Synchrotron X-Ray Scanning Tunneling Microscopy

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Outline

Scanning tunneling microscopy (STM)
– What it is.
– How it works.
– Why you would want to enhance it with X-rays.
Specific papers on synchrotron x-ray enhanced STM.
– Challenges and recent progress
What is scanning tunneling microscopy?

Iron on copper. Michael Crommie, Chris Lutz and Don Eigler, IBM.
1986 Nobel Prize

Gerd Binnig and Heinrich Rohrer

European Press photo Agency

What does it do?

Tunneling: measure electrons near Fermi energy without contact.

Scanning: move the measuring tip around on the sample.
Process

Electrons tunnel into tip.

A piezoelectric actuator moves the tip around.
Process

Two modes:

1. Constant current (feedback loop with piezo to move it up and down).

2. Constant height (faster).
Q: How do you get a tip that sharp?

A:

www.csun.edu/~hpostma/2013-1-466/stm-introduction.pdf

Henk Postma
Q: Doesn't it tunnel from the tip to the sample as well?
A: Yes. This is why they use a bias voltage and a tip material with a stable ("flat") density of states for the energy range of the sample's Fermi surface.

http://hoffman.physics.harvard.edu/research/STMtechnical.php
Typical orders of magnitude for STM

Separation distance: a few Å.

Tunneling current: pA to nA

Bias voltage: a few hundred mV

Spatial resolution (depth): <Å.

Spatial resolution (side to side): ~Å.
Requirements

1. Vacuum to avoid oxidation of tip and sample (not strictly necessary).

2. Flat surfaces.

3. High precision tips.


5. Reliable, precise electronics.
Tip materials

Noble metals (platinum, iridium) because any oxidation would ruin the conductivity

In vacuum, you can use e.g. tungsten.
What STM does well:

Spatial resolution

$I = C \exp(-kz)$

Individual atoms!
What STM does well:

Xenon on nickel.

http://researcher.ibm.com/researcher/view_project_subpage.php?id=4251
What STM does well:

http://www.physics.purdue.edu/nanophys/stm.html
What STM does poorly:

Chemical and magnetic contrast.

At the Fermi level, you can distinguish conductors from insulators, but generally not much more than that.

Energy resolution is highly dependent on temperature, sample cleanliness, vibrations, etc.
Synchrotron X-ray techniques

Beam spot size is on the order of ~10 nm with zone plates (not very good compared to STM).

But, it answers questions like:

Does this sample contain iron?
Is this sample ferromagnetic?
Is the iron in this sample oxidized?
And much more!

Let's combine it with STM!

Let's combine it with STM! (2010)

2010 prototype

Let's combine it with STM! (2011)

How does it work?

http://www.aps.anl.gov/Xray_Science_Division/Sxspm/Research/Physical%20Concept/
How does it work?
How does it work?

– 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).
Partial solution: insulated tips.

See oxidation, even without tunneling!

But there are problems.

It has to keep on tunneling for good spatial resolution.

Extrapolating photo-ejected electrons (the ones we don't care about)

\[ |I_t (1.3\text{nm})| = 0.967 \times |I_t (180\text{nm})| \]

Questions?
Example: Spin-dependent x-ray excitations (2012)

Aside: AFM


http://www.nanoscience.gatech.edu/zlwang/research/afm.html
Aside: not STM

Scanning electron microscope (SEM): emits electron beam, and spatial resolution worse by an order of magnitude.
Aside: not STM

https://commons.wikimedia.org/wiki/File:SEM_image_of_a_Peacock_Head,_slant_view.JPG