolution and low-noise electronics is key for fast and stable operation in air and liquid. The DriveAFM delivers high-quality images of very small structures like atomic or crystal layer steps, or the atomic lattice of crystalline materials. At the same time, the DriveAFM's scanner with its large range of 100 x 100 x 20 µm^3 and direct drive design is ideal for imaging highly corrugated surfaces or high features.



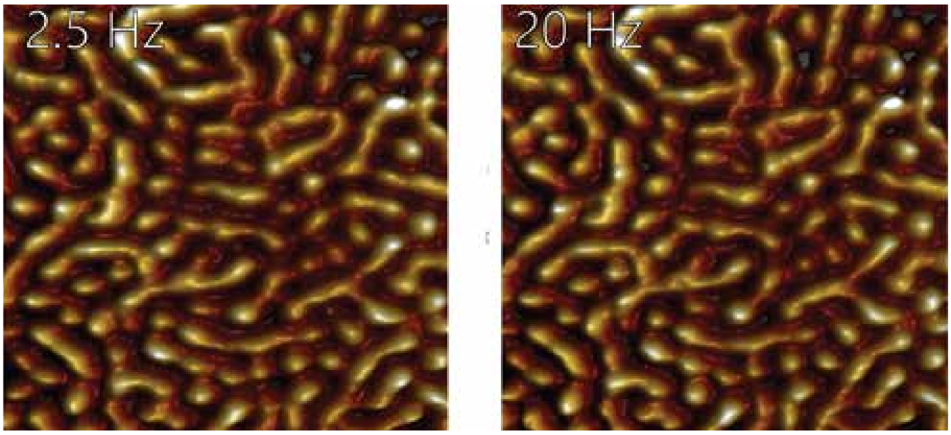
Atomic lattice of mica. Image size 7 x 7 nm^2

Truly flexible design

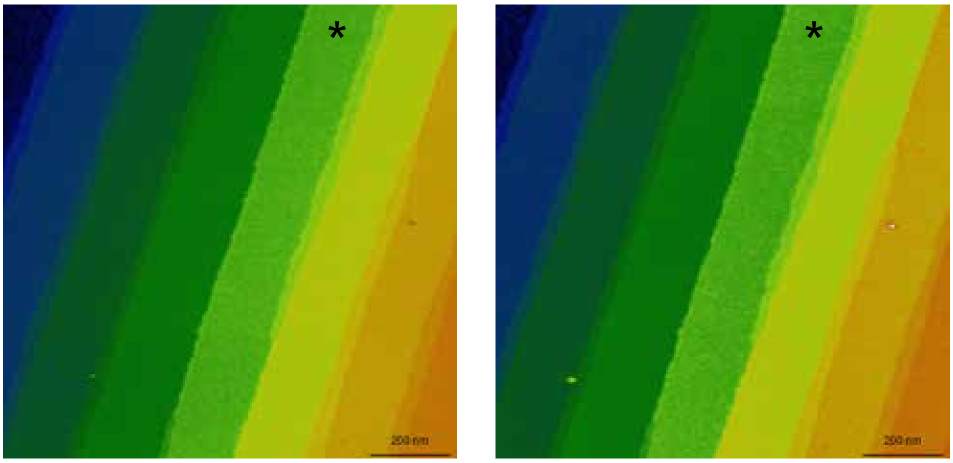
With all the essential components integrated in a single unit, the DriveAFM is a truly flexible instrument. The space under the scan head can be used to accomodate robust, stable and easy to use sample holders that further extend the capabilities and functionality of the DriveAFM. The design of the DriveAFM allows mounting samples of up to 150 mm in diameter. The tip-scanning design guarantees the same scanner performance on any sample, irrespective of its mass, thus compromising on neither speed nor resolution.

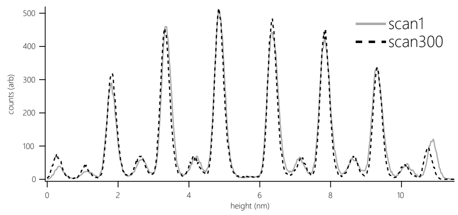
Long-term imaging stability

CleanDrive photothermal excitation contributes significantly to the ease of use and reliablity of the DriveAFM. Thanks to long-term excitation stability, CleanDrive allows obtaining consistent results over a large number of images without having to adapt imaging parameters during the imaging process, and even without the need to change the cantilever.



