NEWSFLYER WINTER 2022

MESSAGE FROM GLOBAL SALES MANAGER PHIL PICKERING

Scienta Omicron to help fabricate, manipulate, and characterise the materials to exploit quantum behaviours

I am delighted to welcome you to the 2022 Winter Newsflyer from Scienta Omicron. There is a quantum theme about this newsflyer following the award of the 2022 Nobel prize for physics to Alain Aspect Alain Aspect, John Clauser and Anton Zeilinger. They each made groundbreaking experiments using entangled quantum states, where two particles behave like a single unit even when they are separated. Their results have cleared the way for new technology based upon quantum information. In this newsflyer, we highlight two of the projects that Scienta Omicron has been involved in which will help to fabricate, manipulate, and characterise the materials that in turn improve our ability to exploit quantum behaviours and will lead to the development of new technologies.

The Scienta Omicron North American team at the AVS68 meeting in Pittsburgh. The team is joined by Henrik Bergersen, the CEO Scienta Scientific group, and Phil Pickering, Global Sales Manager Scienta Omicron.

Also related to quantum, we feature a product overview of our Multiprobe prep product, which provides a versatile environment for sample preparation, and enables other analytical techniques to be easily integrated. When combined with an SPM, the preparation chamber can be isolated from the SPM chamber to maintain optical cleanliness, which is a common requirement of researchers who want to use the VT-SPM as a tool to prepare structures with atomic precision, particularly for research on quantum computing devices.

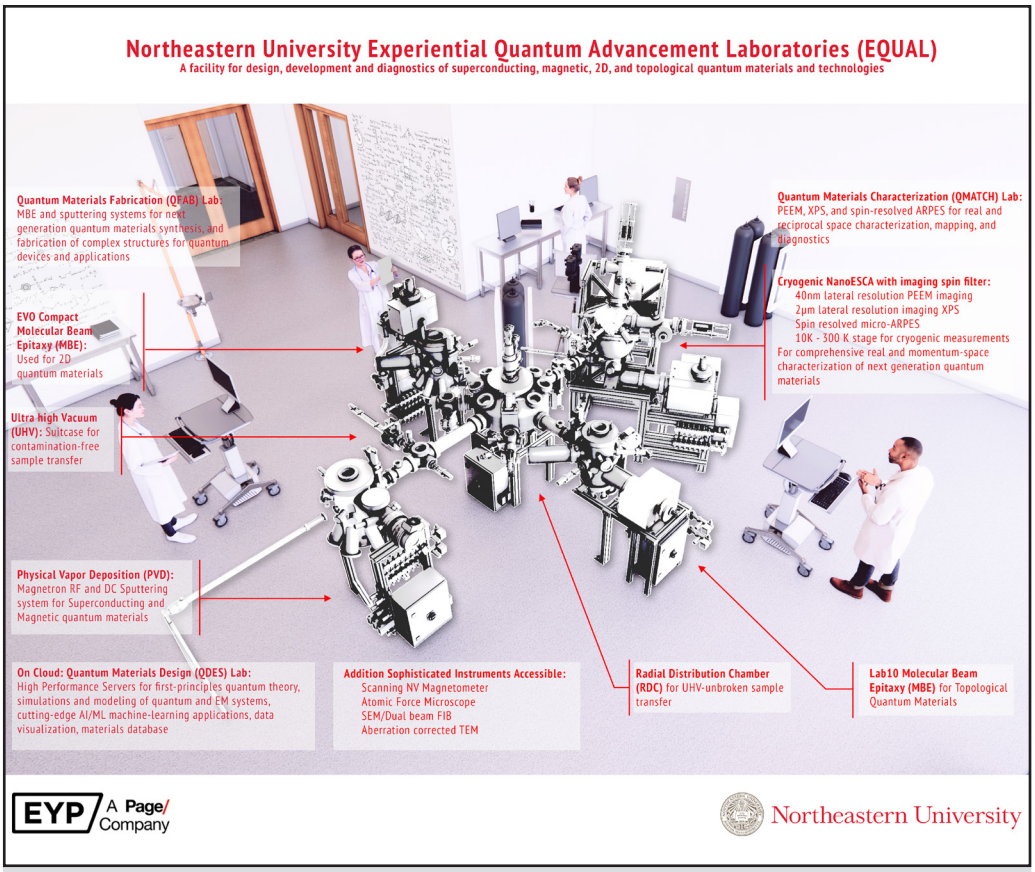
Moving away from quantum, Andreas Lindblad at Uppsala University, Sweden tells us more about his research on his newly installed HAXPES Lab, bringing Hard X-Ray Photoelectron spectroscopy to the laboratory environment without the need for a synchrotron. You can also read about our HiPP Lab ambient pressure photoelectron spectroscopy (APPES) and our latest analyser DFS30 with its dynamic electron optics and the advantages this has for µARPES.

Our commitment to our users continues long after the system warranty has expired. In this newsflyer, we highlight our high-uptime kits, our growing range of product upgrades, and training courses. High-uptime kits are intended to provide our users with the parts and consumables to deal with the most common maintenance and rapid repairs, so that you have them immediately available when needed. Our range of upgrades now comprises of more than 40 options to help our customers to optimise their investment by improving the efficiency or performance of existing instruments. One such upgrade is the PEAK software designed to control acquisition of photoelectron spectra with Scienta Omicron analysers, and we describe the user-training for API and the software development kit that provides advanced users with the capability to integrate external distributed control systems, enabling advanced measurements to be set-up.

MATERIALS INNOVATION PLATFORM (MIP) AT NORTHEASTERN UNIVERSITY

Materials Innovation Platform (MIP) at Northeastern University

Scienta Omicron's newest Materials Innovation Platform (MIP) will arrive in December of 2022 at Northeastern University's Innovation Campus in Burlington, MA. as part of the Experiential Quantum Advancement Laboratories (EQUAL), a nearly $10 million project to advance the emerging quantum sensing and related technology sectors in the state. The Northeastern-led project will establish new partnerships and leverage several ongoing ones with academic institutions and industry partners. The aim is to develop next-generation quantum technologies, boost training in quantum information science and engineering for students and workers, and establish greater partnerships among industry and government around quantum sensing and related technologies.



Scienta Omicron Materials Innovation Platform (MIP) to be installed at the Experiential Quantum Advancement Laboratories (EQUAL), Northeastern University

A Scienta Omicron MIP is a fully integrated instrument for materials research and data-science. By combining advanced instrumentation for synthesis and characterization with UHV sample transfer, MIPs leverage the individual capabilities of each module to provide multi-modal experimental research avoiding complications of contamination or oxidation due to exposure to air. Furthermore, through automated collection and time synchronization of all data from each module; synthesis, characterization, and instrument meta-data to a central server the MIP creates unique high-quality data to enable data-science research.

With a Scienta Omicron MIP, researchers are freed from the need to manually wrangle data from multiple workstations and instrument logs allowing them to focus on data analysis. The collated, labelled and time synchronized data is accessed via the central server where it can then be automatically replicated to a designated secure data vault, used to power dashboards and analytics in which the full array of system metadata informs machine learning algorithms.

