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U.S. Department of Energy

UChicago ▶ Argonne LLC

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A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

High-resolution chemical imaging using synchrotron x-ray scanning tunneling microscopy (SXSTM)

Volker Rose

Advanced Photon Source

Agenda

- Basic principles of SXSTM
- Demonstration of nanoscale imaging with an SXSTM prototype
- Development of SXSTM*beta*

MICROSCOPY

NANOSCOPY

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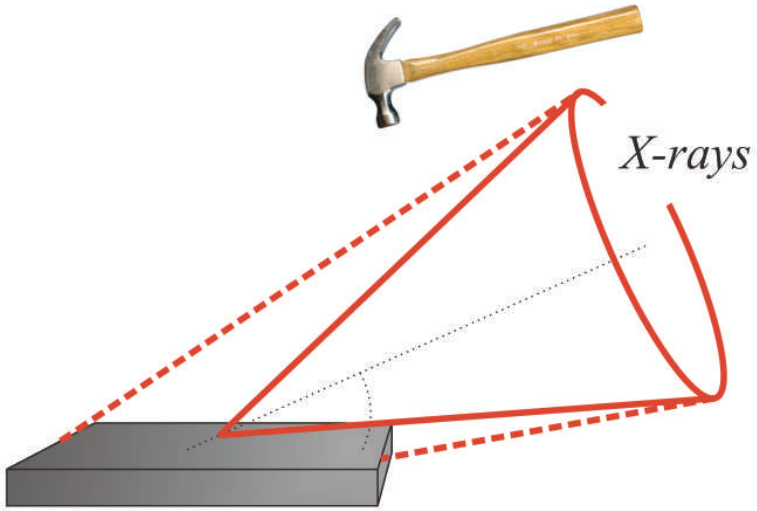
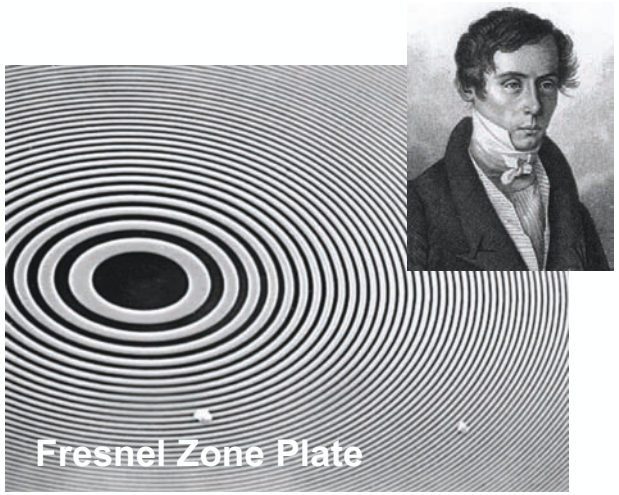
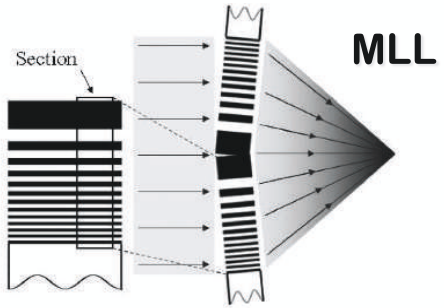
High resolution X-ray science – standard approach

