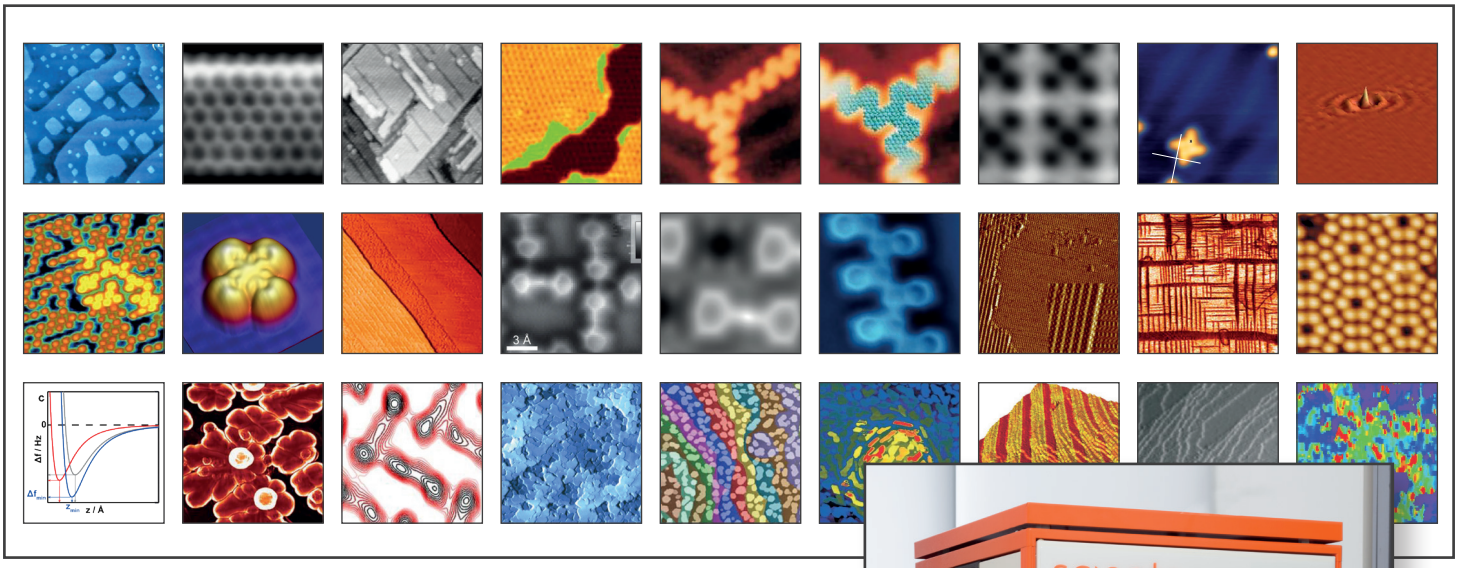
MATRIX 4
The SPM controller evolution

scientaomicron



- Intuitive and flexible experiment control
- Best-in-class noise floor
- Ultimate QPlus® capabilitiy
- Full 64-bit software
- Modular upgrade paths
- Close to 600 installed controllers

MATRIX 4
The SPM controller evolution

The MATRIX 4 Control System builds on 30 years of experience in SPM technology and unlocks the full capacity of our leading-edge Scanning Probe Microscopes.

The MATRIX architecture couples advances in high-speed, low-noise digital electronics with the requirements of the latest SPM applications to offer the user an unprecedented level of signal quality, measurement speed, and experimental flexibility. The expandable design provides solutions for future challenges in Scanning Probe Microscopy.

Best-in-class noise floor

The MATRIX control system is well known for its low noise level when compared to other SPM controllers. In order to guarantee state-of-the-art performance our R&D team is constantly working to optimize all related hardware and software parts.

Ultimate QPlus® performance

QPlus® performance with industry leading Matrix PLL sets a new standard for phase locked loop (PLL) measurements. Customer results demonstrate the highest performance of QPlus® AFM control.

Flexible Experiment Control

The MATRIX Automated Task Environment (MATE) and the remote access interface provide individual experiment control.
The remote access interface can directly be addressed by LabVIEW, C/C++, or many other applications.

Modular upgrade paths

Scienta Omicron's MATRIX concept and architecture allow for easy upgrades of functionality, including the QPlus® Control System and Beam Deflection AFM options. Support to upgrade previous versions of MATRIX ensures modern and up-to-date SPM control.

Full 64-bit software

MATRIX 4 offers full 64-bit software with enhanced features including 4096x4096 pixel images, larger size spectroscopy files, and improved operational stability.
The new version supports full software and remote control of all coarse movement.

