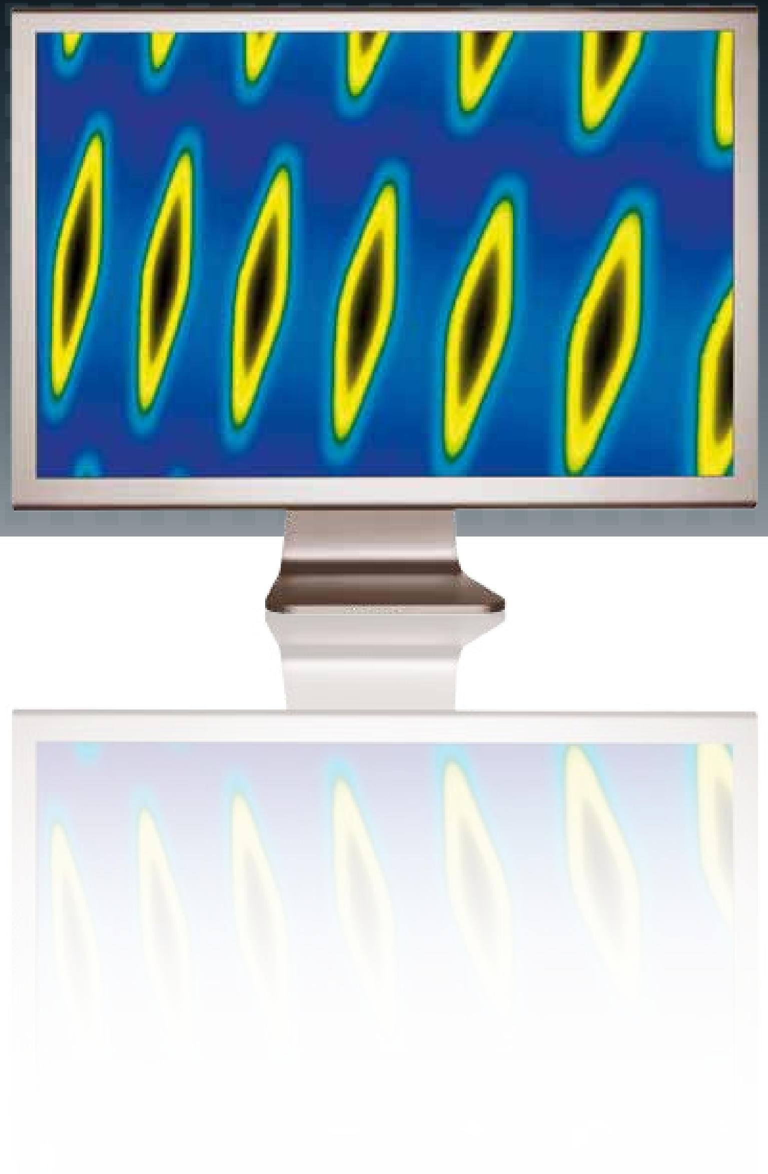
LOW TEMPERATURE
SCANNING PROBE MICROSCOPES



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Brochure version: 2010 - 01

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explore your nanoworld

LOW TEMPERATURE
SCANNING PROBE MICROSCOPES

atto**CFM/SNOM**

Low Temperature Confocal &
Scanning Near-Field Optical Microscopes

attocube systems
explore your nanoworld

01
WORKING PRINCIPLE
CONFOCAL MICROSCOPY (CFM I, CFM II, CFM III)

Confocal Microscopy (CFM) has become the method of choice for obtaining clear, three-dimensional optical images of sample structures. This non-invasive approach has been used for imaging almost anything - from studying biological samples such as cells, fluorescence measurements, to examining physical structures such as semiconductor quantum dots, NEMS/MEMS devices and also for the emerging area of nano-optics.

The confocal imaging system achieves out-of-focus rejection by two strategies:
1. Illuminating a single point of the specimen with a focused beam. Thus, the illumination intensity drops rapidly above and below the plane of focus.
2. Using of a blocking pinhole in the conjugate plane to the specimen that eliminates the degrading out-of-focus information.

By scanning many thin sections through the sample a very clean three-dimensional image can be obtained. Confocal imaging can offer another advantage in favourable situations (small pinhole size, bright specimen):
the obtained resolution can be better than with any microscope operated conventionally. In practice, the best horizontal resolution of a confocal microscope is about 0.4 µm, and the best vertical resolution is about 1.4 µm, assuming an excitation wavelength of 633 nm and a numerical aperture of 0.65.

Cryogenic Confocal Microscopy

To improve the image quality in high resolution microscopy, confocal microscopes are often used at cryogenic temperatures. At these conditions, a combination of high resolution power, clear optical spectra, and reduced thermal noise can be achieved.

Spectral lines become sharper as thermal broadening is reduced due to the lower thermal energy present in the system. Optical signals become stronger as quantum efficiency is improved due to less scattering and non-radiative recombinations. For many optical microscopy applications cryogenic temperatures are therefore inevitably required.

These advantages are beneficial particularly for high resolution optical spectroscopy of semiconductor structures or single molecule detection. Thus, investigation of the emitted optical energy of the sample due to changes in the surrounding material, applied voltages, or the deposited optical energy becomes feasible.