MIPs can be configured to study a wide range of material systems utilizing molecular beam epitaxy (MBE), atomic layer deposition (ALD), physical vapor deposition (PVD) among other synthesis techniques, scanning probe microscopy (STM/AFM), scanning tunneling spectroscopy (STS) and electron spectroscopy for chemical analysis (XPS, AP-XPS, HAXPES) and band structure mapping, (micro S-ARPES, TR-ARPES) for characterization.

HAXPES Lab: CUSTOMER PORTRAIT
Andreas Lindblad, Uppsala University

Andreas Lindblad at Uppsala University, Sweden tells us more about his research on his newly installed HAXPES Lab

Tell us about yourself?
– I work at Uppsala University as an associate professor and currently head the division of X-ray Photon Science at the Department of Physics and Astronomy. Throughout my career, electron spectroscopy has been the unifying theme, especially in conjunction with synchrotron radiation. Together with collaborators, I have studied atoms, molecules, clusters, liquids, and solids. Currently, I am interested in charge and mass transfer over interfaces and between surfaces and adsorbed molecules.

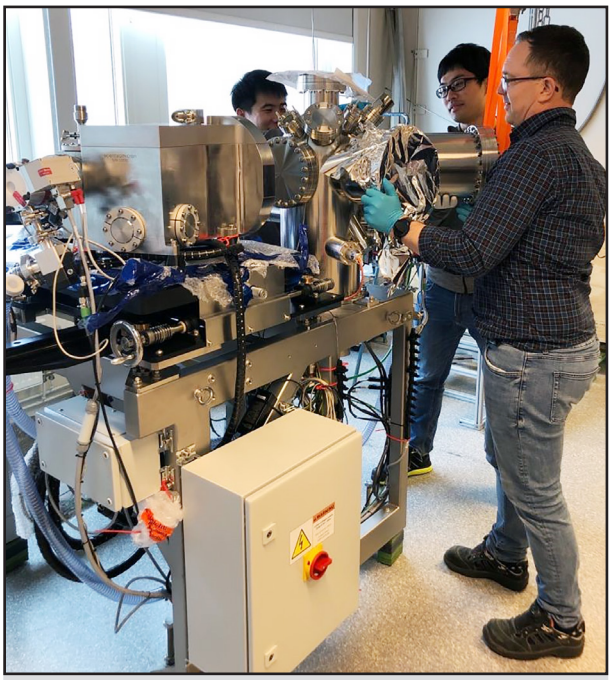
What are the main reasons that got you interested in HAXPES?
– The larger information depth and access to deeper core holes. We worked with chemical characterisation of oxide and sulphide films deposited with ALD/CVD and could not use sputter etching to depth profile the samples.

What kind of research will you perform on the HAXPES Lab?
– Characterisation of basic properties of alloys and thin films which will allow us to follow dynamics, such as mass-transfer with chemical specificity as a function of temperature and/or applied potential. This will be applied to building better interfaces in functional material systems, e.g. for alkali-ion batteries, photovoltaics, and fuel cells. We already have three Ph.D. students utilising the system and the sample preparation part of the system will be extended this autumn.

What do you like most with HAXPES Lab?
– It gives us a powerful home laboratory where we can explore our material systems 24/7. We can also speed up the feedback process to collaborators doing synthesis and theory.

Since the spectrometer and software are the same as on the synchrotron beamlines where we also use the HAXPES Lab, this gives us a wonderful way to train Ph.D. students, so they are confident when they arrive at the beamline. It is user-friendly enough for us to use it for teaching (Surface physics, Advanced materials analysis) and for master thesis projects.

Andreas Lindblad, associate professor at Uppsala University and responsible for the newly installed HAXPES Lab.



Installation of the HAXPES Lab at the Ångström laboratory, Uppsala University, Sweden performed by Scienta Omicron staff.

Scienta Omicron´s HAXPES Lab brings hard X-ray photoelectron spectroscopy (HAXPES) capability directly to the local laboratory environment. Using world class technology and expert engineering, the HAXPES Lab sets the standard for laboratory-based high energy photoelectron spectroscopy. This novel system probes bulk sample properties and accesses deep core level electrons via photoelectron spectroscopy (XPS) without the need for a synchrotron.

MONOLITHIC THREE-DIMENSIONAL FABRICATION

Atomically Defined Tunnel Junctions can now be tuned in Multi-Layered Devices fabricated by Scanning Tunnelling Microscope Lithography and Molecular Beam Epitaxy

Physicist and engineers at the Australian Research Council Centre of Excellence for Quantum Computing and Communication Technology (CQC2T) at the University of New South Wales, Sydney, Australia, have been working steadily towards the development of a universal quantum computer over the last two decades. First proposed in the late nineties, the envisioned quantum computer uses the electron spin on a single donor dopant in silicon as a qubit. The teams at CQC2T, and since 2016 together with Silicon Quantum Computing Pty Ltd (SQC), are led by Prof. Michelle Simmons who pioneered the field of atomic scale electronics. Our devices are fabricated on the atomic scale by scanning tunnelling microscopy (STM) hydrogen lithography, see Figure 1, in which a monolayer of hydrogen serves as a lithographic mask on a silicon surface. The exposed regions are subsequently functionalized using phosphine gas and overgrown with silicon using a Si sublimation cell (in a Scienta Omicron VT SPM Lab). Besides its ability to place dopants with atomic precision, this technique has the advantage that the active region of the device is separated away from any surfaces or interfaces, resulting in a low charge noise environment. At CQC2T and SQC we are using this technique to build quantum electronics and ultimately a scalable universal quantum computer.

To date, critical components for a scalable quantum computer have been realized such as metallic nanowires, single atom transistors, single electron transistors, single electron and nuclear spin control, and two-qubit gates. The atomic precision with which these components can be made, and their overall small size, can be leveraged for scalable quantum computing architectures such as linear arrays of singlet–triplet qubits, or for single spin qubits in a 2D surface code design. Ultimately error correction in a quantum computer will require the realization of the latter with control electrodes above and below the 2D qubit array, see Figure 2, necessitating multi-layered STM lithography.

Central to all nanoscale devices are the junctions between device elements where electrons tunnel

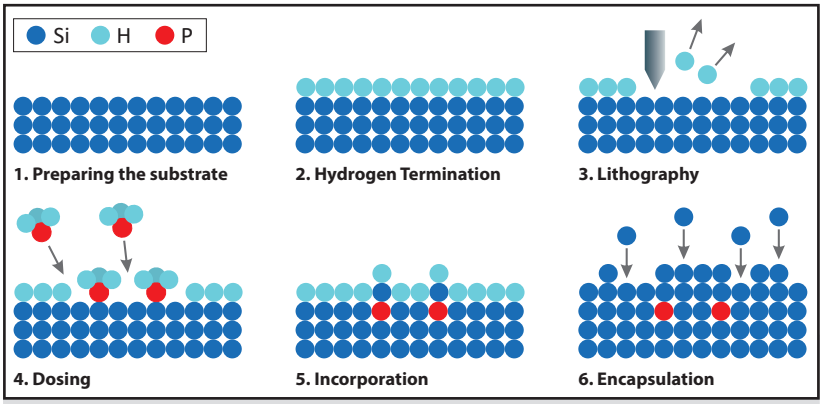


Figure 1: Scanning Tunneling Microscopy Hydrogen Lithography. 1) The silicon is annealed to 1100 °C under UHV conditions to clean and flatten the surface. 2) The silicon is exposed to atomic hydrogen which passivates the surface. 3) The STM tips is used to locally remove H-atoms leaving patterns of bare silicon. 4) PH3 absorbs to the chemically active Si exposed by the openings in the H mask. 5) P atoms are incorporated into the Si Lattice by annealing to 350 °C. 5) The patterned structures are overgrown at 250 °C with Si using a solid source MBE.