PS-SBS-PS co-blockpolymer on mica imaged at 2.5 Hz and 20 Hz line rate in dynamic mode using CleanDrive photothermal excitation. 240 x 240 nm^2; color scale: 4.3 nm





Left: first and last images of a series of 300 consecutive scans of a SiC sample with 1.5 nm step height between the wide terraces. Imaging was performed in dynamic mode using CleanDrive photothermal excitation. The surface roughnesses of the terraces marked with * are 125 pm rms for the first and 126 pm rms for the 300th scan, respectively. **Top:** Height histograms corresponding the the images on the left.

Functional modes and measurement automation

Besides reliable topographic imaging, the DriveAFM features a complete set of different modes to investigate the nanoelectrical (e.g. C-AFM, KPFM, or PFM) or nanomechanical properties of your sample. The universe of accessories developed for the DriveAFM offers extended functionality such as heating or cooling the sample, variable magnetic field generation, low electrical current detection or investigating the changes taking place on a working electrode during electrochemical processes with *in situ* AFM.

The the full system motorization not only simplifies working with the system but also facilitates automated measurements addressing different areas of a sample. The integrated powerful scripting module also allows taking full control of the AFM for user-specific measurement tasks and integration into complex measurement setups.

WaveMode for materials research

Get your results faster – and with less effort

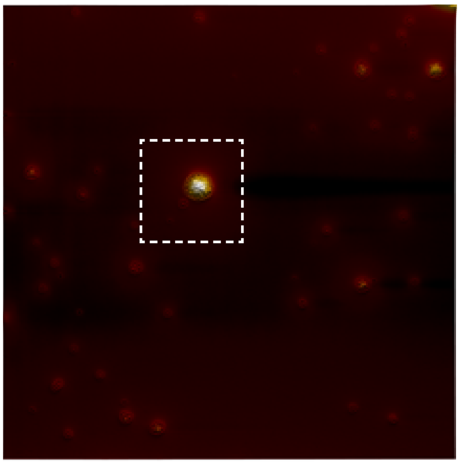
WaveMode and the full automation of the DriveAFM make the workflow to set up a measurement easier than ever:

- Single click, fully automated alignment of read-out and CleanDrive lasers as well as the photodetector
- Contact-free cantilever calibration
- No cantilever resonance frequency tuning

Boosting off-resonance imaging speed

The DriveAFM combines performance with a wide range of applications important in materials research.

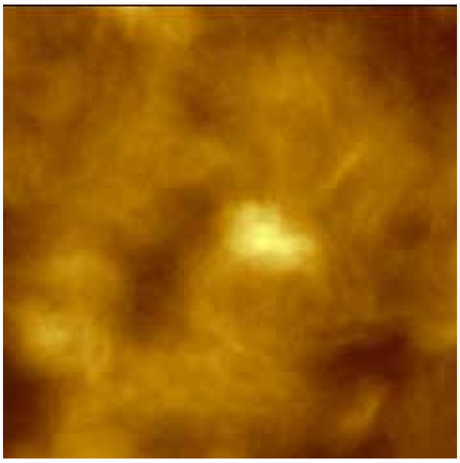
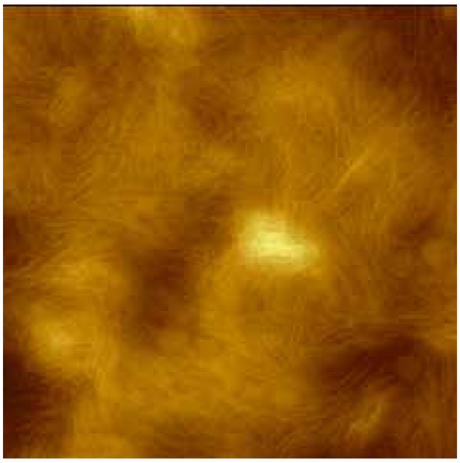
With WaveMode, the DriveAFM elevates off-resonance imaging to a new level of performance. Using the high excitation bandwidth of CleanDrive and the fast response of photothermally excited cantilevers in combination, DriveAFM is able to overcome the limiting factor of z-piezo dynamics in conventional off-resonance modes. The result is an increased actuation bandwidth up to several tens of kHz and therefore enables faster imaging speeds without compromising on image size or resolution.