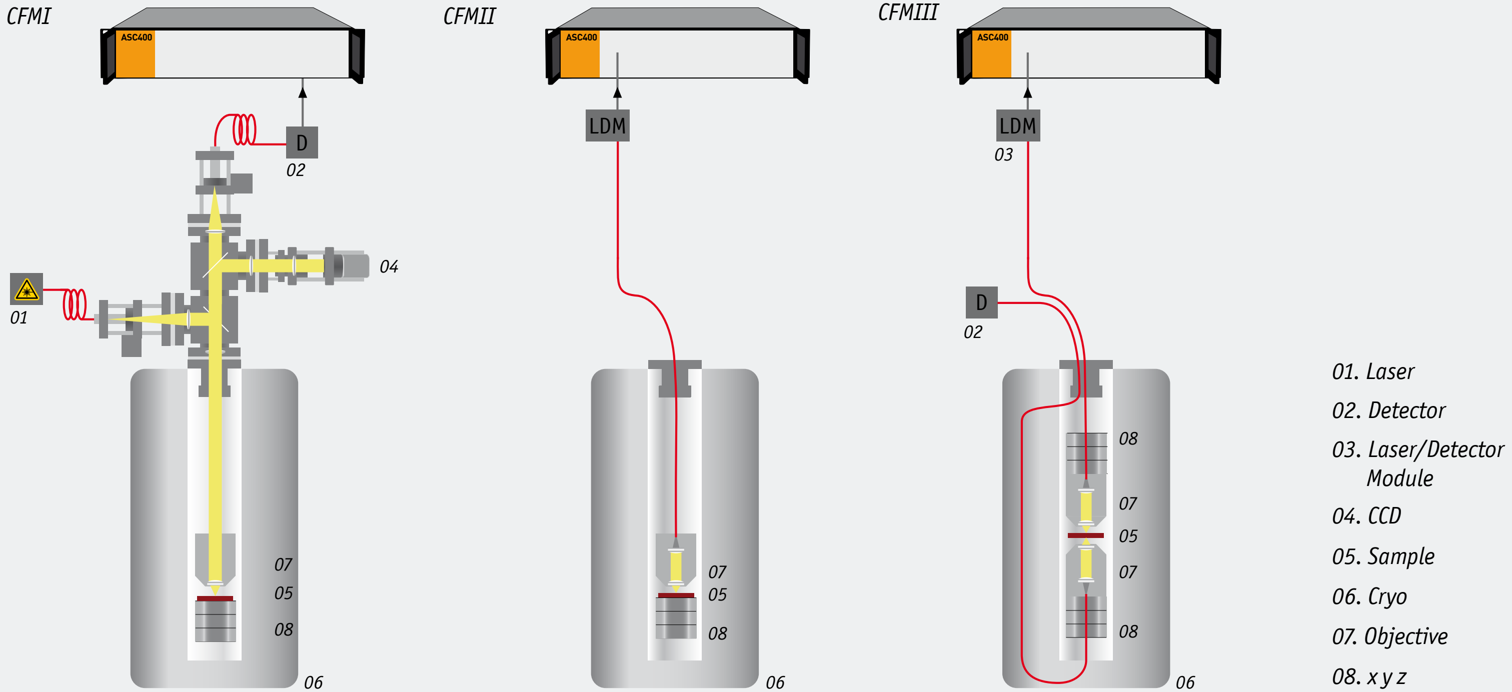
Additionally, high spatial resolution and sharp spectral lines are a prerequisite for investigating photon anti-bunching (single photon emitters).

attocube systems' CFMs
A decade of experience in low temperature optics led to the development of three complementary confocal microscope systems optimized for different applications.

attoCFM I:
This system based on free beam optics has been developed to offer highest flexibility to the customer. The modular beam splitter head is mounted outside of the cryostat and thus, the experiment can be adjusted to the customer's requirements.

attoCFM II:
The key-feature of this system is its unprecedented stability allowing ultra stable long-term investigations. This is also the most compact system, which is available for 2 inch and 1 inch (attoCFM IIxs) bore size cryostats.

attoCFM III:
This is the system of choice for customers interested in both reflection and transmission confocal microscopy. Similar to the attoCFM II, the attoCFM III is also a fiber-based system.

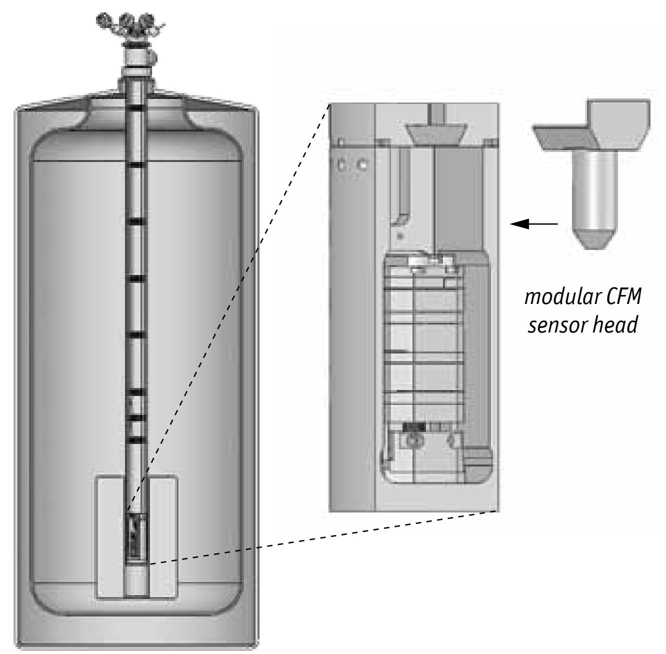


02
attoCFM I
LOW TEMPERATURE CONFOCAL MICROSCOPY

The attoCFM I has been developed to offer highest flexibility in order to enable adaptation of the experimental setup according to the customer's needs. This flexibility is realized by a modular beam splitter head which is positioned outside of the cryostat. Furthermore, the free-beam optical design allows a completely independent adjustment of the excitation and collection port. Therefore, applications such as Raman spectroscopy, fluorescene measurements, or white light scattering become accessible by appropriately filtering the excitation and collection signals. The easy handling opens up new possibilities in quantitative surface characterization in the sub-micron range.

Principle - A photo of the attoCFM I microscope module is shown below. A laser beam is coupled into a single mode optical illumination fiber. Part of this light is reflected on the beam splitter and focused on the sample (free-beam optics inside the cryostat). The reflected light from the sample is collected by the same objective, which acts as the blocking pinhole aperture when collecting the scattered light from the sample.

01

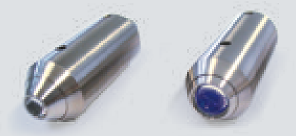


01. Schematic drawing of the low temperature attoCFM I and the surrounding liquid helium dewar (optional)

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

03. The attoCFM I microscope module

02



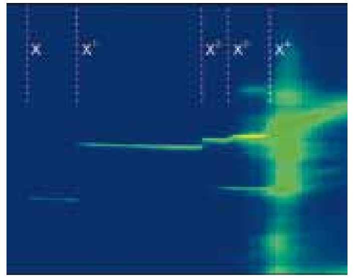
03

PRODUCT KEY FEATURES
> optical setup offering highest flexibility
> modular beam splitter head outside of cryostat
> wavelength and polarization filtering of the excitation and collection signal possible
> large coarse positioning range at low temperatures
> ultra compact version for 1 inch (25.4 mm) setups available

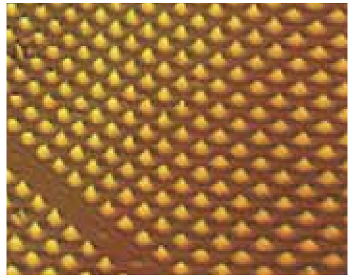
BENEFITS
> fits standard cryogenic and magnet sample spaces
> very broad variety of applications, ranging from classical CFM measurements to Raman spectroscopy
> excellent stability in high magnetic fields
> highest measurement sensitivity
> access to a large area on the sample surface

APPLICATION EXAMPLES
> solid state physics and quantum dot optics
> fluorescence observation
> biological and medical research on tissue samples in cytological and neurological applications
> fast 3D-imaging

04



05



Results

04. A color-scale plot of the photoluminescence (PL) versus gate voltage showing the discrete spectral lines of a quantum dot recorded with the attoCFM I at a temperature of 1.6 K. ('R. J. Warburton et. al., 'Optical emission from a charge-tunable quantum ring', Nature (2000) 405, 926).

