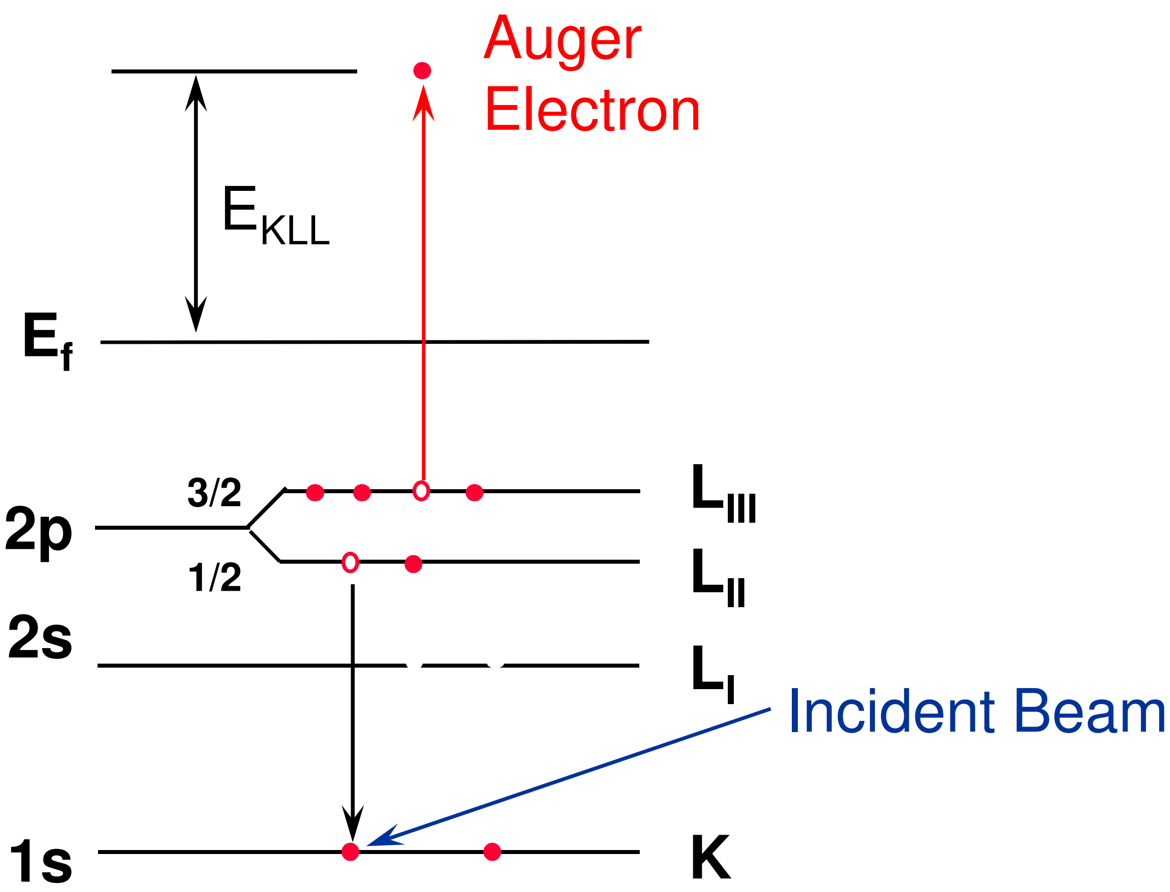
Auger Electron Spectroscopy Overview

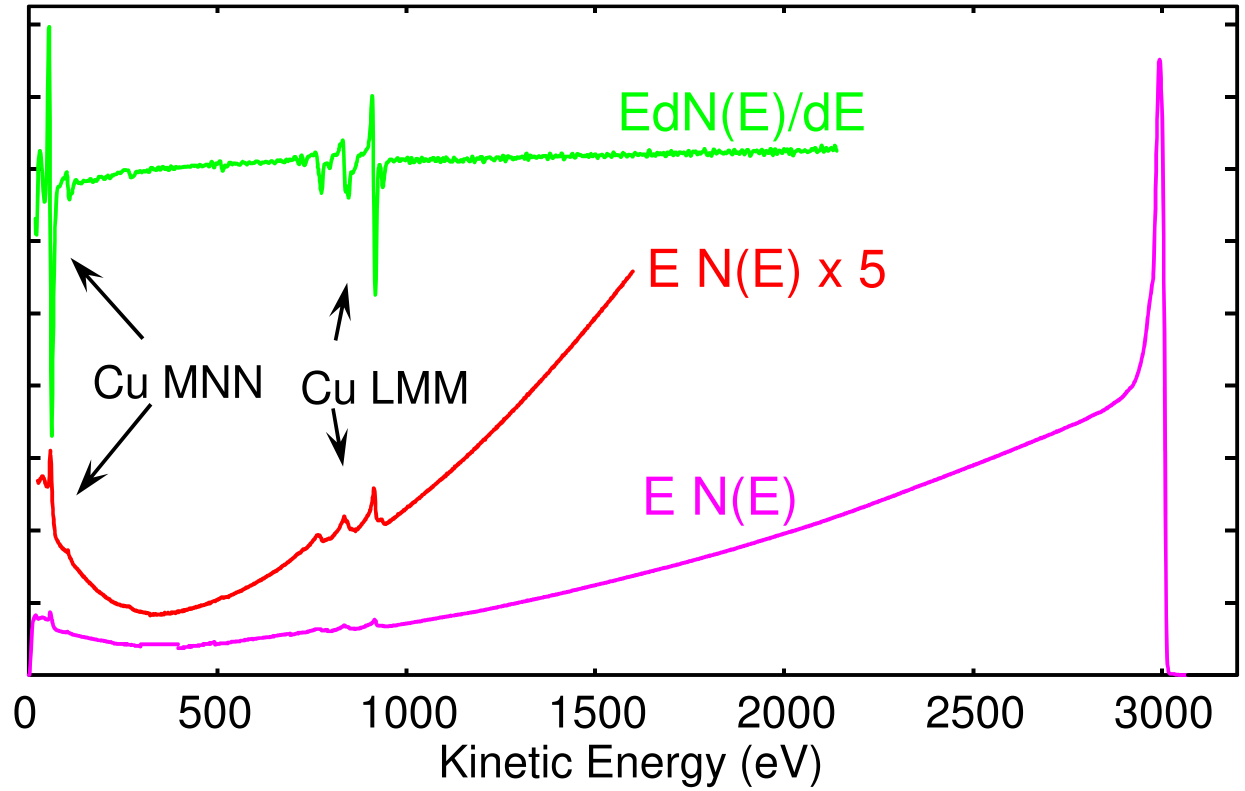
Also known as: AES, Auger, SAM

Auger Electron Spectroscopy

$$E_{KLL} = E_K - E_L - E_{L}'$$



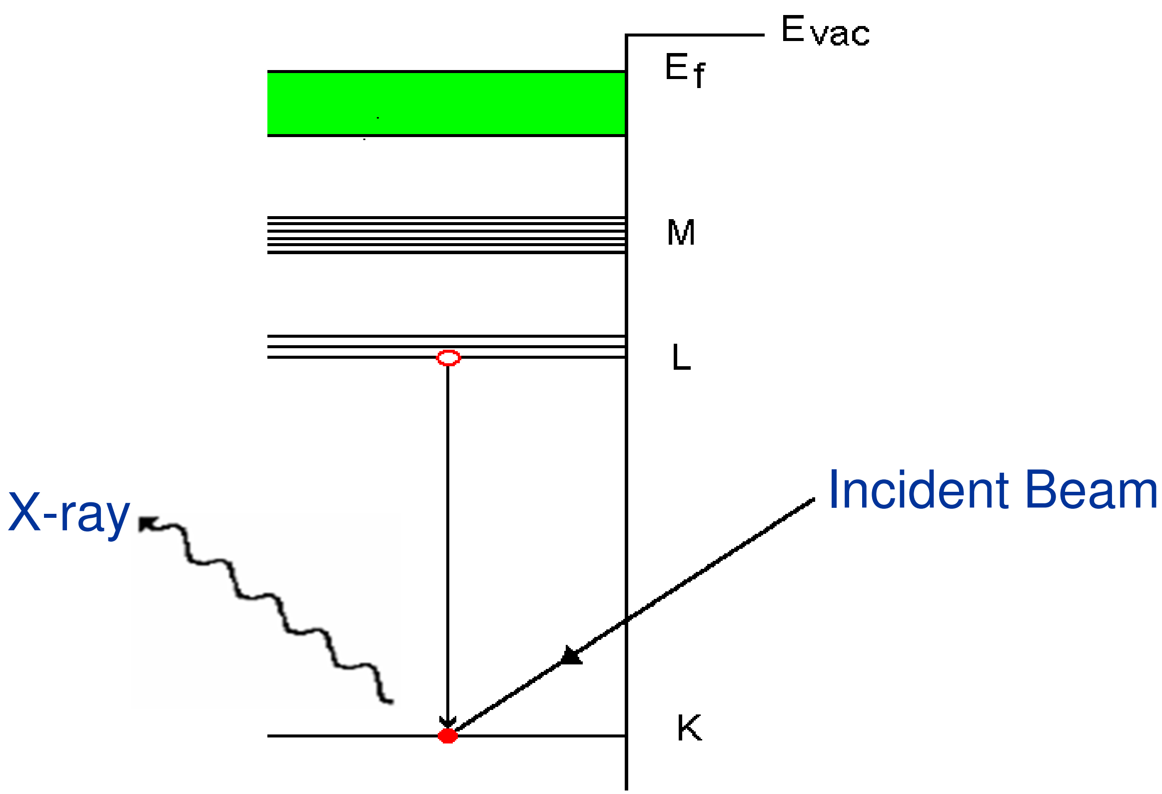
AES Spectra of Cu



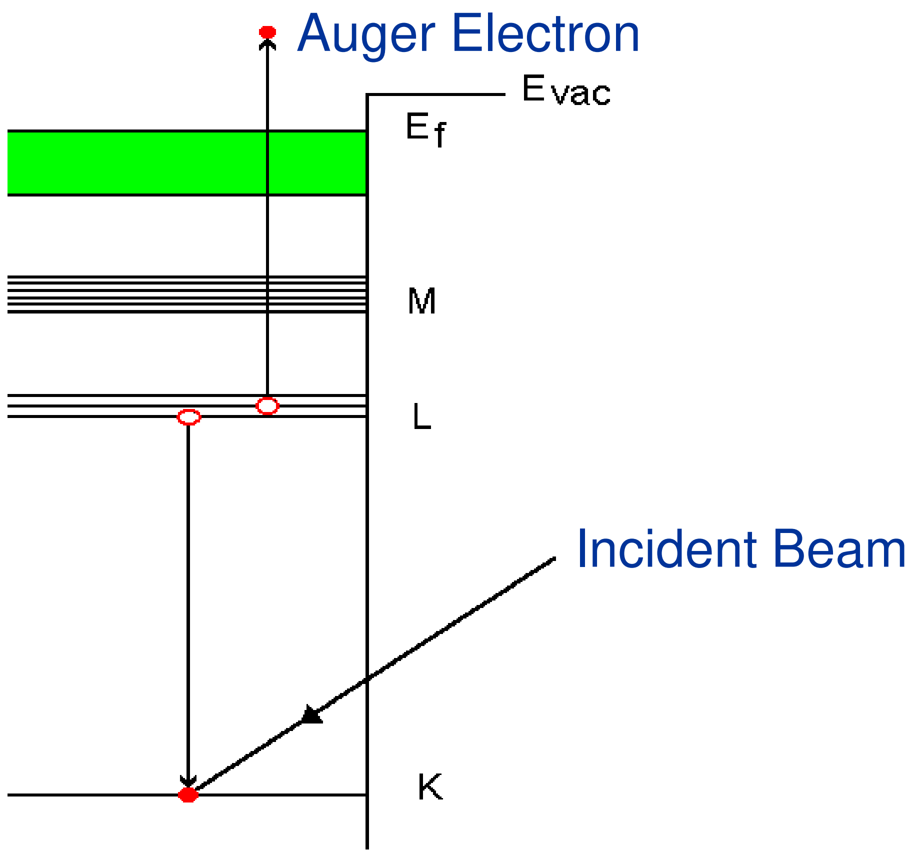
Note that Auger peaks are typically superimposed on a large background (see red and magenta spectra).
For this reason Auger spectra are typically displayed in a differentiated mode as shown in the green spectrum.
Detection limits for AES are approximately 0.1 atomic percent.

