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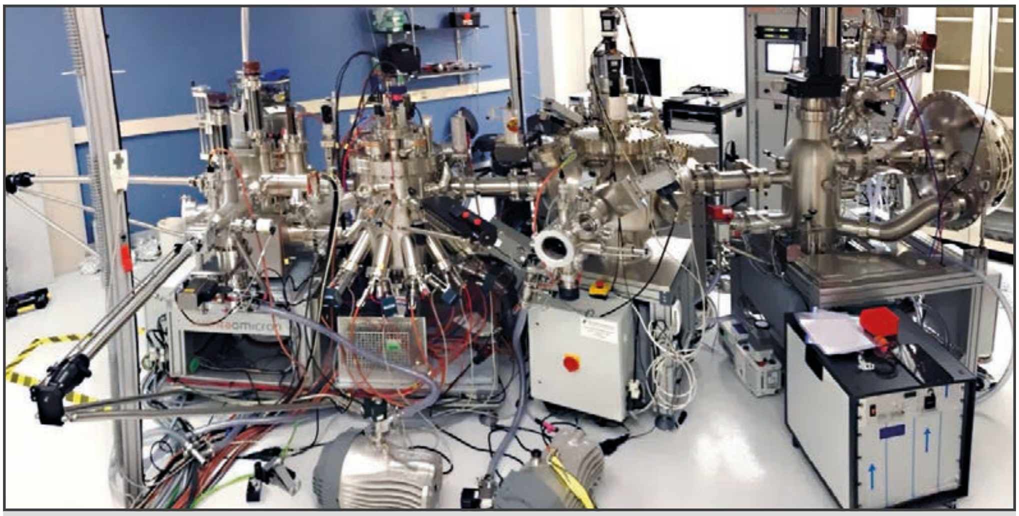
Spring 2019 News

Scienta Omicron - Superior Technology



Two-Dimensional Crystal Consortium Materials Innovation Platform (2DCC-MIP) housed at Pennsylvania State University, which engages in transformational research for bulk crystal and thin film (2D) chalcogenide growth. This system combines an EVO50-MBE for thin film synthesis, an ARPES-Lab system for band structure analysis and a LT Nanoprobe for STM imaging and in-situ transport measurements at atomic levels. These are combined using a reliable UHV rotary distribution that allows independent operation of each module while offering a straight forward path for future expansion.

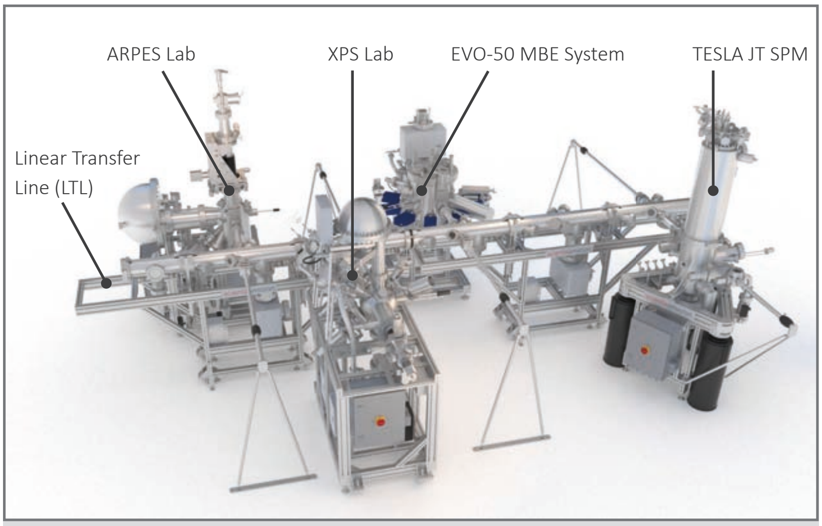
Materials Innovation Platform

Accelerating the development of novel materials

Novel materials with unique combinations of properties are regarded as key enablers for new, disruptive technologies. Of special interest are nanomaterials, which can be engineered for specific physical, electrical, and chemical properties. Understanding cause-effect correlation of these material's growth and structure supports systematic discovery and optimization of the desired properties. A proven and effective approach for this research is to use a 'Materials Innovation Platform'.

Materials Innovation Platforms (MIP) integrate instrumentation for growth and detailed characterization of samples in-situ. Not only is sample quality preserved by maintaining UHV conditions, but analysis and growth can be done at intermediate process steps and performed far more rapidly than if the instrumentation was separated. Further, appropriate design of a MIP provides for expansion and exchange of capabilities as the research evolves. Working with a single supplier and partner to design, produce and support these MIPs ensures highest instrument uptime, ease-of-use, and productivity. (→ Page 2)

Content



Concept of a Materials Innovation Platform consisting of an EVO-50 MBE growth module combined with the surface analysis instruments ARPES-Lab, XPS-Lab, and JT STM connected via an expandable linear transfer line (LTL).

