New Tools for Scanning Tunneling Microscopy

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An easy-to-implement filter that separates photo-excited signals from topography

Nanofabricated coaxial multilayer tips that provide ultra-high spatial resolution

Current

Complex nanoscale materials are at the forefront of fundamental research as well as the keystone for whole new classes of applications. However, comprehensive understanding of nanoscale system requires tools with both the ability to resolve nanometer structure as well as the direct observation of chemical composition. X-ray microscopy methods provide the desired chemical sensitivity, but the spatial resolution is limited. On the other hand, scanning tunneling microscopy (STM) achieves the requisite high spatial resolution; however, it has a fundamental drawback - it is chemically blind. The STM cannot be used alone to directly fingerprint chemical elements on a surface.

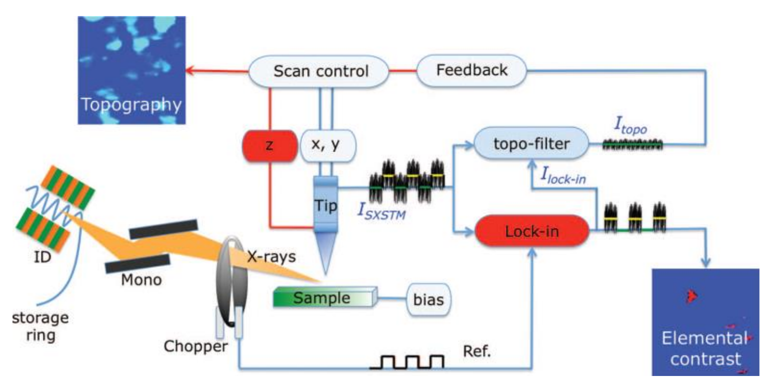

Fig. 1. Experimental schematics of SX-STM. The x-rays pass through a chopper system before arriving at the sample. The measured tip current gets separated into two channels with the help of an amplifier lock and the topo-filter. The conventional I_{topo} is then fed into STM feedback system, which regulates the tip-sample separation, while the other x-ray induced component containing chemical contrasts $I_{lock\text{-}in}$ is recorded in a separate channel. Please refer to Wang, et al for details.

Argonne's Breakthrough

Argonne research team led by physicist, Volker Rose has recently shown that the long-standing goal of direct chemical contrast in STM has finally become a reality through microscopy methods that combines STM with chemical sensitivity of synchrotron radiation. The technological advantages gained can also be applied to variants of STM such as laser STM.

Since its development STM has become an indispensable tool for the understanding of structural, electronic and magnetic properties of surfaces and nanostructures. Despite obtaining a high resolution, STM cannot provide a spatial chemical fingerprint. The lack of direct observation of chemical contrast is due to the fact that tunneling electrons originate from the states close to Fermi energy and do not carry direct chemical information. In last few years, research efforts have been focused on using synchrotron X-rays to excite core-level electrons during tunneling. However, in synchrotron X-ray STM (SX-STM), x-ray photoexcitations result in tip currents that are superimposed on to conventional tunneling currents. This causes the topography and the chemical contrasts that are convoluted together. The x-ray excitations also destabilize the feedback, sometimes causing the tip to fully retract. Argonne research team has solved these problems by developing and implementing a filter circuit that separates the x-ray induced components, which contain chemical and magnetic signatures, from conventional tunneling. This allows the feedback to maintain a stable tunneling condition during operation. While the filter is in place, chemical contrast and topography signals are separated into two different acquisition channels that can be recorded simultaneously without mutual interference. Additional information is provided in Wang, K, et. Al. The filter and schematic shown above can be applied to other variants of light –assisted STM such as laser STM.

Argonne researchers have also developed coaxial multilayer SX-STM and Laser STM (?can we say this here?) tips with nanoscale conducting apex. The larger the area illuminated by the x-rays, the larger the number of photoelectrons ejected from the sample. These electrons could come from anywhere in the sample and would normally be collected by the apex and the sidewalls of a conventional STM tip. Therefore, the spatial resolution of SX-STM will be limited by the size of the x-ray beam. The smart tips developed at Argonne were engineered to resolve the problem. The smart tip enhances the sensitivity and spatial resolution of the measurement by rejecting background of photoejected electrons landing at the sidewall of the tip. The smart tips focus electron detection to the apex; consequently, making it possible to attain ultrahigh spatial resolution. The above suite of technologies also includes an additional novel concept and method for fabricating and testing coaxial multilayer STM Smart Tips.

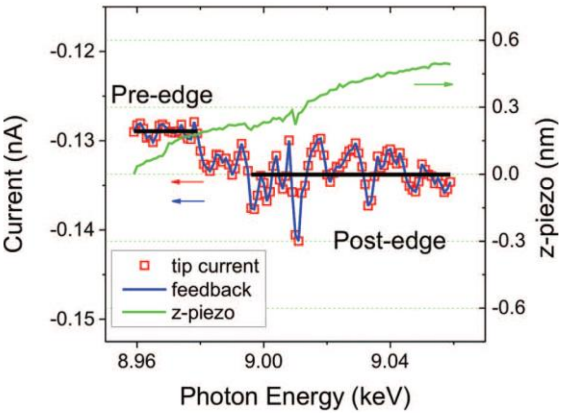

Fig. 2a. Without the topo-filter. Spectroscopy scan of the x-ray energy with tip tunneling over Cu(111) surface. The tip current (red squares) is identical to the signal used for the STM feedback (blue line). The z-piezo voltage (green) retracts during the scan.

Benefits

This technology provides technologies, tools and fabrication methods for surface chemical fingerprinting of samples using SX-STM and Laser STM.

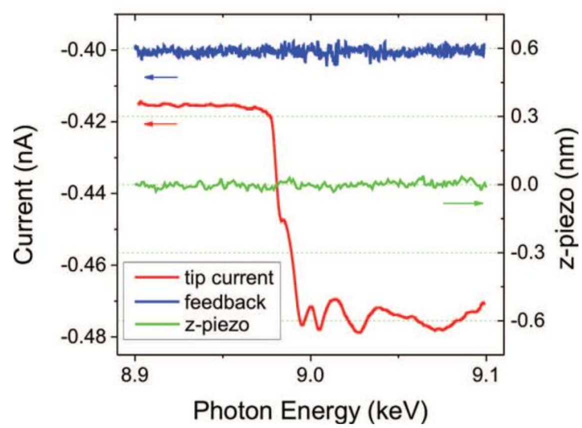

Fig. 2b. With the topo-filter. Although the tip current (red) increases at Cu – edge, the filtered current used for feedback (blue) remains stable. The stable z-piezo voltage (green) clearly shows that the topography and chemical contrast remain well-separated.

Development Status

The technologies, tools, and fabrication methods for surface chemical analysis have been implemented at Argonne's Center for Nanoscale Materials. The Smart Tip fabrication method has also been developed and implemented.

Intellectual Property

Argonne has filed a non-provisional patent application to initiate the patent protection on Smart Tip, its fabrication method and topo-filter. Worldwide rights are also available. Argonne invites interested companies to license the intellectual property.

References

Wang, K., Rosenmann, D., Holt, M., Winarski, R., Hla, S., Rose, V. An easy-to-implement filter for separating photo-excited signals from topography in scanning tunneling microscopy. ***Rev. Sci. Instrum. 84****, 063704 (2013)* .

Shirato, N., Cummings, M., Kersell, Li, Y., Stripe, B., Rosenmann, D., Hla, S., Rose, V. Chemical Imaging of Nanostructures with Single Atomic Height by Synchrotron X-ray Scanning Tunneling Microscopy. *Manuscript in preparation.*