COMPACT LOW TEMPERATURE
SCANNING PROBE MICROSCOPES

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PPMS® SPM

Compact Low Temperature Scanning Probe Microscopes

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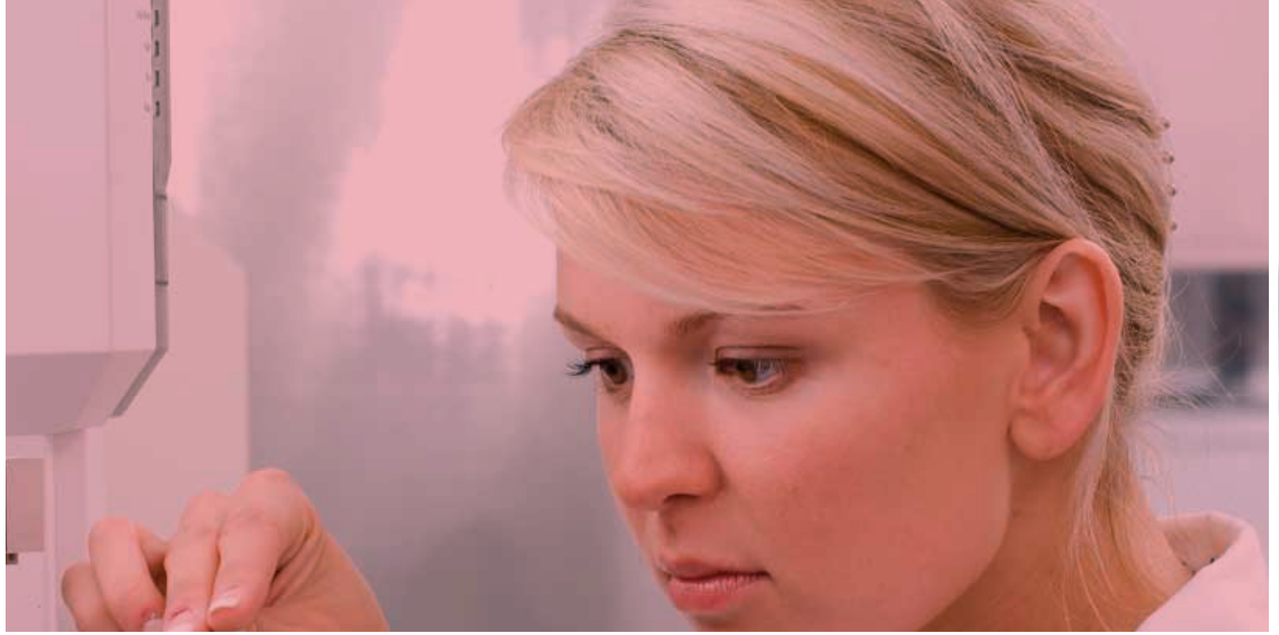
01
SCANNING PROBE MICROSCOPY

FOR THE QUANTUM DESIGN PPMS®

attocube systems' scanning probe microscope family (CFM, AFM, MFM, SNOM*, and STM*) has undergone a redesign to fit any 25 mm (1") static sample space including the Quantum Design PPMS®. Despite the compactness, all microscopes provide a coarse travel range of 3 x 3 x 2.5 mm^3 and a scan range of 12 x 12 μm^2 at low temperature (4 K). The outstanding stability of the microscopes allows investigation of nm-sized structures with highest resolution making these instruments versatile tools for state-of-the-art research on the nanometer scale.

attocube systems and Quantum Design have announced a strategic partnership to promote and distribute attocube's new scanning probe microscopes designed specifically for the PPMS® of Quantum Design. This collaboration expands technology reach and provides both new and existing PPMS® customers with easier access to additional measurement and characterization techniques.



With the SPM insert for the Physical Property Measurement System (PPMS®) of Quantum Design, attocube meets growing demands for highly sophisticated yet easy-to-use scanning probe microscopes.

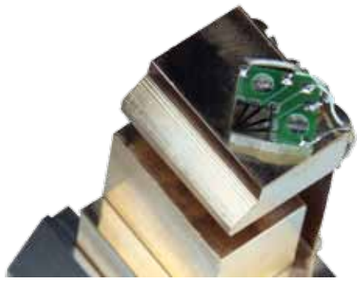
The ultra-compact, high resolution PPMS®-SPM uses advanced technologies such as low temperature compatible objectives for confocal microscopy or a fiber-optical interferometer for force microscopy with outstanding signal-to-noise force detection. The rugged housing construction is made from highest quality Titanium, ensuring maximum stability and minimum sample drift during variation of temperature and/or magnetic field. The patented driving technology of the coarse positioning system warrants a precise and reliable sample approach and positioning in three dimensions with nanometer precision over several millimeters range. Plus, the instrument is fully compatible with commercially available AFM / MFM cantilevers.