Auger Electron and X-ray Emission

Energy Dispersive X-ray Spectroscopy (EDX)

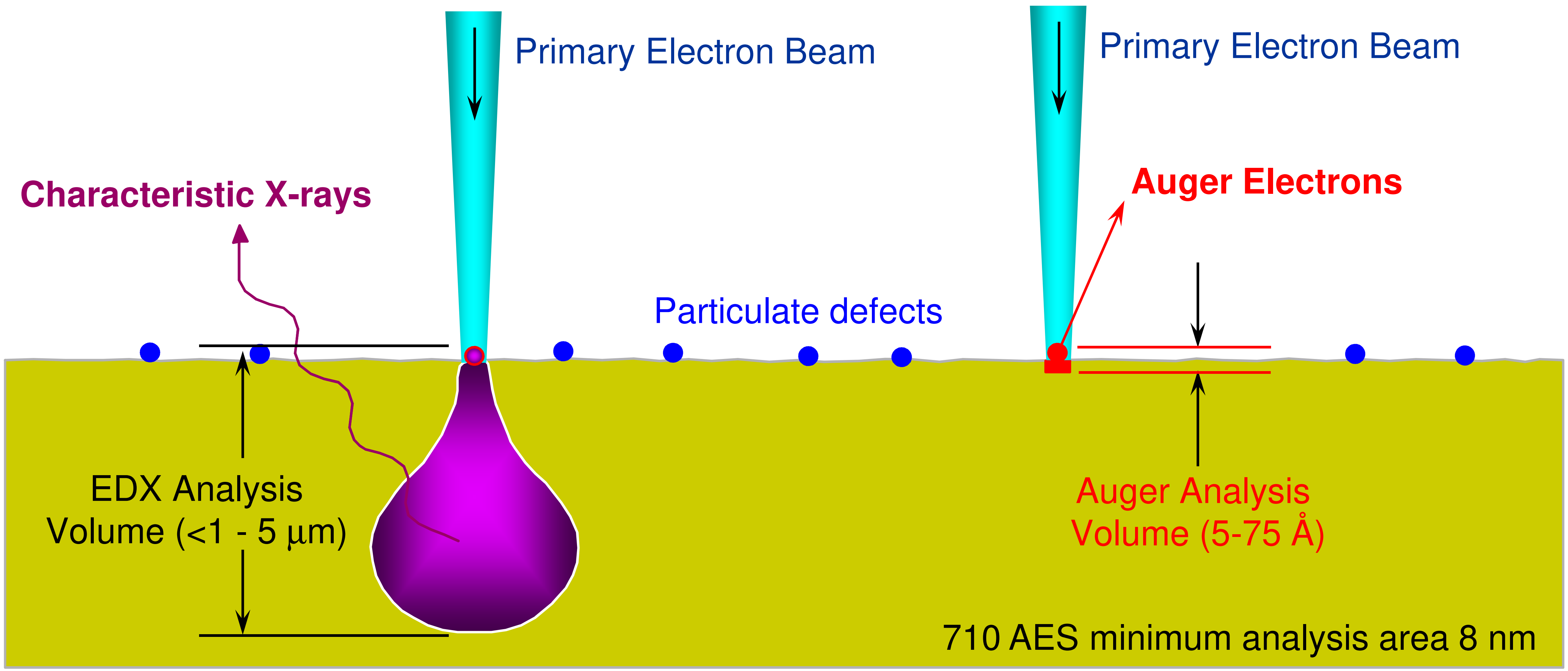


Auger Electron Emission



AES and EDX

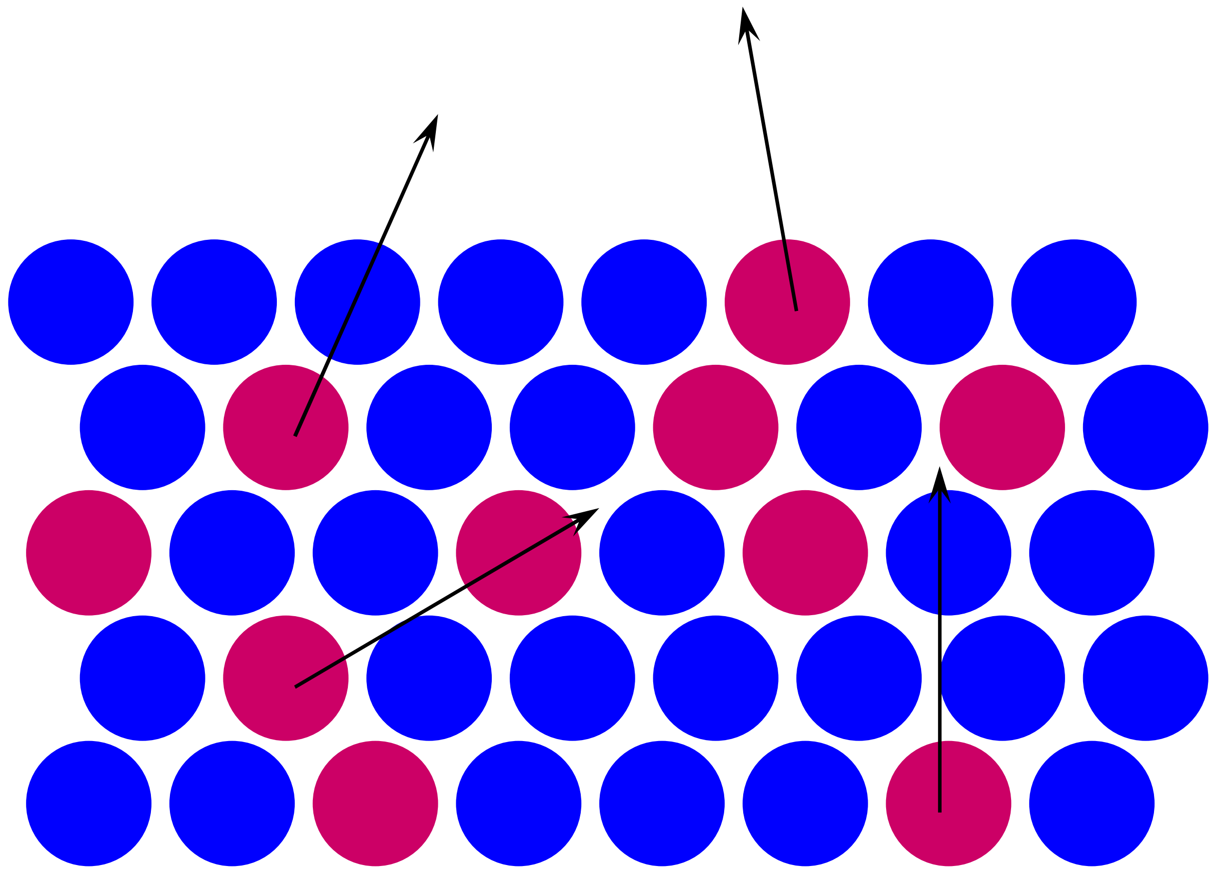
AES Provides Superior Nanovolume Analysis Capabilities



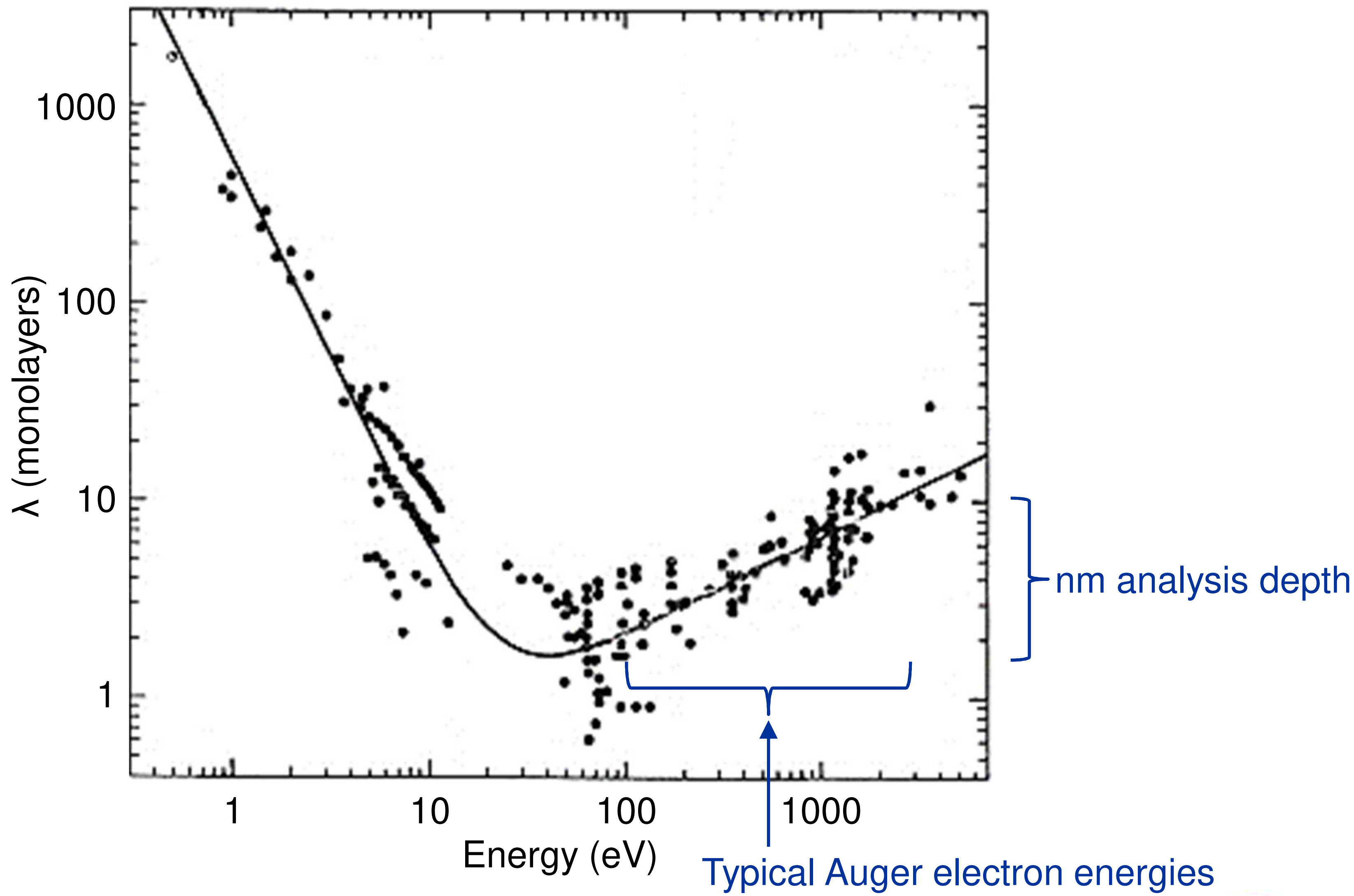
EDX minimum analysis area > 1 µm

AES Analysis Depth

Mean Free Path: Mean distance electrons travel before undergoing inelastic scattering



Analysis Depth – "Universal" Curve



Auger Electron Spectroscopy

- Auger Electron Spectroscopy is an analytical technique that provides compositional information from the top few monolayers of a material

- Detect all elements above He

- Detection limits: 0.1 – 1 atomic %

- Surface sensitive: top 5-75 Å

- Spatial resolution: < 60 Å probe size (PHI 710)

What Information Does Auger Provide ?

- Surface composition at high spatial resolution
  - Secondary Electron Imaging
    - Provides high magnification visualization of the sample
  - Elemental analysis (spectra)
    - Determines what elements are present & their quantity
  - Elemental imaging (mapping)
    - Illustrates two-dimensional elemental distributions
  - High energy resolution spectra, imaging and depth profiling
    - Chemical state analysis for some materials
- Sputter depth profiling
  - Reveals thin film and interfacial composition

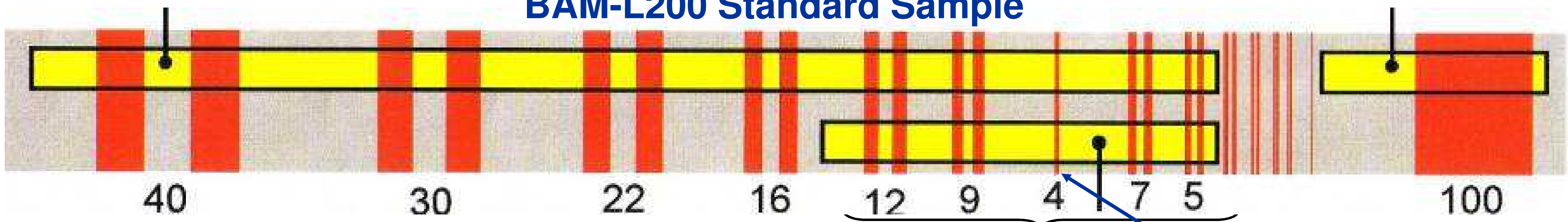
PHI *710* Scanning Auger NanoProbe

PHI *710*: Analytical Capabilities

- Nanoscale image resolution
- Image registration for high sensitivity
- Constant sensitivity for all geometries
- Constant sensitivity with tilt for insulators
- Nano-volume depth profiling
- Chemical state analysis