Proven performance with almost 600 build instruments

With almost 600 units shipped, MATRIX truly enables forefront research around the world.
We continue our investment in developing new hardware and software functions that encompass the latest in technology and continued demands for new SPM applications. All generations of MATRIX are still supported and can utilize these new hardware and software developments.

Benefits and Properties:

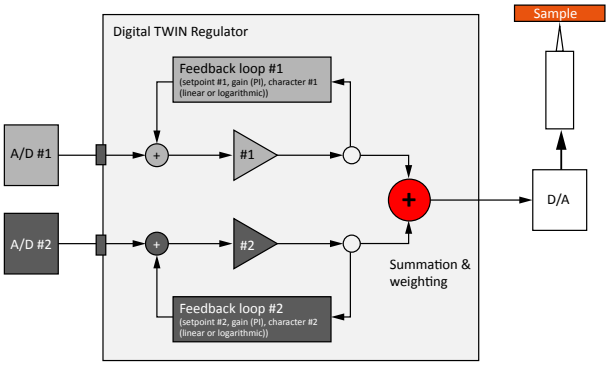
- Intuitive and flexible Experiment Control
- Best-in-class noise floor
- Ultimate QPlus® capabilitiy
- Full 64-bit software
- Modular upgrade paths
- Close to 600 installed controllers

Digital Regulator

The digital feedback employs a two-branch design to optimize distance regulation on one branch by various filter settings while the second branch carries and acquires the primary physical signal. Sophisticated low-noise DAC technology provides true physical 20-bit resolution (monotonic within 1 LSB) over the full z-scanner range. By employing advanced oversampling and filtering algorithms, noise is significantly reduced and effective z-resolution is enhanced to more than 24 bit. Instead of mixing or switching input signals, the TWIN regulator uses two independent fully featured feedback loops, allowing for separate but simultaneous optimization of the two regulation signals.

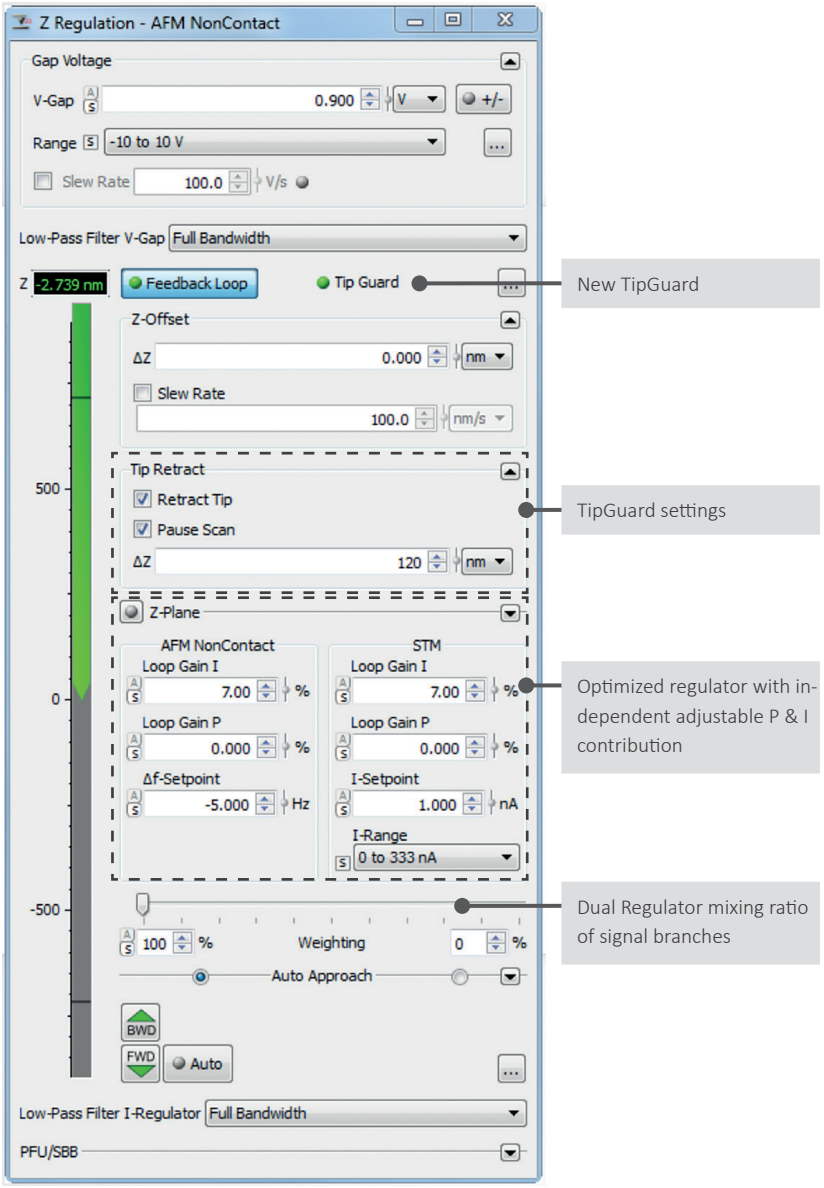
Therefore, the TWIN regulator dramatically improves the efficiency of research work by enabling a seamless transition between modes. An example is QPlus atomic force microscopy on a conductive surface by combining frequency shift (Δf) and tunneling current (It).