05. Confocal image of a chess board grating (SiO2 on Si) with a periodicity of 2 µm, recorded in reflection mode. The sample has some defects on the surface structure which are clearly resolved. The image was recorded with the attoCFM I in reflection mode (attocube application labs, 2003).

Specifications

Microscope configuration	confocal unit pinhole configuration	modular beam splitter microscope head outside of the cryostat, excitation and collection port fully adjustable, free beam optics, optional polarizer and retarder possible two pinholes (fiber apertures), adjustable in x-, y-, z-direction, different illumination and collection wavelength possible, standard configuration for connection of optical fibers
Sample Positioning	coarse range step size scan range temperature range	5 x 5 x 5 mm^3 @ 300 K: 0.05 .. 3 µm @ 4 K: 10 .. 500 nm 40 x 40 $µm^3$ 30 x 30 $µm^3$ 1 .. 300 K (dependent on cryostat)
Operating Conditions	magnetic field range operating pressure	0 .. 15 T+ (dependent on magnet) 1E-6 mbar .. 1 bar (designed for exchange gas atmosphere)
Illumination	excitation wavelength range light source light power on the sample port specification	~400 .. 1500 nm (see objectives description) fiber coupled laser typically 635 nm typically 1 pW .. 500 µW FC/APC-connector for single mode fibers (other connector types on request)
Sample Size	maximum	10 x 10 x 5 mm^3

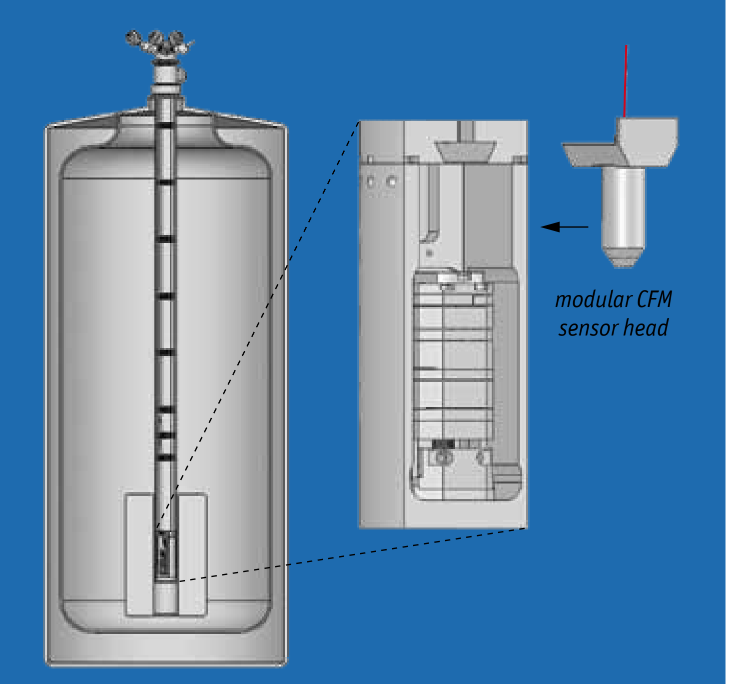
03
attoCFM II
LOW TEMPERATURE CONFOCAL MICROSCOPY

The attoCFM II is a compact confocal microscope, which is designed for in-situ analysis. The microscope is highly stable at low temperature, high magnetic field, and high vacuum. Moreover, all mechanical parts are compensated for differential thermal length contraction. The design is optimized to reduce light losses to a minimum and to capture the maximum amount of light scattered by the illuminated point of the sample.

The one-of-a-kind combination of materials allows absolutely stable single dot measurements at low temperature over weeks, even when refilling the bath cryostat with liquid Helium. Furthermore, combining the attoCFM II with cryogen-free cooling solutions is easily possible, opening up new possibilities in cryogenic long-term investigations while considerably reducing operational costs.

Principle - A laser beam is coupled into one arm of a single mode optical fiber coupler. The fiber end of the second arm is imaged onto the sample using a low temperature compatible objective. In reflection, the core of the fiber plays the role of the blocking pinhole aperture when collecting the scattered light from the sample.

01

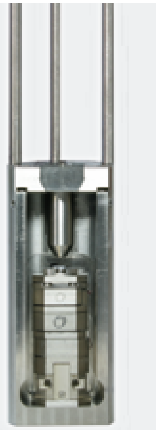


01. Schematic drawing of the low temperature attoCFM II and the surrounding liquid helium dewar (optional).

02. Close-up of the attoCFM II module.

03. Customized wiring, e.g. low temperature compatible coax cables, for cryogenic microscopes are available.

02



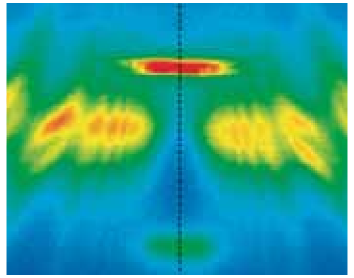
03

PRODUCT KEY FEATURES
- > miniaturized microscopy head
- > designed for highest stability
- > optimized for minimal light loss
- > large coarse positioning range at low temp.
- > ultra compact version for 1 inch (25.4 mm) setups available

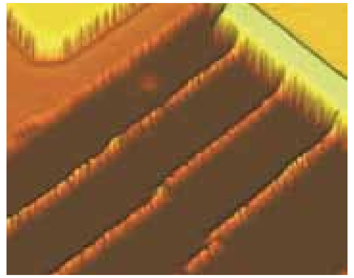
BENEFITS
- > fits standard cryogenic and magnet sample spaces
- > minimized drifts enable long-term measurements
- > excellent stability in high magnetic fields
- > highest measurement sensitivity
- > access to a large area on the sample surface

APPLICATION EXAMPLES
- > solid state physics and quantum dot optics
- > fluorescence measurements
- > highly stable long term experiments on single quantum dots
- > biological and medical research on tissue samples in cytological and neurological applications
- > fast 3D-imaging

04



05



Results

04. Photoluminescence intensity of a triply charged InAs quantum dot vs. magnetic field (red corresponds to high intensity), recorded at cryogenic temperature using the attoCFM II. (K. Karrai et. al., 'Hybridization of electronic states in quantum dots through photon emission', Nature (2004) 427, 135).

05. Confocal image of a tweezer structure; the tweezers are freely suspended. The size of the image is 30 x 30 µm2 recorded in reflection mode. The 200 nm wide structures are resolved with an excitation laser source of 630 nm. (C. Meyer et al., 'Slip-stick step-scanner for scanning probe microscopy', Rev. Sci. Instrum. (2005) 76, 063706).