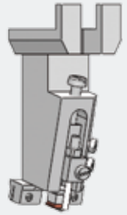
In combination with the Quantum Design PPMS® with its broad temperature and magnetic field range, stability and ease of use, exciting new measurements are only some clicks away ...

** available on request.*

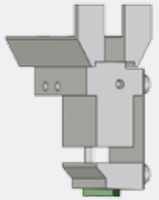
THE NEXT LEVEL PPMS SOLUTION

THE ONLY SCANNING PROBE MICROSCOPES FOR THE PPMS® CERTIFIED & ENDORSED BY *QUANTUM DESIGN*.





Magnetic Force Microscopy (MFM)



Scanning Hall Probe Microscopy (SHPM)

Atomic Force Microscopy (AFM)

Confocal Microscopy (CFM)

attoAFM xs
ultra-stable, compact atomic force microscope
with interferometric deflection detection for highest stability and sensitivity. Compatible with contact and non-contact AFM mode.

attoMFM xs
ultra-stable, compact magnetic force microscope
with interferometric deflection detection for highest stability and sensitivity. Compatible with dual-pass and constant height MFM mode.

attoCFM xs
ultra-stable, compact confocal microscope
based on fiber or free-beam optics for maximum flexibility and stability.

attoSHPM xs
ultra-stable, compact scanning Hall probe microscope
with STM tracking 2DEG Hall sensor for maximum field sensitivity.

02
attoMFM Ixs

LOW TEMPERATURE MAGNETIC FORCE MICROSCOPE

The attoMFM Ixs is an ultra-compact magnetic force microscope designed particularly for applications at low and ultra low temperature. On the basis of a conventional atomic force microscope, the instrument works by scanning a sample below a fixed magnetic cantilever. The magnetic force gradient acting on the tip is then determined by measuring the change in resonance frequency (FM mode) or phase of the cantilever (AM mode) with highest precision using a fiber-based optical interferometer. Both measurement modes are applied at a certain tip-sample distance, typically around 10 - 100 nm. In FM mode, a phase-locked loop (PLL) is used to excite the cantilever at resonance.

Principle - The microscope uses a set of xyz-positioners for coarse positioning of the sample over a range of several mm. Developed particularly for cryogenic applications, the piezo scanner ANSxy50 provides a scan range of 12 x 12 µm² even at liquid helium temperature. The adjustment of the MFM cantilever is performed outside of the cryostat prior to cooling down the microscope. The exceptional combination of materials allows absolutely stable high resolution imaging of surfaces.

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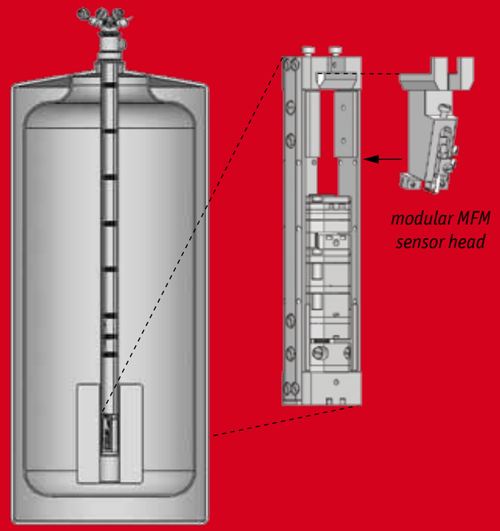

01. Schematic drawing of the low temperature attoMFM Ixs and the surrounding PPMS dewar.

02. The attoMFM Ixs microscope module.

03. ASC500 iBox - manual control unit for the ASC500 SPM controller.

02

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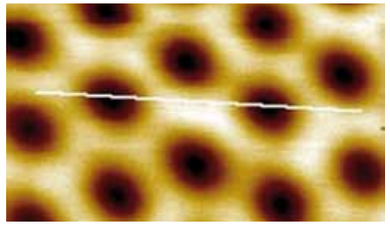