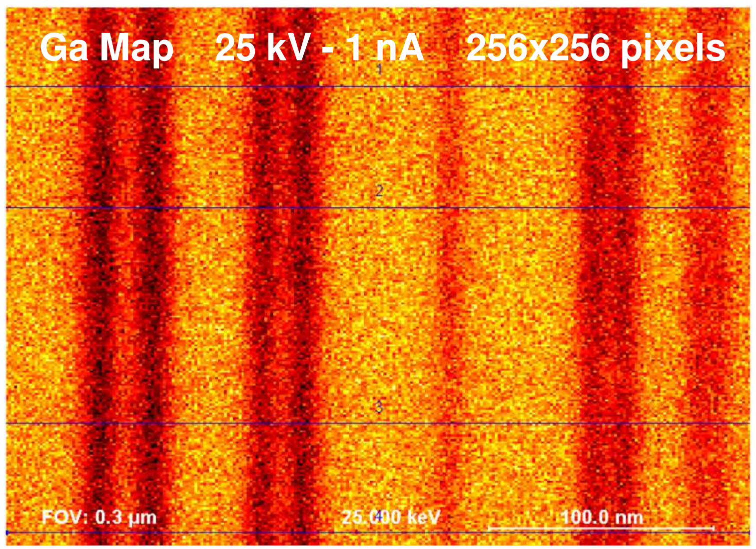
PHI *710*: High Spatial Resolution

BAM-L200 Standard Sample

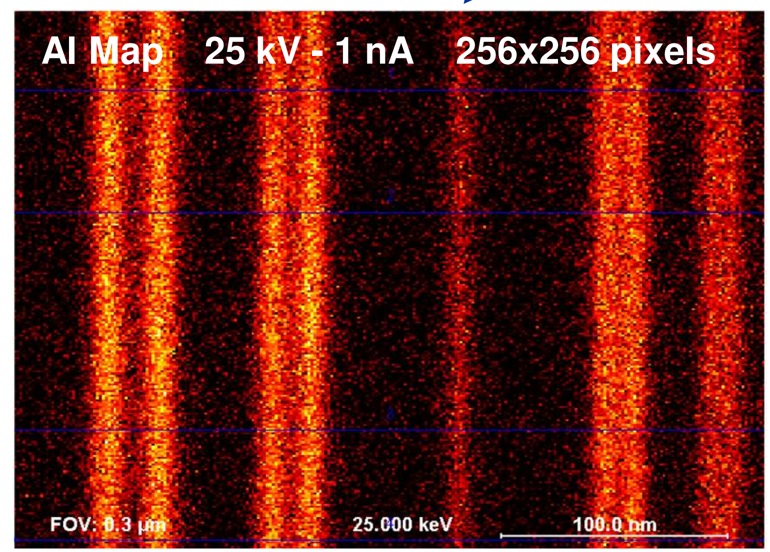


Locations for Line Scans

Sample provided by Federal Institute for Materials Research and Testing (BAM) Berlin, Germany



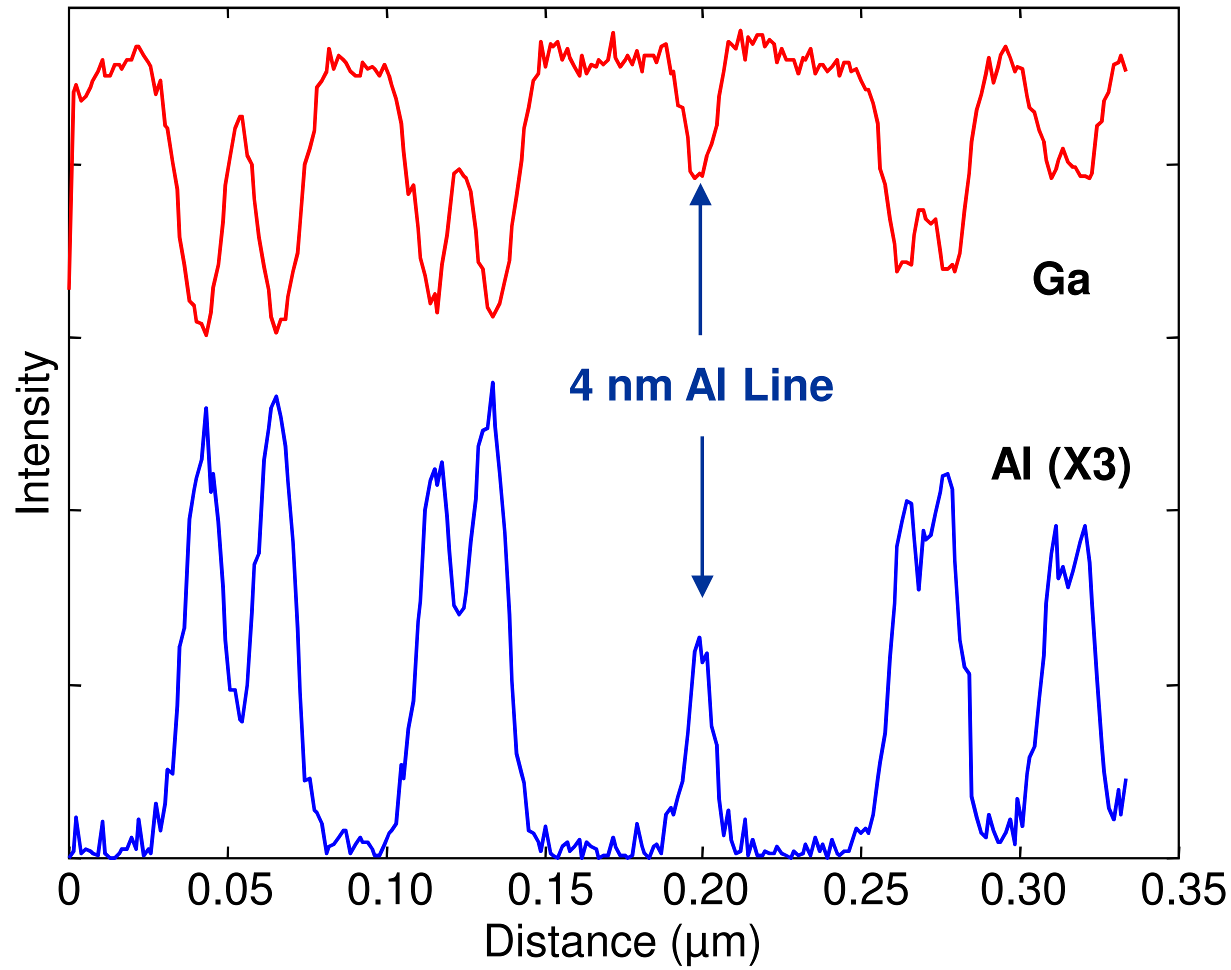
1
2
Auger Line Scans
3
4



24 hour stability test demonstrating exceptional image registry

PHI *710*: High Spatial Resolution

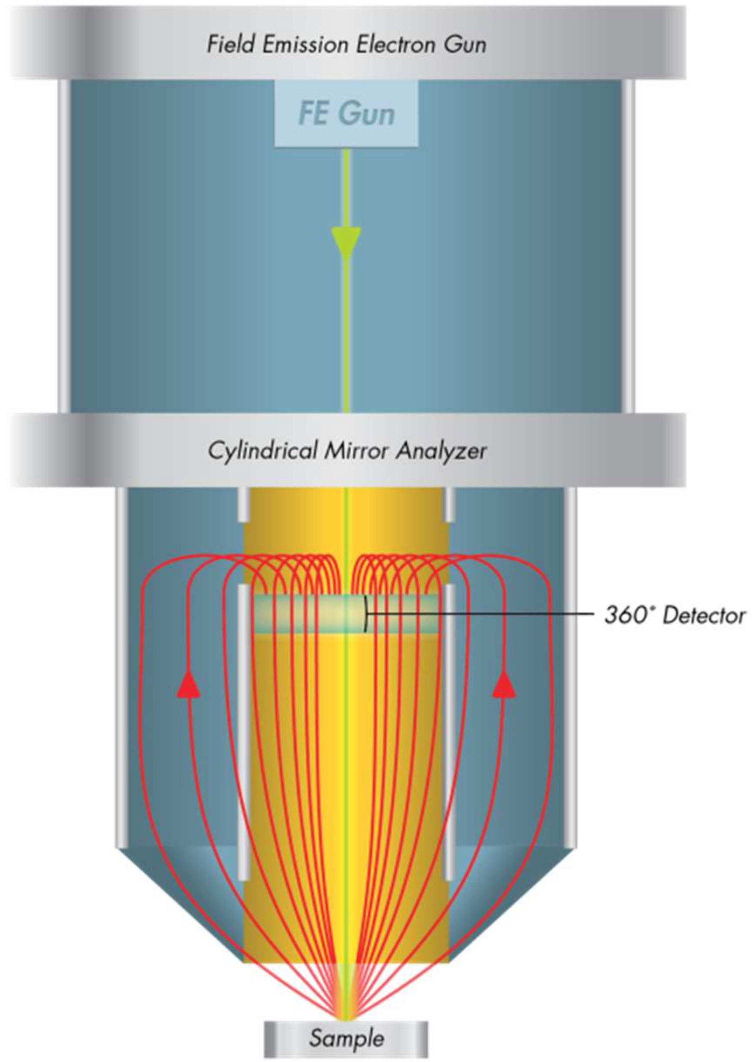
BAM-L200 Standard Sample Line Scan #4



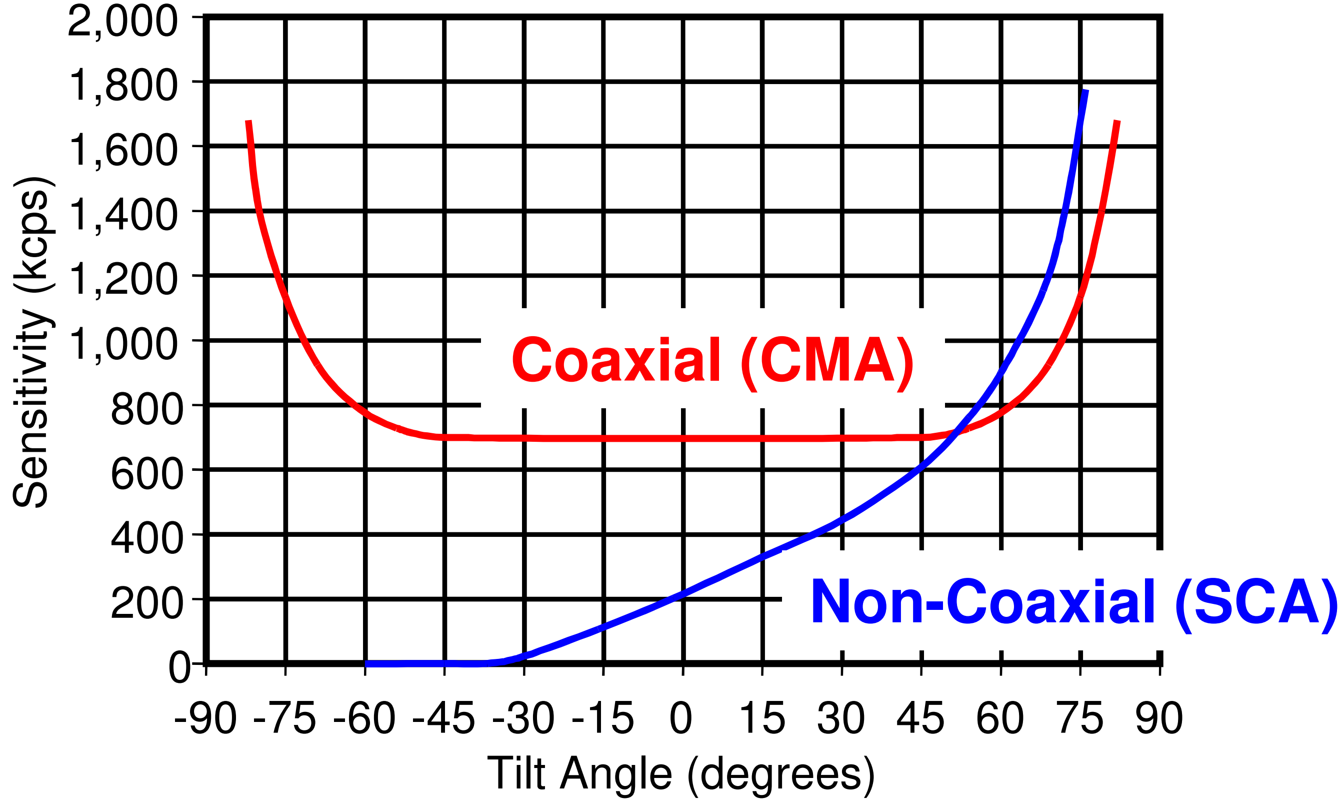
24 hour stability test demonstrating exceptional image registry