(→) Functional examples of MIPs include growing high-quality two-dimensional nanomaterials like transition metal dichalcogenides (TMDCs) and topological insulators (TIs) using molecular beam epitaxy (MBE). Likewise, semiconductor and oxide materials can be synthesized via a number of methods (MBE, ALD, PLD) with high crystallinity and low defect density.
Scienta Omicron is the largest supplier of MIP systems for several key reasons:

- Leading technology for essential capabilities including ARPES, MBE, SPM, and XPS.
- Experienced design and project execution team
- We provide customer support, application training, and service
- Flexibility to include capabilities from other specialist companies

HAXPES Lab

First Deliveries

Scienta Omicron has recently made the first deliveries of the revolutionary HAXPES Lab. With this novel research tool hard X-ray photoelectron spectroscopy (HAXPES), previously only present at synchrotron radiation facilities, becomes available for lab use. The HAXPES Lab features a unique liquid metal jet X-ray source that enables very high X-ray flux in a micrometer sized spot.

Using hard X-rays as ionization source enables far greater penetration depth than traditional X-ray photoelectron spectroscopy (XPS), thus allowing for studies of true bulk material features. The bottom right spectrum of Fig. 1 shows a spectrum of Si covered with 50 nm SiO_2. The clear presence of a Si-Si peak demonstrates that the probing depth is larger than 50 nm.

For further exciting scientific opportunities enabled by this research tool, please see 'A novel laboratory-based hard X-ray photoelectron spectroscopy system', Rev. Sci. Instrum. 89 (2018) 073105.

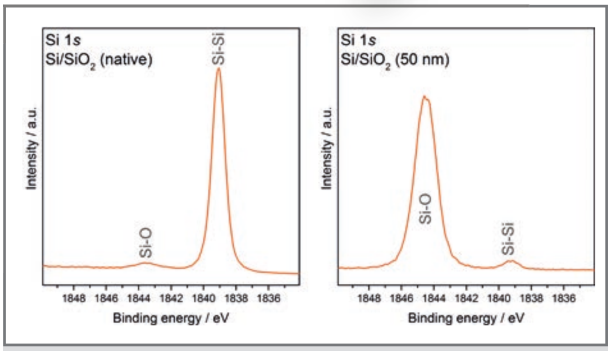


Fig. 1: Si 1s spectra from native silicon with one monolayer of SiO_2 compared to spectra of silicon with 50 nm SiO_2.
Measurement time is less than 8 minutes.

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The new DA20 ARPES Analyser

Compact Instrument with Patented Deflection

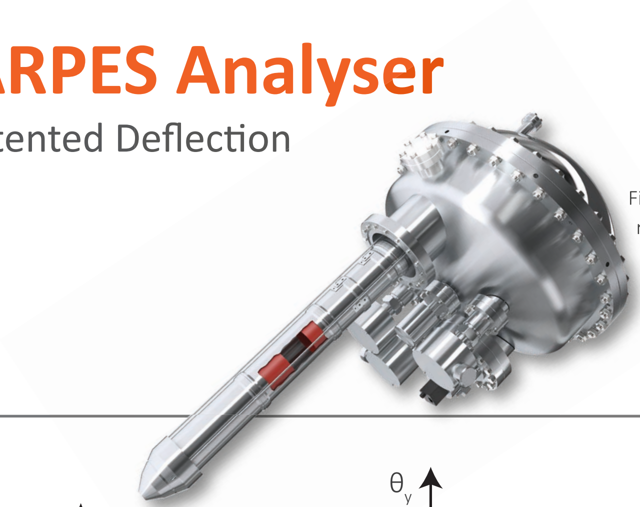


Fig. 1: DA20 analyser with redesigned lens system including two deflector elements (red). The deflection capability allows for ± 10° full cone measurements.

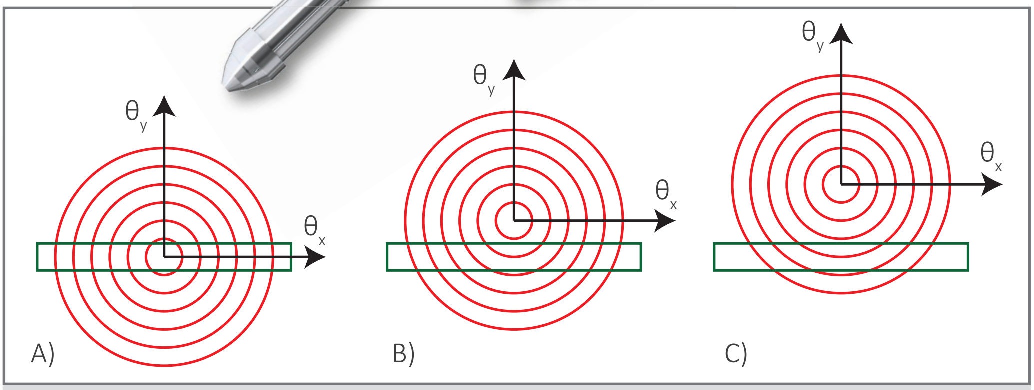


Fig. 2: The lens system projects the angular pattern on to the analyzer slit. Sequential deflection along θ_y enables to move the part of the angular pattern which is projected on to the slit.
A: Deflectors off. B and C: Increasing deflection along θ_y. This enables measurements of the whole acceptance cone without tilting the sample.