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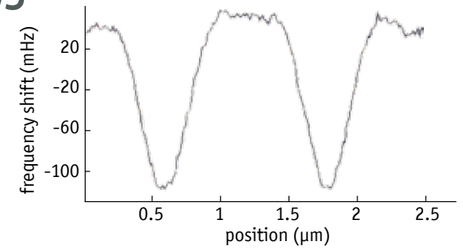

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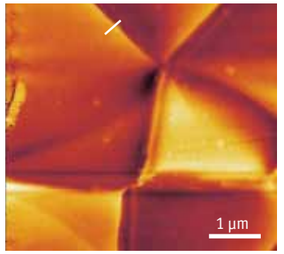
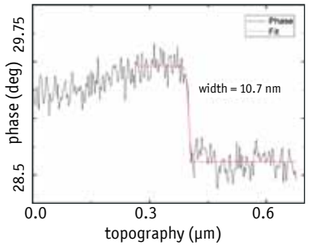




Results

04. Hexagonal vortex lattice in optimum doped Bi-2212 at a temperature of 4.1 K and a magnetic field of 45 Gauss. The image shows unprocessed, as-measured MFM phase data recorded at 70 nm constant height.

05. Line scan of the above shown vortex lattice in optimum doped Bi-2212.

06. MFM measurement on 300 nm NiFe Pads showing their magnetic structure. The image was recorded at 300 K with 20 nm tip-sample separation in dual-pass mode, yielding a spatial resolution of 10.7 nm and a phase contrast of 2.3 degrees.

Specifications

Operation Mode	feedback imaging modes	PI feedback loop with additional PLL contact mode, non-contact mode, high-resolution MFM mode, EFM, SGM
Sample Positioning	coarse range step size fine scan range temperature range	3 x 3 x 2.5 mm³ @ 300 K: 0.025 .. 2 µm @ 4 K: 10 .. 500 nm 30 x 30 x 5 µm³ 12 x 12 x 2 µm³ 1.9 .. 400 K (full PPMS® temperature range)
Operating Conditions	magnetic field range operating pressure	0 .. 16 T (full PPMS® magnetic field range) 1E-6 mbar .. 1 bar (designed for exchange gas atmosphere)
Noise	measured RMS z-noise (contact mode; 4 K, 5 ms int. time) deflection noise density measured force noise (0.2 N/m)	0.12 nm (guaranteed) 0.05 nm (expected) 0.5 pm/Hz $^{1/2}$ (dependent on laser system) < 100 pN in a 1 kHz bandwidth
Resolution	lateral magnetic resolution control electronics lateral (xy) bit resolution at 300 K z bit resolution at 300 K lateral (xy) bit resolution at 4 K z bit resolution at 4 K	< 20 nm 16 bit over selected scan range (virtually unlimited bit resolution) 0.61 nm at 40 µm scan range 0.36 nm at 15 µm scan range 0.46 nm at 30 µm scan range 0.23 nm at 15 µm scan range
Sample Size	maximum	10 x 10 x 5 mm³

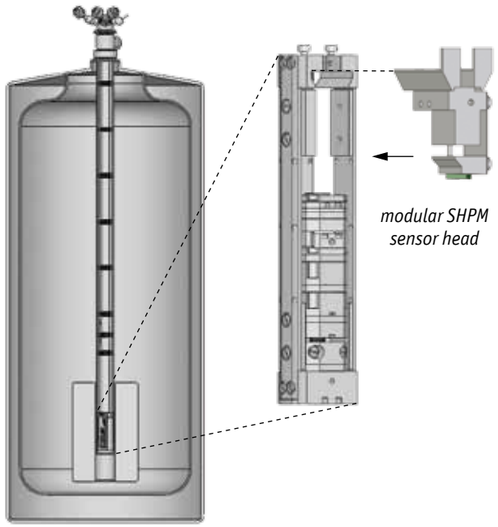
03
attoSHPM xs

LOW TEMPERATURE SCANNING HALL PROBE MICROSCOPE

The attoSHPM xs is an ultra-compact scanning Hall probe microscope, designed particularly for the operation at low temperature and high magnetic fields. At the heart of the SHPM, a molecular beam epitaxy (MBE) grown GaAs/AlGaAs Hall sensor measures magnetic fields with unrevealed sensitivity. Local measurements of the magnetization of a sample are obtained by scanning the sample underneath the Hall sensor and simultaneously recording the Hall voltage, directly yielding the local magnetic field. While other local probes may outperform the Hall sensor with respect to its lateral resolution, its ability to non-invasively obtain quantitative values for the local magnetic field makes the Hall sensor a unique tool for the study of superconductors and other magnetic materials.