The TWIN regulator also opens up chances for unique experiments by combining different feedback signals. The MATRIX software already comes with a selection of predefined experiments for using the TWIN regulator like frequency shift (Δf) & tunneling current (It), frequency shift (Δf) & damping(D) or using an external input as second feedback channel.



Channels

Numerous internal and external channels for all signals can be set automatically ore individually for initial delay & oversampling. The maximum sampling rate of 400 kHz, is usually used to oversample the acquired data reducing noise and improving resolution.

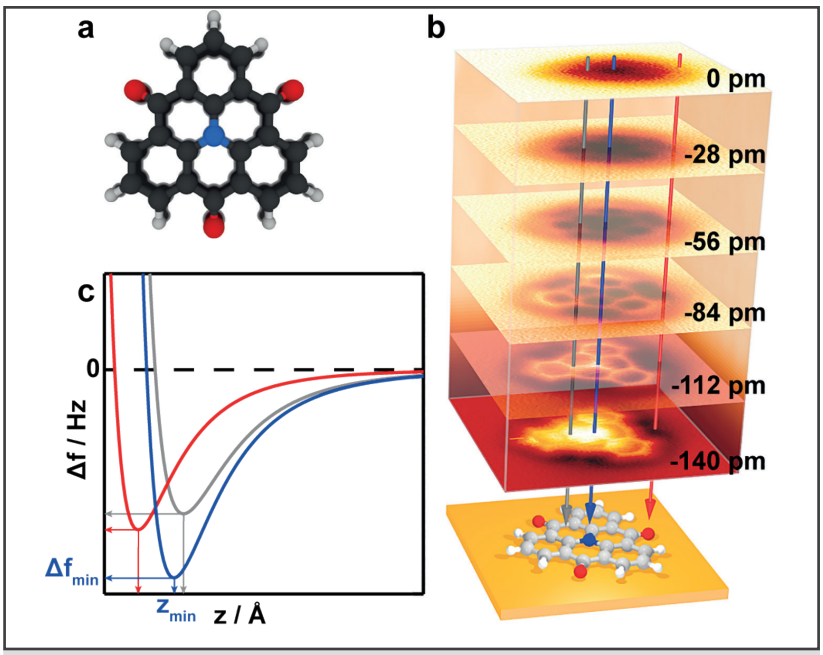


Spectroscopy

MATRIX 4 offers a broad range of tools for spectroscopy applications including single point or volume spectroscopy. Any channel can be recorded as a function of V, Z, or a combination of both. Hardware advancements including a multiprocessor approach and the proprietary MATRIX Bus System ensure accurate timing and synchronization.
The spectroscopy panel provides the convenient ability to set parameters such as start and end values, number of data points, grid settings, slew rates, delay times etc. In addition MATRIX 4 offers advanced and customizable spectroscopy modes.
Standard Point spectroscopy actions are initiated using the 'mouse tools' in data display windows.

The available operating modes include

- I (V), dI/dV
- Δf (Z) and Δf (V) (Kelvin parabolas)
- z-ramps (Z)
- Combinations of I(V) and z-ramps