PHI *710*: Constant Sensitivity for All Geometries

PHI *710*
Coaxial Analyzer & Electron Gun Geometry



Sensitivity vs. Sample Tilt Angle

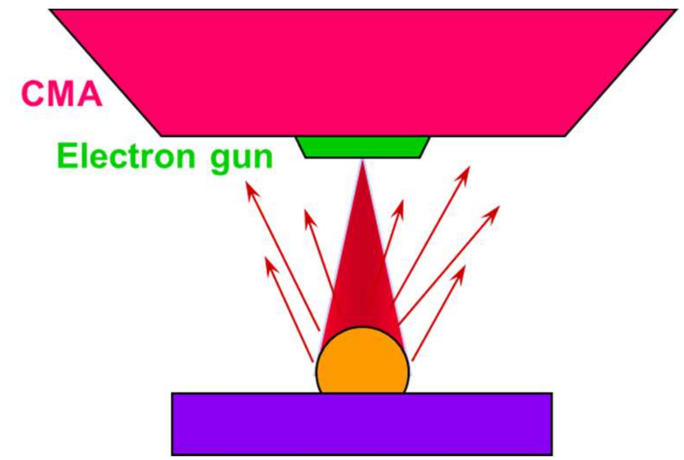


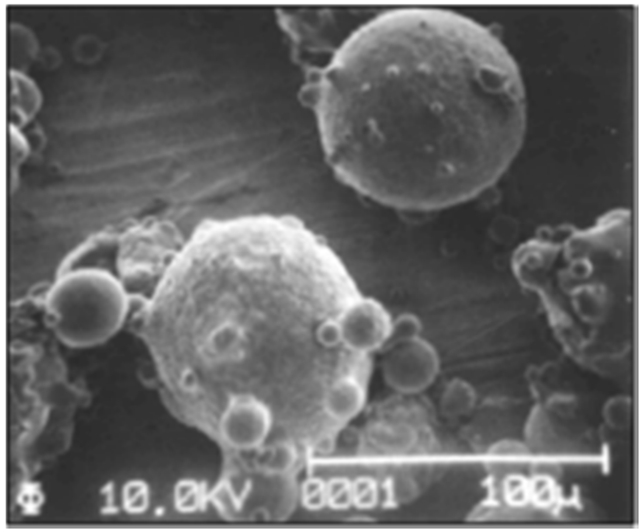
The CMA with coaxial electron gun provides high sensitivity at all sample tilt angles which is essential for insulator analysis and samples with topography

PHI *710*: CMA with Coaxial Geometry

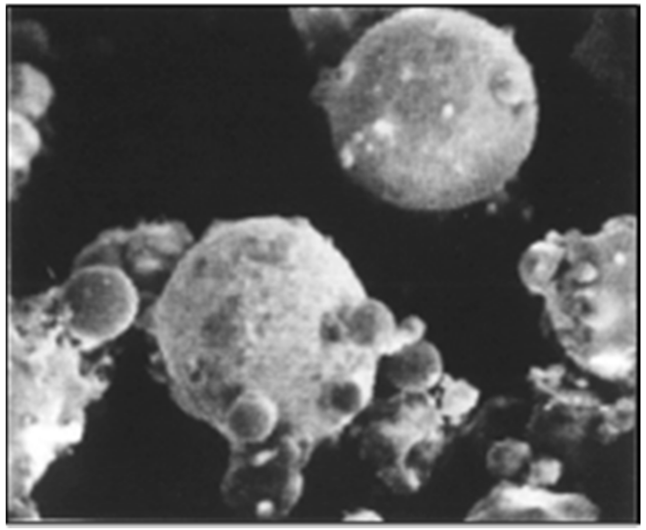
No shadowing

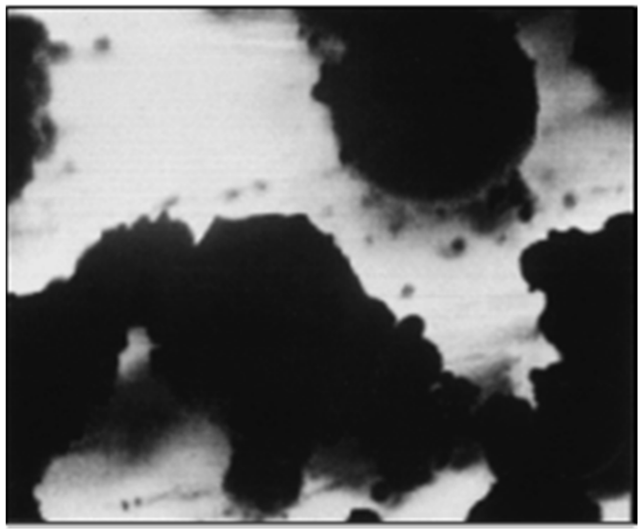
- Every pixel can be identified as part of a Ni sphere or as part of the In substrate.
- The Ni particles are complete spheres and the substrate fills in around the particles.
- Variations in In and Ni intensity provide meaningful compositional information.





Secondary Electron Image

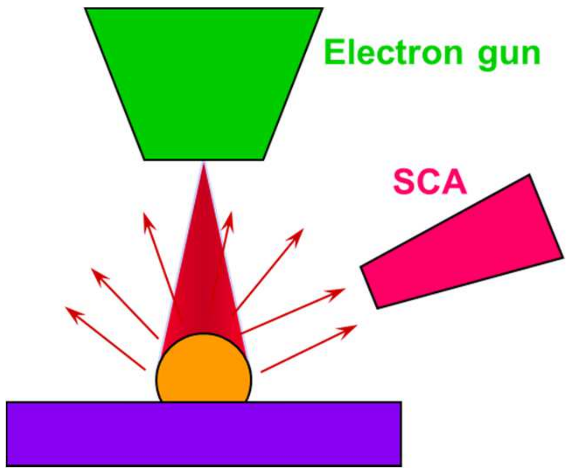

Ni Map

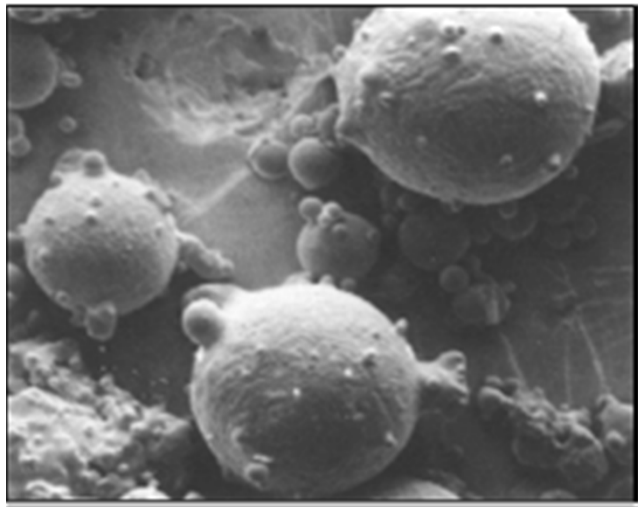

In Map

Non-Coaxial Geometry

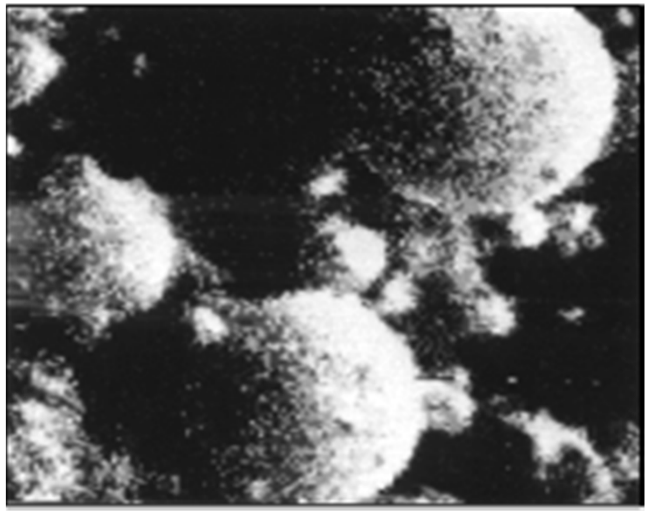
Shadowing

- Many pixels are of unknown composition, apparently neither Ni balls nor In substrate.
- The Ni particles are not observed as complete spheres and very little of the substrate is seen.
- Variations in In and Ni intensity do not provide meaningful compositional information.