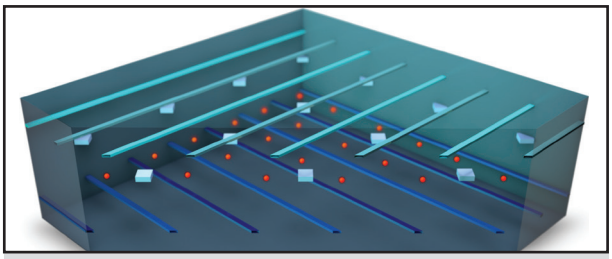


Figure 2: The proposed 2D surface code architecture consisting of three functional layers. The target dimensions are marked in the figure, with the qubits (red) and single electron transistors (squares) in the middle layer addressed by control lines vertically placed in separated places above and below the qubit plane.

from one electrode to another. In atomically precise qubit devices, these tunnel junctions exist either between the qubits themselves, typically on the order of ~10–15 nm or between the qubit and the readout sensor (~20 nm). Tunnel junctions can also be formed between the terminated ends of two nanowires and form a key component in qubit readout applications such as in single-electron transistors, in single-lead quantum dots, and in charge-sensing tunnel junctions. To control these devices, in-plane gates are capacitively coupled to elements within the device and, depending on the distance to the gates (typically 50–100 nm), the lever arm α, *i.e.* the ratio of the potential change at the active region of the device to the potential change on the gate, is typically ~0.1. The ability to create vertically separated gates using 3D STM lithography has shown that larger lever arms of α ~0.3 are possible. In the work highlighted here we have leveraged this increased coupling of 3D epitaxial gates to control tunnelling in Si:P tunnel junctions, providing a functionally useful component for Si:P based quantum processors that can be used for on-chip logic and has the potential to facilitate qubit control and readout schemes.

We have fabricated a top-gate on a tunnel junction in a monolithic Si:P architecture, see Figure 3, using two separate silicon overgrowths to provide vertically separated lithographic planes. The barrier height of the tunnel junction can be tuned in the range 0-186 meV, equating to a lever arm α ~0.35 compared to the typical in-plane lever arm of α ~0.1. This increased lever arm will provide improved tunability in the next generation of Si:P quantum computing devices incorporating vertically separated gates. When two of these top-gated tunnel junctions are combined in series within a single device, see Figure 4, we can operate them as classical logic gates, with current on/off ratios of ~1000-2000, similar to other nanoscale transistor designs. This transistor-like behaviour can be leveraged

The team at the Australian Research Centre of Excellence for Quantum Computing and Quantum Communication (CQC2T) and Silicon Quantum Computing Pty Ltd (SQC) at the University of New South Wales, Sydney, Australia.

in quantum computing architectures where small numbers of top-gated Si:P tunnel junctions are integrated within the monolithic silicon devices to provide on-chip logic.

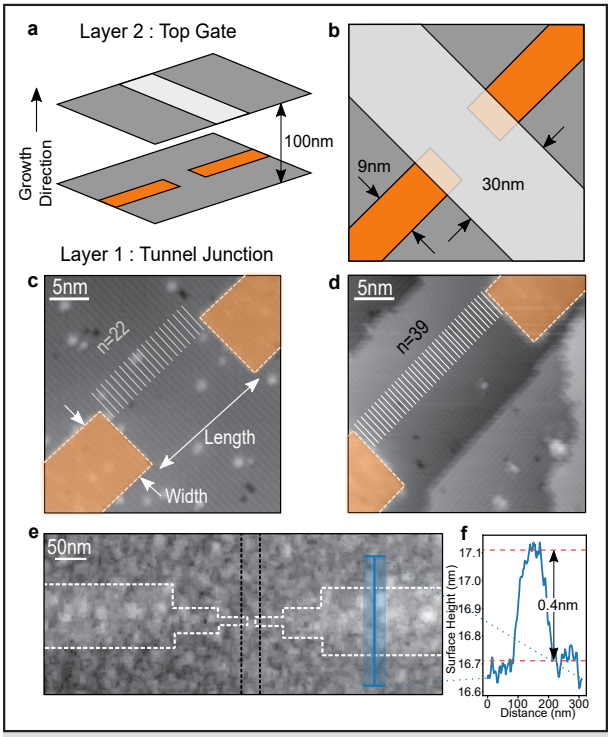


Figure 3: Precision alignment of a 30 nm wide epitaxial top gate above a 8.8 nm × 16.9 nm and 10.0 nm × 30.0 nm Si:P tunnel junction. (a) An illustration of a vertically gated 3D tunnel junction in layer 1 (orange leads) separated from the top-gate in layer 2 (grey lead) by 100 nm of epitaxially grown silicon. (b) A top-down illustration of the device showing the ~5 nm alignment accuracy of the top-gate in layer 2 with respect to the tunnel junction in layer 1. (c) An STM image of the tunnel junction with a short (n = 22 dimer rows = 16.9 nm ± 0.8 nm) channel length, with the bright outlined areas indicating the desorbed regions where phosphorus atoms will be incorporated into the silicon lattice. (d) An STM image of a long channel length junction separated by n = 39 dimer rows, giving a junction length $L = n \times 0.768$ nm = 30.0 nm. (e) An STM image of the surface of layer 2 showing the topographic outline of the device on Layer 1 (white dashed line) surviving encapsulation with 100 nm of silicon. The 30 nm wide top-gate (black dashed line) is aligned directly over the tunnel junction with alignment accuracy of ±5 nm. (f) An averaged line profile from the STM image in (e) of layer 2, showing the ~0.4 nm difference in surface height caused by the phosphorus doped region of layer 1.

The current results are the latest step towards the integration of 3D epitaxial gates into multi-layered Si:P devices, with work now focussing on replacing the qubit control gates, traditionally placed in the same plane as the qubit, with 3D epitaxial gates freeing up space in the qubit plane and enabling scale-up. Additionally, the 3D epitaxial gates have the potential to tune tunnel rates, tunnel couplings, and hyperfine couplings, facilitating more flexible and precise control in quantum information applications.