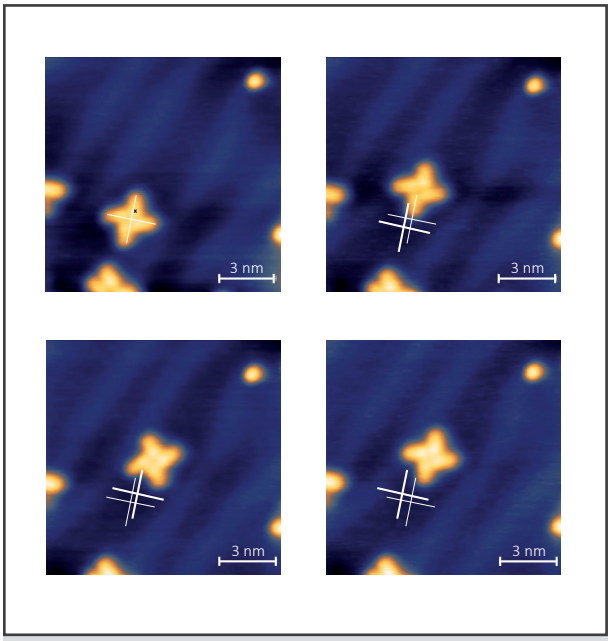


Spectroscopy recorded on a TOAT molecule. A) Model, B) Stacked Δf (z) maps recorded at different hights above the molecule. C) Each pixel in the stack represents a Δf (z) spectroscopy curve. Data courtesy: I. Swart, ACS Nano, 2016, 10 (9), pp 8517–8525

Manipulation

Manipulation and lithography applications are an essential part of the MATRIX 4 tool box.
An exciting example of molecule manipulation using MATRIX controllers was demonstrated in the international molecule-car race in April 2017 in Toulouse (France). Vehicles consisting of a few hundred atoms were powered by electrical pulses during the 3 hour race. MATRIX 4 allowed them to successfully navigate on a racecourse made of gold atoms, 100 nanometers in length. Four of the six nanocars were simultaneously driven with the LT NANOPROBE.
The race, which was organized by the CNZS, was a scientific and technological challenge made possible through the advancements of the MATRIX 4 SPM controller.

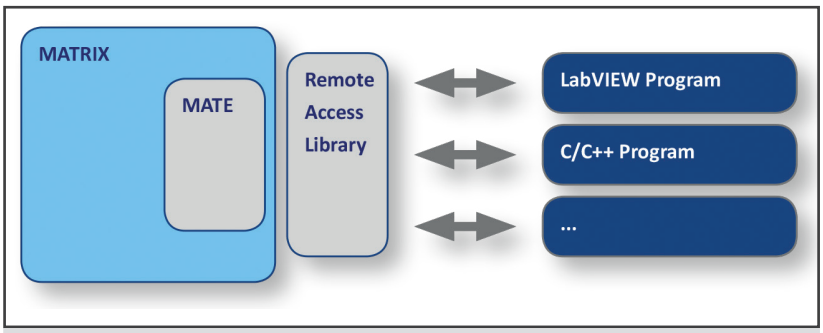
The race teams in the remote control room.



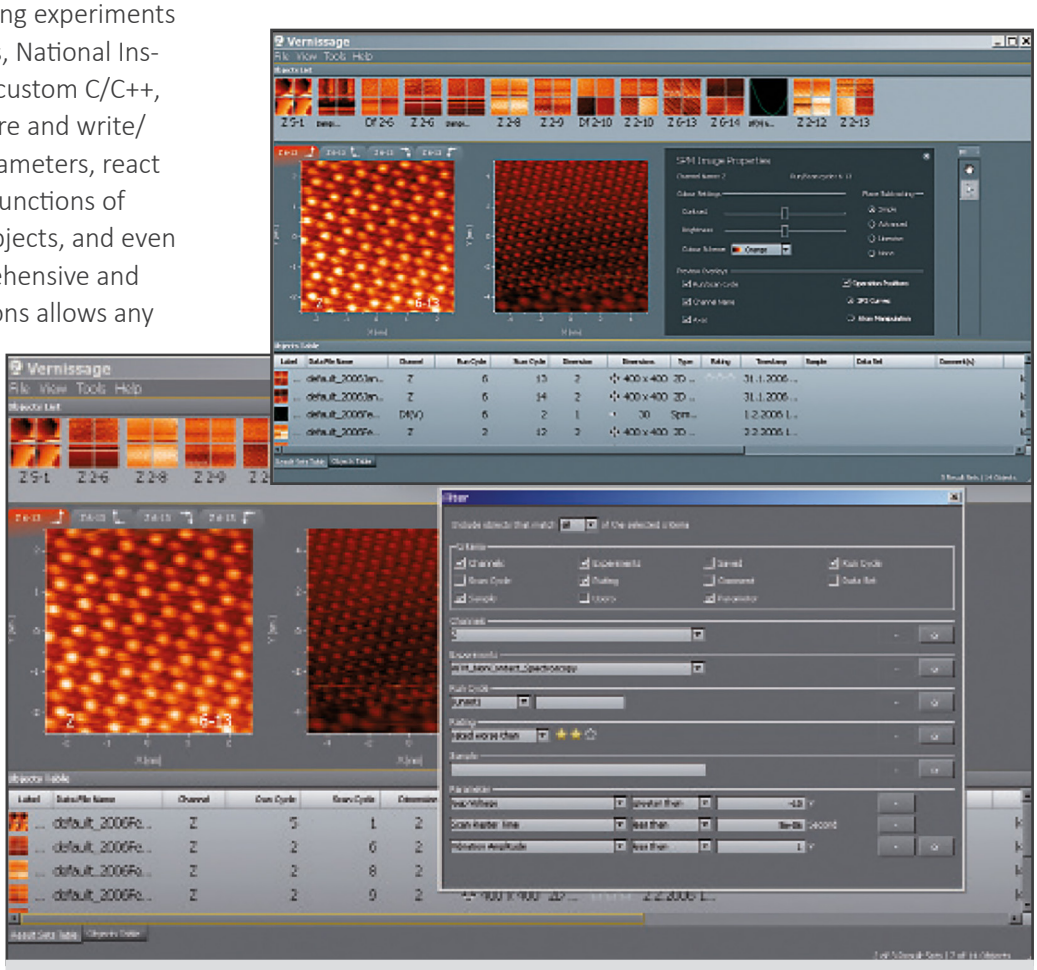
Manipulation of a 4-Acetyl-biphenyl (ABP) molecule [1,2] on Au(111), driven by inelastic tunneling effect. Data obtained during the TU Dresden team training session for the nanocar race at the PicoLab in Toulouse. Data by courtesy of F. Moresco, TU Dresden, Germany.
References: [1] F. Moresco et al., ACS Nano, 7, 191 (2013);
[2] F. Moresco et al., ACS Nano, 9, 8394 (2015)