The DA20 is the most recent addition to our hemispherical analyser product line. It provides state-of-the-art ARPES as well as XPS and UPS while maintaining a compact foot-print. The DA20 includes the ground-breaking and patented deflection technology that was previously only available in the larger DA30-L (see Fig. 1) enabling full cone ARPES measurements without sample rotation.

The DA20 employs a 135 mm mean radius hemispherical analyser with interchangeable slits. It is capable of handling kinetic energies up to 1500 eV in both transmission and angular mode. The high voltage electronics provide ultra-stable conditions for reliable and accurate measurements. In combination with the 2-D low-noise electron detector (<0.01 cps/channel) the DA20 provides 3 meV energy resolution at 2 eV pass energy in transmission and angular mode. An energy resolution of 5 meV at 2 eV pass energy is achieved in deflection mode. The unique feature of the DA20 is the implementation of our patented deflection technology into the lens for advanced ARPES measurements.

Traditional ARPES analysers have an angular mode which is restricted to the angular dispersive θ_x direction, resulting in a 2D image of intensity for angle θ_x and energy E on the 2-D detector. In such a set-up, obtaining full cone measurements requires the sample be physically rotated to probe the θ_y angular space. This physical movement can introduce multiple artifacts into the ARPES measurement. First order issues include measuring different areas of the sample as the sample is moved. Matrix effects are also introduced as incident and exit angles are changed, affecting angle dependent electron escape. Our flagship analyser, the DA30-L, overcomes these limits by using an internal deflection mode for the θ_y direction.

With this deflection mode, individual slices of θ_x vs E spectra are collected on the detector for a given θ_y angle (see Fig. 2). Recording these individual slices while changing the θ_y deflector angle builds a cube of reliable data containing intensity for all θ_x, θ_y, E values (see Fig. 3). The deflection mode enables the DA20 to obtain these full cone measurements with an opening angle of up to +/- 10 degrees while avoiding sample rotation, making it an ideal workhorse for ARPES measurements.

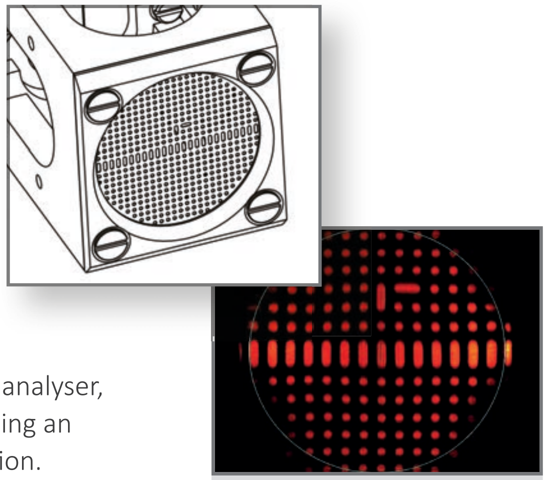


Fig. 3: A) Angular test device with a wire as a point source of electrons and a mask generating an angular pattern before the electrons reach the analyser lens. B) Using the DA20 deflection capability a full θ_x, θ_y data set is acquired of the generated angular test pattern.