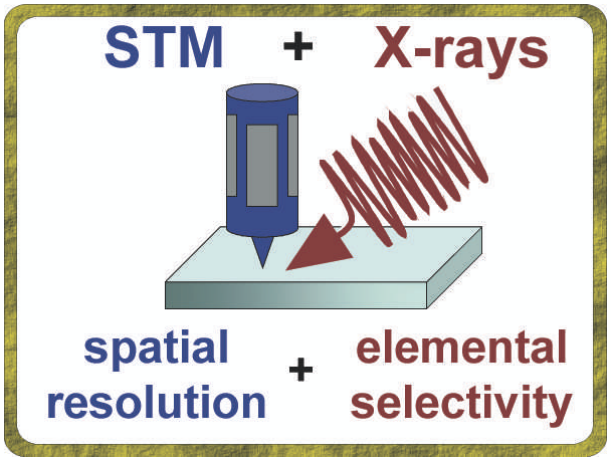
refractive/reflective focusing

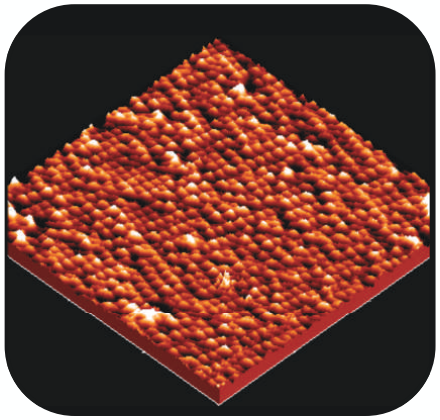


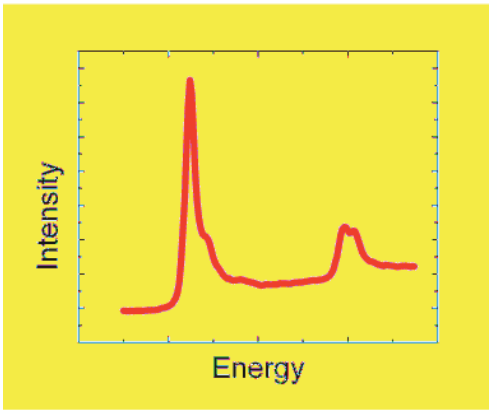




SXSTM – a new concept



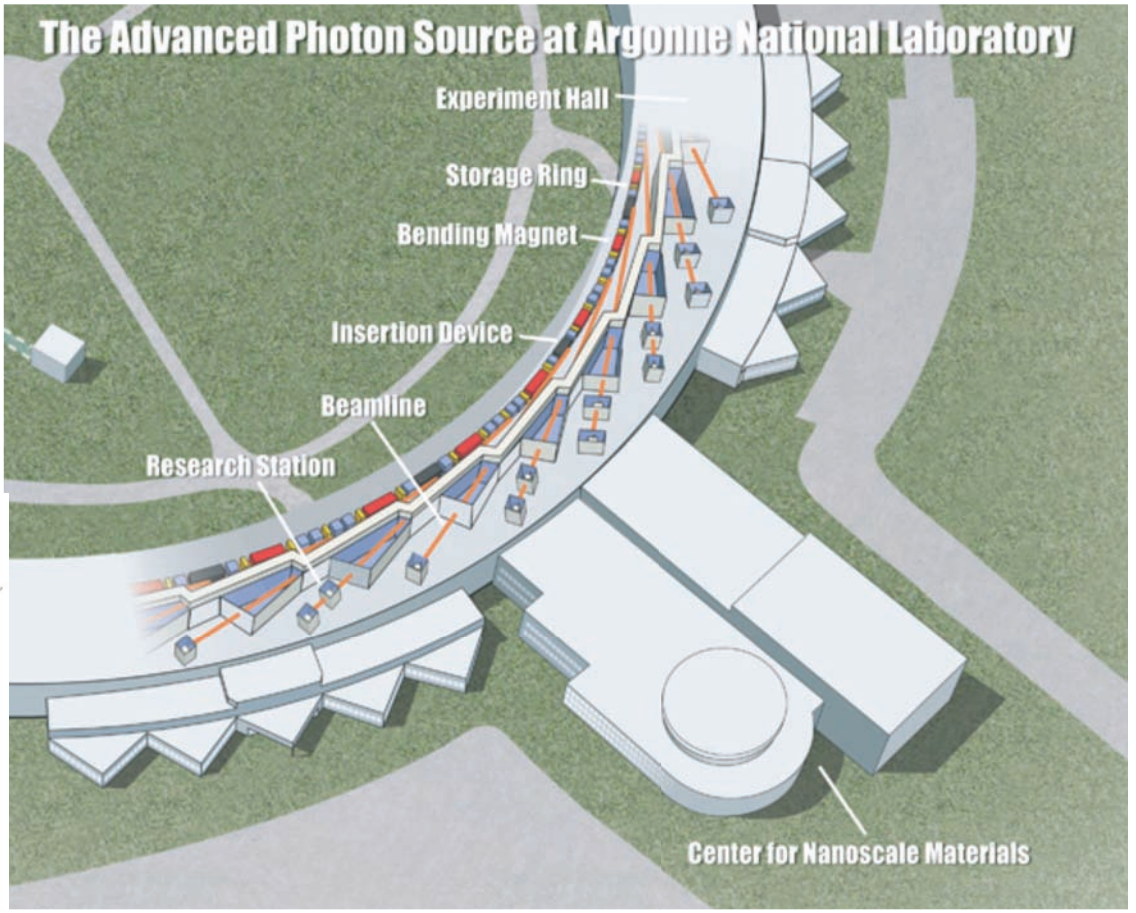


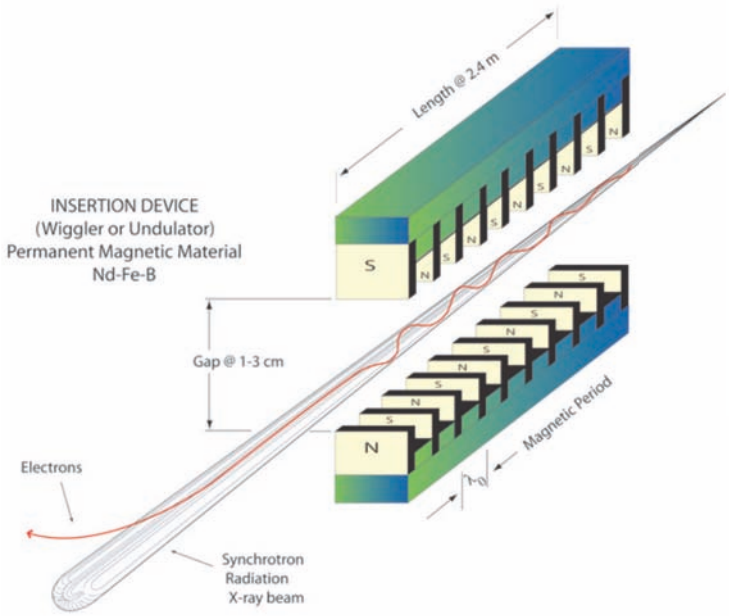


STM
spatial resolution

X-rays
chemical selectivity

Advanced Photon Source at Argonne National Laboratory

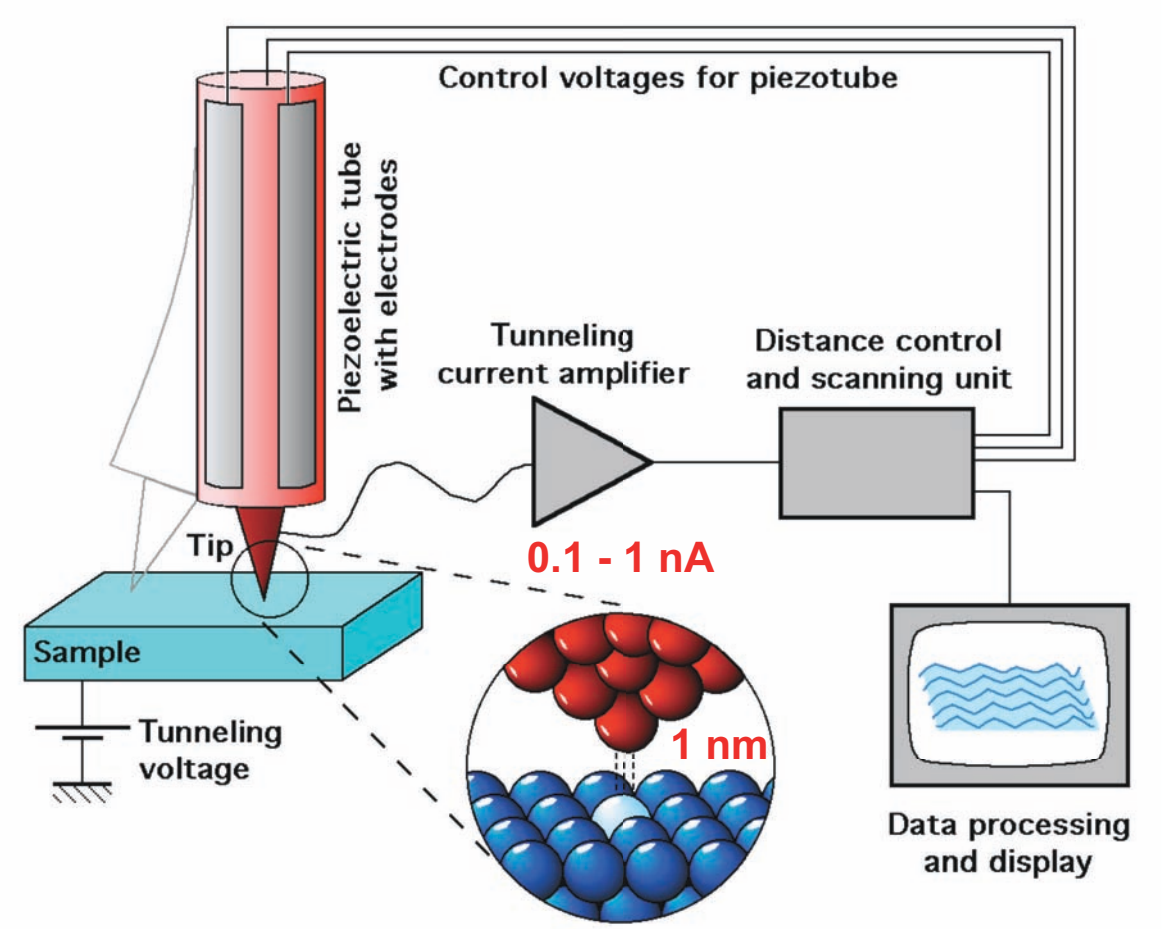




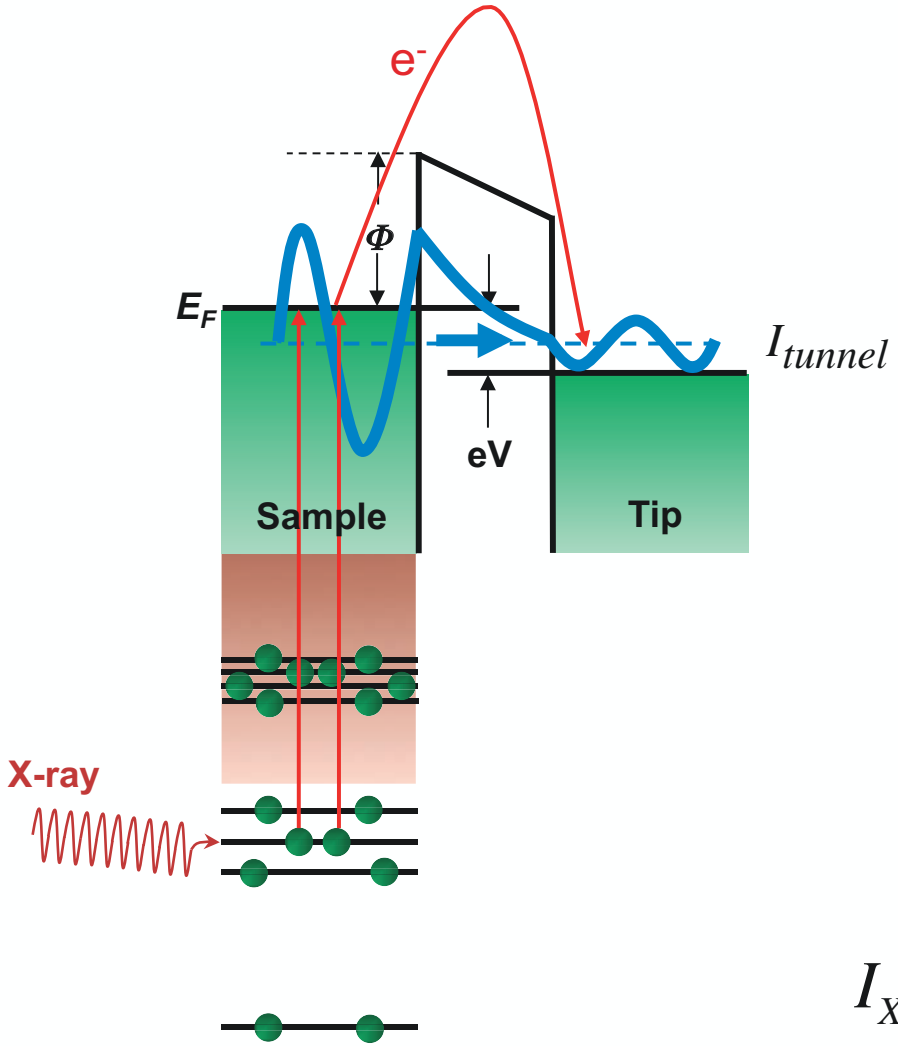
Brightest x-ray beam in Western Hemisphere