Principle - The microscope uses a set of xyz-positioners for coarse positioning of the sample over a range of several mm. The scanning motion of the sample is provided by an ANSxy50 piezo scanner, providing a scan range of 12 x 12 µm² at 4.2 K. The adjustment of the Hall sensor is performed outside of the cryostat prior to cooling down the microscope. The exceptional combination of materials allows absolutely stable high resolution imaging of surfaces/ local magnetic fields.

01



01. Schematic drawing of the low temperature attoSHPM xs and the surrounding PPMS dewar.

02. Close-up of the attoSHPM xs microscope module.

03. Photograph of the attoSHPM xs microscope head, showing the Hall chip and its carrier (green). The tilt angle of the Hall sensor with respect to the sample can be arbitrarily adjusted between 0° and approximately 5°.

02

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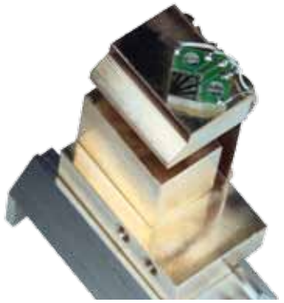

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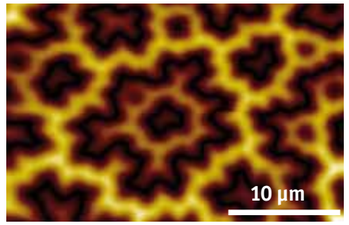
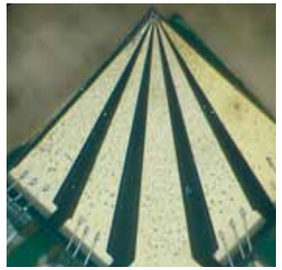
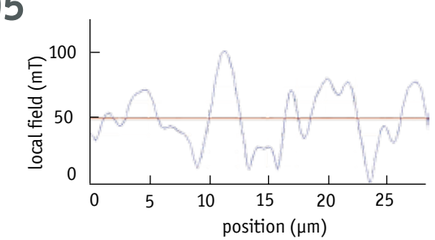




Close-up of the MBE grown SHPM chip, showing its Hall-sensor/STM leads and the bond wires for electrical connection to the chip carrier. The Hall sensors are available as high resolution and ultra-high resolution version, featuring an active Hall area of 500x500 nm² and 300x300 nm², respectively.

05



Results

04. SHPM image of BaFeO, recorded at a 4.2 K in constant height mode. The color scale spans 106 mT (black to white), while the S/N ratio of this measurement yields 2x10⁻⁵ T.

05. Linecut through the full SHPM scan of BaFeO as depicted in Fig. 04, recorded at 4.2 K in constant height mode.

Specifications

Operation Mode	feedback imaging modes	STM tracking distance detection, tuning fork tracking on request STM tracking, constant height, or dual pass mode
Sample Positioning	coarse range step size scan range temperature range	3 x 3 x 2.5 mm³ @ 300 K: 0.025 .. 2 µm @ 4 K: 10 .. 500 nm 30 x 30 x 5 µm³ 12 x 12 x 2 µm³ 1.9 .. 400 K (full PPMS® temperature range)
Operating Conditions	magnetic field range operating pressure	0 .. 16 T (full PPMS® magnetic field range) 1E-6 mbar .. 1 bar (designed for exchange gas atmosphere)
Resolution	control electronics lateral (xy) bit resolution at 300 K z bit resolution at 300 K lateral (xy) bit resolution at 4 K z bit resolution at 4 K	16 bit over selected scan range (virtually unlimited bit resolution) 0.61 nm at 40 µm scan range 0.36 nm at 24 µm scan range 0.45 nm at 30 µm scan range 0.23 nm at 15 µm scan range
Hall Sensor	design spatial resolution field sensitivity noise-equivalent magnetic field attainable field detection limit	MBE grown GaAs/AlGaAs heterostructure (Bi sensors for RT operation on request) 500 nm (high resolution), 300 nm (ultra-high resolution) 1500 V/AT 15 nT/Hz$^{1/2}$ at 4 K, 80 nT/Hz$^{1/2}$ at 77 K 10 µT at 4 K typ.
Sample Size	maximum	10 x 10 x 5 mm³