The full article in Nano Letters can be accessed here: https://doi.org/10.1021/acs.nanolett.1c03879

Original publication:
Matthew B. Donnelly, Joris G. Keizer, Yousun Chung, and Michelle Y. Simmons. Nano Lett. 21, 23, 10092-10098 (2021)

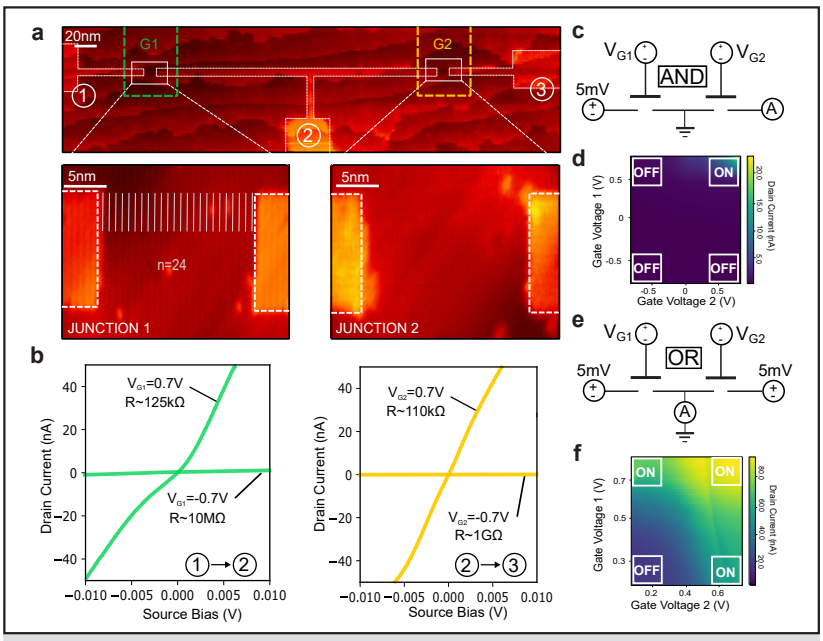
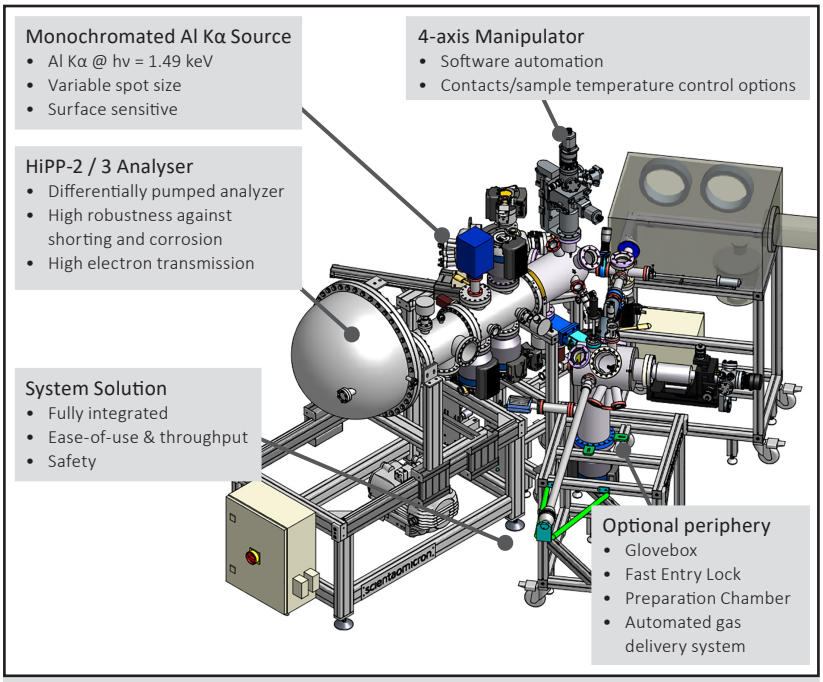


Figure 4: Logic operations in a three terminal tunnel junction device. (a) (top) Constant-current STM images of the inner part of the device indicating three terminals (①, ②, ③) used to measure two gated tunnel junctions (white boxes), and the alignment of the top-gates G1 (green-dashed) and G2 (yellow-dashed). The light-colored regions indicate where the hydrogen termination has been desorbed by the STM tip, revealing regions of bare silicon dangling bonds. (b) Source–drain I-V curves of junction 1 (① → ②, green) and junction 2 (② → ③, yellow) as their respective top-gates G1 and G2 are swept from −0.7 to 0.7 V. (c,e) AND and OR logic circuits. (d,f) Maps of the measured drain current (nA) as a function of gate voltages VG1 and VG2. The white boxes in the corners of the maps represent the regions of high/low current which correspond to the ON/OFF logic outputs for each operation.

HiPP Lab. Ambient Pressure Photoelectron Spectroscopy – For Your Home Laboratory



Scienta Omicron HiPP Lab: Advanced Measurements Made Easy

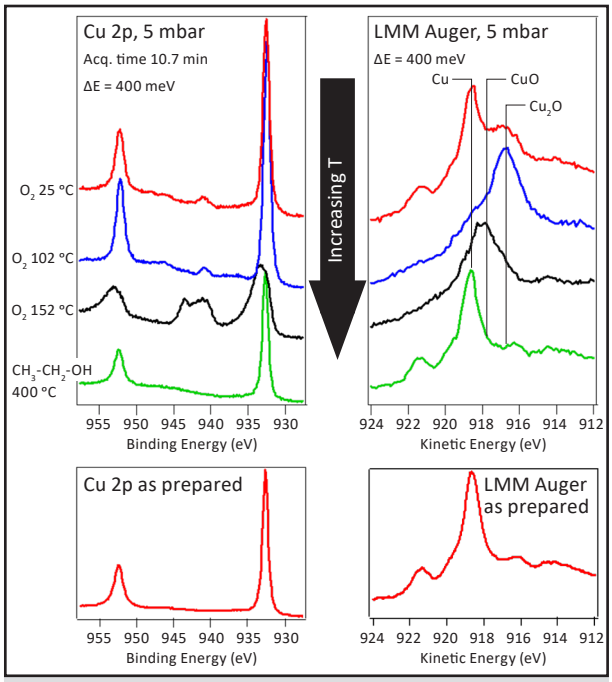


Figure 1: Oxidation and reduction study of polycrystalline copper at 5 mbar and variable temperature.

With the HiPP Lab Scienta Omicron provides a novel solution for laboratory based ambient pressure photoelectron spectroscopy (APPES). Drawing on extensive experience in the fields of photoelectron spectroscopy (PES), UHV technology, and system design, Scienta Omicron has designed the HiPP Lab as an easy to use system that encourages user creativity through flexibility, modularity and an innovate chamber design.

The HiPP Lab is an innovative modular system that is easily adapted to the scientist´s need. It combines a state of the art HiPP analyser with a high flux, variable focus X-ray source. Multiple options complement the HiPP Lab offer, these include: Glovebox, preparation chamber, electrochemical cells, dip & pull method, options for photo-induced electrochemistry, laser heating, mass-spectroscopy and UV-light source and many more.

Using automated gas-flow controllers, experiments can be conducted in a controlled way.

The HiPP-3 analyser features a 2D detector allowing for spatial resolved measurements, the swift acceleration mode for high electron transmission and a double cone principle for enhanced corrosion resistance. Figure 1 shows an application example following the oxidation and reduction of polycrystalline Copper at 5 mbar.