The Scanning Tunneling Microscope

what it is and how it works…



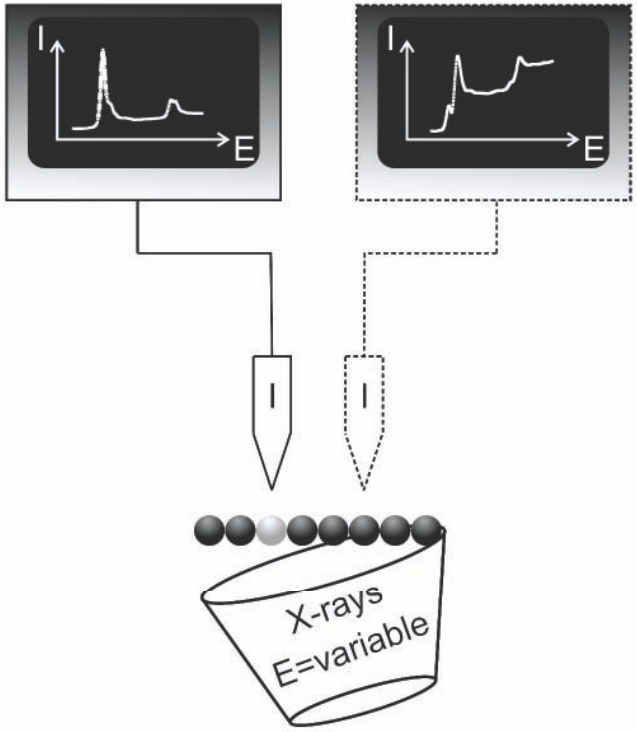
The physics of X-ray enhanced scanning tunneling microscopy



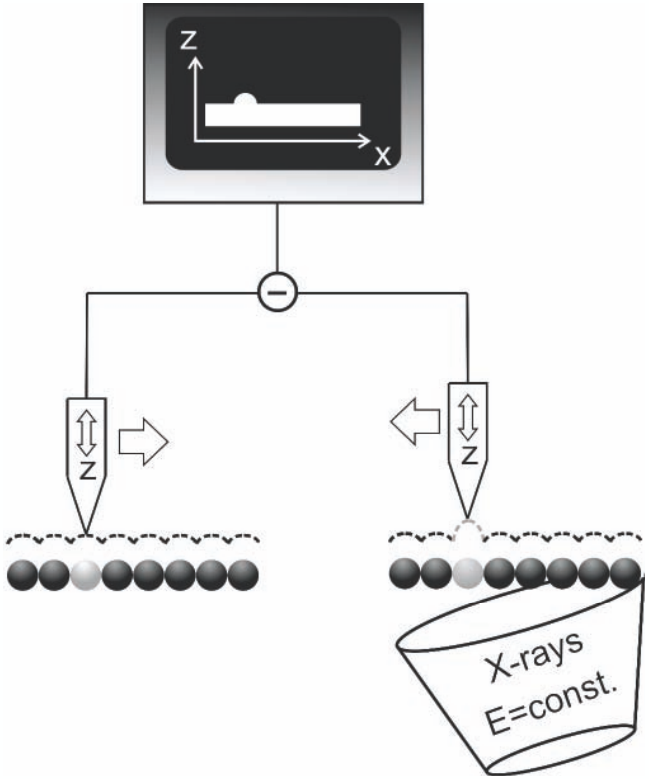
- primary photoelectrons (from the photoabsorption of the incident X-rays)
- primary Auger electrons (from the de-excitation after photoionization)
- secondary photoelectrons (due to photoabsorption of fluorescent radiation in the sample)
- secondary Auger electrons (from the relaxation of secondary excited atoms).