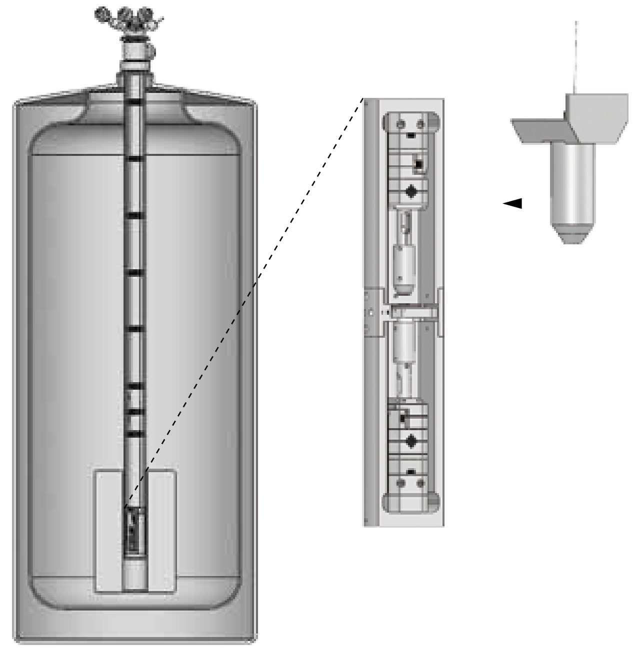
Specifications

Microscope configuration	confocal unit	ultra-stable confocal microscope head fiber optic based
	pinhole configuration	one illumination and collection fiber (blocking pinhole)
Sample Positioning	coarse range	5 x 5 x 5 mm³
	step size	@ 300 K: 0.05 .. 3 µm @ 4 K: 10 .. 500 nm
	scan range	40 x 40 µm³ 30 x 30 µm³
	temperature range	1 .. 300 K (dependent on cryostat)
Operating Conditions	magnetic field range	0 .. 15 T+ (dependent on magnet)
	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 635 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

04
attoCFM III
LOW TEMPERATURE CONFOCAL MICROSCOPY

The attoCFM III is a highly stable, compact cryogenic microscope optimized for both reflection and transmission measurements. The attoCFM III confocal microscope is compensated for differential thermal length contraction to guarantee highest stability suitable for spectroscopic measurements over extended periods of time. The instrument opens up new possibilities in quantitative sub-micron range investigations and routine inspection in extreme environments: temperatures down to 0.3 K, magnetic fields up to 15 T, and high vacuum. The one-of-a-kind combination of materials allows absolutely stable measurements, even when refilling the bath cryostat with liquid Helium. The adjustable transmission mode operation integrated in the instrument is absolutely unique in the field of low temperature microscopy!

Principle - A laser beam is coupled into one arm of a single mode optical fiber coupler. The fiber end of the second arm is imaged onto the sample using a low temperature compatible objective. In reflection, the core of the fiber plays the role of the blocking pinhole aperture when collecting the scattered light from the sample. The intensity of this scattered light is measured by a detector connected to the fourth arm of the fiber coupler. A second, low-temperature compatible confocal objective underneath the sample is used for transmission measurements. The transmitted light collected by the objective is guided to an additional detector using a separate single mode fiber.

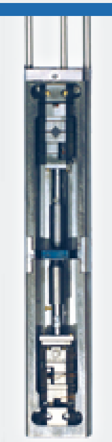


01. Schematic drawing of the low temperature attoCFM III and the surrounding liquid helium dewar (optional).

02. Close-up of the The attoCFM III microscope module.

03. ASC400 - attocube's state-of-the-art Confocal Microscopy controller featuring an open architecture and high flexibility to meet the customers' individual needs.

02



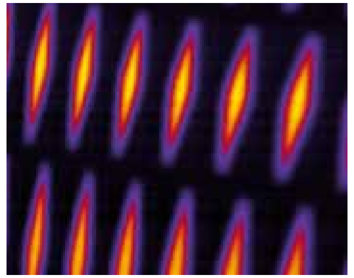
03

PRODUCT KEY FEATURES
> optimized for reflection and transmission experiments
> miniaturized microscopy head
> designed for highest stability
> optimized for minimal light loss
> large coarse positioning range at low temperatures

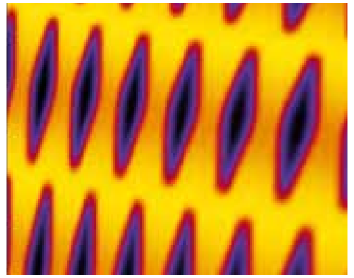
BENEFITS
> fits standard cryogenic and magnet sample spaces
> minimized drifts enable long-term measurements
> excellent stability in high magnetic fields
> highest measurement sensitivity
> access to a large area on the sample surface

APPLICATION EXAMPLES
> absorption, scattering, and fluorescence properties, investigation of complex nanostructures, single molecules, and quantum dots
> low coherence tomography
> single molecule life-time measurements

04



05



Results

04. Reflection image of a Vanadium rhomb-structure on a glass substrate with a layer thickness of 50 nm and a periodicity of 5 µm, recorded with the attoCFM III. (attocube application labs, 2007).

05. Transmission image of a Vanadium rhomb-structure on a glass substrate with a layer thickness of 50 nm and a periodicity of 5 µm, recorded with the attoCFM III. (attocube application labs, 2007).