04
attoAFM Ixs

LOW TEMPERATURE ATOMIC FORCE MICROSCOPE

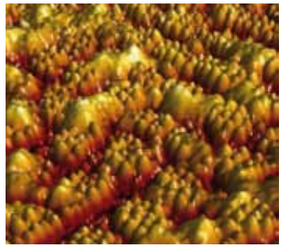
The attoAFM Ixs is an ultra-compact atomic force microscope designed particularly for applications at low and ultra low temperature. The instrument works by scanning a sample below a fixed cantilever while measuring its deflection with highest precision using a fiber based optical interferometer. Combined with the ASC500 SPM controller, both contact and non-contact modes are applicable, making the attoAFM Ixs a powerful tool for topographic measurements, force spectroscopy and other imaging modes. Apart from these capabilities, the superior mechanical stability of the measurement head allows an operation inside of cryogen free pulse-tube based cooling systems, providing access to applications where liquid Helium is not available or not desired.

Principle - The microscope uses a set of xyz-positioners for coarse positioning of the sample over a range of several mm. Developed particularly for cryogenic applications, the piezo scanner ANSxy50 provides a scan range of 12 x 12 μm^2 even at liquid helium temperature. The adjustment of the cantilever is performed outside of the cryostat prior to cooling down the microscope. The exceptional combination of materials allows absolutely stable high resolution imaging of surfaces.

PRODUCT KEY FEATURES
> ultra compact AFM head
> highly sensitive interferometric deflection detection
> unreached mechanical stability
> adjustment of the cantilever outside of the cryostat prior to cooling the microscope
> in-situ, long range positioning at low temperature

BENEFITS
> fits standard cryogenic and magnet sample spaces
> high resolution AFM imaging
> quick sample and cantilever exchange
> highest stability in variable magnetic fields
> highest stability at variable temperature
> offers all common contact and non-contact modes (contact, intermittent contact, true non-contact)
> interferometric deflection detection
> large scan range at low temperature
> designed to work seamlessly with the QD PPMS®
> large range, patented coarse positioning system
> patented coarse positioning driving technology

04



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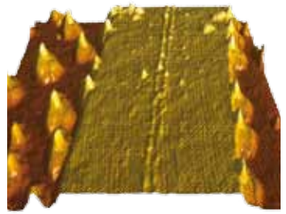
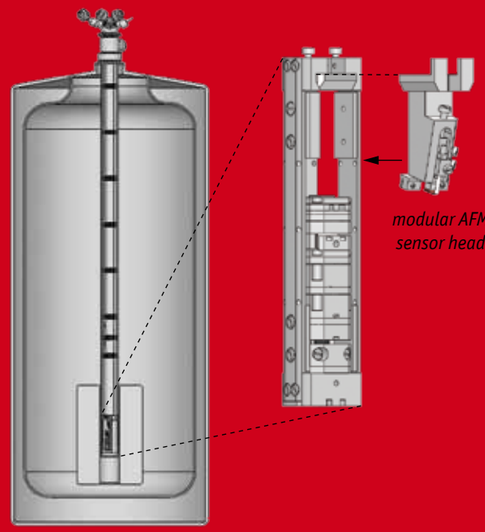


Results

04. AFM contact mode image of an ordered lattice of InAs quantum dot molecules recorded at 4.2 K (attocube application labs, 2007).

05. AFM contact mode image of a layered Si/SiO2-Substrate (height: 20 nm +/- 2 nm) recorded at 4.2 K. Height of surface contaminations: ~ 1 nm. (attocube application labs 2007).

01



01. Schematic drawing of the low temperature attoAFM Ixs and the surrounding PPMS dewar.

02. Close-up of the attoAFM Ixs microscope module.

03. ASC500 - attocube's state-of-the-art Scanning Probe Microscopy controller featuring an open architecture and high flexibility to meet the customers' individual needs.