$$I_{XSTM}(E_{X-ray}) = I_{tunnel} + I_{photo-ejected}$$

Spectroscopy and Imaging Mode

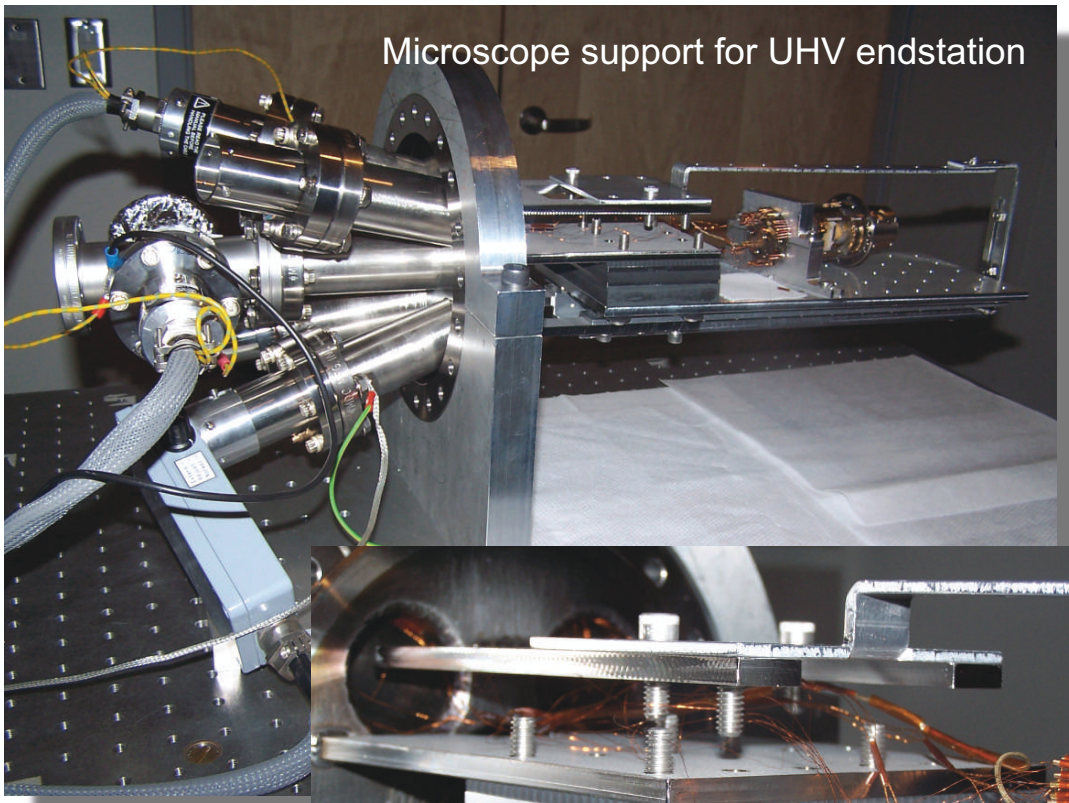


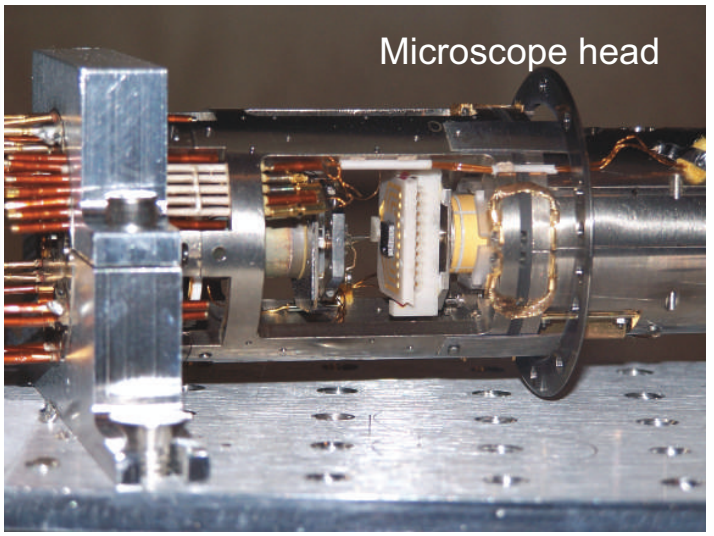
Spectroscopy

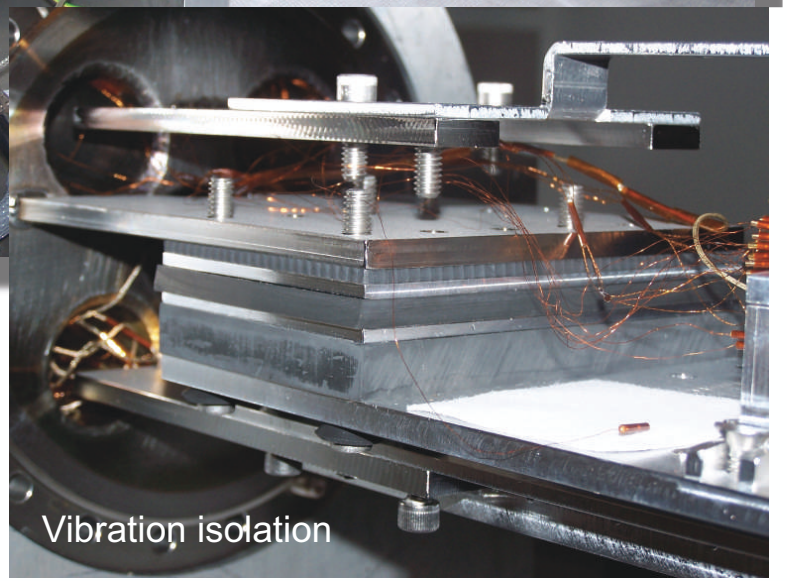