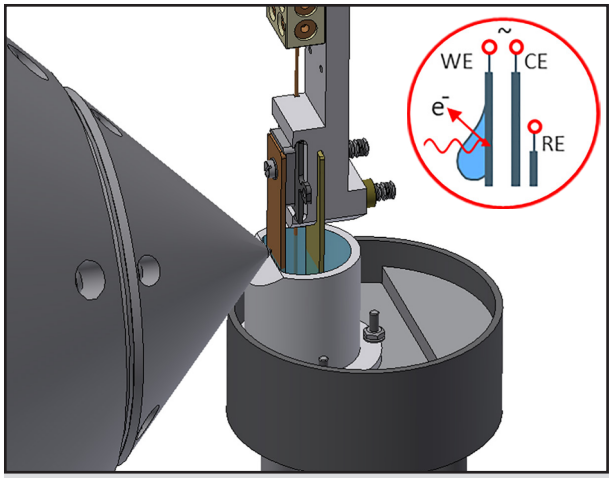


Figure 2: Analyser front-cone and dip & pull set-up using a three electrode system with working electrode (WE), counter electrode (CE) and reference electrode (RE).

HiPP Lab advantages:

- Easy to operate and high flexibility
- Swift acceleration mode and small spot X-rays source for highest information rate
- Innovative design with high uptime and enhanced corrosion resistance for electrochemical measurements

PEAK DEVELOPMENT AND API TRAINING
Full Analyser Control with Scripts and Clients

PEAK is designed to control acquisition of photoelectron spectra with Scienta Omicron analysers. The modular design and the modern network based application programming interface (API) facilitate full integration of the analyser in external distributed control systems (DCS) such as TANGO, EPICS, Python or LabView. This allows setting up advanced measurements, including arbitrary hardware control, not directly supported in the PEAK GUI.

PEAK API for External Control Systems
With the client server model it is possible to control the analyser acquisition from outside of the instrument PC and to run a DCS concurrent with the use of the PEAK GUI. Hence, while the analyser is controlled through the external DCS the PEAK GUI displays the live analyser settings and the live spectrum monitor. This is especially helpful during development to verify the expected behaviour.

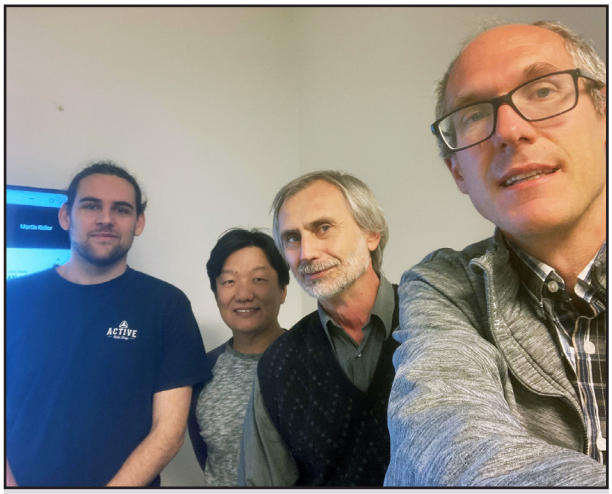
API Training & Software Development Kit (SDK)
To facilitate external control, the PEAK development team offers SDK and API training classes. The training is typically two full day sessions with *The 1st* session focuses on architecture, design and vision of PEAK, installation and using the PEAK GUI. Based on that knowledge, the *2nd session* moves into the SDK with interactive Python notebooks that demonstrate best use of the API to perform acquisitions, setting up sequences, exporting data and monitoring the system, while having the PEAK GUI to support the development.

The training is based on use cases and has been attended by research groups and staff from among others the MAX IV, SPring-8, PSI and ALS synchrotrons. The training is primarily offered in Uppsala or online.

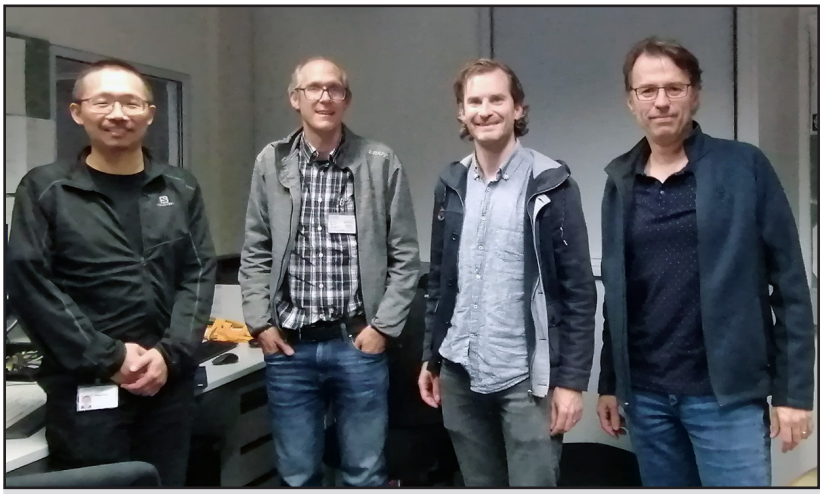
Upgrade to PEAK
PEAK is available as an upgrade for most Scienta Omicron analysers, originally delivered with SES. Parts of the analyser electronics, detector and computer may need to be upgraded to be compatible with PEAK. Hardware upgrade packages are available. This provides access to new software functionality, and the service life time of old instruments is substantially extended.

Improved PEAK API and Software Development Kit

- Easy to use, updated intuitive command set with access to all functions
- PEAK demo environment with emulation drivers for independent offline development
- Motorized control of analyser slit mechanism
- Added support for storing data in HDF5, VAMAS



Dr. Anders Frisk from the Scienta Omicron Software team visited the ALS and Jacob Gobbo, Dr Sung-Kwan Mo, and Dr. Alexei Federov for PEAK API training and exchange with the beamline control group.



Dr Anders Frisk together with the SIS beamline team at SLS (PSI) for collaboration and collecting input on the PEAK development. From left: Dr Xiaoqiang Wang, Dr Anders Frisk, Dr Nicholas Plumb, Alex Gobbo

DFS30 ON-SITE TESTING

Advantages of Electrostatic 3D Focus Adjustment

On-site collaborations are an exciting way to stay at the cutting edge of science. Before summer we went to Max IV to demonstrate the DFS30, our latest analyser model, and the advantages it brings for µARPES on flakes. The DFS30 boasts dynamic electron optics that are quickly adjusted electronically to the emission spot and as experimental parameters are changed. This technology replaces time consuming yet critical mechanical optimisation of sample and photon source necessary for highest quality deflection ARPES. With the DFS30, the experimental geometry is kept fixed while still ensuring highest quality µARPES measurements.

ARPES data is ideally collected using an aperture-slit combination for best energy fidelity. For high quality, this requires precise alignment of sample, photon source, and analyser. Poor alignment of emission spot and analyser focal point results in an overall drop of intensity in transmission mode and a loss of intensity across parts of the angular range in deflection mode measurement. An example is seen in Figure 2 (middle column) where part of the non-dispersive background is lost.