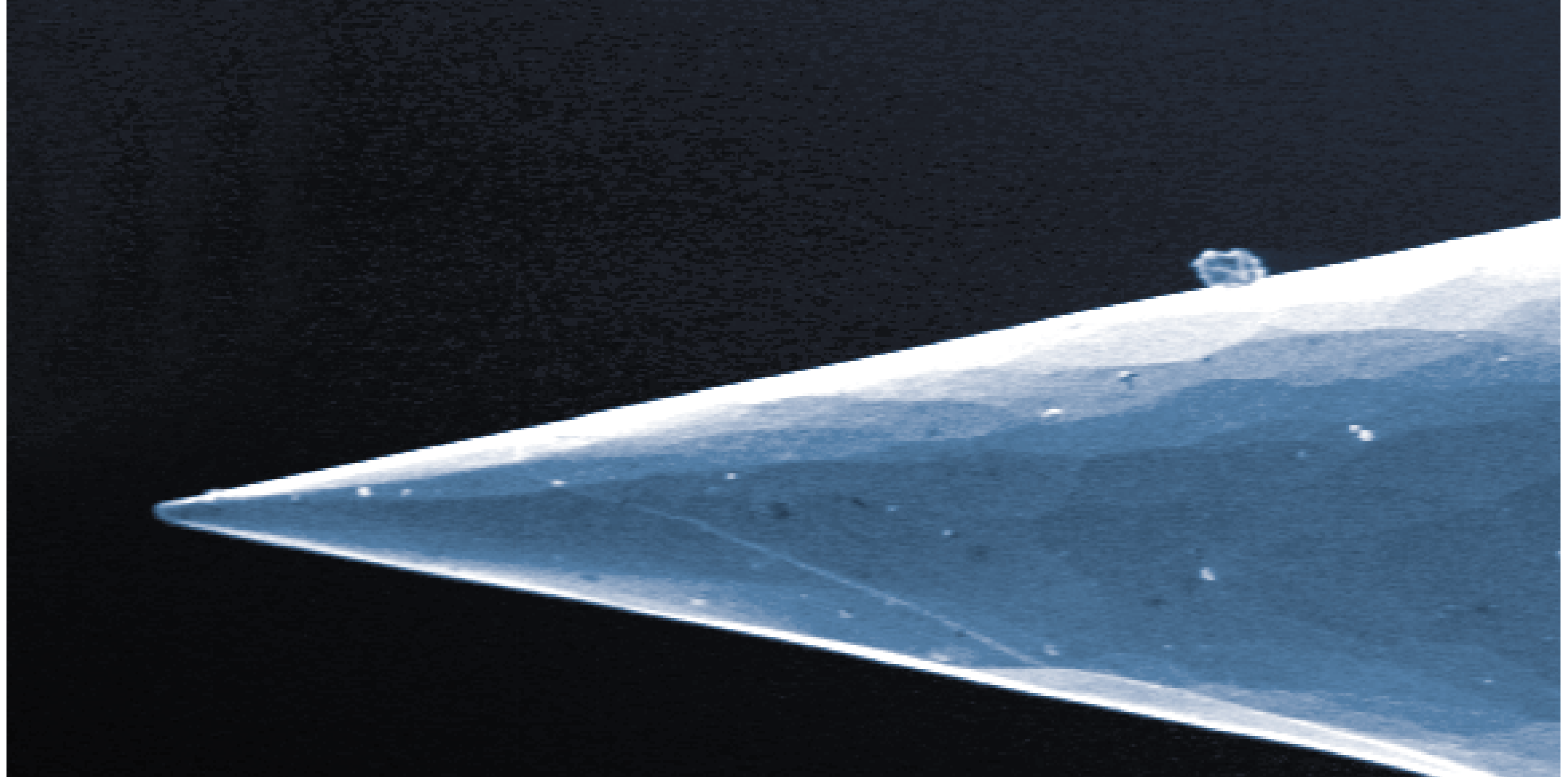
Specifications

Microscope configuration	confocal unit	microscope head for transmission and reflection mode fiber optic based
	pinhole configuration	one fiber for illumination and reflection collection, one fiber for transmission collection
Sample Positioning	coarse range	5 x 5 x 5 mm³
	step size	@ 300 K: 0.05 .. 3 µm @ 4 K: 10 .. 500 nm
	scan range	40 x 40 µm³ 30 x 30 µm³
	temperature range	1 .. 300 K (dependent on cryostat)
Operating Conditions	magnetic field range	0 .. 15 T+ (dependent on magnet)
	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 635 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)
	maximum	10 x 10 x 5 mm³

05
WORKING PRINCIPLE
SCANNING NEAR-FIELD OPTICAL MICROSCOPY (SNOM)

Scanning Near-Field Optical Microscopy (SNOM, also called NSOM) allows optical microscopy with a spatial resolution down to 10 nm, i.e. beyond the diffraction limit in the visible spectrum. In principle, a small nanometer sized optical probe is scanned very close to the sample surface. The sample interacts with the evanescent field of the optical probe, leading e.g. in tip-enhanced experiments to a modulation in reflected or transmitted signal intensity.

The near-field optical signal depends strongly on the separation of optical probe and sample surface: only slight changes of this distance in the nanometer range are sufficient to considerably alter the recorded optical signal. It is therefore important to keep the optical probe and the sample at constant separation. In case of the attoSNOM III, a tuning fork sensor connected to an electronic feedback loop achieves this task with highest precision. As a result, not only measurements of transmission, reflection, and lateral scattering of light become possible with highest stability, but also simultaneous topographic and force measurements can now be conducted.
Probes - attocube systems' probes are mainly fabricated from an optical fiber, which has been tapered to reduce its size and coated with an opaque metal layer from the sides leaving only a small aperture at its very end.

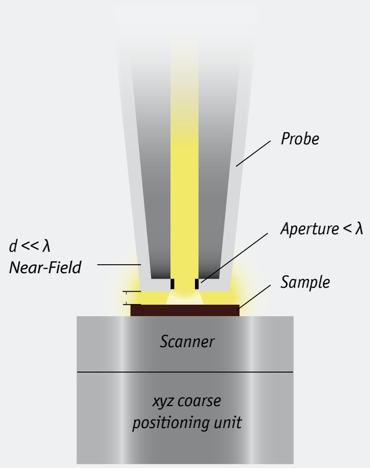


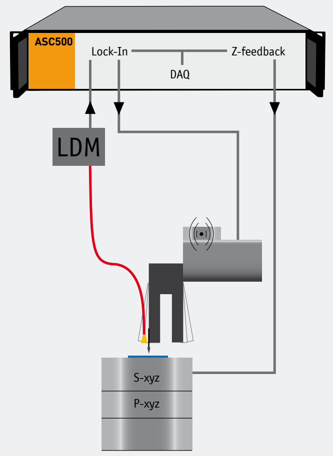
The **attoSNOM** is designed particularly for the use at extreme environmental conditions such as ultra low temperature, high magnetic field, and high vacuum. Reliable functionality at these extreme conditions is provided by implementing the outstanding attocube systems nanopositioning modules.

Tip-Sample Distance Control:
The tuning fork sensor as a tip-sample distance control mechanism is a non-optical method for measuring small vibrations of the SNOM probe by means of a quartz tuning fork. In general, the glass fiber tip is glued onto one leg of a small quartz tuning fork. The fiber based tip is excited in horizontal direction with an amplitude of typically 100 pm. As the tip approaches the sample in the nanometer range, the vibrational amplitude of the tip and the resonance frequency shifts.

This reduction in amplitude caused by lateral forces, the so-called shear forces, is monitored and kept constant, leading to a constant force and therefore separation between SNOM probe and sample surface.

The sensor allows measurement of the tip–sample friction and shear forces ranging down to approximately 0.1 pN. In this configuration, the whole system behaves like a simple forced harmonic oscillator.