Imaging

SXSTM Prototype







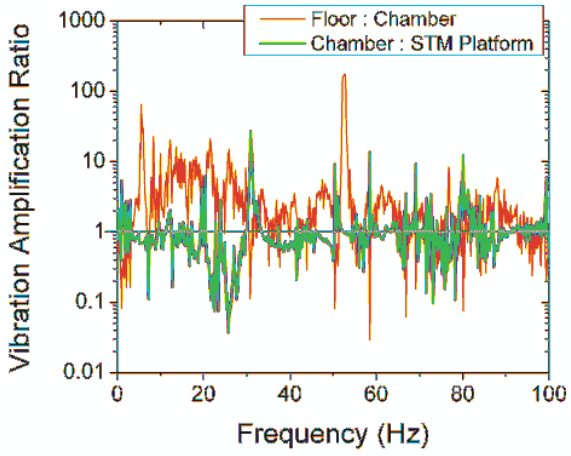
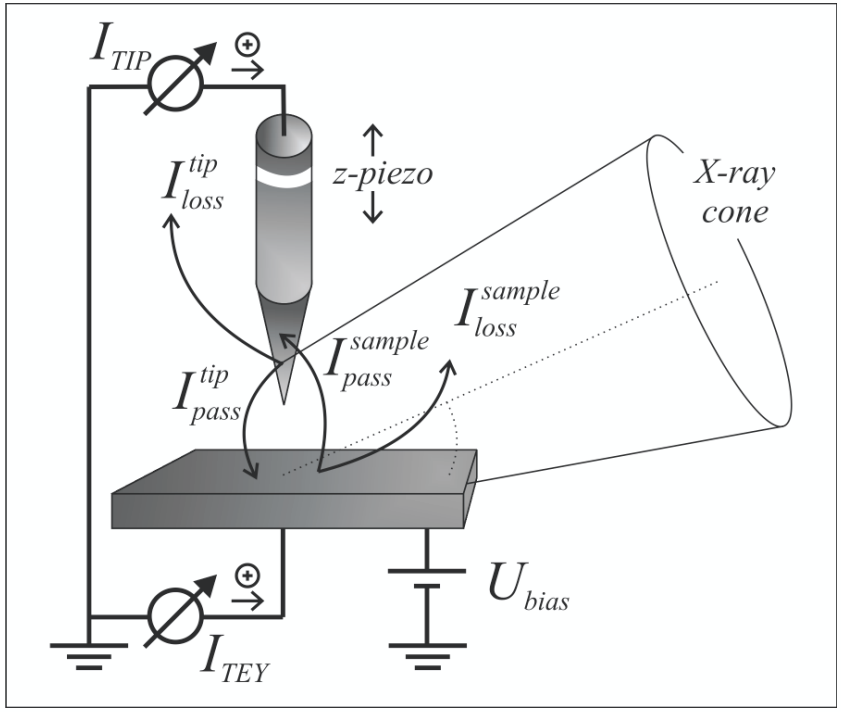
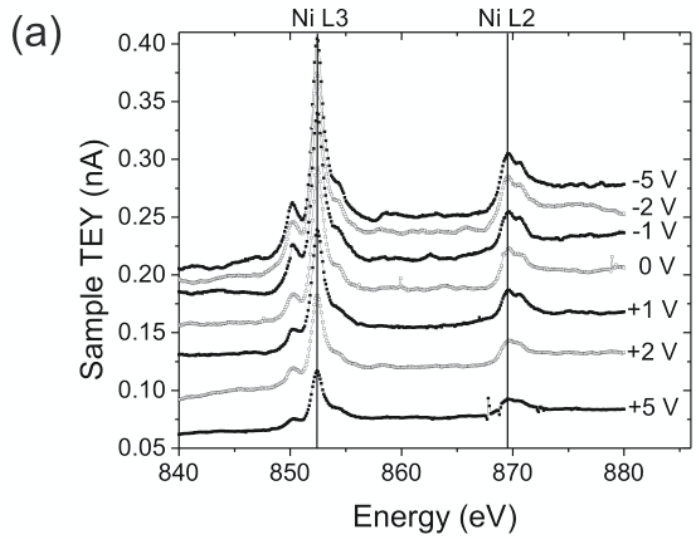
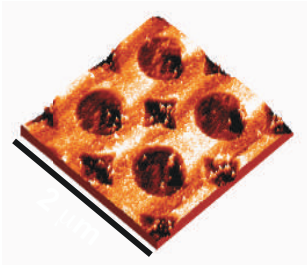
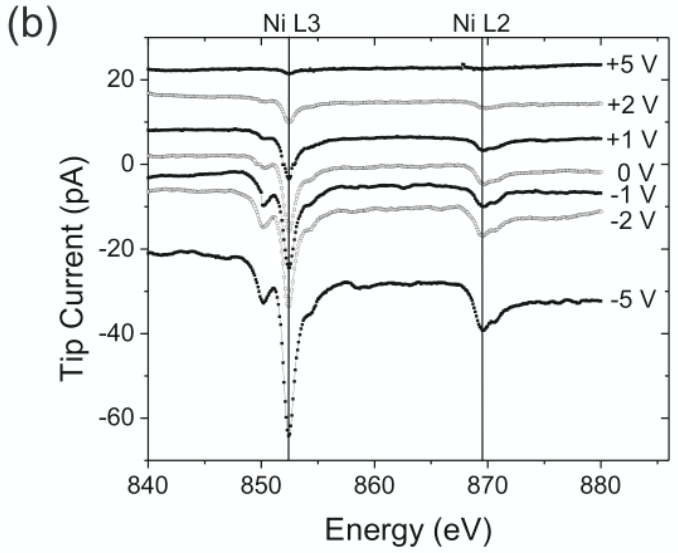