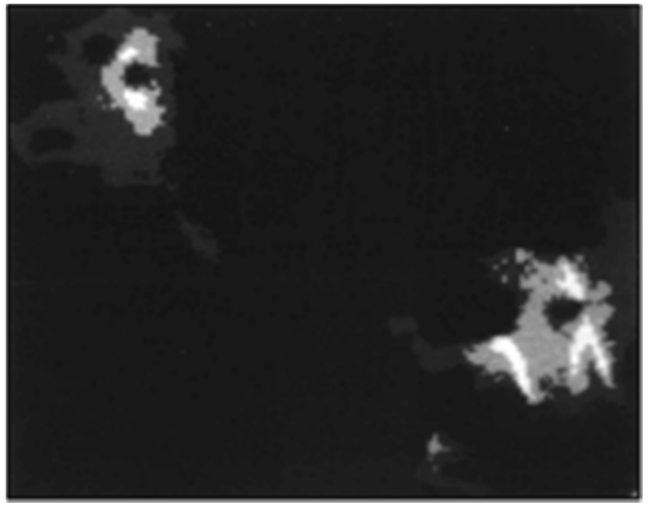




Secondary Electron Image



Ni Map

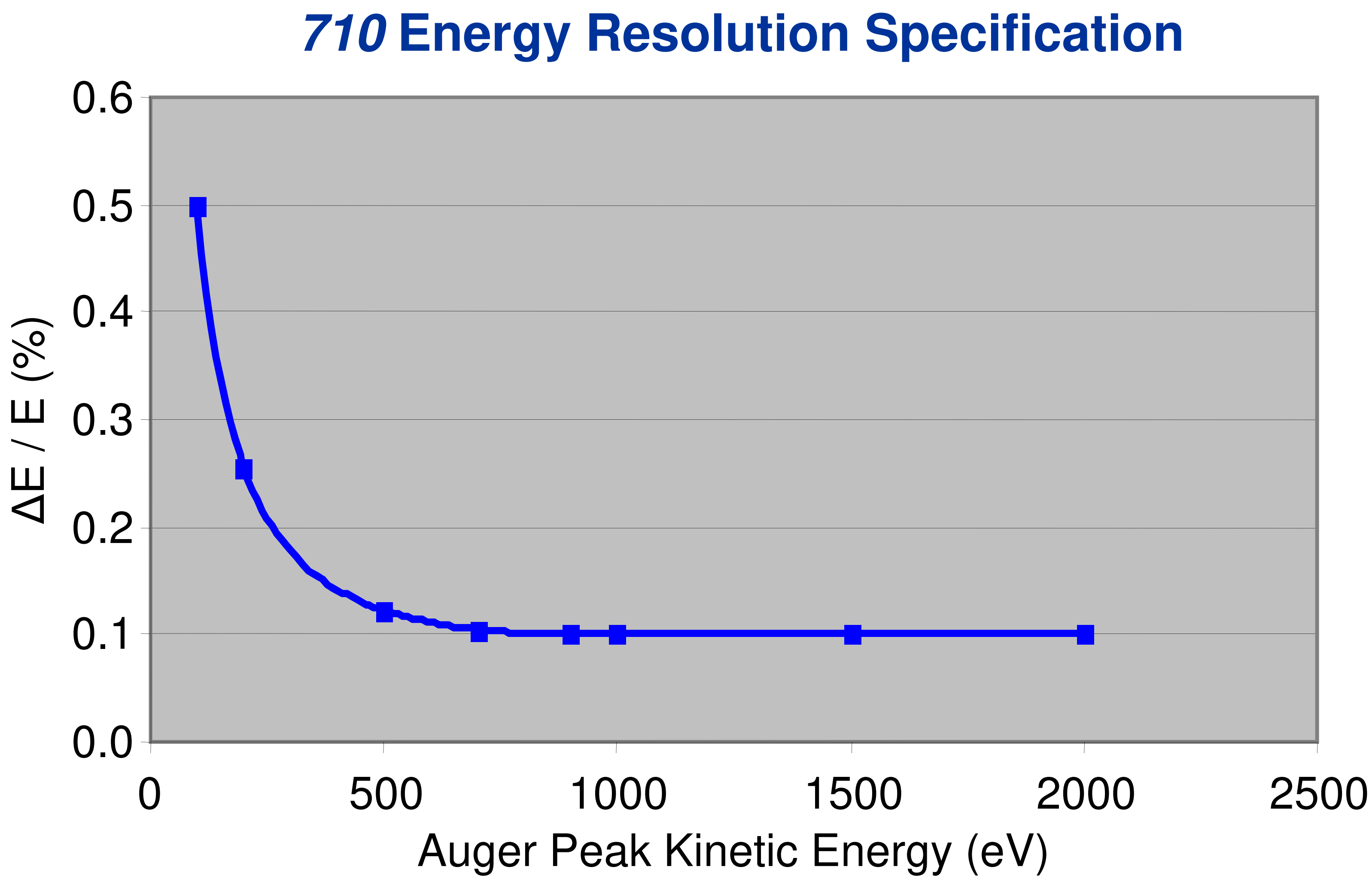


In Map

PHI *710* High Energy Resolution Mode

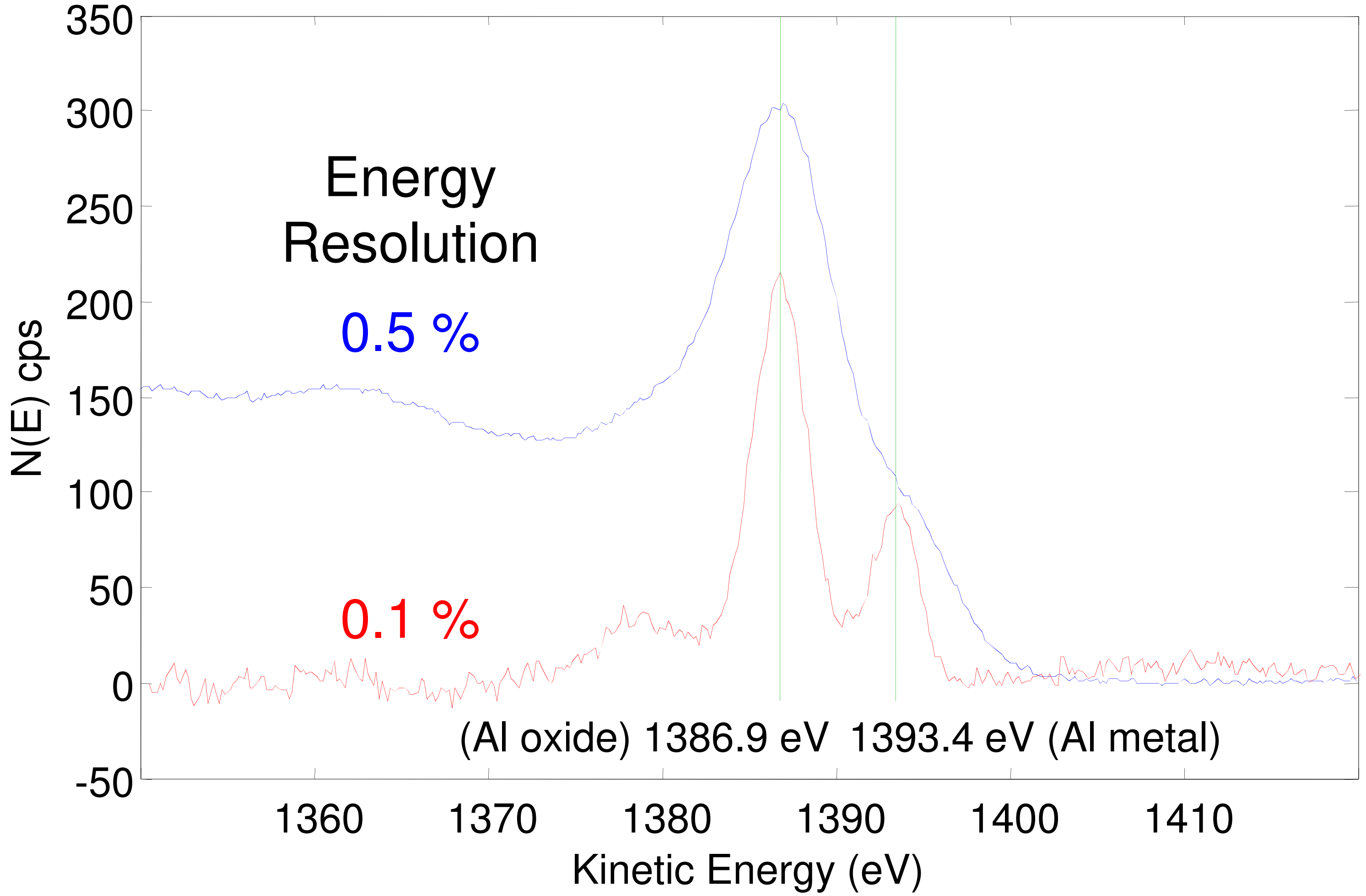
- How does the high energy resolution mode work?
  - The CMA energy resolution is given as:
  - $\Delta E / E = 0.5\%$
  - An optics element placed between the sample surface and the entrance to the standard CMA retards the Auger electrons, reducing their energy, E
  - From the energy resolution equation, if E is reduced, ΔE is also reduced and so is the Auger peak width; energy resolution is improved
  - The CMA is not modified in any way and retains a 360º coaxial view of the sample relative to the axis of the electron gun
  - US Patent 12 / 705,261