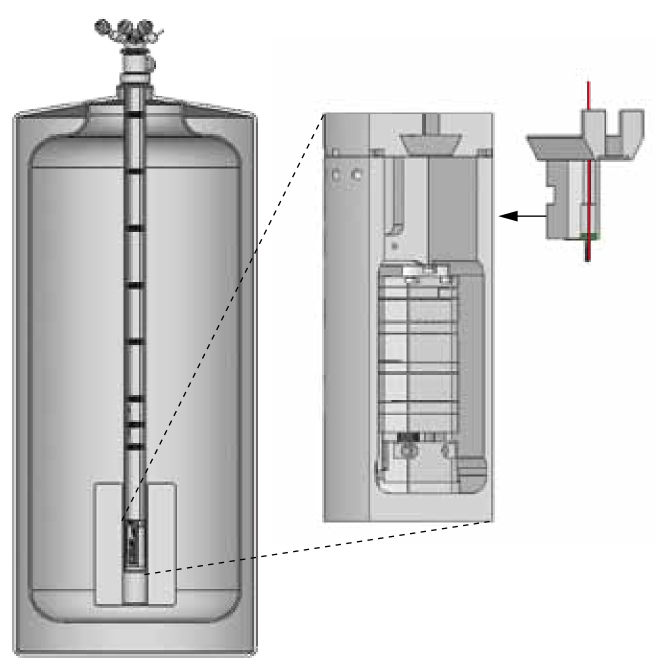
06
attoSNOM III
FIBER BASED LOW TEMPERATURE SCANNING NEAR-FIELD OPTICAL MICROSCOPE

The attoSNOM III uses a non-optical, tuning fork based distance control system for highest stability and accuracy. This control system uses a piezoelectric quartz sensor for highly sensitive shear force detection and an electronic feedback loop (phase-locked loop, PLL) to keep the tip-sample separation constant. In addition to these mechanical properties, a high-quality optical fiber probe tip ensures highest light throughput and resolution.

As an optional configuration, the system can also be equipped with an ellipsoidal aluminum mirror in order to collect the signal scattered by the sample surface. Overall, the attoSNOM III impresses by its outstanding sensitivity combined with high spatial resolution.

Principle - The excellent spatial resolution of the attoSNOM III is achieved by approaching the aperture of an aluminum coated, tapered optical fiber tip to close proximity of the sample surface and by precisely controlling the tip-sample separation by means of a tuning fork sensor. In order to achieve highest stability and to minimize parasitic cable capacitance, the tuning fork is directly mounted onto a low temperature preamplifier. In a typical imaging application, the vibrational amplitude of the tip is adjusted to about 50 pm and the tip-sample separation is kept constant by using a phase-locked loop and a PI controller on the frequency shift. The optical fiber-based probe is used to illuminate or excite the sample surface locally. The reflected signal containing the information about local sample surface properties (such as refractive index, chemical properties, photoluminescence etc.) is either collected through the same fiber or by an ellipsoidal aluminum mirror (optional).

01

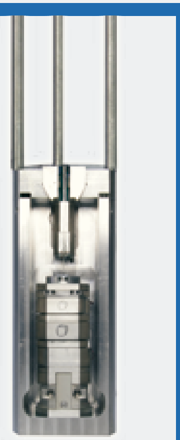


01. Schematic drawing of the low temperature attoSNOM III and the surrounding liquid helium dewar (optional)

02. Close-up of the attoSNOM III 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



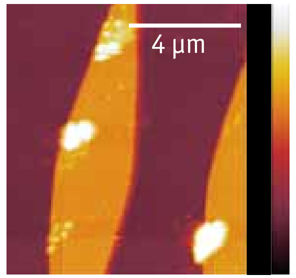
03

PRODUCT KEY FEATURES
> designed for highest stability
> non-optical distance control by quartz tuning fork
> simple transmission detection possible
> flexible design

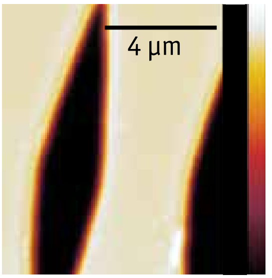
BENEFITS
>high spatial resolution imaging
> simultaneous ultra high resolution topographic and optical imaging
> compatible with any fiber-based SNOM probe
> enables reflection measurements with ellipsoidal mirror

APPLICATION EXAMPLES
> investigation of complex nanostructures, single molecules, and quantum dots
> materials science

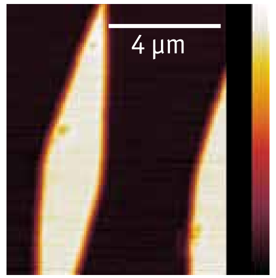
04



05



06



Results

Tuning fork topographic measurement (04.) and simultaneously obtained near-field measurement in reflection (05) and transmission (06) at 4.2 K. Sample: Vanadium rhomb-structure on a glass substrate with a layer thickness of 50 nm (attocube application labs, 2007).

Specifications

Operation Mode	feedback topography light detection optional	PI feedback loop with additional PLL shear force mode (non contact) transmission, collection through fiber low temperature compatible detector below the sample for transmission measurement (intensity)
Sample Positioning	coarse range step size fine scan ranges temperature range	5 x 5 x 5 mm³ @ 300 K: 0.05 .. 3 µm; @ 4 K: 10 .. 500 nm 40 x 40 x 4.3 µm³; 9 x 9 x 2 µm³ (larger range on request) mK .. 300 K (dependent on cryostat)
Operating Conditions	magnetic field range operating pressure	0 .. 15 T + (dependent on magnet) 1E-6 mbar .. 1 bar (designed for exchange gas atmosphere)
Noise	measured z-noise density	< 50 pm/Hz$^{1/2}$
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) 0.46 nm at 30 µm scan range 0.075 nm at 5 µm scan range 0.18 nm at 12 µm scan range 0.03 nm at 2 µm scan range
Sample Size	maximum	10 x 10 x 5 mm³

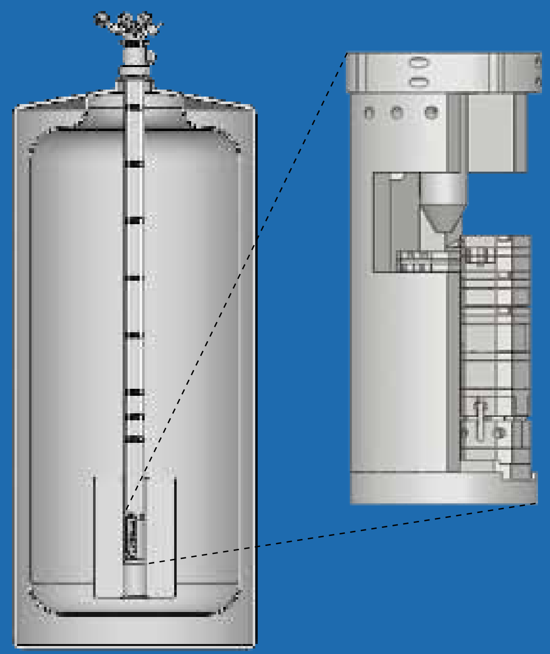
07
attoAFM/CFM

COMBINED LOW TEMPERATURE ATOMIC FORCE AND CONFOCAL MICROSCOPE, for apertureless SNOM applications

The tuning fork based attoAFM/CFM not only allows fast optical investigation of the sample prior to detailed AFM studies, it also enables precise positioning of the AFM tip over small structures and optical control of the scanning process or surface manipulation. Plus, optical experiments such as scattering SNOM, Raman Spectroscopy, and Tip Enhanced Raman Spectroscopy (TERS) can be conducted. Needless to say that all of these tasks can be performed in extreme environments such as ultra low temperature, high vacuum, and high magnetic field.