02

03

Specifications

Operation Mode	feedback imaging modes	PI feedback loop with additional PLL contact mode, non-contact mode, AFM, EFM, SGM, PRFM
Sample Positioning	coarse range step size fine scan range temperature range	3 x 3 x 2.5 mm^3 @ 300 K: 0.025 .. 2 µm @ 4 K: 10 .. 500 nm 30 x 30 x 5 μm^3 12 x 12 x 2 μm^3 1.9 .. 400 K (full PPMS® temperature range)
Operating Conditions	magnetic field range operating pressure	0 .. 16 T (full PPMS® magnetic field range) 1E-6 mbar .. 1 bar (designed for exchange gas atmosphere)
Noise	measured RMS z-noise (contact mode; 4K, 5ms int. time) deflection noise density measured force noise (0.2N/m)	0.12 nm (guaranteed) 0.05 nm (expected) 0.5 pm/Hz $^{1/2}$ (dependent on laser system) <100 pN in a 1 kHz bandwidth
Resolution	control electronics lateral (xy) bit resolution at 300 K z bit resolution at 300 K lateral (xy) bit resolution at 4 K z bit resolution at 4 K	16 bit over selected scan range (virtually unlimited bit resolution) 0.61 nm at 40 µm scan range 0.36 nm at 15 µm scan range 0.46 nm at 30 µm scan range 0.23 nm at 15 µm scan range
Sample Size	maximum	10 x 10 x 5 mm^3

05
attoCFM xs

LOW TEMPERATURE CONFOCAL MICROSCOPE

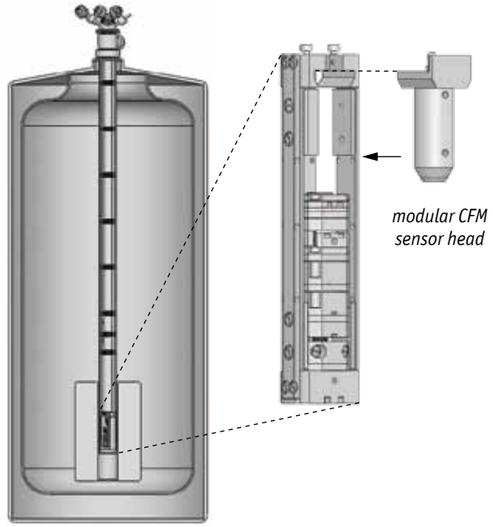
The attoCFM xs has been developed to offer highest flexibility combined with maximum mechanical stability for low temperature confocal microscopy experiments. The attoCFM xs can be ordered with either free-beam or fiber based optics. In case of the free-beam optics, excitation and collection ports are completely independent, allowing the introduction of further optical components (e.g. filter or polarizer) and enabling measurements such as Raman spectroscopy. Offering slightly less flexibility, the fiber based setup is designed for highest mechanical stability allowing single quantum dot measurements over a timespan of several weeks and operation in cryogen-free cryostats.

Principle - The microscope uses a set of xyz-positioners for coarse positioning of the sample over a range of several mm. Developed particularly for cryogenic applications, the piezo scanner ANSxy50 provides a scan range of 12 x 12 µm² even at liquid helium temperature. The exceptional combination of materials allows absolutely stable high resolution imaging of surfaces.

PRODUCT KEY FEATURES
> ultra compact CFM head
> fiber based or free-beam optics
> fully adjustable excitation and collection ports (free-beam)
> wavelength or polarization filtering (free-beam)
> ultra-stable design (fiber based)
> in-situ, long range positioning at low temperature

BENEFITS
> fits 1" clear bore cryostats and magnets
> highest flexibility and sensitivity combined with minimal light loss
> access to optical spectroscopy such as Raman spectroscopy (free-beam)
> highly stable long term measurements

01



01. Schematic drawing of the low temperature attoCFM xs and the surrounding PPMS dewar.

02. Close-up of the attoCFM xs microscope module.

03. attocube offers various low temperature compatible objectives with different numerical apertures and working distances.

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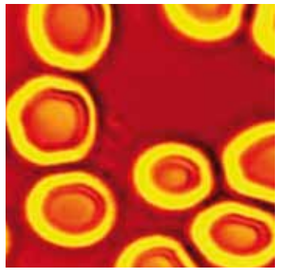
04



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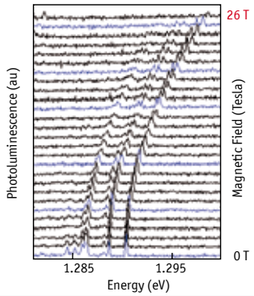


Results

04. Confocal image of red blood cells fixed on a glass slide. The image was recorded with the fiber based CFM in reflection mode (scan voltage 30 V).