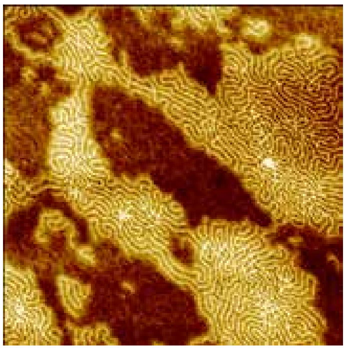

Images of a SBR-PMMA blend recorded in WaveMode at 20 kHz actuation frequency. **Left:** Large range scan (35 x 35 μm^2) recorded at 10 Hz line rate. **Right:** Zoom-in (6 x 6 μm^2) recorded at 10 Hz line rate.

More detailed images

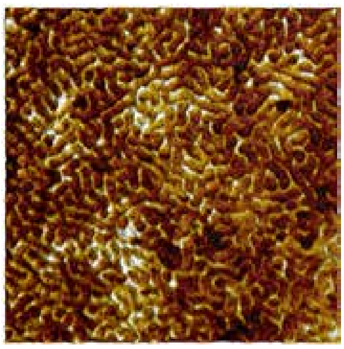
WaveMode relies on a different contrast mechanism compared to the widely-used dynamic mode imaging. In WaveMode, the tip-sample interaction can be precisely controlled and adapted to obtain optimal imaging results. WaveMode can reliably visualize features that are otherwise hard to resolve using regular static or dynamic mode imaging. It can thus provide more detailed insights into the structure and surface topography of a large variety of different samples.

LDPE thin film on silicon imaged in dynamic mode (**left**) and WaveMode (**right**). The dynamic mode image appears blurred compared to the detail-rich WaveMode image which reveals the lamellar LDPE structure. Image size: 500 x 500 nm^2.

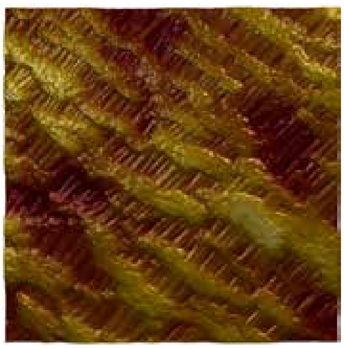


Bottle brush macromolecules on silicon with clearly visible polymer backbone. Image size 1 x 1 μm^2



SBS-PS block copolymer thin film on silicon. Image size 1 x 1 μm^2

Lamellar structure of LDPE domains embedded in a polystyrene matrix. Image size 1 x 1 μm^2



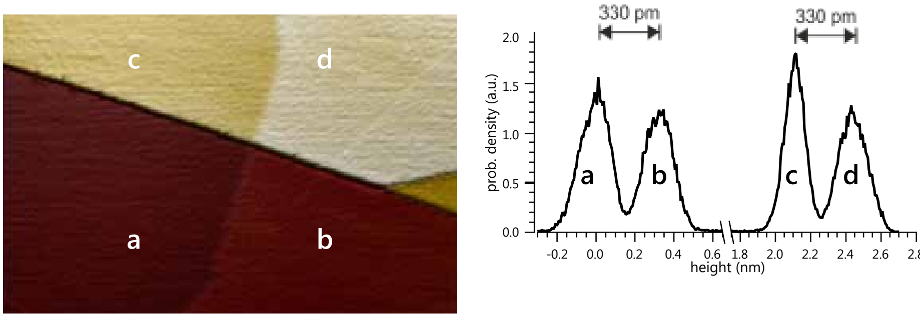
Celgard membrane imaged at 10 Hz line rate. Image size 1.85 x 1.85 μm^2

2D materials: New frontiers

2D materials such as graphene or hexagonal boron nitride (hBN) are a relatively new class of materials that over the past decade have gained more and more attention due to their special mechanical and electrical properties. AFM has become the method of choice to investigate these materials due to its high spatial resolution and the availability of a number of modes that allow characterizing their nanomechanical or nanoelectrical properties. Typical applications for 2D materials include:

- Determination of flake or layer thickness
- Material growth defect analysis
- Stacked layer mismatch
- Electrical properties of single layers or stacks
- Mechanical properties of single layers or stacks
- Local modification, e.g. cutting

Physical properties of 2D materials depend very much on the number of layers stacked on top of each other. Thus, controlling and determining the number of layers with atomic layer accuracy is of utmost importance. The DriveAFM with its overall low noise floor is well-prepared for this task.