Scripting by MATE

The **MATRIX Control System** includes the **MATRIX Automated Task Environment** (MATE) as standard. The MATE environment provides a flexible and effective way of designing advanced experiments using either the internal script editor or external software packages. Using either solution any user can expand upon the capabilities of standard experiments, automate repetitive tasks, and change the behaviour of experiments at execution time. Combined with a Remote Access Library, any application that is capable of calling C-language functions can utilize the full set of MATE features for controlling experiments remotely. With MATE Remote Access, National Instruments LabVIEW, Matlab, Python, custom C/C++, or other applications can read/ inquire and write/ modify the values of experiment parameters, react to changes of such parameters, call functions of MATRIX Experiment Elements and objects, and even interact with MATE scripts. A comprehensive and easy-to-use set of C-language functions allows any software package to control MATRIX experiments.



The MATRIX Automated Task Environment (MATE) allows to control MATRIX remotely by script or third party software.



Vernissage allows to brows, filter, select and export your data. Configurable views give access to all relevant data parameters.

Vernissage

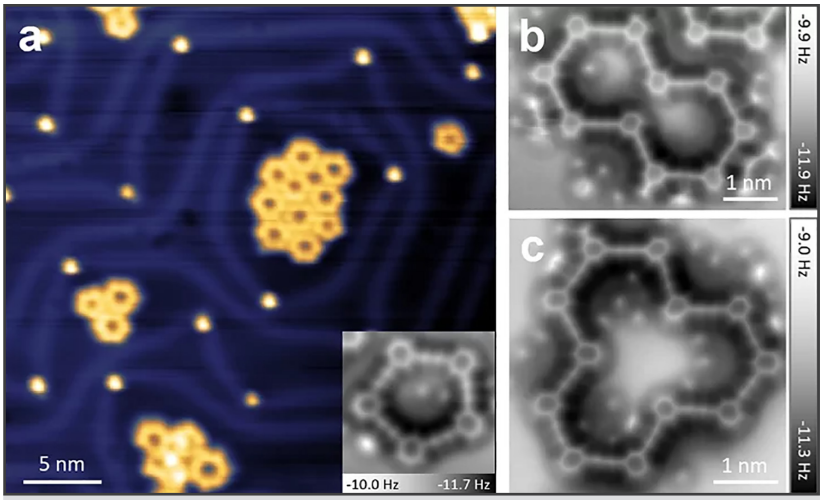
The ability to manage huge amounts of data sets is crucial for successful research work! Simply use the MATRIX software tool 'Vernissage' for this job. Vernissage is a databased tool and supports data preview, browsing, advanced filtering and sorting. Also provided are dedicated plug-ins for data export. Supported formats include: JPG, TIFF, BMP, ASCII, IGOR Pro and the Scienta Omicron Flat File Format (FFF). Vernissage also supports user written plug-ins for specific file formats.
These plug-ins can be used to export data directly from the preview window. 'Vernissage' also gives direct access to the MATRIX Raw Data for self-written data processing routines, for self written converters to specialized software (such as MATLAB, Origin, etc.), or direct link to third-party SPM data processing software using the dedicated Application Programming Interface (API).
Users that are familiar with C++ programing can build and integrate own Vernissage exporter plug- ins. Vernissage is included in the MATRIX Control system, but runs independently from the MATRIX data acquisition software. As a proprietary Scienta Omicron product MATRIX users can install the software on as many computers as required. This offers users an efficient and cost-effective way to manage and work with data.