Photo Current Spectroscopy



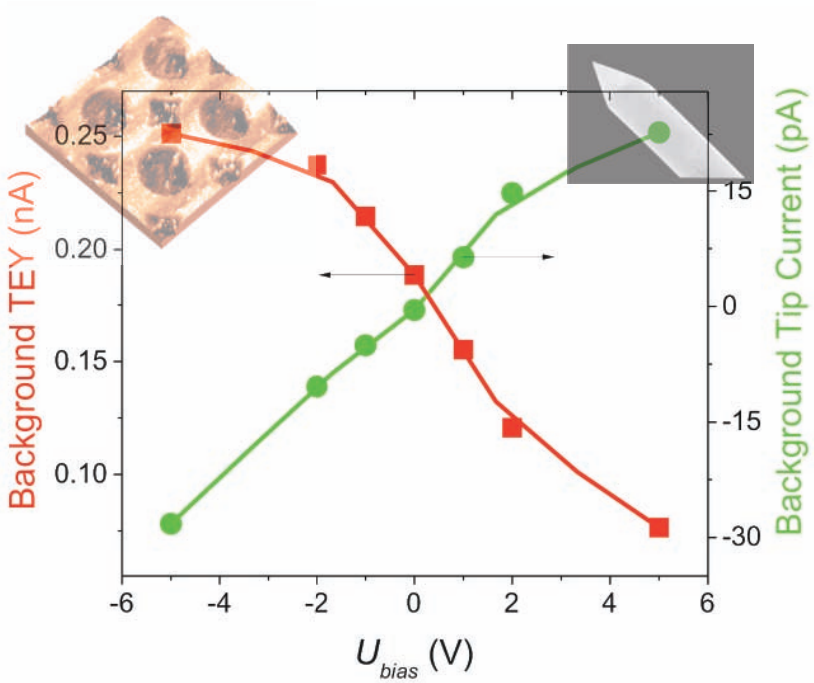


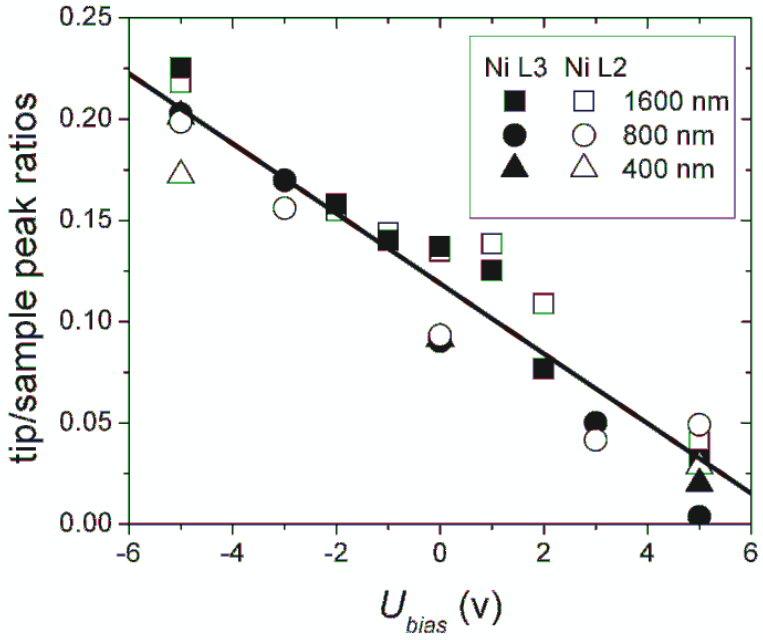




V. Rose et al., Appl. Phys. Lett. 92, 193510 (2008)

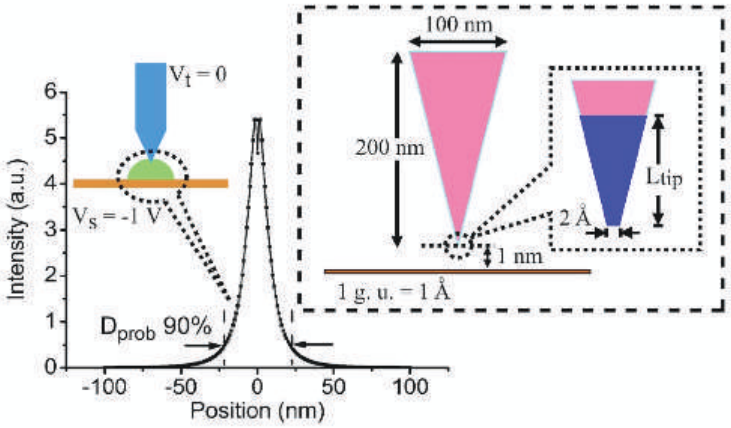
Photo Current Spectroscopy





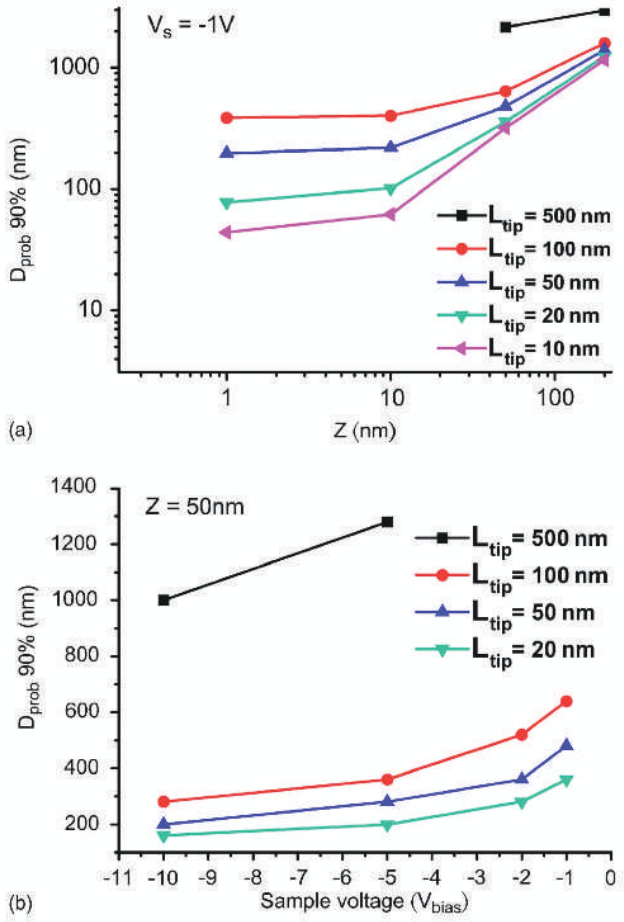
V. Rose et al., Appl. Phys. Lett. 92, 193510 (2008)

Spatial resolution of photoelectron detection



$$I_{tip} = \pi\left(\frac{10}{9}\frac{D_{prob}}{2}\right)^2 \frac{I_{sample}}{A_{ph}}.$$

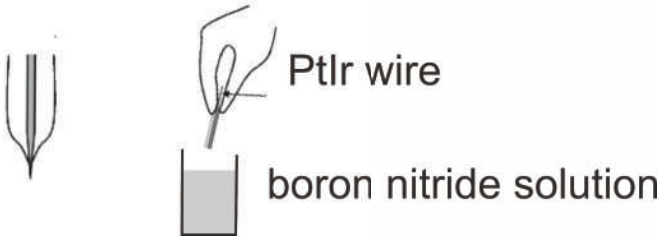
high resolution =
- small distance z
- minimize area of detection L_z
- strong accelaration field V_{bias}



C.-Y. Chiu, Y.-L. Chan, Y.J. Hsu, D.H. Wei, APL 92 (2008) 103101.