Breakthrough in spin-filtered momentum microscopy

Two trend-setting publications from NanoESCA@Elettra

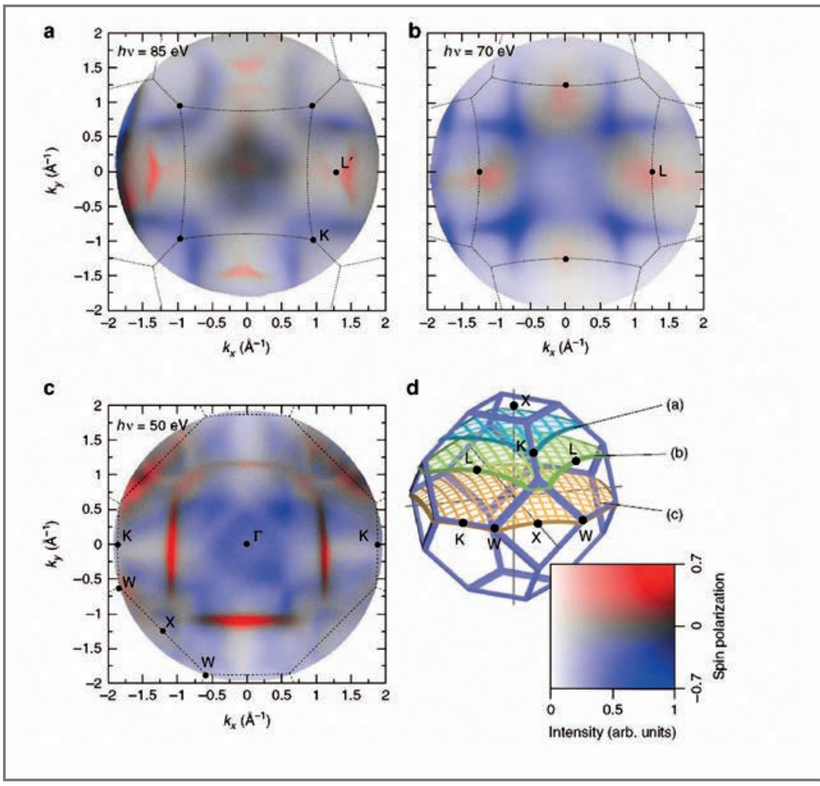
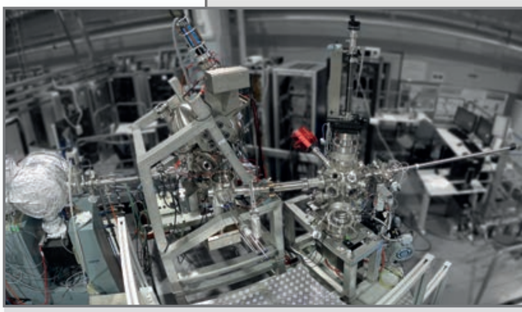


Figure 1: Measured spin-resolved Fermi surface of fcc cobalt. Spin-resolved photo-emission intensities in selected sections through the three-dimensional Fermi surface of 18 ML Co/Cu(100) measured at photon energies of hv = 85 eV (a), hv = 70 eV (b), and hv = 50 eV (c).
(d) The fcc Brillouin zone together with the corresponding cuts sampled by a–c.
According to the 2D colour code at the lower right, red and blue intensities correspond to majority and minority electronic states.
Taken from [2] (CC BY 4.0) [4].



NanoESCA endstation at synchrotron Elettra (Trieste, Italy)

In the six months since Dr. Christian Tusche (Forschungszentrum Jülich, Germany) was awarded the Kai Siegbahn Award 2018 for his contributions in the development of momentum microscopy with imaging spin filter, two important articles using this technique have been published in Nature Communications. Both were based on experiments using the NanoESCA end-station at the synchrotron Elettra, Italy [1], demonstrating its extraordinary capabilities as one of the most promising spin- and momentum-resolved photoemission instruments available.
The NanoESCA directly forms an image of the distribution of photoelectrons as function of the lateral crystal momentum (k_x, k_y). An imaging spin filter allows the simultaneous measurement of the spin polarization of photoelectrons in the entire surface Brillouin zone [2]. The monochromatic electron distribution behind the unique double-hemispherical analyzer of the NanoESCA is retarded to the necessary scattering energy of the W(100) single crystal, allowing for spin-dependent reflection.

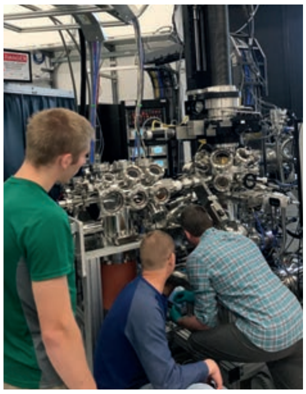
Figure 1 demonstrates how this technique was used to separately detect majority and minority spin-states in a thin cobalt film (grown on Cu (001)) to study the non-local origin of electron correlations in magnetic materials and to improve the knowledge about magnetism itself.
The approach to understand the interplay between band structure, magnetism and many-body correlations was supported by calculations using the OMNI code [2].

The same experimental technique, in combination with many-body calculations, was also carried out in conjunction with a newly developed first-principle method (implemented in the FLEUR code) to examine a thin iron film (grown on Au(001)). The observed spectral signature reflects the formation of a special many-body state which gives new insight into the physics of electron-magnon interaction, which is essential in the fields of spintronics and Fe-based superconductivity [3].

References and Related websites:
[1] http://www.elettra.trieste.it/elettra-beamlines/nanoesca.html
[2] C. Tusche et al., Nature Comm. 9 (2018) 3727, DOI: 10.1038/s41467-018-05960-5
[3] E. Mlynczak et al., Nature Comm. 10 (2019) 505, DOI: 10.1038/s41467-019-08445-1
[4] http://creativecommons.org/licenses/by/4.0/

Service contracts

'Maintaining customer relationships is our business'



As a world-leading supplier of UHV analytical and deposition tools, we ensure that our research clients enjoy not only the best instruments but also first-class support.