For larger emission spots these effects are less dominant, while for small emission spots (< 100 µm) precise alignment becomes crucial. However, mechanical adjustments of the sample position and light source will change the probed sample region which is ideally avoided when working with flakes or domains.

Advantage for µARPES

The dynamic electron optics in the DFS30 solve this alignment predicament by tuning analyser lens focal point to a given emission spot position. Alignment is optimised by checking that the non-dispersive background of the sample has a uniform shape. After such an electronic adjustment, the full angular range of a deflection mode is restored and uniformly filled with intensity despite the poor mechanical alignment. By eliminating sample and photon source movements, the experimental geometry is kept fixed and ensures the emission spot remains fixed on the same region (e.g. a flake). Since the electronic alignment is adjusted in mm these values are also easily used as input for mechanical manipulator movement. In either way, using electronic alignment reduces the time to measurement and avoids contamination build up.

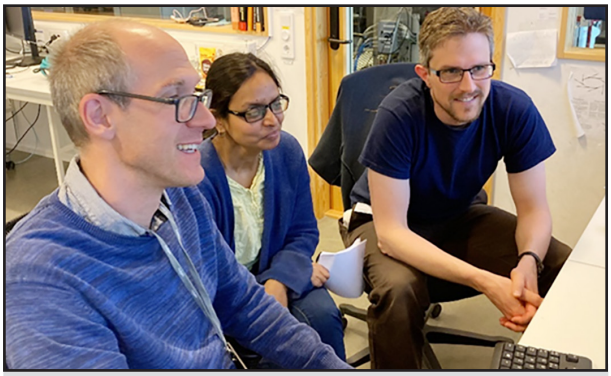


Figure 1: Scienta Omicron´s Anders Frisk together with part of the Bloch beamline team (Khadiza Ali and Craig Polley) at Max IV in Sweden.

DFS30 advantages:

- Electronically shift the analyser focal point to the emission spot
- Increase effective sample life-time through fast and precise alignment
- Electrostatic 3D Focus Adjustment in X, Y, Z (WD) for best results
- Deflection mode full cone measurements without matrix element effects
- Upgrade from DA30-L available

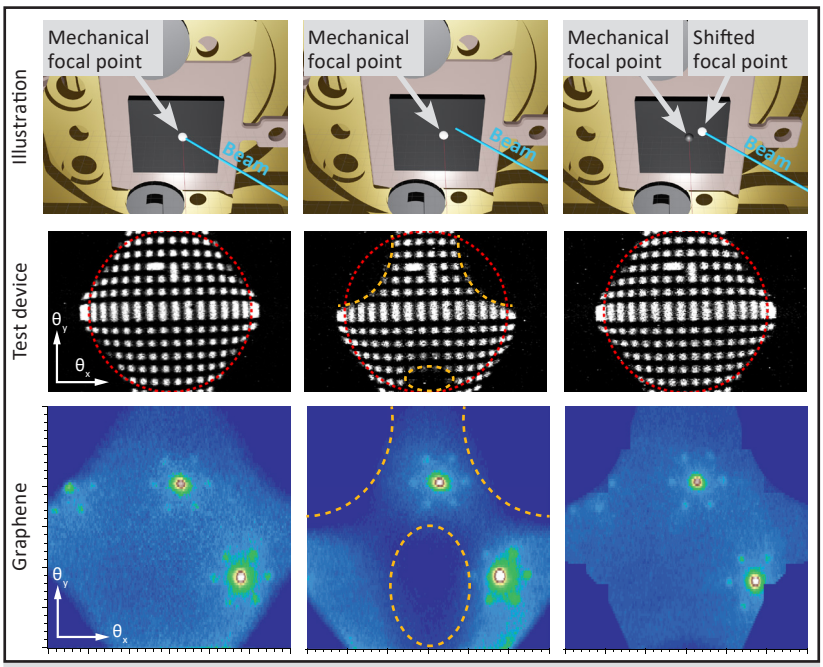


Figure 2: Middle row, angular test device. Bottom row, Graphene sample measured at Bloch beamline at Max IV. When emission spot and analyser focal point are well aligned the full angular range is filled with intensity (left). For a 10 µm spot and a small misalignment (200 µm) parts of the non-dispersive background are lost (middle). This mechanical misalignment is compensated by electrostatic 3D focus adjustment, restoring the alignment and the non-dispersive background intensity (right). Sharp intensity cut-offs are due to measurement settings (not present in respective test device data).

THE MULTIPROBE PREP
A Modular Platform for Sample Preparation and SPM

The Multiprobe Prep is a UHV module for sample preparation that can be combined with almost all Scienta Omicron platforms. Its versatile main chamber offers ports for all common preparation techniques, such as LEED, sample sputtering, evaporators, as well as several spare ports, which can also be used for custom components.

Its modular design allows the customer to tailor the sample manipulator with several heating and cooling options. The pump configuration can be adjusted from a simple turbo-molecular pump to several more advanced UHV pumping schemes.

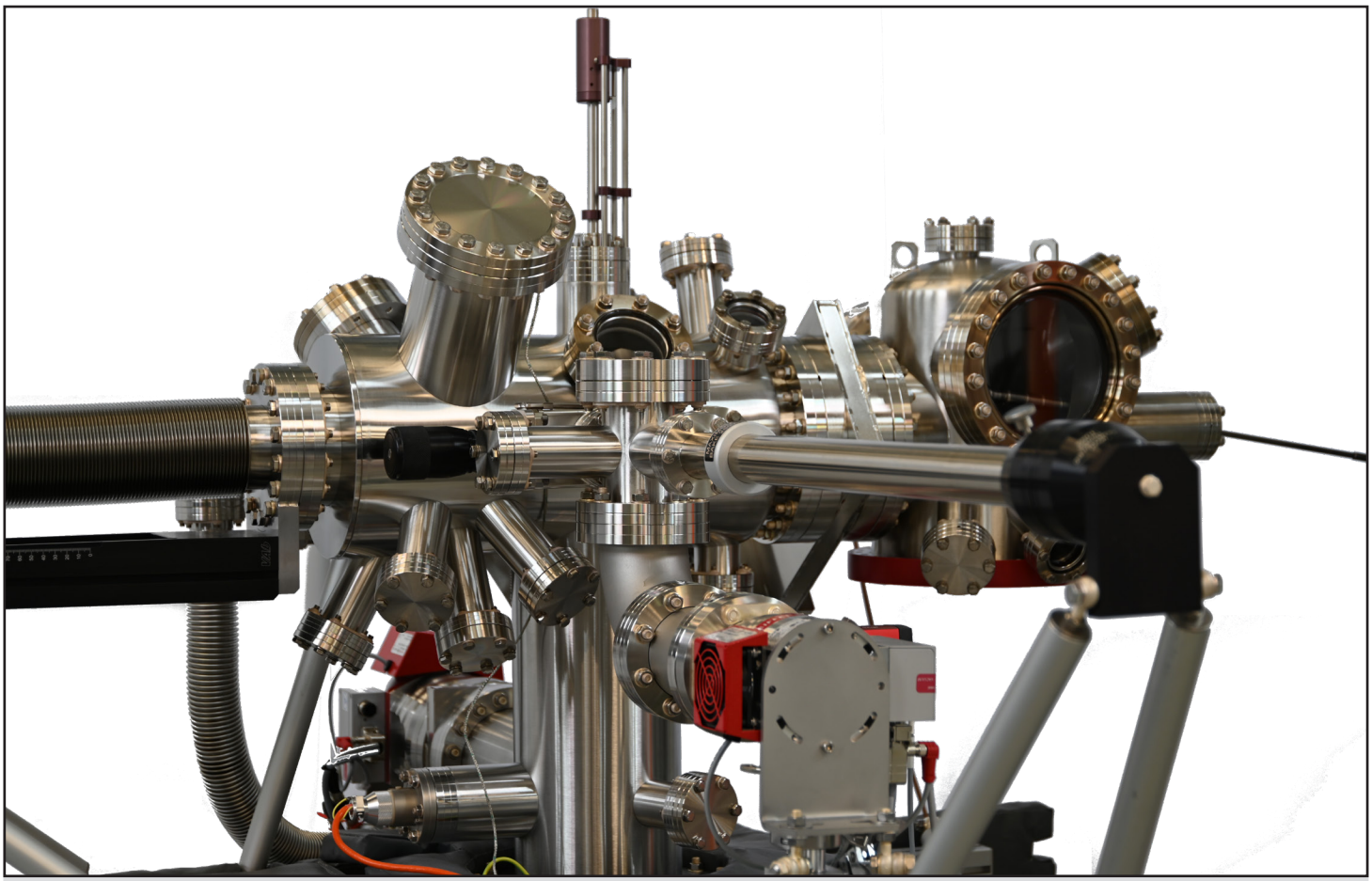
A central wobble stick on top of the main chamber is used for sample transfer within the Multiprobe Prep as well as for sample exchange with modules connected through a magnetic transfer arm or a transfer back-bone, such as a Radial Distribution Chamber (RDC) or Linear Transfer Line (LTL). This ensures a safe and convenient sample handling.