Leading edge QPlus® performance

Matrix PLL

MATRIX 4 QPlus® Control System includes advanced AFM PLL hardware. The PLL is well proven and has supported many leading scientists in their daily work by offering all standard types of AFM measurements as well the flexibility to program advanced experiments via the MATE control interface. There is a basic mode for reliable and safe measurements, requiring minimum effort to initiate the experiments. Users can also directly switch to an expert mode giving access to the complete parameter space of an AFM PLL.

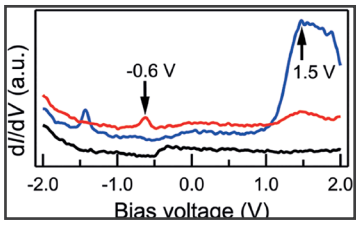
Preset options in MATRIX 4 for AFM perform high quality, high resolution QPlus® with easy switching to other modes with a few mouse clicks.

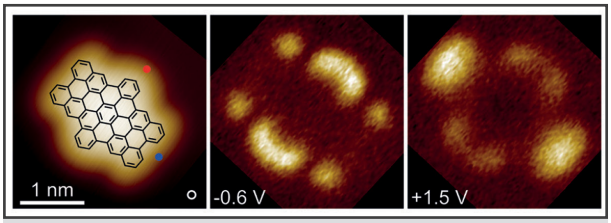


High-yield formation of graphdiyne macrocycles on Au(111) under the condition of a low coverage of organometallic intermediates (d-BEB-Au)6.
Data courtesy: Xiaohui Qiu et al. ACS Nano / DOI: 10.1021/acsnano.8b07349

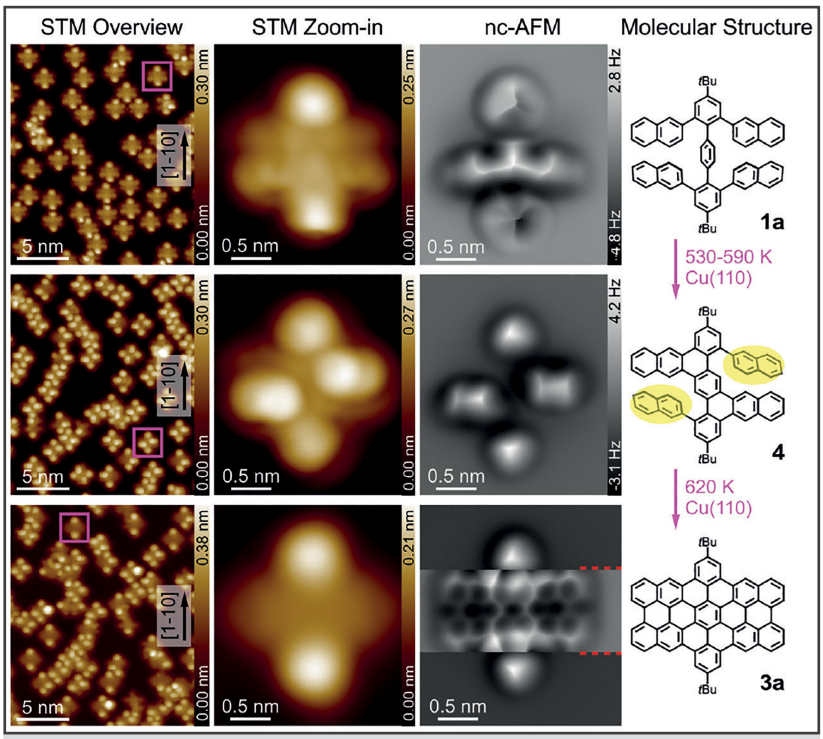
TipGuard - Tip protection

MATRIX 4 includes an advanced TipGuard system that extends tip life time and facilitates uninterrupted measurements in non-ideal environments. The TipGuard is convenient, and automatically continues experiments after a safety event. The TipGuard hardware and software take several parameters like phase or amplitude into account. Advanced users can individually parameterize the TipGuard and weight the individual trigger thresholds.