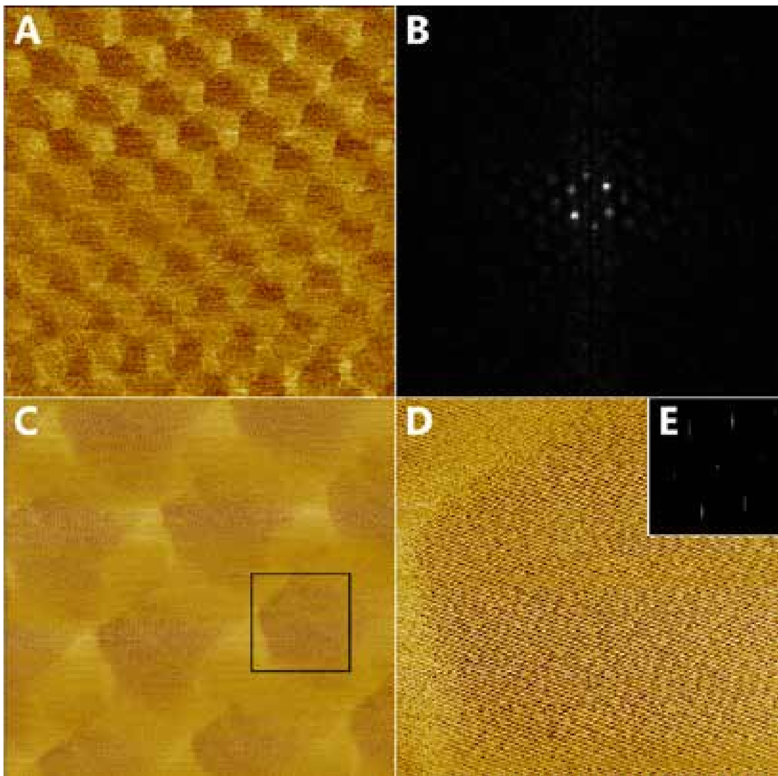
Left: Dynamic mode topography image of an HOPG surface imaged in air. The surface shows different steps between different graphite layers. Image size: 500 x 345 nm^2. **Right:** Height histogram of the HOPG surface shown on the left. The spacing of two neighboring peaks in the histogram corresponds to 330 pm, the expected step height between two graphite layers.

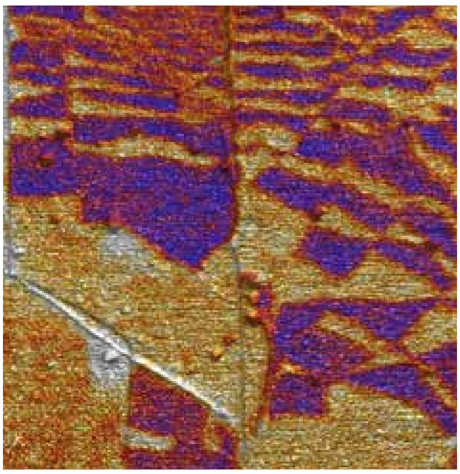
Resolving properties of twisted layers: Moiré superlattices, atomic lattice and electrical properties

Stacks of 2D materials such as graphene, hexagonal boron nitride (hBN) or transition metal dichalcogenides can show extraordinary optical but also electronical properties. These originate from the interaction between different layers of 2D materials and how they are modulated by e.g. differences in lattice constants, translational shift or twisted angles between the layers. Such interactions can result in moiré superlattices.

The ultra-low noise floor and high-resolution imaging capabilities, and the availability of different electrical imaging modes make the DriveAFM the instrument of choice for investigating such moiré patterns and superlattices. The examples below show that the high-resolution imaging capabilities not only allow imaging the moiré superlattice of twisted graphene layers but also the underlying atomic lattice of the uppermost graphene layer. The capability of performing nanoelectrical measurements helps visualizing the varying surface potential properties of twisted hBN layers.