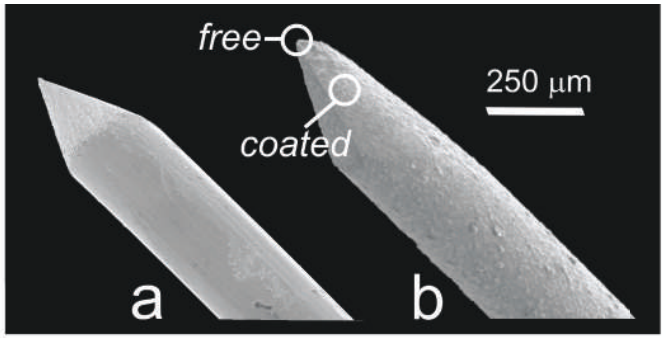
Smart STM tips

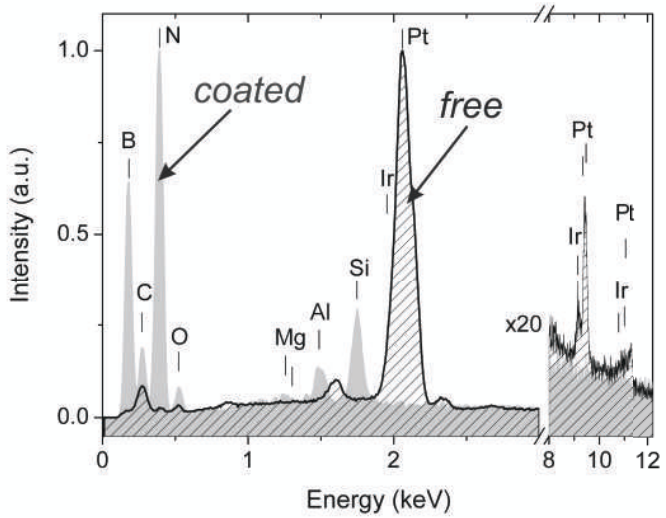
Boron nitride coated tips



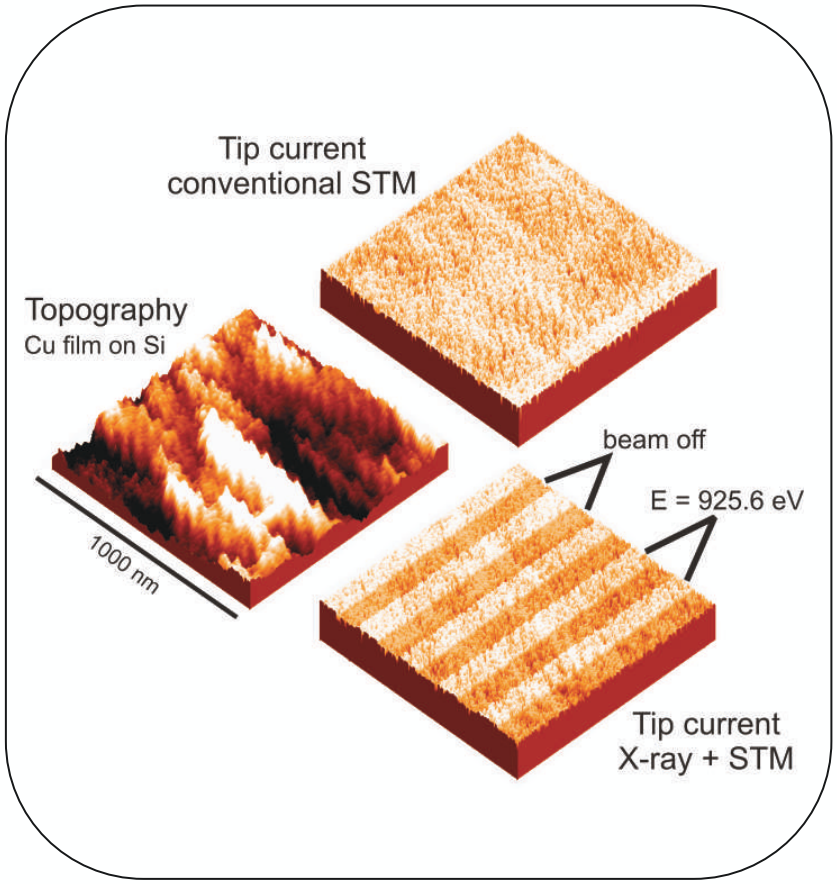
Why boron nitride?

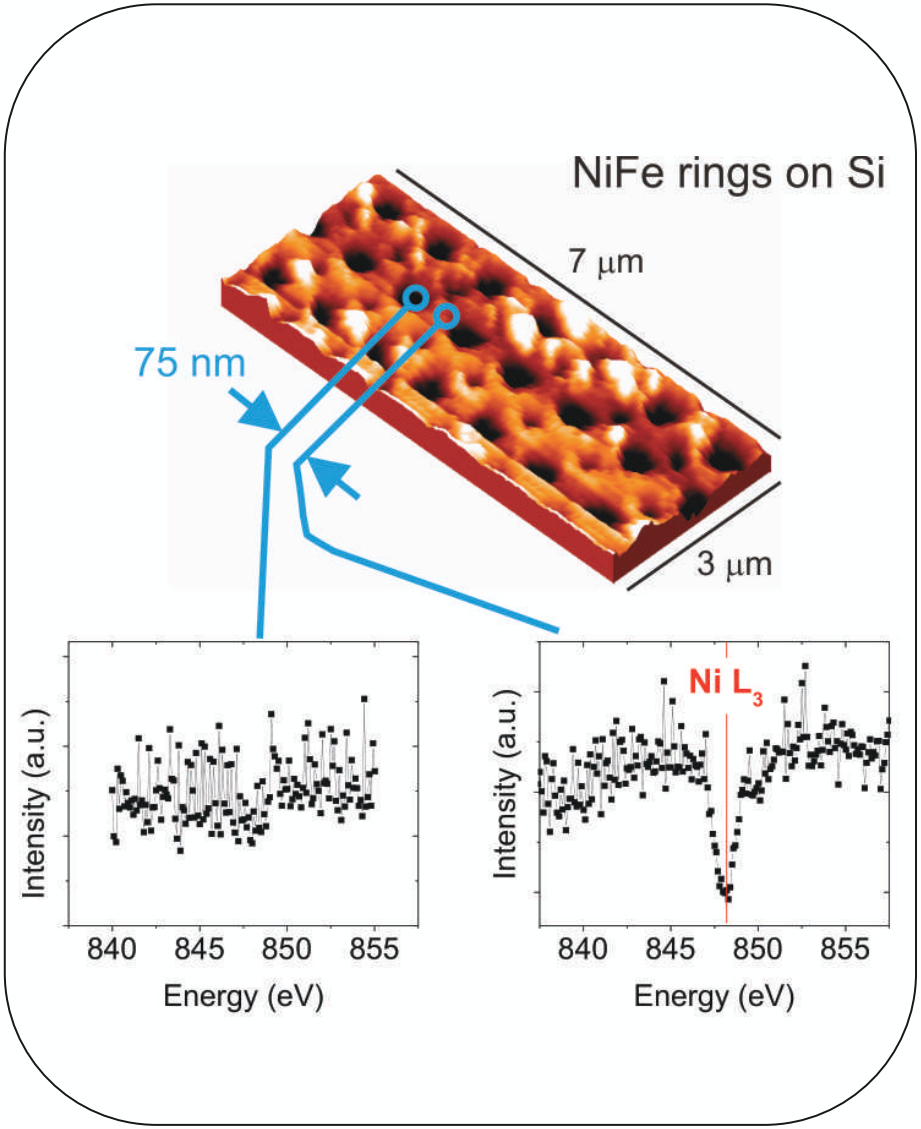
- electrical large band gap insulator
- superior thermal conductivity
- thermal stability:
  - 1000 °C in air
  - 1400 °C in vacuum
  - 2800 °C inert atmosphere



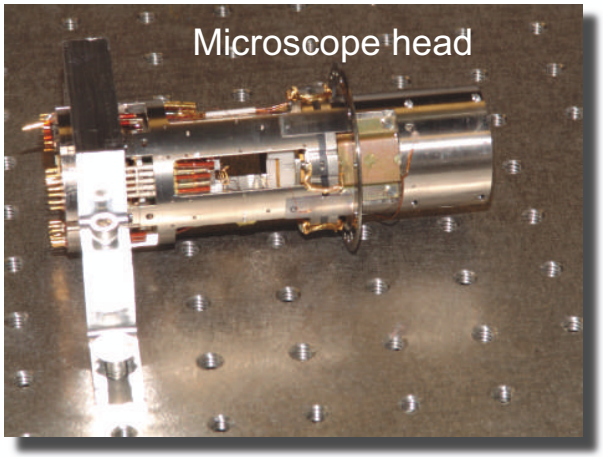


Dry composition: 97% BN, 2% SiO_2, 1% MgO


Tip current
conventional STM
Topography
Cu film on Si
1000 nm
beam off
E = 925.6 eV
Tip current
X-ray + STM