Principle - The attoAFM/CFM uses an Akiyama probe tip to investigate tip-sample interaction forces on the nanometer scale. The Akiyama probe is typically operated in non-contact mode using a phase-locked loop to excite the probe at resonance and track any shift in frequency due to tip-sample interactions. An additional PI controller keeps the frequency shift at a constant value while scanning over the surface. Simultaneously to the information provided by the Akiyama probe, the CFM reveals complementary optical information of the sample surface. Since the z-scanning motion is provided by a dedicated scanner on the side of the AFM, the focal distance between the low-temperature compatible lens and the sample does not change.

01



01. Schematic drawing of the low temperature attoAFM/CFM and the surrounding liquid helium dewar (optional).

02. Close-up of the attoAFM/CFM microscope module.

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

02

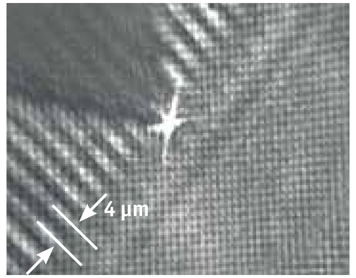
03

PRODUCT KEY FEATURES
> scan area at 4 K: 12 x 12 µm^2
> independent sample scanning and scanning of the AFM module
> tuning fork based and PLL controlled systems available
> non contact measurement mode
> objectives with various working distances available (e.g. 1.56 mm or 2.91 mm)

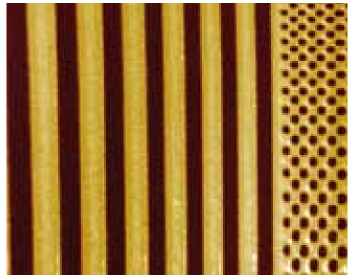
BENEFITS
> suitable for conductive and non-conductive samples
> enables exact positioning of the AFM tip
> optical access to the sample with high magnification

APPLICATION EXAMPLES
> solid state physics and quantum dot optics
> fluorescence observation
> highly stable long term experiments on single quantum dots
> biological and medical research on tissue samples in cytological and neurological applications
> fast 3D-imaging

04



05



Results

04. Confocal image of the Akiyama probe in close proximity of a patterned SiO_2/Si substrate. The image clearly shows a pronounced backscattering of light at the AFM tip apex (attocube application labs, 2009).

05. Tuning fork AFM image of the SiO_2/Si substrate as imaged beforehand using the CFM (see figure above). The height modulation corresponds to 51 nm (attocube application labs, 2009).

Specifications

Operation Mode	detection mode imaging modes	PI feedback loop with additional PLL AFM non-contact mode, CFM in reflection, luminescence, fluorescence	
Sample Positioning	coarse range step size scan range temperature range	3 x 3 x 2.5 mm^3 @ 300 K: 0.025 .. 2 µm 30 x 30 x 4.3 µm^3 mK .. 300 K (dependent on cryostat)	 @ 4 K: 10 .. 500 nm 12 x 12 x 2 µm^3
Operating Conditions	magnetic field range operating pressure	0 .. 15 T + (dependent on magnet) 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) 0.46 nm at 30 µm scan range 0.065 nm at 4.3 µm scan range 0.18 nm at 12 µm scan range 0.03 nm at 2 µm scan range	
Sample Size	maximum	10 x 10 x 5 mm^3	

08
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.

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.

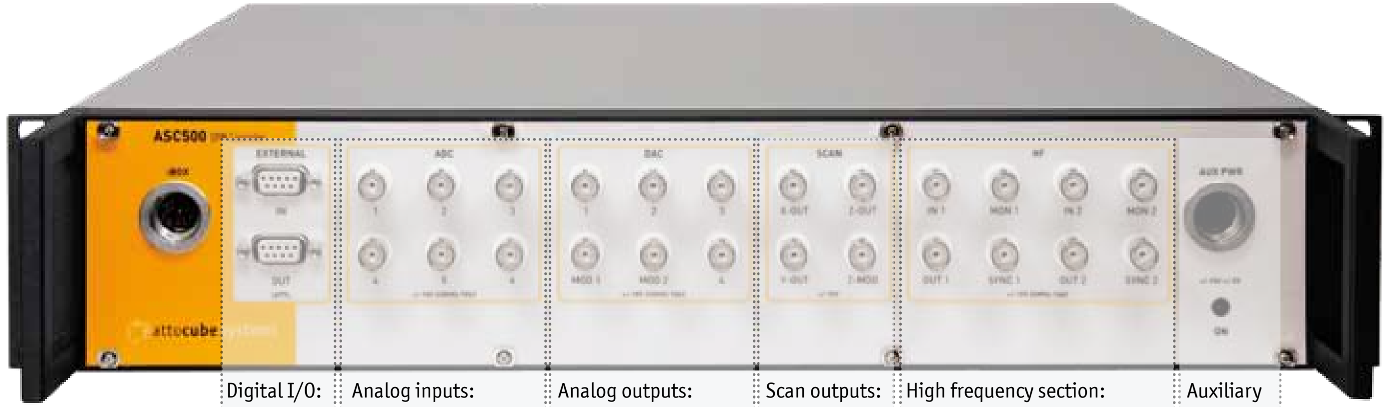
Z controller:

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.

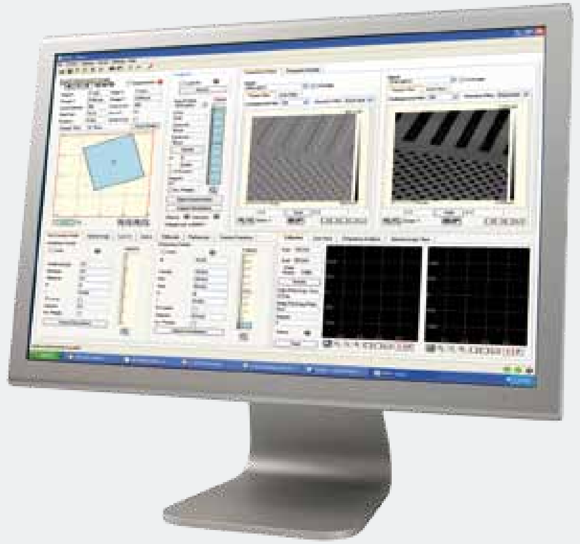
PLL:

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.

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



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).

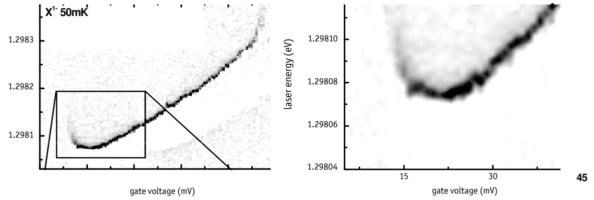
LabVIEW™ control

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.