Moiré superlattice of twisted graphene on hBN imaged in force modulation mode on the contact resonance frequency. (A) phase image with scan size of: 190 x 190 nm^2 (B) Center part of the Fourier transform image used to determine the lattice constant of the moiré pattern (C) phase image of 68 x 68 nm^2 area rescanned with 1024 x 1024 px^2 containing both the moiré superlattice and atomic lattice. (D) Digital zoom of the (C) of 17 x 17 nm^2. (E) Fourier transform showing the diffraction spots from the atomic lattice. Sample courtesy: Nanoelectronics group TIFR, India.

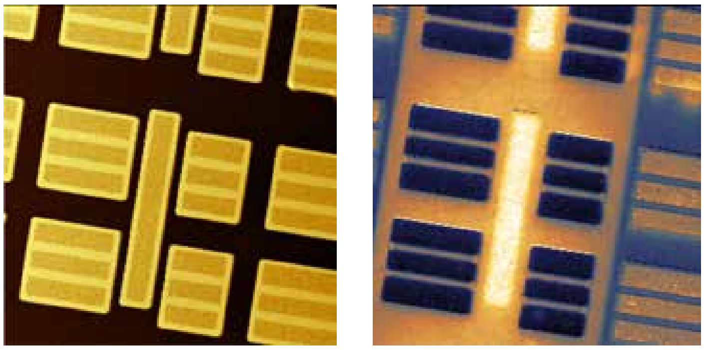




3D surface topography of a twisted hBN bilayer superimposed with the corresponding KPFM signal. Image size 4.9 µm, color scale (blue-red-yellow): 0.3 V. Sample courtesy: Yiming Song & Thilo Glatzel, University of Basel

Material characterization

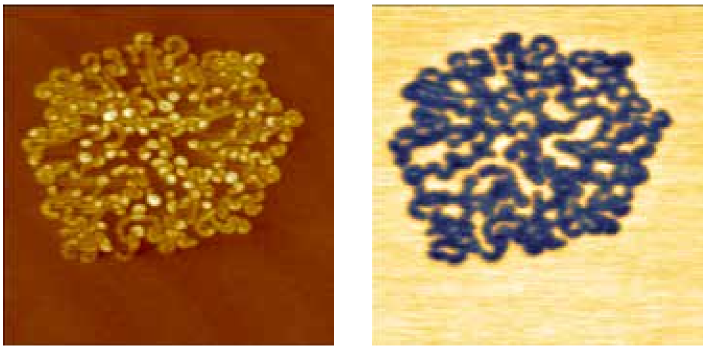
The DriveAFM offers extended functionality to address the needs of researchers from different fields of application to characterize materials. The universe of options and accessories offer capabilities for nanoelectrical (EFM, KPFM, PFM), nanomagnetic (MFM), or nanomechanical (force modulation, force mapping) analysis of your sample.



Left: Topograpyh of a SRAM sample. **Right:** Corresponding AM-KPFM signal at 2^{nd} eigenmode. Image size 40 x 40 μm^2. KPFM color range: 700 mV

Kelvin Probe Force Microscopy

Kelvin Probe Force Microscopy (KPFM) is one of the most commonly used electrical AFM modes. It measures the surface potential, one of the fundamental properties of a material, which is also often referred to as contact potential difference (CPD) or work function between AFM tip and sample. KPFM measurements have gained great importance in characterization of a variety of materials from different areas of application, such as semiconductor materials, solar cells, battery research, metallurgy, and 2D materials. The DriveAFM allows performing and implementing a variety of different KPFM measurement modes.