05. Photoluminescence spectroscopy of a single quantum dot as exposed to magnetic fields of up to 26 T.

Specifications

Microscope configuration	confocal unit	ultra-stable and compact confocal microscope head
	pinhole configuration	fiber optic or free-beam based illumination / collection fiber (blocking pinhole)
Sample Positioning	step size	@ 300 K: 0.025 .. 2 µm @ 4 K: 10 .. 500 nm
	scan range	30 x 30 x 5 µm³ 12 x 12 x 2 µm³
	temperature range	1.9 .. 400 K (full PPMS® temperature range)
Operating Conditions	magnetic field range	0 .. 16 T (full PPMS® magnetic field range)
	operating pressure	1E-6 mbar .. 1 bar (designed for exchange gas atmosphere)
Illumination	excitation wavelength range	~400 .. 1500 nm (see objectives description)
	light source	fiber coupled laser (typically 400 .. 1500 nm)
	light power on the sample	typically 1 pW .. 500 µW
	port specification	FC/APC-connector for single mode fibers (other connector types on request)
Sample Size	maximum	10 x 10 x 5 mm³

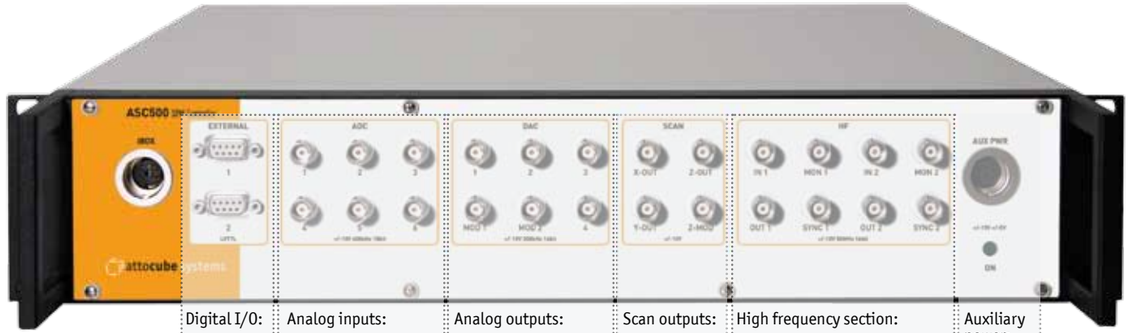
06
ASC500

FULLY DIGITAL SPM CONTROLLER

The ASC500 is a modular and flexible digital SPM controller which combines state-of-the-art hardware with innovative software architecture, offering superior performance and an unprecedented variety of control concepts. The ASC500 controller was developed with the goal to never be the limiting factor in any SPM experiment. All desirable functions and high-end specifications for conducting the experiment of your choice in MFM, SHPM, AFM, CFM, SNOM, STM, and many more are available.

Are you missing the sensitive adjustment possibilities provided by former analog SPM-units? Every ASC500 can be equipped with the ASC-iBox unit allowing fast and controlled manual adjustment of all major parameters. Now you are able to combine the advantages of manual and software control of your experiments.

STATE-OF-THE-ART CONTROLLER (ASC500)



Digital I/O:	Analog inputs:	Analog outputs:	Scan outputs:	High frequency section:	Auxiliary power:
8 inputs 8 outputs 40 MHz	6 converters 400 kHz 18 bit	4 converters 200 kHz 16 bit 2 analog modulation inputs	3 converters 5 MHz in xy; highest resolution, z modulation input	2 independent HF channels with each: 50 MHz 16 bit input 50 MHz 16 bit output Sync output Preamplified signal monitor	+/- 5 V +/- 15 V

Scan Engine:

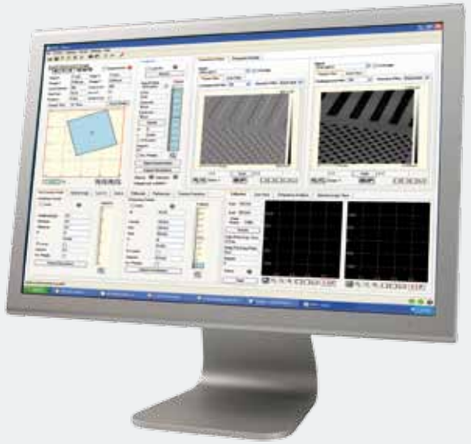
The ASC500 uses a dedicated hardware with a 5 MHz scan generator, creating the scan voltages necessary for any Scanning Probe Microscope. The 16 bits of the xy outputs are always automatically mapped to the actual scan field, yielding a virtually unlimited bit resolution.