Service contracts – from preventive maintenance only to all-inclusive, or loaner/exchange agreements – are central to this commitment. They create a productivity partnership between us and our users for the lifetime of the instrument.

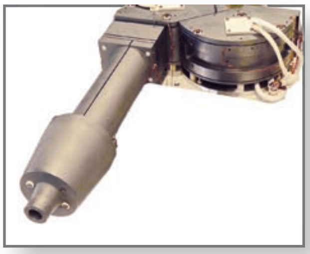
As a contract holder, you receive prioritized support. Here's what two cutting-edge groups say about our service teams:
'Easy to contact and responsive via e-mail. Very up-front on lead-times for parts and what we need to keep the SPMs running.' Sykes group, Tufts University.

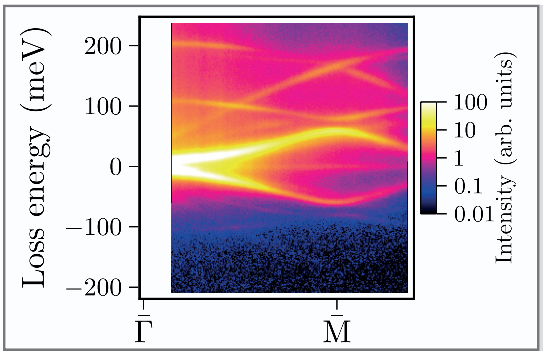
'Extremely knowledgeable and helpful. Provided invaluable advice on troubleshooting instrumentation.' Chen group, Univ. of South Carolina.

Working closely with our service teams will help keep your tools operating like new. Great science isn't done overnight.
So, it's good to know your Scienta Omicron systems and instruments will be ready and waiting for you every morning.

HREELS for the ARPES-Lab

High Energy Resolution Monochromatized Electron Source (MES)





Phonon dispersion of single crystal graphite, measured along the $\bar{\Gamma}$-$\bar{M}$ direction. Single spectrum, primary energy 110 eV. (Data courtesy: Dr. F. C. Bocquet and Prof. F. S. Tautz, PGI-3 @ FZ Jülich, Dr. S. Tanaka, Osaka Univ.)

Scienta Omicron welcomes an additional functionality to our family of electron spectroscopy products, a high energy resolution monochromatized electron source (MES).
Scienta Omicron has partnered with the home of high-resolution electron energy loss spectroscopy (HREELS), Forschungszentrum Jülich, where this method has been developed and refined over several decades. This source is based on the instrument design of Ibach et al, Review of Scientific Instruments 88(2017)033903, and serves as an add-on device for our ARPES Lab systems which use our parallel angular detection hemispherical analysers, such as the DA30-L.
The combination of a fully integrated MES with a hemispherical analyser renders the possibility to measure localized vibrations of adsorbed species, surface phonons, plasmons, excitons and magnons in a user-friendly way.
As such, it is a fantastic complement to ARPES electronic band structure mapping. The ARPES Lab system can record the electronic and phonon band structures of the same sample using the same instrument. Like ARPES measurements prior to 1994 (when the parallel angular detection analyser was introduced) HREELS has historically been measured using a single channel, mechanically rotating the analyser. Acquiring angle dependent spectra with such a setup is time consuming and limited in angular resolution. Combining the MES with the DA30-L's parallel angle detection for both θ_x and θ_y greatly enhances speed, resolution, and reliability.
We expect our customers will soon be discovering new phenomena with this instrument just as the kink in superconductors was discovered using our parallel angular detection analyser.

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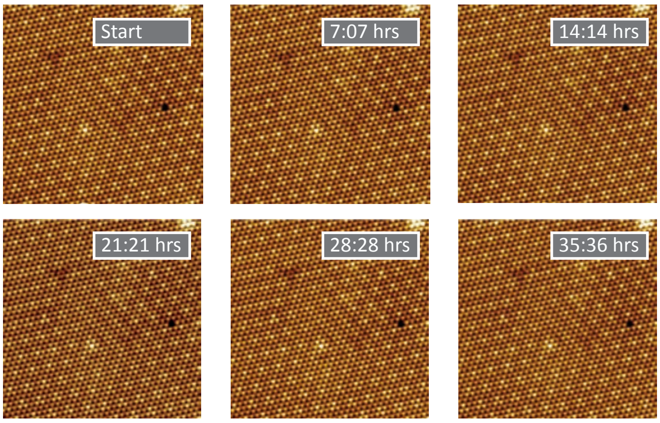
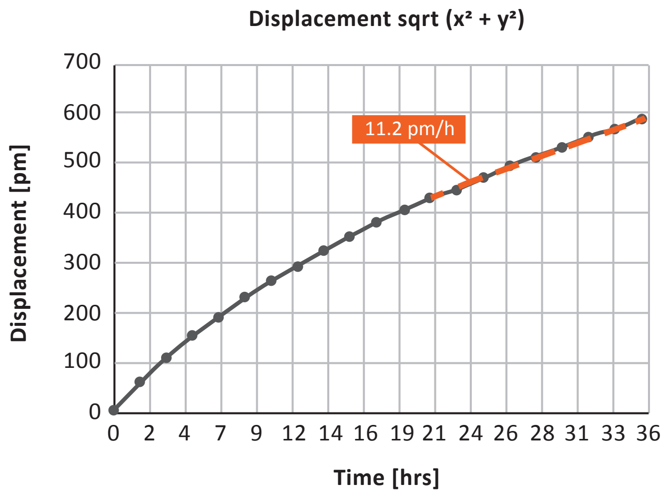
TESLA JT SPM – a versatile 1K-SPM