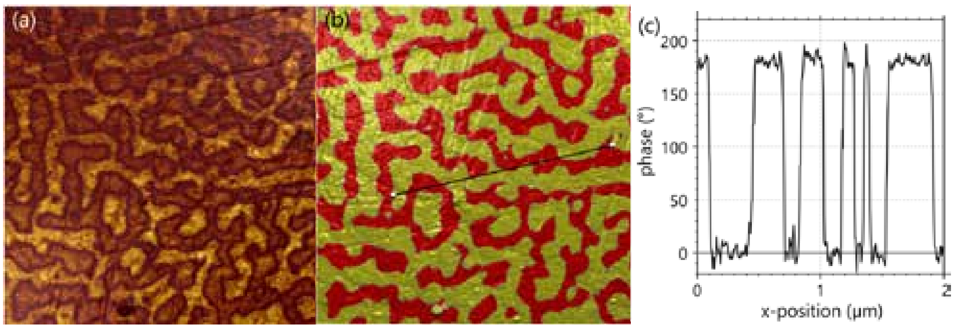


Left: Topography of a fluorinated alkane. **Right:** Corresponding heterodyne FM-KPFM signal. Image size 2 x 2 μm^2. KPFM color range: 2 V

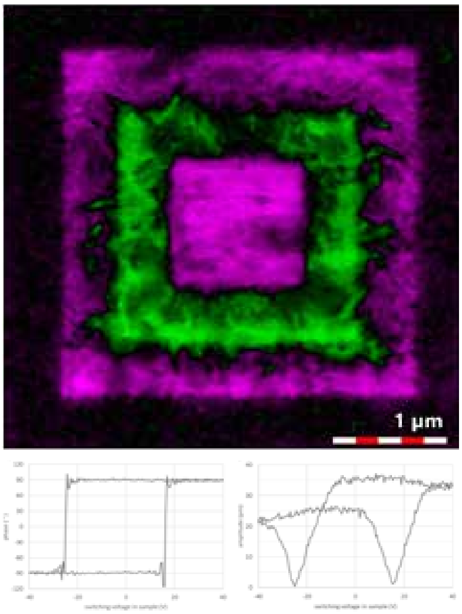
Piezo-response Force Microscopy

Piezoelectric materials are ubiquitous in our daily life and many new and emerging technologies rely on such materials. Piezo-response Force Microscopy (PFM) can measure the local inverse piezoelectric response with high spatial resolution. This information is directly correlated to the simultaneously acquired surface topography. PFM measurement thus help to better understand structure-function relationships.

PFM is a part of the DriveAFM's nanoelectrical measurement toolbox. Depending on the requirements, the DriveAFM provides different flavors of PFM measurements: Traditional PFM, lateral PFM, dual-frequency resonance tracking PFM, PFM spectroscopy, high-voltage PFM, and PFM lithography.



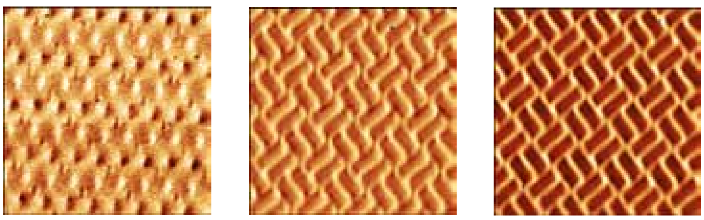
PFM measurement at contact resonance frequency (a) amplitude (arbitrary units), (b) phase (c) profile in the phase, showing domain widths ~100 nm range. Image size: 3 x 3 μm^2. Sample courtesy: Prof. A. Kholkin, University of Aveiro, Portugal, data courtesy: Sergei Magonov, SPM labs, AZ



PFM on a P(VDF-TrFE) thin film. **Top:** Amplitude projection after applying DC sample bias of 40 V, -40 V, and 40 V during consecutive scanning of 3 x 3 μm^2, 2 x 2 μm^2, and 1 x 1 μm^2 areas, respectively. The pink and green areas indicate areas of opposite polarization. AC amplitude 5 V. **Bottom:** Piezo-response hysteresis loop of both amplitude (left) and phase (right) vs applied voltage obtained by SS-PFM.
Sample courtesy: Joanneum Research Forschungsgesellschaft mbH, Austria

Magnetic Force Microscopy

Magnetic Force Microscopy (MFM) is commonly used to reconstruct the magnetic structure of a sample and to correlate it to the sample topography by measuring the magnetic stray field of the sample. Some areas of application include metal alloy or storage media research. Nanosurf's Variable Magnetic Field (VMF) sample holder extends the applicability of MFM measurements to samples that show field-dependent effects. The VMF allows software-controlled adjustment of the applied in-plane magnetic field.