Scanning tunneling spectroscopic (STS dI/dV) results of the on-surface synthesized dibenzoperihexacenes on Au(111).
The measured energy gap between HOMO and LUMO is 2.1 eV.



Cyclodehydrogenation reactions of TNTP-tBu 1a on Cu(110). (a–c) STM overview images. (d–f) STM zoomed-in images of an initial TNTP- tBu molecule, a typical intermediate molecule and a final product molecule, respectively. (g–i) Constant-height frequency shift AFM images of the three molecules shown in (d–f); (j–k) corresponding chemical structures.
Data Courtesy: Zhong, Q. G.; Hu, Y. B.; Niu, K. F.; Zhang, H. M.; Yang, B.; Ebeling, D.; Tschakert, J.; Cheng, T.; Schirmeisen, A.; Narita, A.; Müllen, K.; Chi. L. F.
Benzo-Fused Periacenes or Double Helicenes? Different Cyclodehydrogenation Pathways on Surface and in Solution. J. Am. Chem. Soc. 141, 7399-7406 (2019).

Beam Deflection AFM

The MATRIX 4 beam deflection AFM package, for both contact and various non-contact force modes, consists of a digital AFM control board including frequency detection, analog signal preamplifiers, light source control, digital processor board, and software modules for AFM operation.

Provided are signal detection mechanisms for beam deflection and interferometer AFM and QPlus AFM. The MATRIX AFM Controller includes a digital phase-locked loop (PLL) that can be run in constant amplitude and constant excitation mode. The integrated solution for the MATRIX Control System increases the flexibility and usability for AFM control and acquisition. The AFM signals such as the normal force, lateral force, frequency shift, dissipation and Kelvin probe signals are all directly accessible through the MATRIX Bus System with a time resolution in the nanosecond range.
For advanced customer experiments, there are 6 additional analogue input ports available in the standard configuration, with a further 12 available on request.

Signal-to-Noise Characteristics

The MATRIX AFM Control Board is integrated in the MATRIX Control Unit. Digital AFM signals are directly fed via the digital internal bus system for further processing. The fully digital approach ensures signals are kept at highest signal quality throughout the entire MATRIX controller ensuring ultimate AFM performance all the way from cantilever sample interaction to data stored on hard drive.

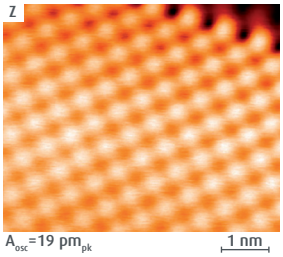
Measurement Modes

Beam deflection AFM contact modes:
Normal force & lateral force, Force-Distance Curves, Conductive AFM, Piezo Response AFM (PFM).

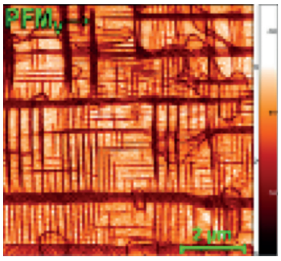
Beam deflection AFM non-contact modes including: EFM, MFM, Kelvin Probe (FM & AM Mode), Multimode Operation & Spectroscopy, Constant Damping.

Detection Modes:

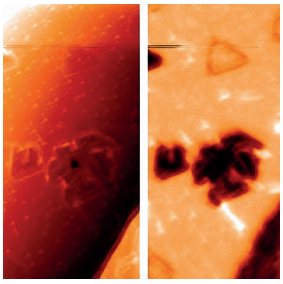
- PLL modes (const. amplitude & const. excitation)
- Self-excitation (constant amplitude)



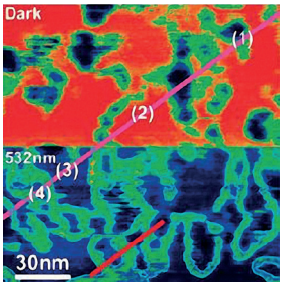
Non-Contact AFM



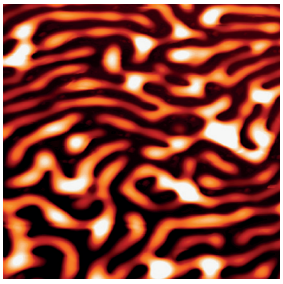
Piezo Force Microscopy



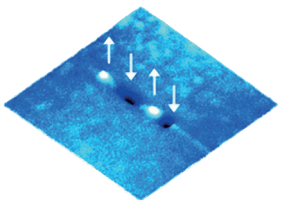
Kelvinprobe Microscopy



Workfunction Mapping (KPFM)