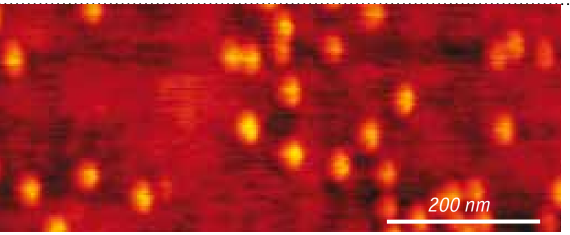
Spectroscopy

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.

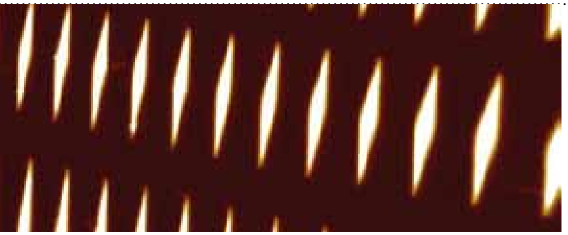
09
ATTOCUBE SYSTEMS' MICROSCOPES
OPEN UP NEW POSSIBILITIES



A confocal microscope was manufactured for the detailed investigation of quantum dots in an ultra low temperature environment (< 44 mK) by using photoluminescence and transmission measurement techniques inside a magnetic field of up to 7 Tesla. For this purpose, a customized attoCFM II module was implemented into a dilution refrigerator with a cooling power of 400 µW at 120 mK on the cold finger and a base temperature on the sample plate of less than 44 mK.



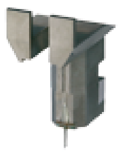
Topographic image of quantum dots performed in vacuum using the attoSNOM III. The z-noise in the measurement was determined to be well below 0.1 nm. The image was recorded at a temperature of 4 K in zero magnetic field.



Reflection near-field measurement recorded with the ASC500 PLL feedback loop & attoSNOM III. Sample: Vanadium rhomb-structure on glass substrate with a layer thickness of 50 nm (attocube application labs, 2008).

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.

CFM



SNOM

AFM/MFM

Switching between CFM, AFM, MFM, and SNOM is now only a matter of minutes – simply interchange the respective sensor head. The housings feature two different diameter models: the standard 2 inch version for all attocube LTSYS systems and a 1 inch version to fit into most of the smaller sized low temperature systems, including the QD PPMS®.

CFM head including a low temperature objective.
SNOM head based on tuning fork technology.
Cantilever based AFM/MFM head.

10
ATTOCUBE SYSTEMS
CREATING SCIENTIFIC IMPACT

S. Gröblacher , J. B. Hertzberg , M. R. Vanner , G. D. Cole , S. Gigan , K. C. Schwab, M. Aspelmeyer
Demonstration of an ultracold micro-optomechanical oscillator in a cryogenic cavity
Nature Physics 5, 485–488 (2009).

B.D. Gerardot, D. Brunner, P.A. Dalgarno, P. Öhberg, S. Seidl, M. Kroner, K. Karrai, N.G. Stoltz, P.M. Petroff, R.J. Warburton
Optical pumping of a single hole spin in a quantum dot
Nature 451, 441-444 (2008).

M. Kroner, A.O. Govorov, S. Remi, B. Biedermann, S. Seidl, A. Badolato. P.M. Petroff, W. Zhang, R. Barbour, B.D. Gerardot, R.J. Warburton, K. Karrai
The nonlinear Fano effect
Nature 451, 311-314 (2008).

M. Kroner, C. Lux, S. Seidl, A.W. Holleitner, K. Karrai, A. Badolato, P.M. Petroff, R.J. Warburton
Rabi splitting and ac-Stark shift of a charged exciton
Appl. Phys. Lett. 92, 031108 (2008).

M. Ediger, G. Bester, A. Badolato, P.M. Petroff, K. Karrai, A. Zunger, R.J. Warburton
Peculiar many-body effects revealed in the spectroscopy of highly charged quantum dots
Nature Physics 3, 774-779 (2007).

B.D. Gerardot, S.Seidl, P.A. Dalgarno, R.J. Warburton, M. Kroner, K. Karrai, A. Badolato, P.M. Petroff
Contrast in transmission spectroscopy of a single quantum dot
Appl. Phys. Lett. 90, 041101 (2007).

I. Favero, C. Metzger, S. Camerer, D. König, H. Lorenz, J.P. Kotthaus, K. Karrai
Optical cooling of a micromirror of wavelength size
Appl. Phys. Lett. 90, 104101 (2007).

B.D. Gerardot, S.Seidl, P.A. Dalgarno, R.J. Warburton, D. Granados, J.M. Garcia, K. Kowalik, O. Krebs
Manipulating exciton fine structure in quantum dots with a lateral electric field
Appl. Phys. Lett. 90, 041101 (2007).

A. Babiñski, G. Ortner, S.Raymond, M. Potemski, M. Bayer, W.Sheng, P.Hawrylak, Z.Wasilewski, S.Fafard, A. Forchel
Ground-state emission from a single InAs/GaAs quantum dot structure in ultrahigh magnetic fields
Phys. Rev. B 74 , 075310 (2006).

M. Atatüre, J. Dreiser , A. Badolato, A. Högele, K. Karrai, A. Imamoglu
Quantum-Dot Spin-State Preparation with Near-Unity Fidelity
Science, 312(5773), 551 (2006).

A. Högele, S. Seidl, M. Kroner, K. Karrai, M. Atatüre, J. Dreiser, A. Imamoglu, R. J. Warburton, B. D. Gerardot, P. M. Petroff
Spin-selective optical absorption of singly charged excitons in a quantum dot
Appl. Phys. Lett., 86, 221905 (2005).

M. Kroutvar, Y. Ducommun, D. Heiss, M. Bichler, D. Schuh, G. Abstreiter, J. Finley
Optically programmable electron spin memory using semiconductor quantum dots
Nature, 432, 81 (2004).

K. Karrai, R.J. Warburton, C. Schulhauser, A. Högele, B. Urbaszek, E. J. McGhee, A. O. Govorov, J. M. Garcia, B. D. Gerardot, P. M. Petroff
Hybridization of electronic states in quantum dots through photon emission
Nature, 247, 135 (2004).

A. Högele, S. Seidl, M. Kroner, K. Karrai, R. J. Warburton, B. D. Gerardot, P. M. Petroff
Voltage-Controlled Optics of a Quantum Dot
Phys. Rev. Lett., 93, 217401 (2004).

A. Babinski, S. Awirothananon, J. Lapointe, Z. Wasilewski, S. Raymond, M. Potemski
Single-Dot Spectroscopy in High Magnetic Fields
Physica E, 22, 603 (2004).

R. J. Warburton, C. Schäflein, D. Haft, F. Bickel, A. Lorke, K. Karrai, J. M. Garcia, W. Schoenfeld, P. M. Petroff
Optical emission from a charge-tunable quantum ring
Nature 405, 926 (2000).