Care has been taken to achieve a rigid bench design suitable for high-resolution microscopy. This facilitates the extension of the Multiprobe Prep with a workhorse SPM from Scienta Omicron's VT-XA series, even as an on-site upgrade.

Customers who initially buy the Multiprobe Prep as a preparation module for an analytical tool thus have an easy means of adding an SPM to their system in the future.

The SPM chamber can optionally be equipped with a UHV gate valve and a dedicated UHV pump (NEG or ion getter pump) to separate it from the preparation chamber and thus maintain optimal cleanliness.

This is a common requirement of researchers who want to use the VT-SPM as a tool to prepare structures with atomic precision, particularly for research on quantum computing devices. The combination with the full-blown sample preparation chamber provides the perfect platform for this type of experiments.



Scienta Omicron's Multiprobe Prep with ports for LEED and a set of 3 DN40CF ports for evaporators underneath. The chamber is extended with a separately pumped SPM bolt-on chamber and a loadlock chamber with a dedicated turbo pump.

ENERGY TRANSPORT AT THE MOLECULAR SCALE:
A Light-Emission Scanning Tunneling Microscopy Viewpoint

Photosynthesis is a multiple-step process in which light is first absorbed by a molecular dye; the corresponding energy is then transferred to a reaction centre where it allows initiating chemical reactions leading to the plant growth. This energy transfer occurs through a series of intermediate molecules via different mechanisms, like longrange dipole-dipole coupling (Förster transfer) or short-range coupling involving an overlap of molecular orbitals (Dexter transfer). To get some insight in these complex mechanisms at work in plants, the scanning tunneling microscopy team of the IPCMS (Institut de Physique et Chimie des Matériaux de Strasbourg, CNRS & University of Strasbourg) used a model system based on three different molecular dyes that were arranged in various configurations on a surface by STM-tip manipulation [1].
These molecules, namely free-base and metal phthalocyanines (H_2Pc, ZnPc, PdPc) have slightly different optical gaps (in increasing order). One molecule acts as a donor, another as an intermediate element that mediates the energy transfer and the last as an acceptor. Depending on their arrangement, several gap sequences are possible, and the efficiency of the energy transfer will be different. In this experiment, the visible-range light emission of the different molecules serves to visualize the energy transfer process.

The molecules are thermally evaporated on thin salt (NaCl) layers (3 to 4 atomic layers) themselves deposited on a Au(111) substrate. During the molecule deposition, the substrate is maintained at low temperature (< 10 K) to prevent molecular diffusion. The NaCl insulating layers serve to electronically decouple the molecules from the gold substrate; otherwise, the molecules in direct contact with the underlying metal, would not show fluorescence. Once arranged in a trimer configuration by tip manipulation, the acceptor molecule is excited by the current passing through the STM tip. This can be done very precisely at selected places of the molecule. The distance between the molecules and their relative orientation can also be controlled as well.

The light emitted by the molecules is collected by a lens fixed on the cold STM stage (4.5 K) of a Scienta Omicron LT-STM, its focal point matching the tip position. The light is directed outside the vacuum vessel through windows in the cryogenic shields, sent through a spectrometer and eventually detected by a cooled CCD camera. The global light collection efficiency is in the order of 2 to 3 %. The optical signal from a single molecule is however measurable thanks to the plasmonic enhancement of the emitted light in the tunnel junction (the so-called Purcell effect) which acts as a picocavity resonator.

Figure 1 shows the light emission spectra recorded for two sequences of a trimer. In the first configuration (Fig. 1a), the large gap – donor - molecule (PdPc), directly excited by the STM tip, is