PHI *710* High Energy Resolution Mode



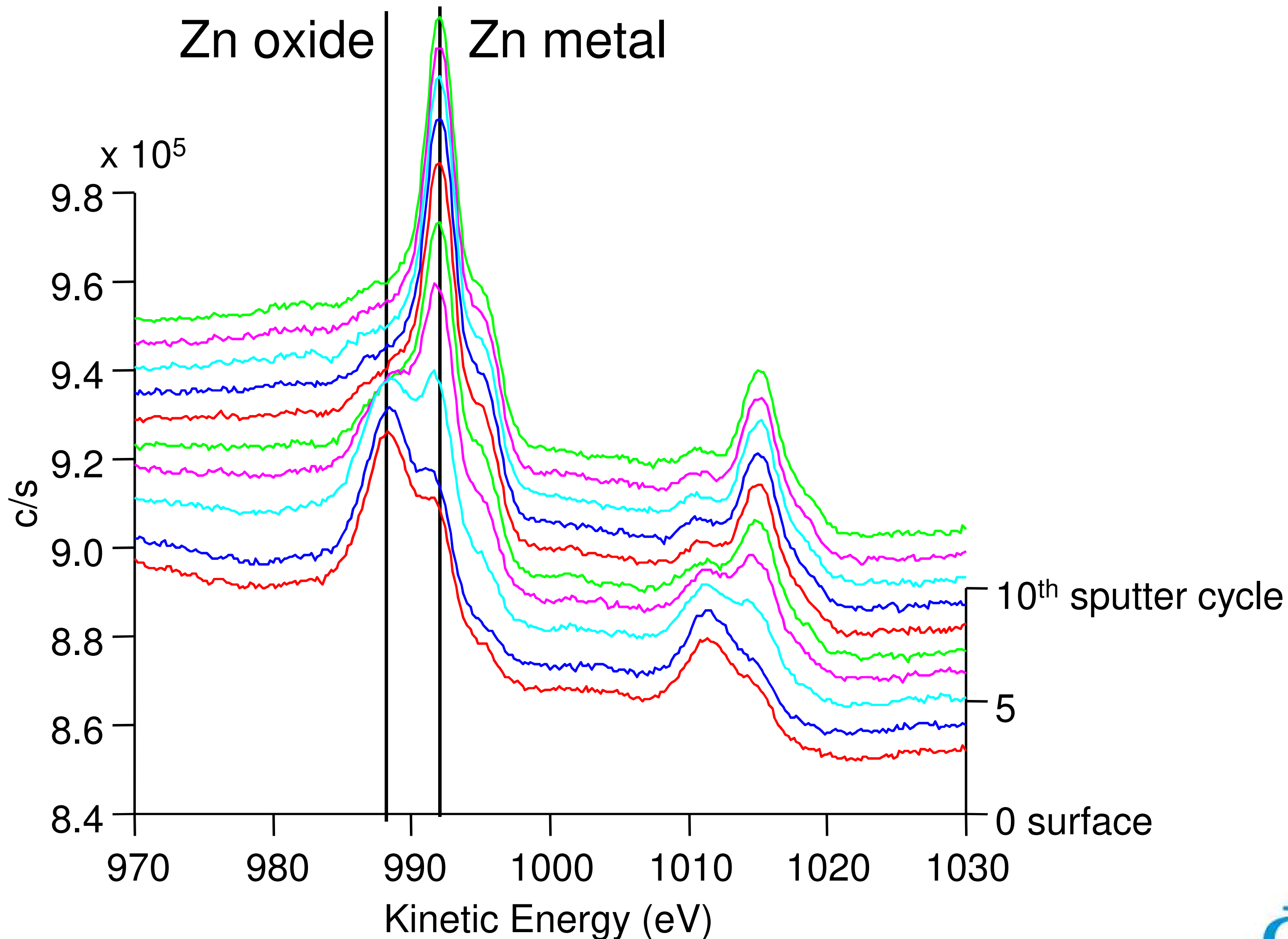
PHI *710* High Energy Resolution Mode

Al KLL Spectra of Native Oxide on Al Foil



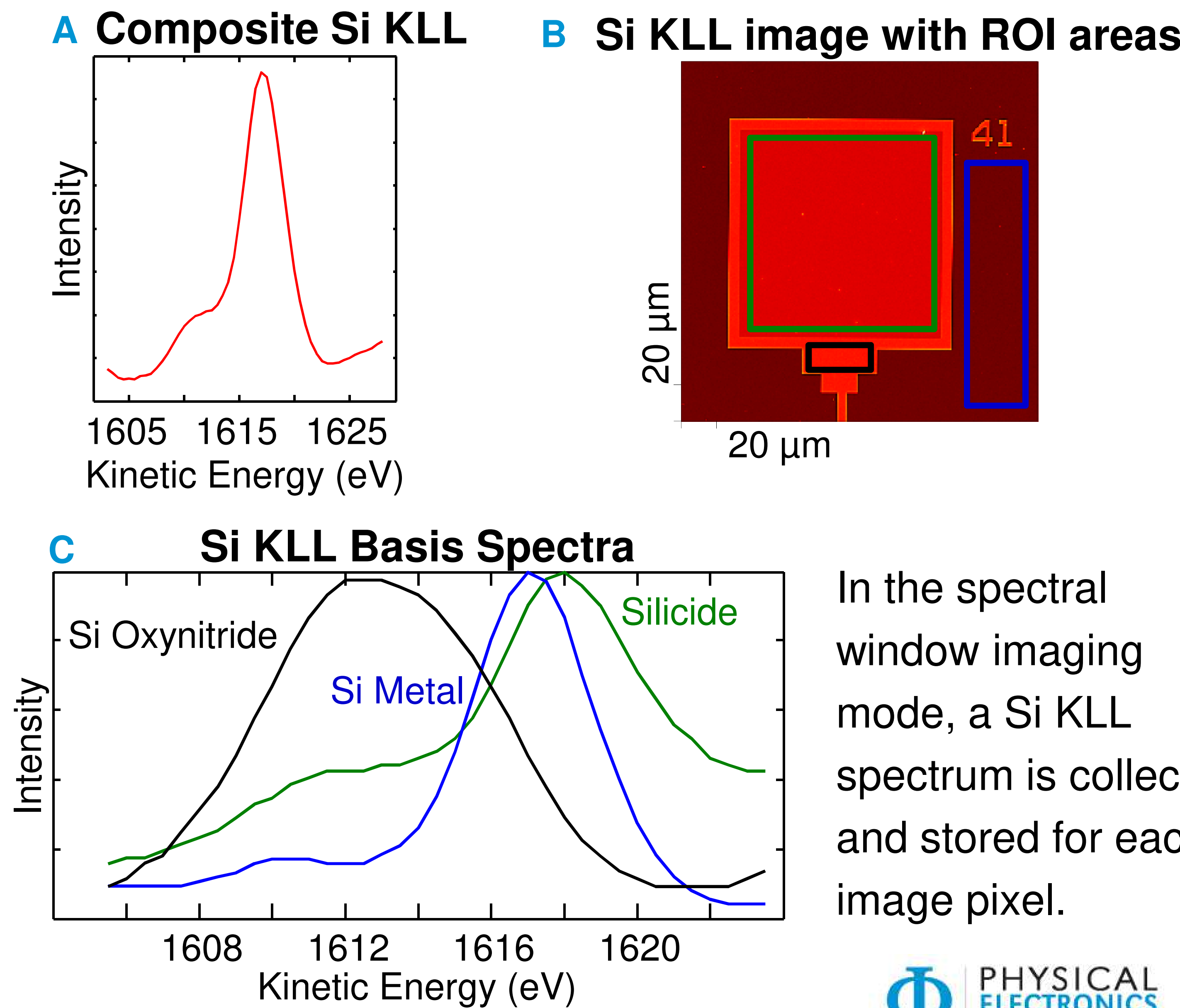
PHI *710* High Energy Resolution Mode

Depth Profile of Zn Oxide on Zn



PHI *710*: Spectral Window Imaging

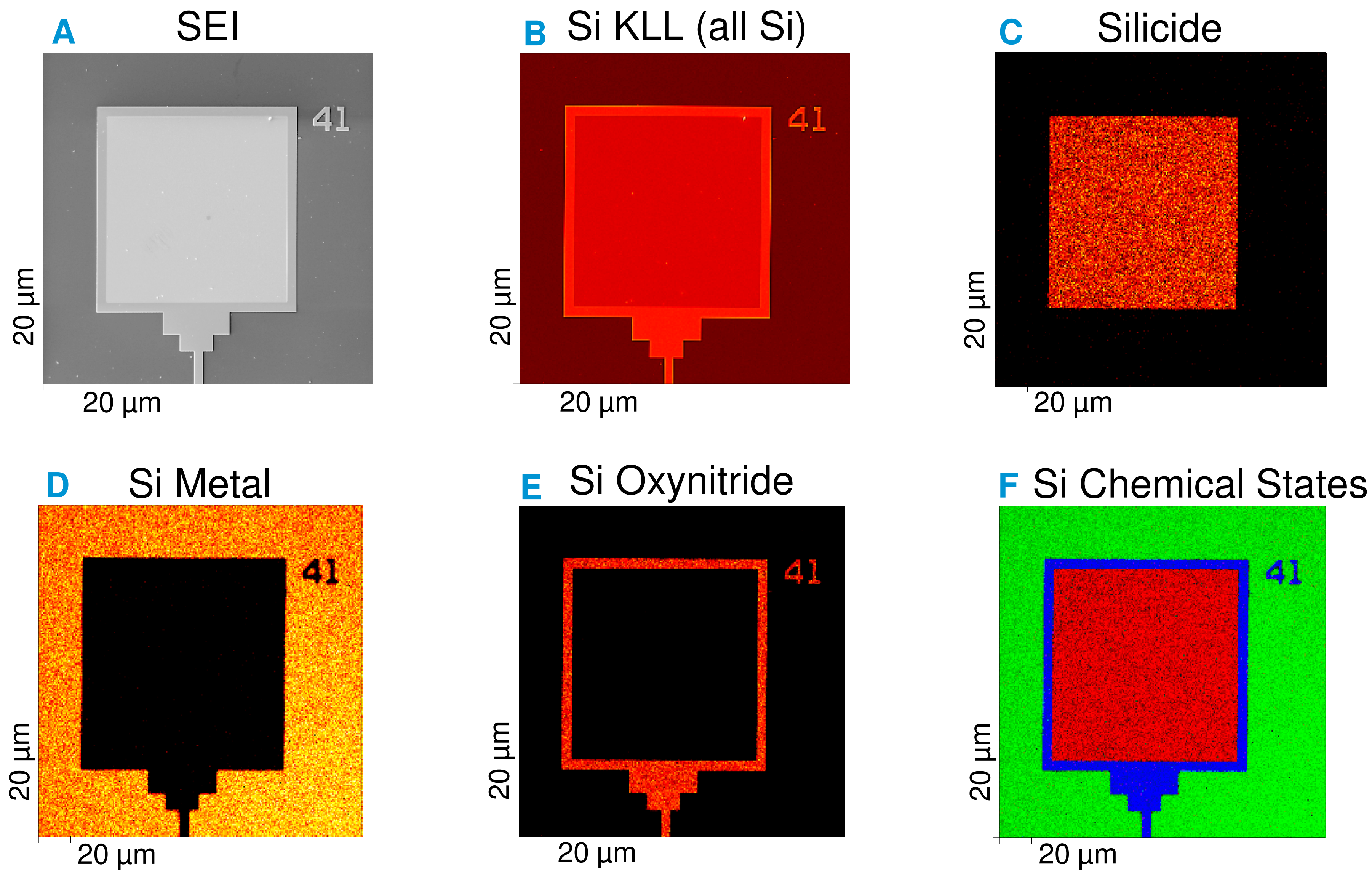
Panel A shows the Si KLL spectrum from the sum of all pixel spectra in the Si KLL Auger image shown in panel B. Panel B shows the three Regions Of Interest (ROI) selected for creation of the basis spectra for Linear Least Squares (LLS) fitting of the Si KLL image data set. Panel C shows the three basis spectra with their corresponding chemical state identifications.



In the spectral window imaging mode, a Si KLL spectrum is collected and stored for each image pixel.

PHI *710*: Spectral Window Imaging

Panel A shows a 200 µm FOV SEI of a semiconductor bond pad. Panel B shows the Si KLL peak area image from the area of panel A. Panels C, D and E show the chemical state images of silicide, elemental Si and Si oxynitride respectively. Panel F shows a color overlay of elemental silicon, silicide and silicon oxynitride images.



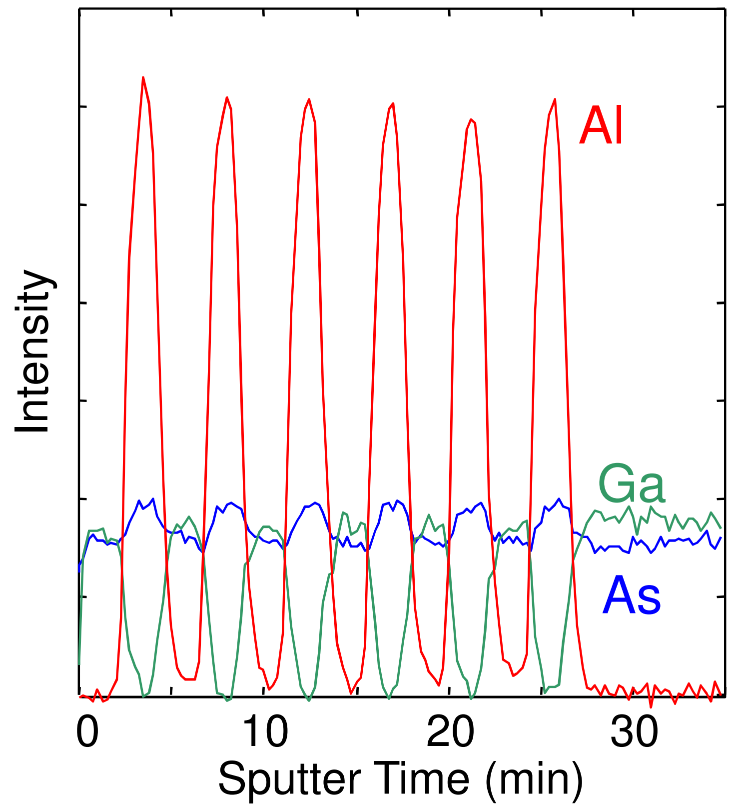
PHI *710*: Thin Film Analysis

- World's best Auger sputter depth profiling
  - Floating column ion gun for high current, low voltage sputter depth profiling
  - Compucentric Zalar Rotation™ minimizes sputtering artifacts and maximizes depth resolution
  - Image registration maintains field-of-view

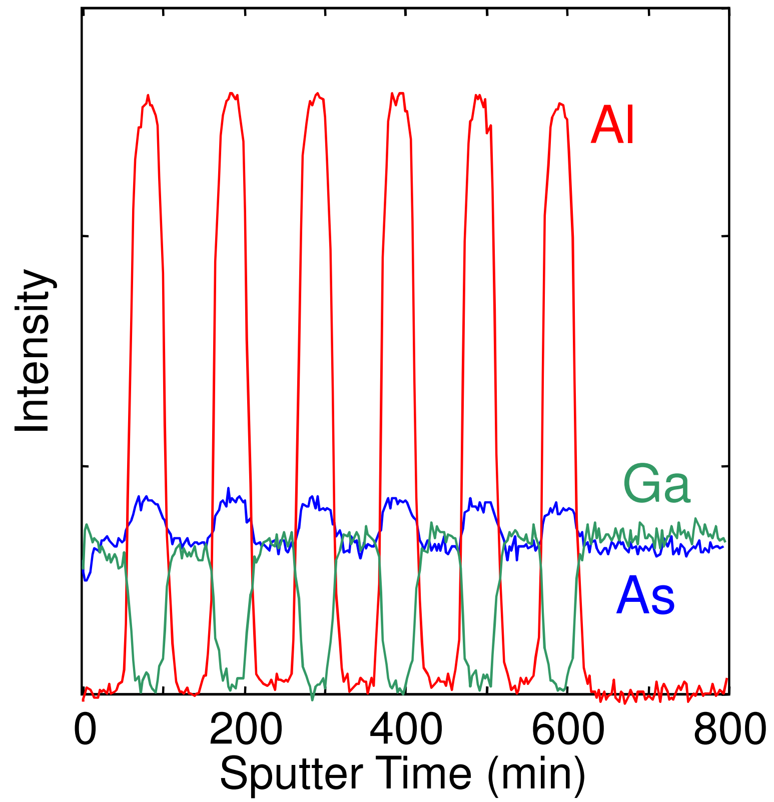
PHI 710: Low Voltage Depth Profiling

Improved Interface Definition with use of Ultra Low Ion Energies

500 eV Depth Profile



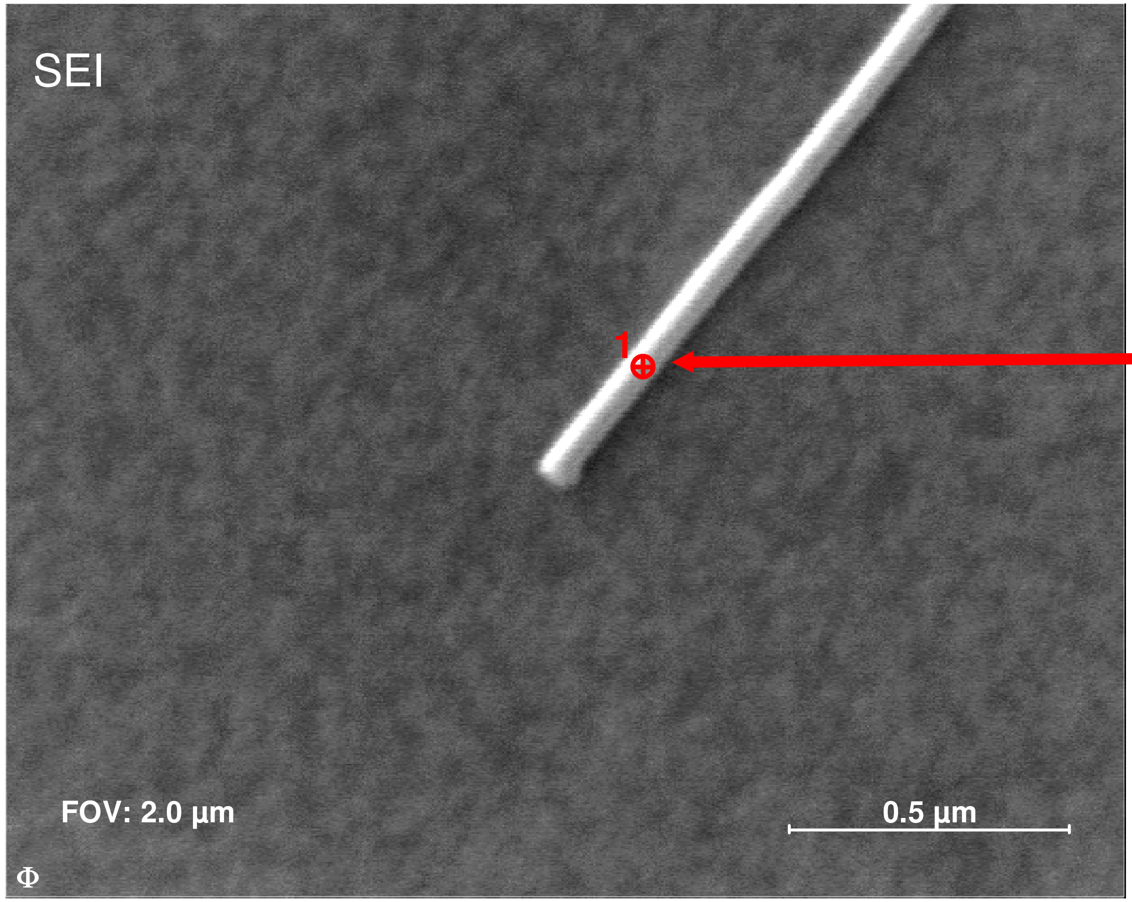
100 eV Depth Profile



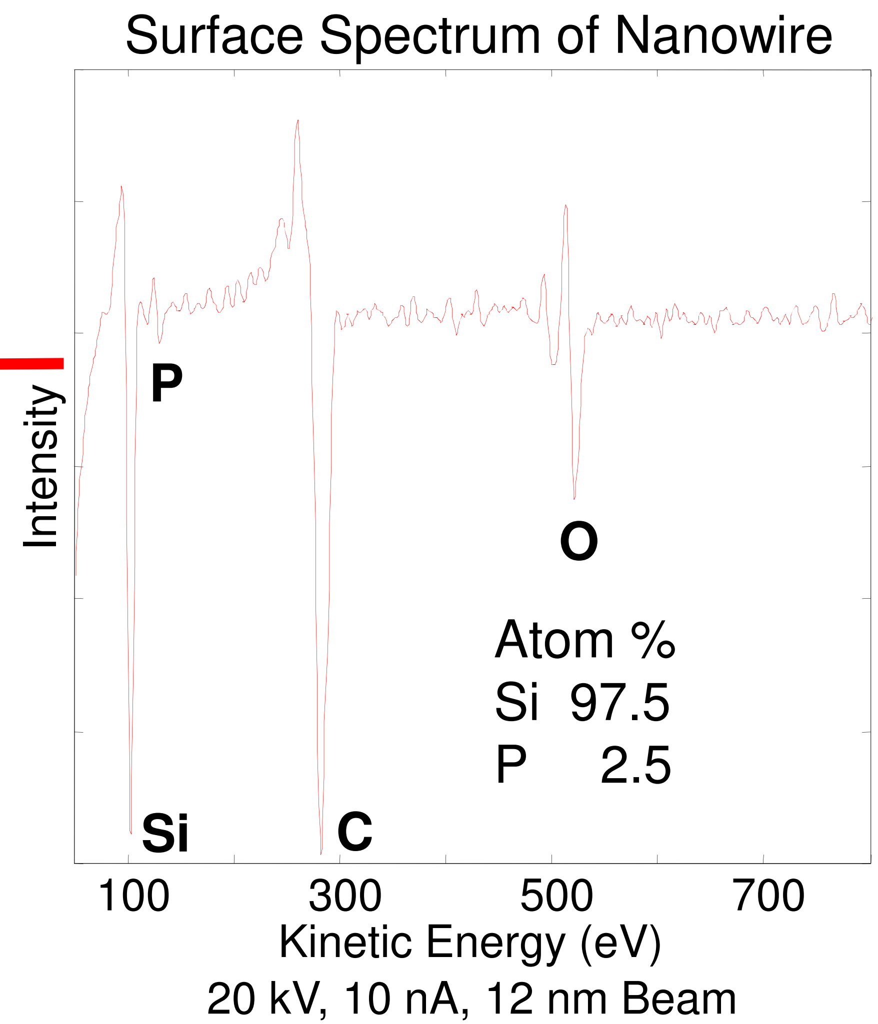
AlAs/GaAs Super Lattice Thin Film Structure