An ideal tool for SPM labs who plan to expand their experiments





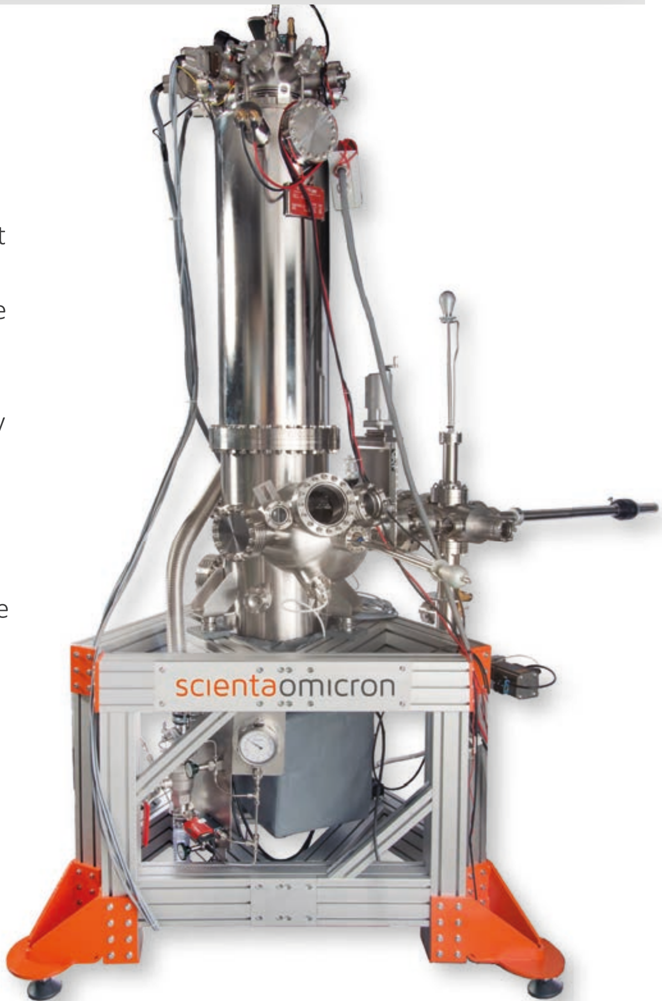
Exceptionally low thermal drift at T=1 K.
36 hours total acquisition time showing a thermal drift stabilising at 11.2 pm/h.

TESLA JT SPM has already shown a number of exciting applications such as fast variation of B-field while keeping the tip in tunneling contact [1], QPlus AFM during 3 Tesla B-field operation at 1K and advanced optical pump-probe scanning tunnelling microscopy technique, which enables the nanoscale probing of spin dynamics with the temporal resolution of the optical pulse width [2].

The microscope positions itself between tightly enclosed SPMs working under extreme environments of high B-field at milli-Kelvin temperatures and routine 4 Kelvin LT-STMs.
TESLA´s flexibility, open architecture, fast B-field variation and it´s low Helium consumption makes it an ideal next tool for SPM labs who plan to expand their experiments below 4 Kelvin without increasing the annual spend of liquid Helium while keeping the complexity of the experiments under control.

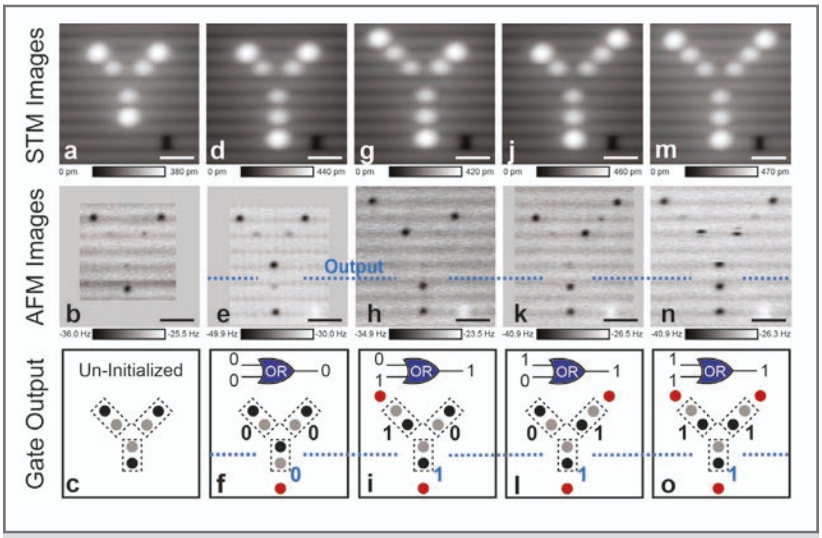
A special focus of this instrument will be on studying hysteresis effects on a single molecule scale with excellent energy resolution faster than ever. In addition, the combination with high frequency wiring will allow e.g. forefront research in the field of ESR-SPM. For this application the 1K-environment offers sufficient population of spin states while the easily variable B-field separates their levels by the Zeeman-effect.