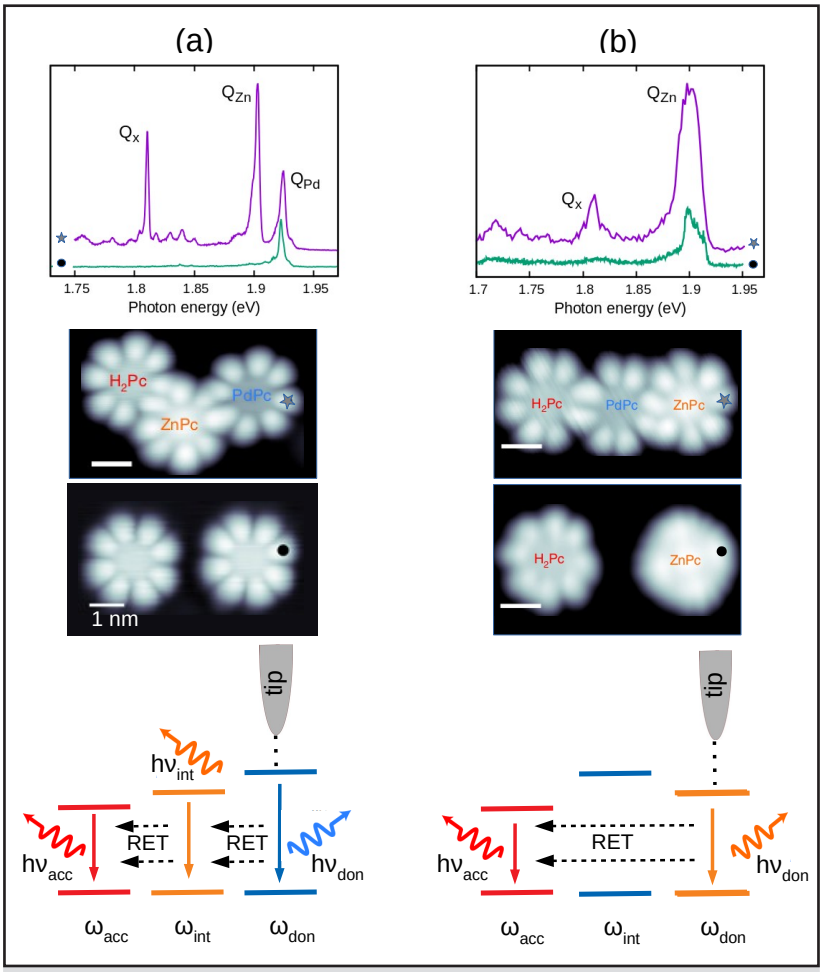


Figure 1: Energy funneling in molecular trimers. Top: STM light emission spectra recorded when exciting a donor from the different molecular configurations (middle). Qi i=x, Zn, Pd indicates the dipolar moment responsible for the light emission (x stands for H_2Pc which has actually two nonequivalent dipole moments).

Bottom: scheme of the different gap arrangement leading to different energy transfer efficiencies. Markers (disks and stars) indicate the excitation position on the donor molecule. When the central molecule is removed no energy transfer is observed.

Figure 2 : IPCMS STM team in Strasbourg, France. From left to right: Song Jiang, Fabrice Scheurer, Michelangelo Romeo, Anna Roslawska, Guillaume Schull, Virginie Speisser, Laurent Limot, Katharina Kaiser.

separated from the smaller gap molecule (H_2Pc) by the intermediate gap molecule (ZnPc). The recorded fluorescence spectrum reveals emission lines characteristic of the three chromophores, including the distant H_2Pc acceptor. This reveals that the central ZnPc chromophore acts as an ancillary molecule, accepting energy from PdPc before transferring it to H_2Pc, a cascaded energy transfer that one finds in living photosynthetic systems.

In the second arrangement (Fig. 1b) ZnPc is excited by the tip (position marked) and acts as the donor. There is light emission from the donor (QZn at ~1.90 eV). The second peak (Q_x at ~1.81 eV) is due to a transition of H_2Pc, the distant acceptor. No light is emitted from the PdPc molecule in the middle. This may somehow be expected since its optical gap is the largest. However, if one removes the central molecule, either ZnPc or PdPc, there is no light observable from the acceptor (bottom spectra). In the case of a central PdPc molecule, that was expected to be ''passive'' as its excited state cannot be populated, it nevertheless promotes energy transfer between the donor and the acceptor. Similar superexchange mechanisms have been reported in photosynthetic bacteria, where ''passive'' carotenoid molecules promote energy transfer between donor and acceptor pigments. Actually, these three-dye systems can be modeled in a simple way by three coupled oscillators with different eigenfrequencies, which stand for the different optical gaps (bottom of Fig. 1.a,b).

The IPCMS STM team (Fig.2) runs three low temperature STMs, among them two LT Omicron microscopes (version 1). One of them will be replaced soon by a Polar STM with a 5 T magnetic field, which will be devoted to developing high resolution imaging of the exchange field in magnetic structures, via a functionalised STM tip [2].

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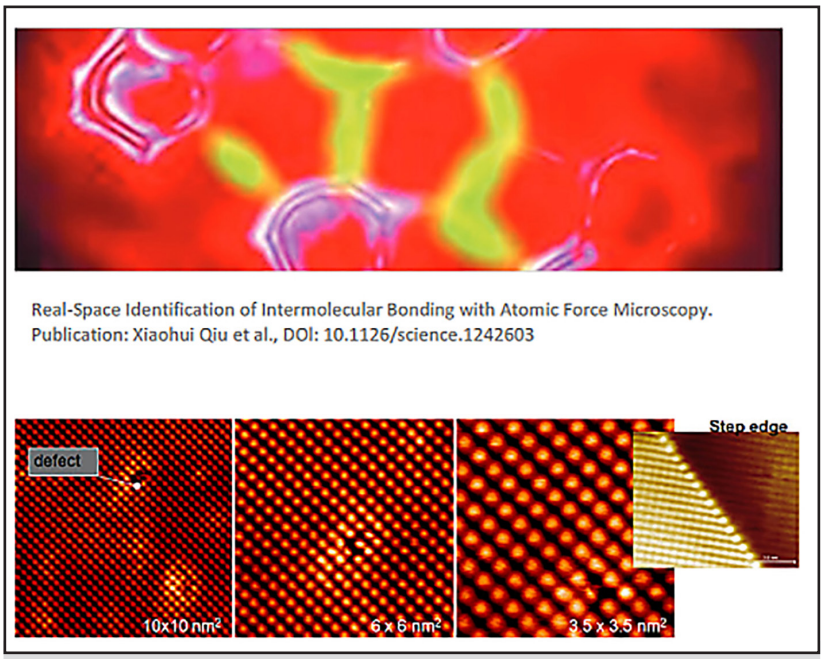

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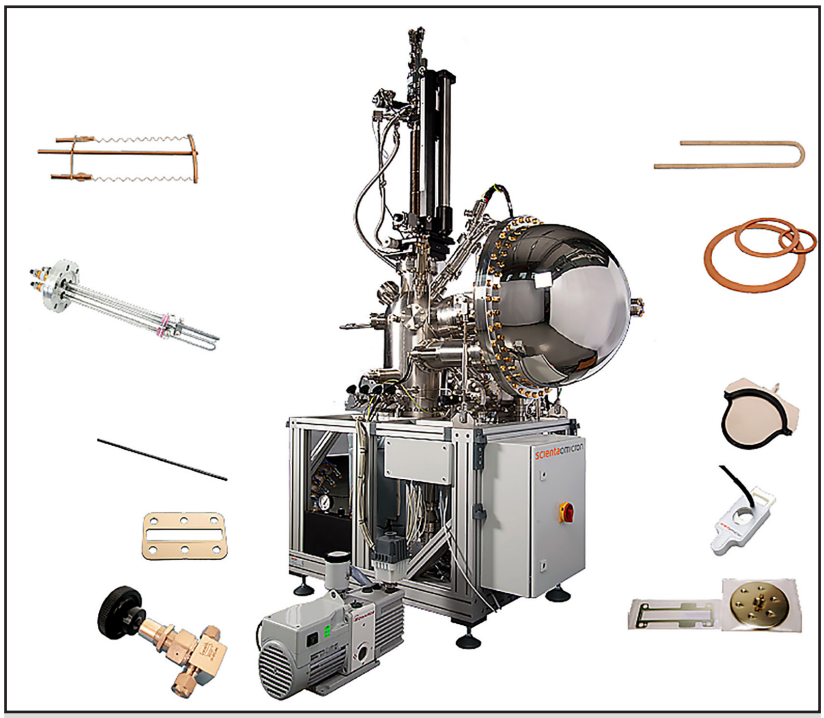

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