# A Scanning Tunneling Microscope at SOLEIL

**At SOLEIL, as in many other synchrotron radiation facilities, research in the surface/ interface domain will be a major component of materials research. A Scanning Tunneling Microscope or STM, a tool which has become a must for all studies regarding nano-structures, has been installed at SOLEIL.**

Evolution towards the nano-structuration of devices tends to increase the significance of surfaces and interfaces, the crystallographic, electronic or magnetic structures of which will be determined on the SOLEIL beamlines. However, the prospective, characterization and control of new systems, essential for the development of original and innovative research subjects, do not necessitate in a first stage the use of synchrotron radiation. Thus, the LURE teams working in the field of surfaces and nano-structures had expressed already a long time ago the wish to see the creation of a surface laboratory equipped with instruments for carrying out measurements complementary to those made through synchrotron radiation. The acquisition of a scanning tunneling microscope was among the priorities of this strategy. In 2004, an operation jointly financed by LURE and SOLEIL made it possible to purchase an Omicron system. This device is now installed in the Surface Laboratory of SOLEIL with Stefan Kubsky in charge. Its access will be available to users whose projects, accepted by the program committee, require STM images.

## STM anatomy...

The system consists of two ultra-high vacuum chambers (UHV chambers) in which a $10^{-10}$ mbar vacuum is obtained through a pump system, thereby ensuring the cleanliness of the surface studied (Figure 1). The first chamber, dedicated to the preparation of samples, is equipped with "conventional" surface characterization tools, such as a LEED (Low Energy Electron Diffraction) and an Auger spectrometer. In the second chamber, connected under ultra-high vacuum to the first one, images of the sample surface in a 25 to 850 K temperature range can be obtained with the STM microscope. The operating principle of the microscope is described in the box on the right.

### Principle of scanning tunneling microscopy

When a tip is close enough to a surface (about one nanometer), current may run through the "insulating" barrier created by the vacuum between the tip and the surface. This purely quantum phenomenon is called "tunnel effect". The tunnel probability, which represents the chance that an electron will move from one electrode to another, decreases exponentially with the tip-surface distance, therefore, this also applies to the tunnel current. This strong variation in tunnel current depending on the tip-surface distance is the key to the excellent resolution of the images obtained through scanning tunneling microscopy. Tunnel imaging consists in scanning the tip over the surface while maintaining a constant tunnel current. The measurement is performed through a feedback which acts on a piezoelectric module ensuring the extremely precise movements of the tip in the three spatial directions; a difference of potential of about one Volt is imposed between the two electrodes (tip and surface). The reading of the coordinates (x,y,z) of the tip during its scanning makes it possible to reconstitute the surface topography. The spatial (lateral) resolution of the microscope, which depends mostly on the quality of the tip used (radius of curvature), may reach the atomic scale.

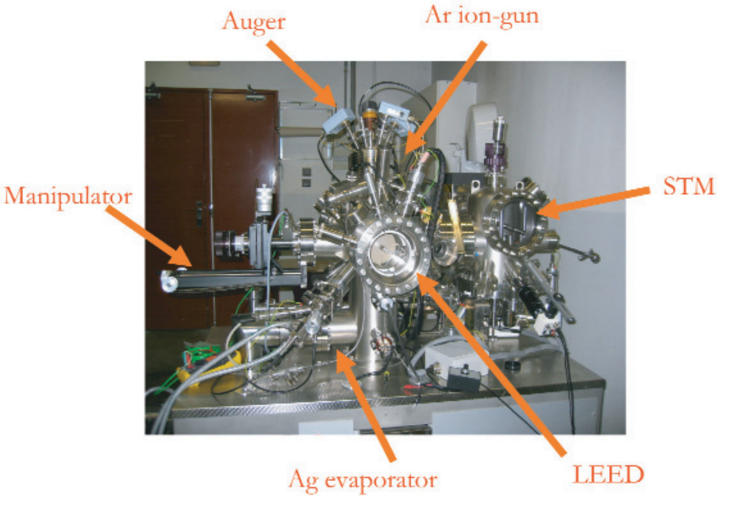
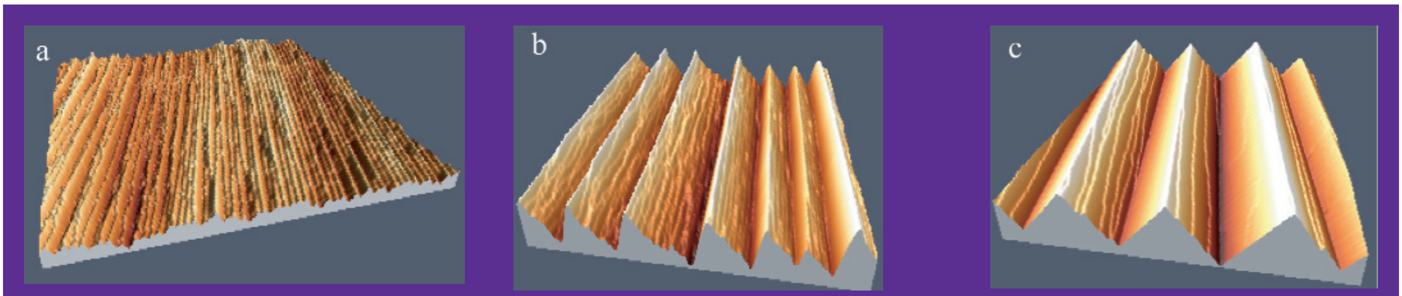