[1] Scienta Omicron fall newsletter 2018
[2] Yoshida & Shigekawa et al., Nature Nanotechnology 9, 2014



The new Tri-Leg TESLA JT UHV System offers a space efficient footprint allowing for easy integration to our various Materials Innovation Platforms.

Autonomous Atomic Scale Manufacturing Through Machine Learning



A logical OR gate constructed from just six atoms. Inputs fabricated or erased at the end of the branches toggle the logical state of the gate through its full truth table. The charge sensitivity of atomic force microscopy (AFM) scanning is employed to see where the electrons re-arrange in the two-dimensional structure. Scale bars are 2 nm.

'Until now, we printed with atoms about as efficiently as medieval monks produced books. For a long while, we have had the equivalent of a pen for writing with atoms, but we had to write manually. So, we couldn't mass produce atom-scale devices, and we couldn't commercialize anything. Now that has all changed, much like the disruption following the arrival of the printing press for those medieval monks. Machine learning has automated the atom fabrication process, and an atom-scale manufacturing revolution is sure to follow.'[1]
Bob Wolkow, Univ. of Alberta / Canada
Department of Physics

The imaging of individual atoms has gone from a Nobel-prize-winning effort in the early 80's to a widely used research tool today. Scanning probe microscopes (SPM) are used in thousands of laboratories around the globe to explore and study matter at the atomic scale. Many of the efforts are focused on using SPM to create functional devices from atomic building blocks. Continued progress on this front depends on refining the ability to position, fabricate, and connect nano-scale structures with increasing speed, accuracy, and efficiency.

Researchers at the University of Alberta lead by Robert Wolkow have recently addressed some of these issues. Manufacturing of atomic patterns and interconnects traditionally has involved methodically conditioning a scan probe tip in situ with pulses and controlled indentations to the surface. Once sharp enough, the tip can then be manually instructed by the operator to manipulate the atoms into the desired patterns. This cycle of conditioning and patterning is one of the most time-consuming processes for SPM operators, and a limiting factor in making these atomic circuits economically viable. Wolkow's group has streamlined aspects of this process through the application of machine learning to the problem. The SPM can now recognize when the tip needs to be conditioned and automatically completes the process[2].

This automation supports an emerging range of atomic-scale applications, including the production of room-temperature-stable binary logic structures[3], ultra-dense data storage[4], and the spatial control of electrons[5]. Additional work integrating machine learning into other steps of the fabrication process, is intended to eventually eliminate the need for an operator to oversee manufacturing altogether[6]. This full-scale comprehensive approach paves the way for the practical implantation of computing using the properties of individual atoms[3].

1. Pascoe, J. Atomic-scale manufacturing now a reality. https://www.ualberta.ca/science/science-news/2018/may/atomic-scale-manufacturing-now-a-reality
2. Rashidi, M. & Wolkow, R. A. Autonomous Scanning Probe Microscopy in Situ Tip Conditioning through Machine Learning. ACS Nano 12, 5185–5189 (2018).
3. Huff, T. et al. Binary atomic silicon logic. Nat. Electron. 1, 636-643 (2018).
4. Achal, R. et al. Lithography for robust and editable atomic-scale silicon devices and memories. Nat. Commun. 9, 2778 (2018).
5. Rashidi, M. et al. Initiating and Monitoring the Evolution of Single Electrons Within Atom-Defined Structures, Phys. Rev. Lett. 121, 166801 (2018).
6. Rashidi, M. et al. Autonomous Atomic Scale Manufacturing Through Machine Learning. eprint arXiv:1902.08818 arXiv:1902.08818 (2019).