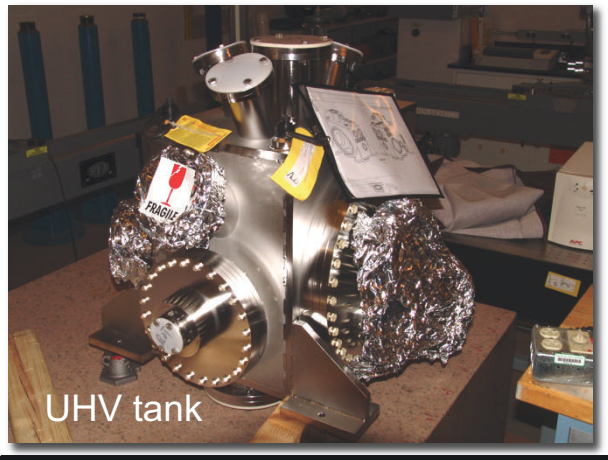

NiFe rings on Si
7 μm
75 nm
3 μm
Intensity (a.u.)
840
845
850
855
Energy (eV)
Ni L3
Intensity (a.u.)
840
845
850
855
Energy (eV)

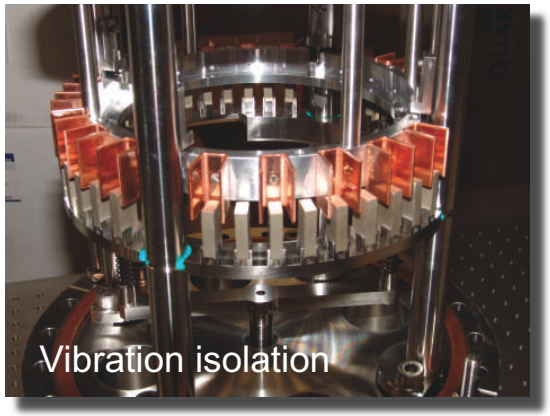
SXSTM$_{beta}$ development

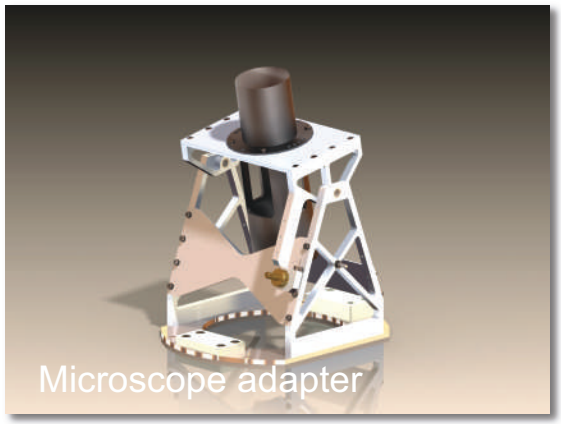


Highlights:

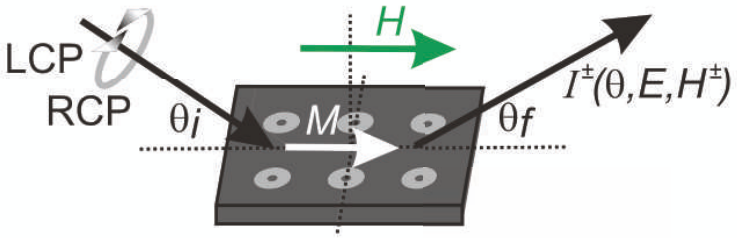
- ❖ Sample preparation capability
- ❖ Vibration isolation
- ❖ “portable” instrument

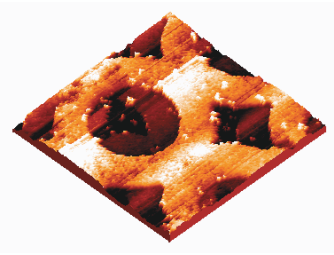




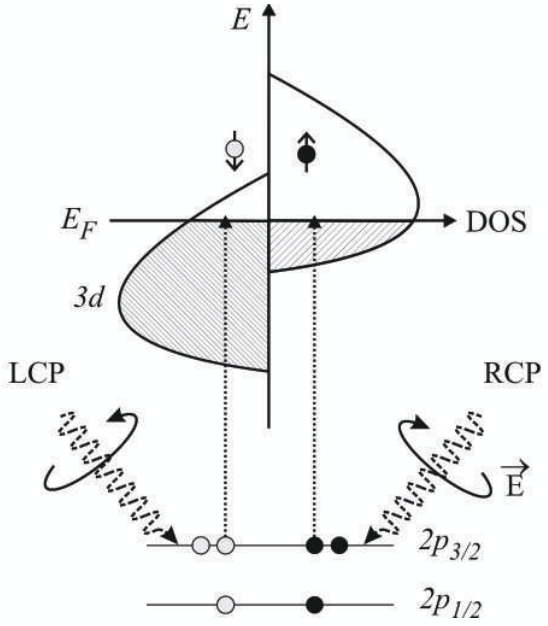


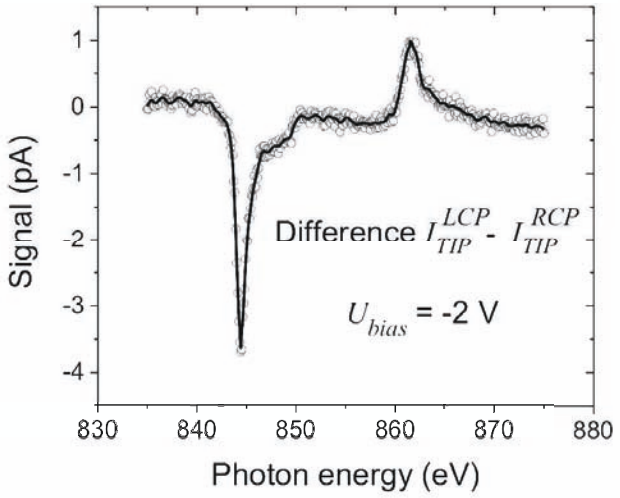
Measuring the SIZE of individual spins in nanoclusters

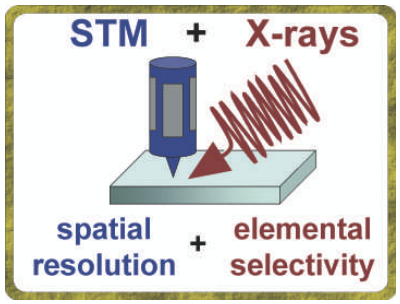




X-ray magnetic circular dichroism







Take home

- **SXSTM enables nanoscale chemical imaging with magnetic contrast**
- **SXSTM*beta* operational in 2010**

Acknowledgements

Marvin Cummings	Rice University
John Freeland, Curt Preissner	Advanced Photon Source
Kenneth Gray	Materials Science Division
Matthias Bode, Stephen Streiffer	Center for Nanoscale Materials

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More

Volker Rose, John W. Freeland, Stephen K. Streiffer, *"New capabilities on the interface of X-ray and scanning tunneling microscopy"*, in *"Scanning Probe Microscopy of Functional Materials: Nanoscale Imaging and Spectroscopy"*, eds. S.V. Kalinin, A. Gruverman, to be published by Springer 2010.

V. Rose, J.W. Freeland, K.E. Gray, S.K. Streiffer, Appl. Phys. Lett. 92, 193510 (2008).