Z controller:

The z scanner output is controlled by a digital PI algorithm with a bandwidth of 50 kHz. The z output DAC has a resolution of 18 bit, yielding a 4 pm resolution on a 1 µm scan range. This resolution can be increased to a theoretical value of 60 **attometer** by limiting the control range.

PLL

A fully digital phase locked loop is implemented into the ASC500, taking advantage of the the high frequency inputs/outputs with 50 MHz bandwidth. A high-speed Lock-in demodulator and two PI control loops are used to control the amplitude of an oscillator and to follow any shifts in resonance. The frequency resolution is below 0.2 µHz in a range of 1 kHz up to 2 MHz.



Q Control

The ASC500 provides full control over the Q factor of any driven lever system by means of electronic Q control. The natural Q factor of the lever can be varied by typically more than one order of magnitude in each direction (increase/decrease).

LabVIEW™ control

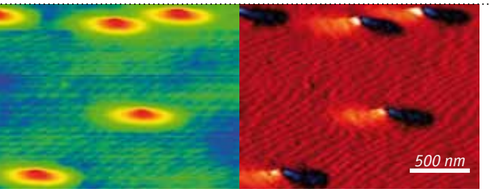
The new LabVIEW™ interface provides full control over all ASC500 functions. Benefits are: measurement automatization, user definable experiments, and easy implementation with 3rd party instrumentation.

Spectroscopy

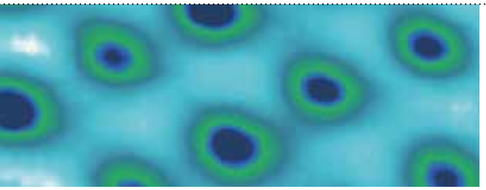
The ASC500 features advanced spectroscopy techniques such as z spectroscopy and bias voltage spectroscopy. These measurements are supported by an internal Lock-in amplifier and a limiter functionality which drastically reduces the likelihood of a tip crash. Spectroscopy measurements can be automatically triggered on line, grid, or point-by-point paths. Combinations of spectroscopies can be defined in action lists.

07
ATTOCUBE SYSTEMS' CONTROLLER

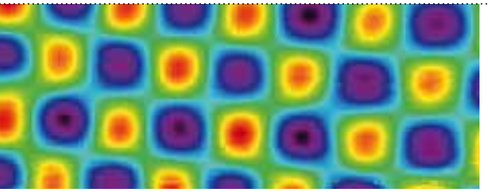
OPEN UP NEW POSSIBILITIES



The internal PLL of the ASC500 was used to control a high Q tuning fork AFM. Topography measurements were performed on uncapped, stacked InAs Quantum Dots in a GaAs matrix. The evaluation of the height distribution revealed atomic steps with a spacing of ~2 Ångstrom. Topography and error signal were recorded simultaneously.



A cantilever based low temperature MFM was used to image single vortices on BSCCO. The signal quality could be significantly enhanced by using the Q control functionality of the ASC500. The Q factor of the MFM lever was increased by a factor of 4 to record this image. For non-flat surfaces, dual pass mode can be employed for highest magnetic resolution.



The ASC500 provides a step scan function to gain unlimited scan range at low temperatures. The above image was taken using a confocal microscope on a test grating. The raster motion was achieved by single step coarse movement of xy positioners. The ASC500 controls the coarse movement and synchronizes data collection.

The ANC350 is attocube's multi-functional piezo controller which meets the highly demanding dynamic performance and accuracy requirements of multi-axis nanopositioning setups. The real-time operating system enables the closed loop control of attocube's nanopositioners with optoelectronic and resistive encoders. All functionalites are accessible via USB 2.0 or an optional Ethernet port.

The ANC250 is a dedicated, ultra low noise scan voltage amplifier for piezo scanning tubes and flexure scanners. With an output noise of 20 μV_{RMS} @ a 500 kHz bandwidth, the ANC250 offers the lowest noise specs on the market. Its three input channels drive five bipolar output channels with an amplification of +/- 20. The output voltages (x+, x-, y+, y-,z) of up to +/- 200 V are ideally suited to drive piezo tube scanners.

08
ATTOCUBE SYSTEMS

CREATING SCIENTIFIC IMPACT

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