PHI *710*: Nanoscale Depth Profiling

60 nm Diameter Si Nanowire

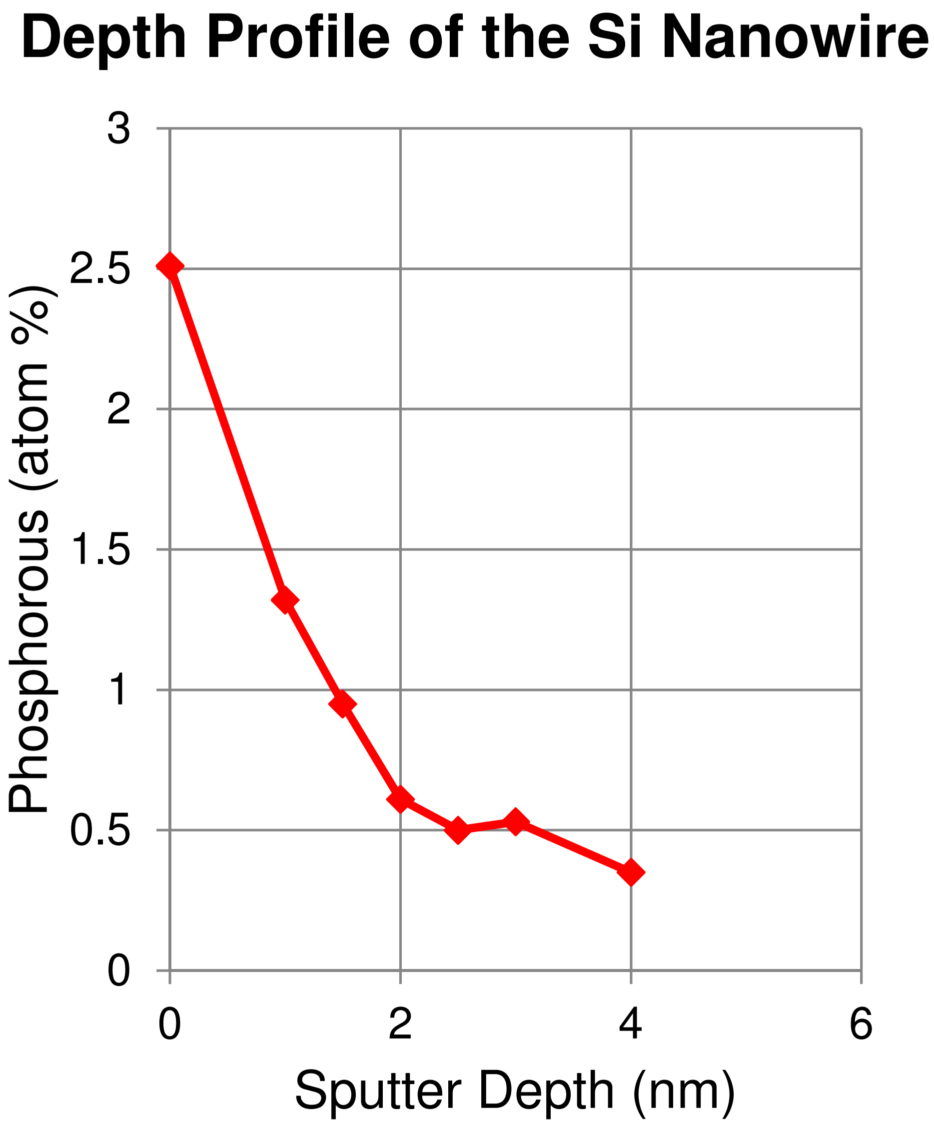


P from the growth gas is detected on the surface of a Si nanowire

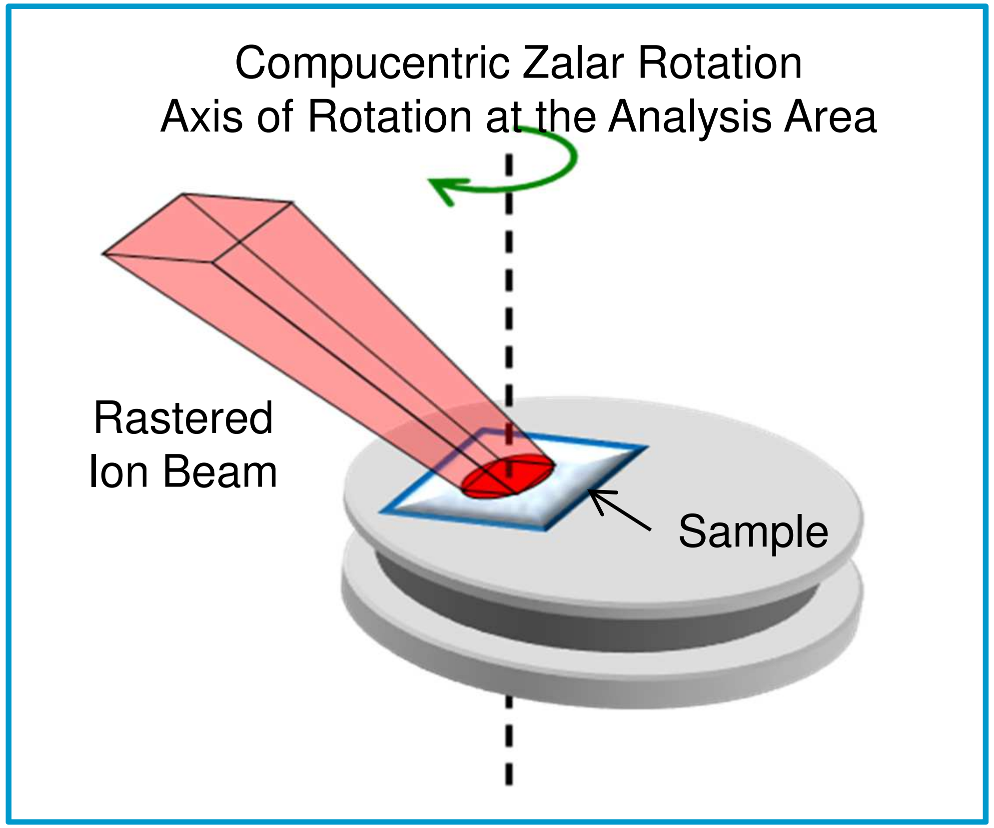


PHI *710*: Nanoscale Depth Profiling

- **500 V Ar sputter depth profiling shows a non-homogeneous radial P distribution**
- **The data suggests Vapor-Solid incorporation of P rather than Vapor-Liquid-Solid P incorporation**



PHI *710*: Compucentric Zalar Rotation



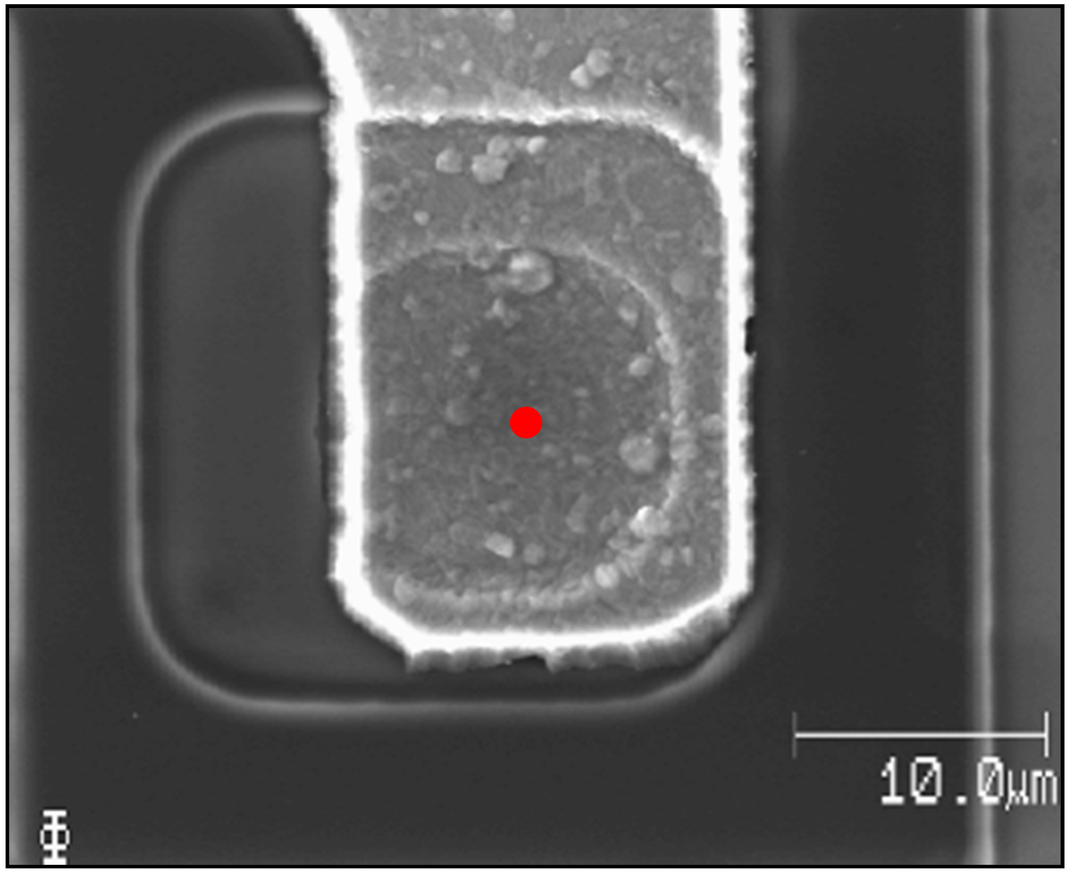
Zalar rotation is used to reduce or eliminate sputtering artifacts that can occur when sputtering at a fixed angle.

Compucentric Zalar rotation depth profiling defines the selected analysis point as the center of rotation. This is accomplished by moving the sample in X and Y while rotating, all under software control.

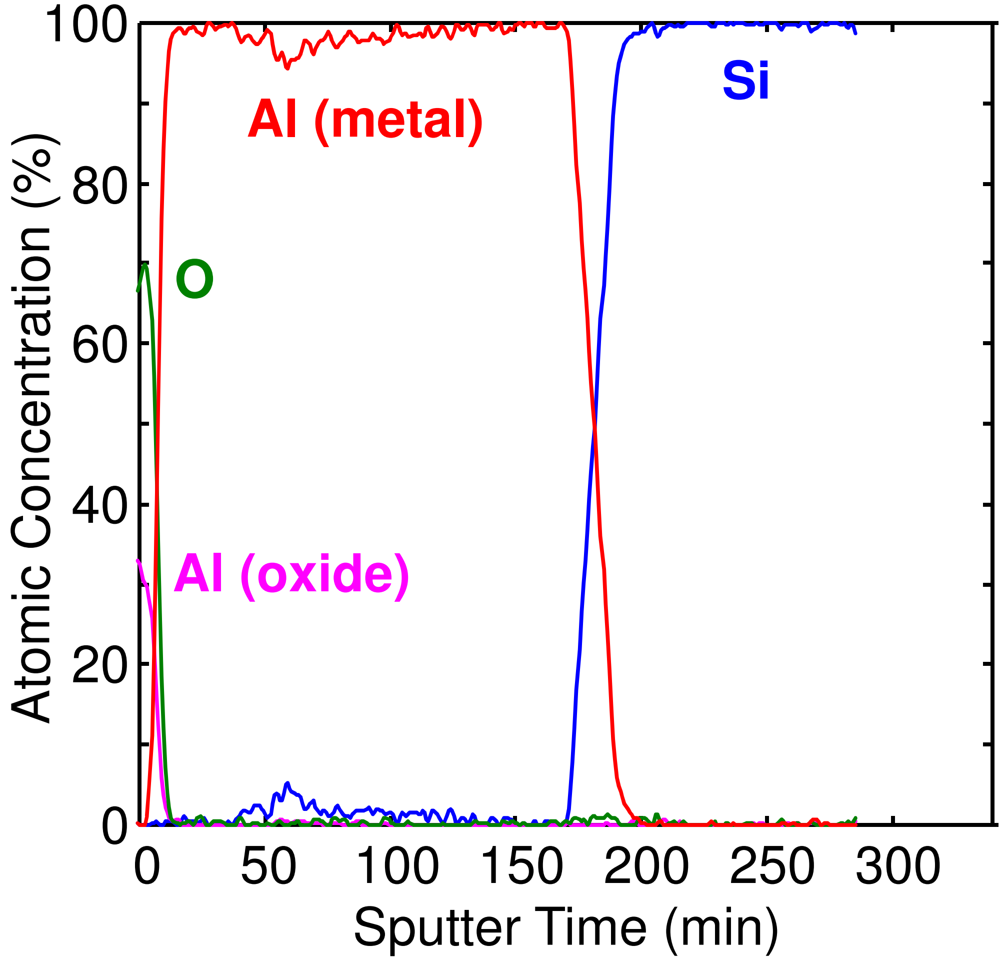
Micro-area Zalar depth profiling is possible on features as small as 10 µm with the *710's* automated sample stage.