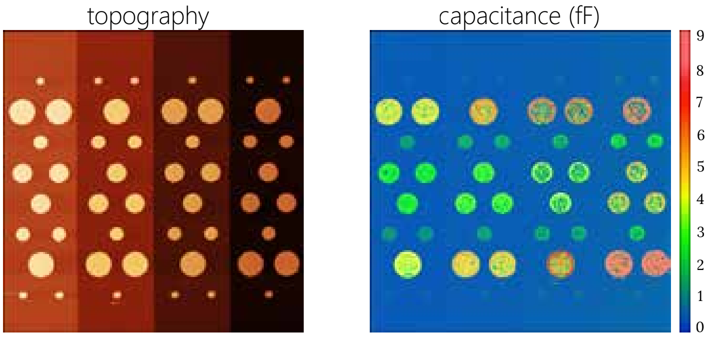


Shakti lattice measured in the variable magnetic field holder under varying horizontal magnetic fields of 10 mT, -50 mT, and -200 mT (left to right)

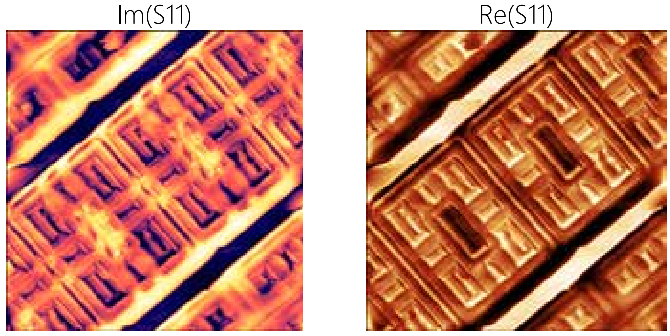
Scanning Microwave Microscopy

Scanning Microwave Microscopy (SMM) is a technique that provides information about the local capacitance and resistance of samples. From these parameters other local sample properties like the dielectric constant (ε), conductivity (σ), carrier density (n), and dopant type can be deduced. SMM can even reveal buried structures that are prevalent in modern multilayered integrated circuits.

With its ultra-high capacitance sensitivity and the ability to differentiate dopant types, Nanosurf's SMM option is an indespensible technique for characterizating semiconductor materials and electronic structures. It extends the DriveAFM's capabilities to provide deep insights into nanoelectrical properties of a variety of materials and miniaturized electronics that are vital for research and development.



Topography (left) and capacitance (right) image of the MC2 Technology capacitance calibration sample. Image size 52 x 52 µm^2, height range topography: 430 nm, smallest capacitance 0.3fF, steps between terraces 0.04 fF.

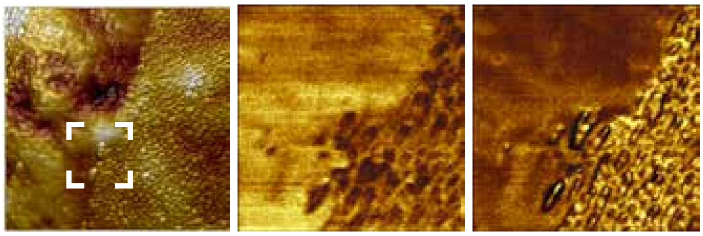


Imaginary (left) and real (right) part of the complex S11 parameter on an SRAM sample. In a calibrated measurement, the imaginary part reports differences in capacitance while the real part reflects local sample resistance. Image size 25 x 25 µm^2.

Force spectroscopy and nanomechanical characterization

The DriveAFM offers a large z-range of 20 µm and is therefore the ideal solution for force spectroscopy-based nanomechanical analysis of a wide range of materials - from soft to stiff. Force curves can be analyzed to extract e.g. the adhesion force or, using different contact mechanics models, to deduce the sample's local Young's modulus. The large z-range also allows analyzing samples with strong corrugation or long-range adehsion.

Calibration of spring constant and deflection sensitivity can be performed without sample contact to preserve the tip.