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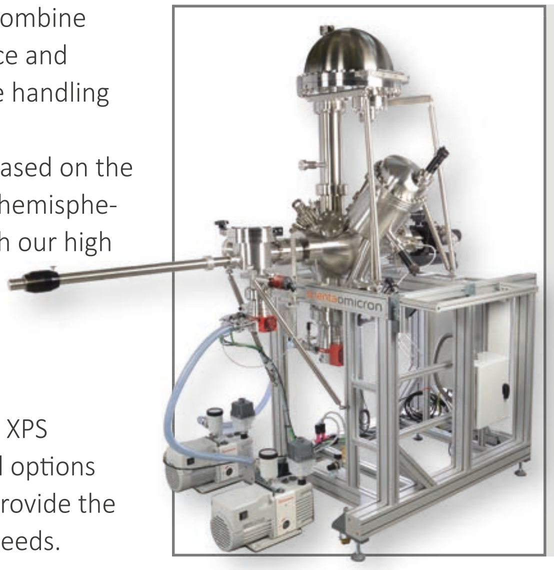
XPS-Lab

Versatile electron spectroscopy platform

The new XPS-Lab has been designed to combine outstanding quantitative XPS performance and ease of operation with a modular sample handling concept.
The exceptional value of the XPS-Lab is based on the high-transmission, high-speed Argus CU hemispherical analyser. In optimized geometry with our high power monochromated Al Kα X-ray source, the system provides highest sensitivity quantitative XPS analysis.

To complement and extend the standard XPS functions, a complete range of dedicated options are available, ensuring the XPS-Lab will provide the experimental solutions your laboratory needs.



Broad range of dedicated XPS-Lab options:
- Imaging XPS & selected area analysis (SA-XPS)
- Integrated electron charge neutralization
- Scanned small spot ion beam for uniform sputtering and depth profiling
- Argon gas cluster ion beam for sample preparation & depth profiling of sensitive materials
- Dedicated electron source for Auger electron spectroscopy (AES)
- VUV lamp for ultraviolet photoelectron spectroscopy (UPS)
- Handling of small flags, semi-automated handling of multiple samples or wafers up to 4” diameter
- Customized sample preparation facilities

LT STM & QSpeed AFM™

Up to 100 times faster QPlus® AFM imaging

2018 LT STM has demonstrated again its outstanding capabilities and versatility by remarkably high scientific output from over 120 referenced publications covering a wide range of applications from basic topography studies using STM and QPlus AFM modes to advanced experiments such as STS mapping [1], atom manipulation based device fabrication [2,3], applications with light interaction in the tunnelling regime [4] or on-surface chemistry studies [5,6,7]. Several of these experiments are using advanced QPlus AFM techniques specifically to investigate single molecule properties.
By adding Scienta Omicron´s latest development QSpeed AFM to its toolbox LT STM Gen III is prepared for future scientific challenges by offering higher productivity while enabling a range of new applications like fast large area navigation on insulators or mapping long range ordering of molecules.
Fig.1 shows an example of a high-resolution large area scan on NaCl. QSpeed AFM incorporates TO AFM [8] and is now available with MATRIX 4 using Zurich Instruments powered PLL AFM controller making QPlus faster and easier - a new workhorse scan technique for everyone!

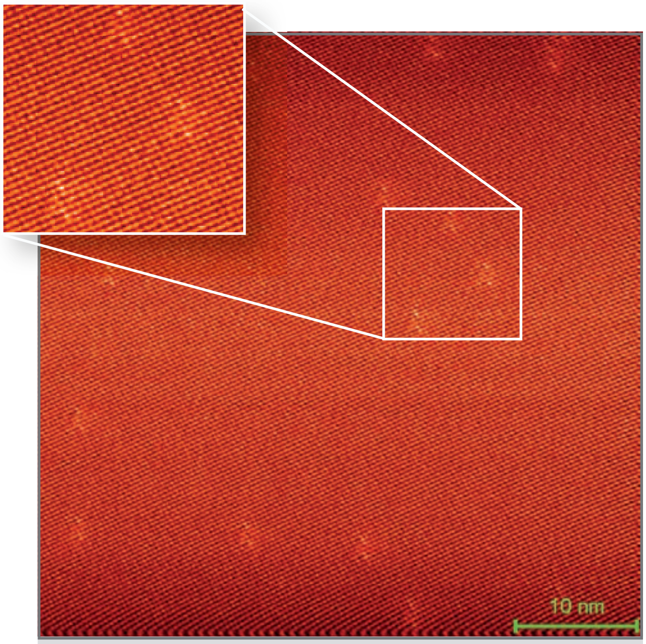


Figure 1: QSpeed AFM high resolution large area scan on NaCl (001) showing defect distribution after cleaving. The 1000x1000 points image has been recorded within 50 minutes at LN_2 temperatures. The insert shows a digital zoom of the grey marked area.

[1] Gröning et al, Nature 560, 209–213 (2018)
[2] Kempkes et al., Nature Physics 15, 127–131 (2019)
[3] Huff et al., Nature Electronics 1, 636–643 (2018)
[4] Anggara et al., Sci. Adv. 2018; 4 : eaau2821
[5] Liu et al, ACS Nano 2018 12 (12), 12612-12618
[6] Shu et al., Nature communications 9 (2018):2322
[7] Ebeling et al., Nature communications 9 (2018):2420
[8] Tuned-Oscillator Atomic Force Microscopy, licensed from Yale University, O.E. Dagdeviren et al.