Magnetic Force Microscopy MFM



Electrostatic Force Microscopy (EFM)

Measurement Modes (Examples)

Technical Data

MATRIX 4 STM Control System STM Signal Conversion:
Two branch design for signal measurement and signal feedback

- ADC resolution 16-bit; 400 kHz sampling rate, switchable low pass (300 Hz, 1 kHz, 3 kHz, 10 kHz, 30 kHz).
- Gap voltage range: +/- 10 V and +/- 1 V (Standard configuration) 16-bit resolution, external input for modulation with switchable low pass (300 Hz, 3 kHz, 20 kHz, 56 kHz, full BW).
- Maximum spectroscopy acquisition time per spectroscopy point: 19 seconds
- Simultaneous over-sampling of all ADCs.

Channels:

- min. 24 internal plus 6 external measurement channels in the basic STM configuration.
- external inputs for gap voltage (modulation spectroscopy).

Regulator:

- DAC: true 20-bit resolution over full z-scanner range, monotonic within 1 LSB, low noise.
- Z-imaging with dynamic resolution of >24 bit.
- 2 independent digital processor inputs, configurable link to any digital signal source.
- 2 independent analogue processor inputs, 16 bit, 400 kHz with switchable low pass: 1 kHz, 3 kHz, 10 kHz, 30 kHz, 100 kHz.
- External offset input (ZOFFSET) with switchable low pass: 3 kHz, 10 kHz, 20 kHz, 60 kHz.

Up to 12 ADCs:	3 x 4 independent analogue input channels, ADC: 16-bit resolution, DC...400 kHz. Simultaneous oversampling of all ADCs.
XY Scanner:	3 x 2 independent analogue output channels, DAC: 16-bit resolution, DC ... 400 kHz switchable regeneration low pass (300 Hz, 3 kHz, 30 kHz, 100 kHz). • Scan Generation & Data sampling • Digital scan generation • Output channels for external devices • Image rotation • Hardware supported zoom

A superior hardware technology allows for 200 kHz acquisition rate (5 µs per image pixel) which equals to 10 images per second at 100 x100 pixel in forward/ backward operation for fast scan operations. With a const. sampling rate of 400 kHz, noise is automatically reduced.

CRTC:	Trigger control input/output
Piezo driver:	Output voltage range +/- 135 V low noise (< 300 nVrms/√Hz, 100 kHz bandwidth)
Coarse positioning:	16-channels, variable step size and frequency, control by remote-box, MATRIX-SPM-Software or scripting.
Signal access:	Through front panel mounted BNC connectors.
Configuration includes:	MATRIX Control System, Software, Vernissage Data Management Tool, Windows 10 PRO (64-bit) control computer, 1 x 27" LCD monitor.

Functions included

TWIN Regulator:	Two independent branches for feedback parameters with independent settings for feedback value and loop gain (i.e. It & Δf, Δf & D (Damping), It & Aux channel, etc.).
AFM control:	Sensor alignment & control, light source control, resonance/phase curve acquisition, amplitude channel, automatic phase adjustment, tip protection, frequency finder.
AFM contact modes:	Normal & lateral force, force-distance curves, PFM, LFM, C-AFM, SSRM.
AFM non-contact modes:	EFM, MFM, KPFM (FM & AM Mode), SCM, multi-mode operation & spectroscopy, constant damping.
PLL Modes:	Constant amplitude & constant excitation, oscillation amplitudes < 4 pmpk with QPlus AFM at 5 K, self-excitation (constant amplitude). • Integrated controller for KPFM (extra lock in needed) • Remote Interface The software offers remote access for controlling/integrating external software packages (i.e. LabVIEW) with the MATRIX Automated Task Environment (MATE).
AFM Controller:	Analog Bandwidth: Contact mode: 0 – 50 kHz Non-contact mode: 4 kHz – 3 MHz Input Voltage Noise: 11 nV/sqrt [Hz] Max. input signal: Contact mode: +/-10 V Non-contact mode: 3 Vpp PLL: Demodulation bandwidth: 1 Hz – 2 kHz Tip Protection
Spectroscopy:	Single point & grid, voltage & z-ramps, varied z-spectroscopy, dual mode spectroscopy, user specific spectroscopy with MATE (MATRIX Automated Task Environment), multiple curves, reversal ramp, modulation switches, trigger signals to synchronize with third party equipment, gap pre-set (parameters VGap, current set point, feedback loop gain can be set to different values for a spectroscopy measurement).

How to contact us:

www.ScientaOmicron.com
info@ScientaOmicron.com