Left: Topography of a metalized polymer film. Image size 770 x 770 nm^2
Middle and right: Adhesion and DMT modulus maps of the of the area. Image sizes: 250 nm x 250 nm^2; adhesion range: 5 nN; modulus range: 1.5 GPa

Scripting access - not only for pioneers

At Nanosurf we have realized that leading researchers often want to modify the standard routines of an instrument – or else everyone would be doing the same science with the same hardware. For the cases where application-specific routines, the scope of which we cannot predict and provide out of the box, we developed the Nanosurf Scripting Interface. It can be used to automate routine tasks and for creating new experiments. It gives the users full control over the user interface, and some control over the hardware functionality.

The Nanosurf control software publishes its functionality via the COM interface, by running an instance of COM Automation Server. COM Automation Clients can ask the server during the runtime about its functions and access them. These functions can be accessed through most modern programming languages: Python, C++, C#, VBS, Matlab, JS, LabView, etc.

For ease of use, Nanosurf has created a Python API for its COM interface. We chose Python as our API language, because of its practicality, popularity and universality, and because of the large number of data and image processing libraries already used in academia and industry.

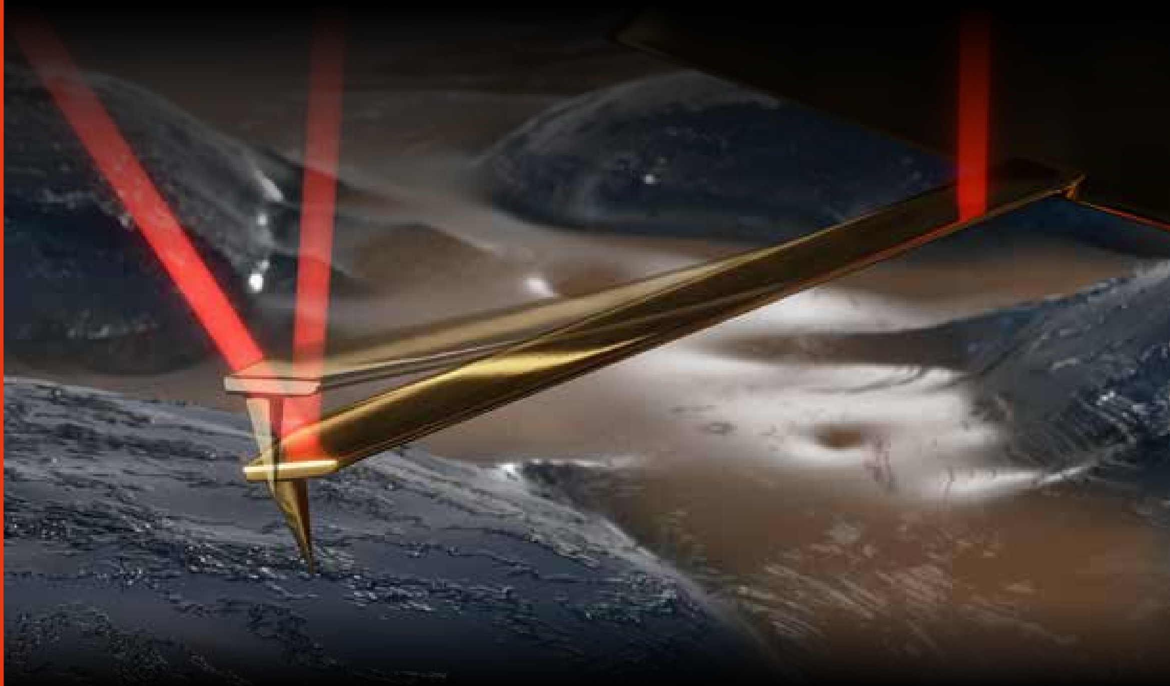
Add-on slot

Staying true to the idea of a versatile and modular system, the DriveAFM is equipped with a slot for add-on modules. The add-on modules can be easily installed by a user to expand the functionality of the DriveAFM. Add-on modules may provide access to the tip or allow interfacing with other devices. Currently, two add-on modules are available:

- Tip-current module: Variable gain low-noise current preamplifier
- Tip-access module: Direct tip connection for up to ±100 V tip bias

DriveAFM with its top-view camera and tip-current module installed

The development continues and new, exciting add-ons will follow to make the DriveAFM even more versatile and powerful.



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