**Figure 1: Experimental device consisting of a preparation chamber and a chamber containing the STM microscope.**

## Nano structure studies

The first studies carried out with this microscope were performed to characterize the nano- structuration of metal surfaces. This research subject, developed by the SOLEIL SixS (Surface and Interface X-ray Scattering) beamline team fits into the broader framework of the studies on self-organized nano-structures, which currently elicit great interest at both fundamental and technological levels. When the size of an object becomes nano-metric, new and interesting properties appear, in particular in the fields of catalysis and magnetism. Different approaches are being developed with the view to produce these small objects. The first ones, highly interventionist, consist either in pushing lithography techniques to their extreme, or in manipulating the atoms or molecules individually with, for instance, the tip of a scanning tunneling microscope. This approach is intrinsically limited to low productions. The so-called "bottom-up" approach consists in understanding and getting to grips with the phenomena of spontaneous nano-structu-



**STM images of the stepped surface (433) of copper.**
**a) original surface (100nm²) ; b) after the deposit of 0.3 monolayers of Ag (200nm²) ; c) after the deposit of 0.6 monolayers of Ag (200nm²).**

ration present in certain systems. We have been involved in the study of these processes for several years now.

At a later stage, these nano-structured systems used as substrates open a very promising pathway for making nano-objects in parallel. We have studied the evolution of the morphology of copper stepped surfaces induced by a silver deposit inferior to monolayer[1]. Before the deposit, the copper surface shows an even array of terraces separated by mono-atomic steps. The image of such a surface obtained with the microscope (Figure 2a) shows about 1.5 nm wide terraces.

After a silver deposit, followed by annealing at 600 K, the morphology of the surface changes (Figures 2b and 2c) revealing a periodic faceting of the substrate. This so-called "hill to valley" structure is obtained by alternating regularly the bare copper facets with silver covered facets. We notice that according to the amount of silver atoms deposited, the period of the structure changes.

This property accounts for the great interest of this type of system: here we have a template with a period (ranging from about 10 - 100 nm) easily adjustable to the dimensions of the nano-objects to be subsequently manufactured. For low coverages, the silver covered facets correspond to (211) copper planes. On these planes, the silver atoms organize themselves by creating a superstructure (surface reconstruction) with a C(2x10) symmetry with respect to the substrate.

The study of this reconstruction through grazing incidence X ray diffraction (GIXD) at the LURE, combined with simulations in quenched molecular dynamics, enabled us to determine the positions of the atoms in the super cell[3] and to propose a reconstruction model. The obtained structure is shown in Figure 3a, where the grey scale corresponds to the silver atoms height levels. The atomic scale STM images on the silver covered facets, obtained long after, made it possible to observe this superstructure (Figure 3b) and to compare directly with Figure 3a: the similarity between both the simulated and measured images is remarkable.

Finally, the combination of information obtained through the STM, X-ray diffraction and numerical simulations, enables us to draw a conclusion as to the origin of the faceting phenomenon in the Ag/Cu system.

Moreover, we are now able to obtain nano-structured copper substrates with controlled periods.

The next stage will be the use of such a template to produce nano-objects with magnetic properties.

Contacts: Alessandro Coati
alessandro.coati@synchrotron-soleil.fr
Yves Garreau
yves.garreau@synchrotron-soleil.fr

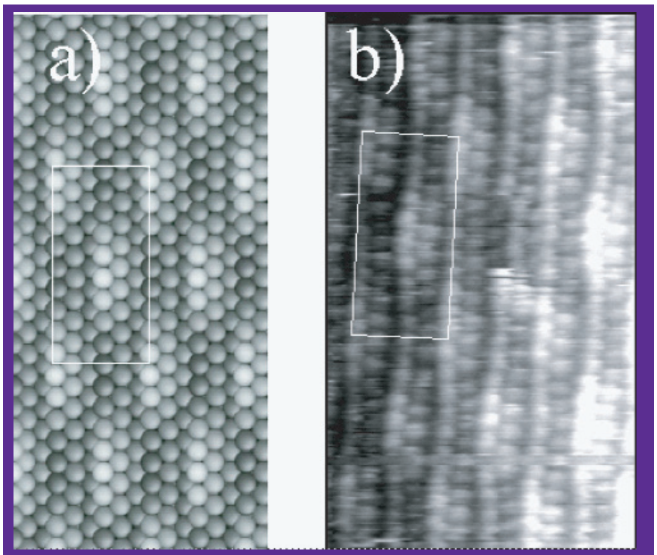


**Figure 3. a) Atomic model of the reconstruction C(2x10) Ag/Cu(211) obtained by combining diffraction measurements and numerical simulation.**
**b) STM atomic resolved image showing the structure of a covered facet.**

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[1] A. Coati, J. Creuze, and Y. Garreau (2005) *Phys. Rev.* **B72**, 115424.

[2] Y. Garreau, A. Coati, A. Zobelli, and J. Creuze (2003) *Phys. Rev. Lett.* **91** (2003) 116101.