PHI *710*: Compucentric Zalar Rotation

Compucentric Zalar Depth Profile of 10 μm Via Contact

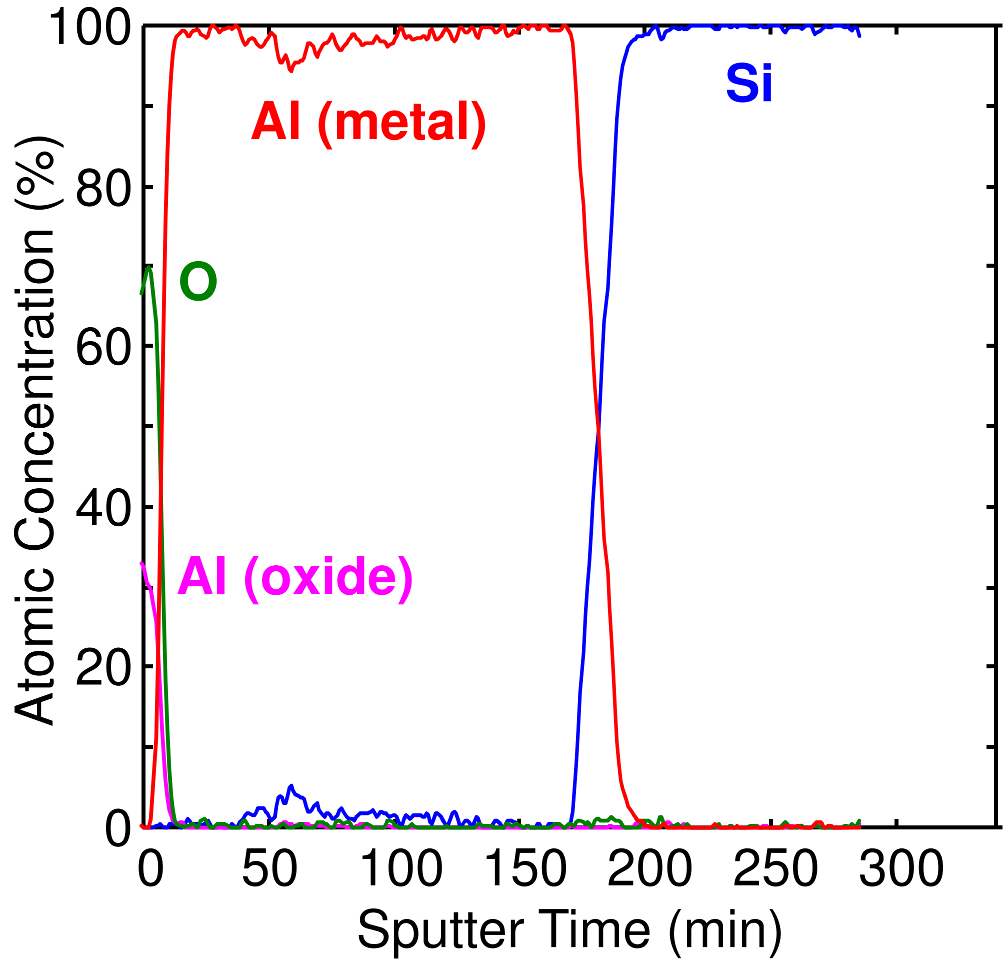


Secondary Electron Image
(Before Sputtering)

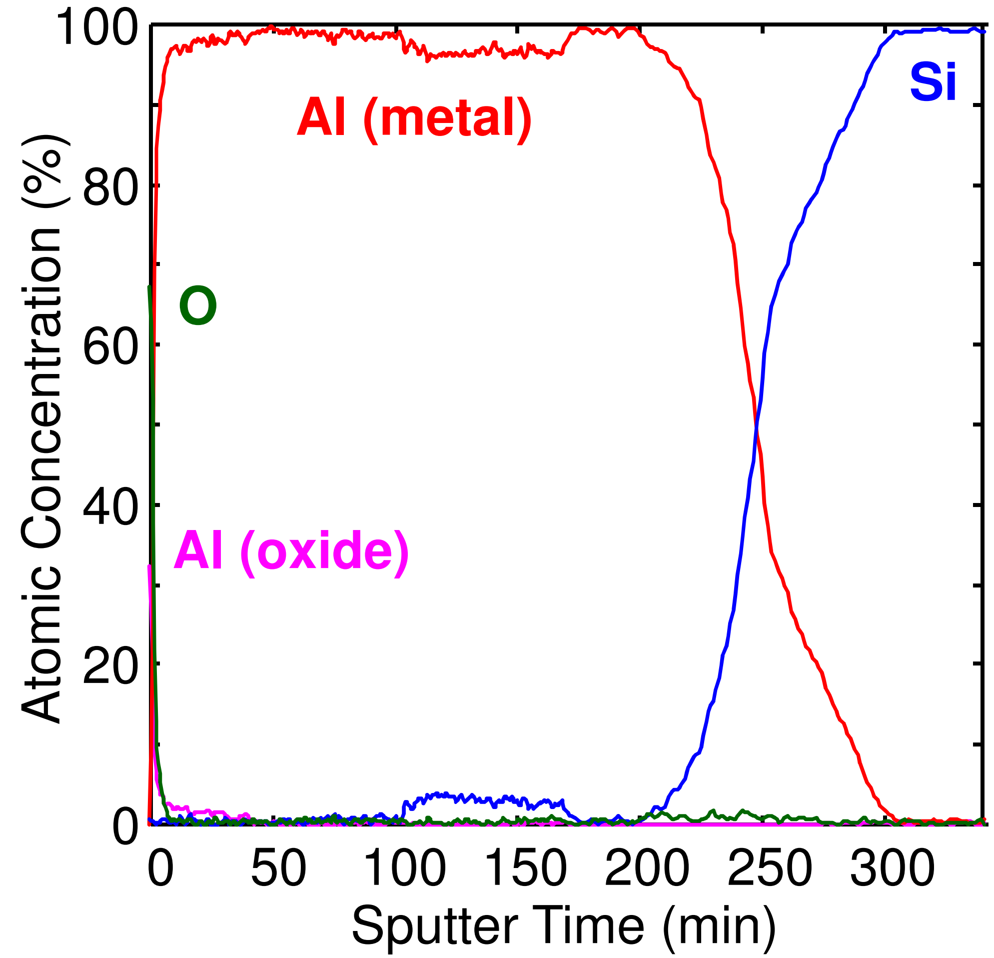


PHI *710*: Compucentric Zalar Rotation

Depth Profile Comparison With and Without Zalar Rotation



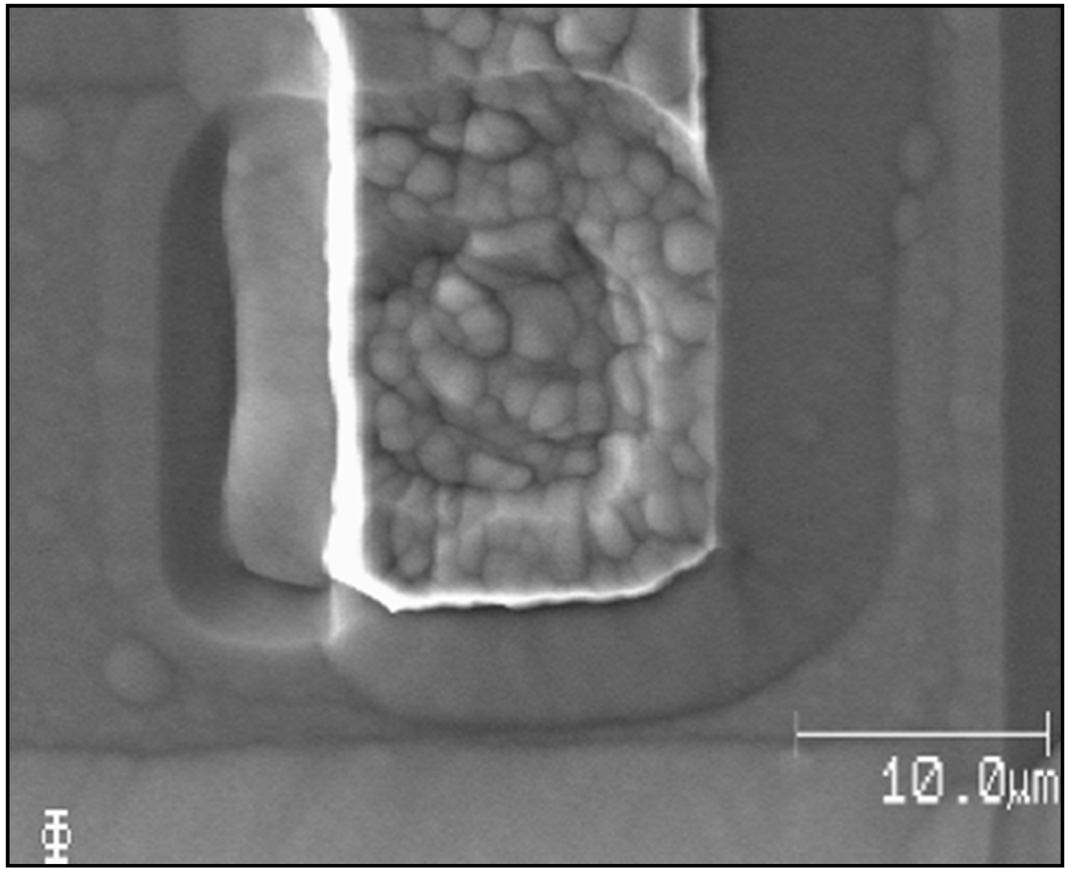
With Zalar Rotation



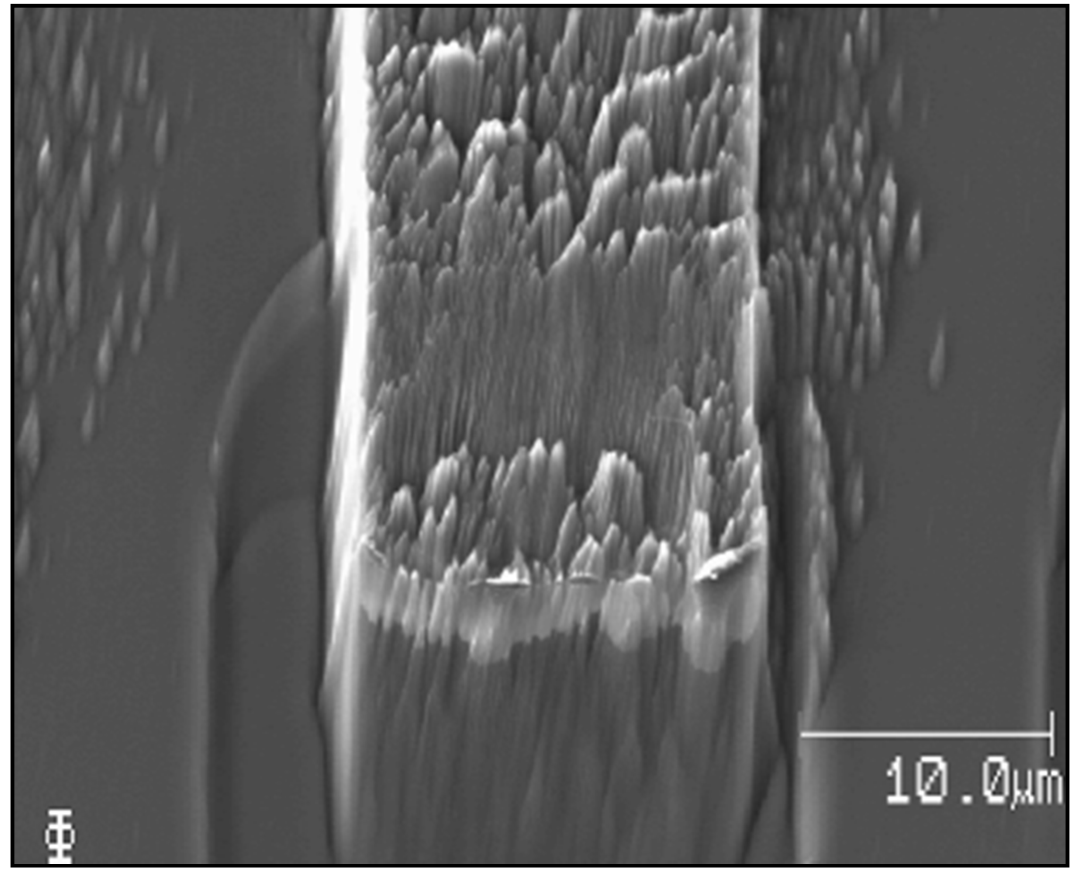
Without Zalar Rotation

PHI *710*: Compucentric Zalar Rotation

SE Images of 10 µm Via Contacts after Depth Profiling

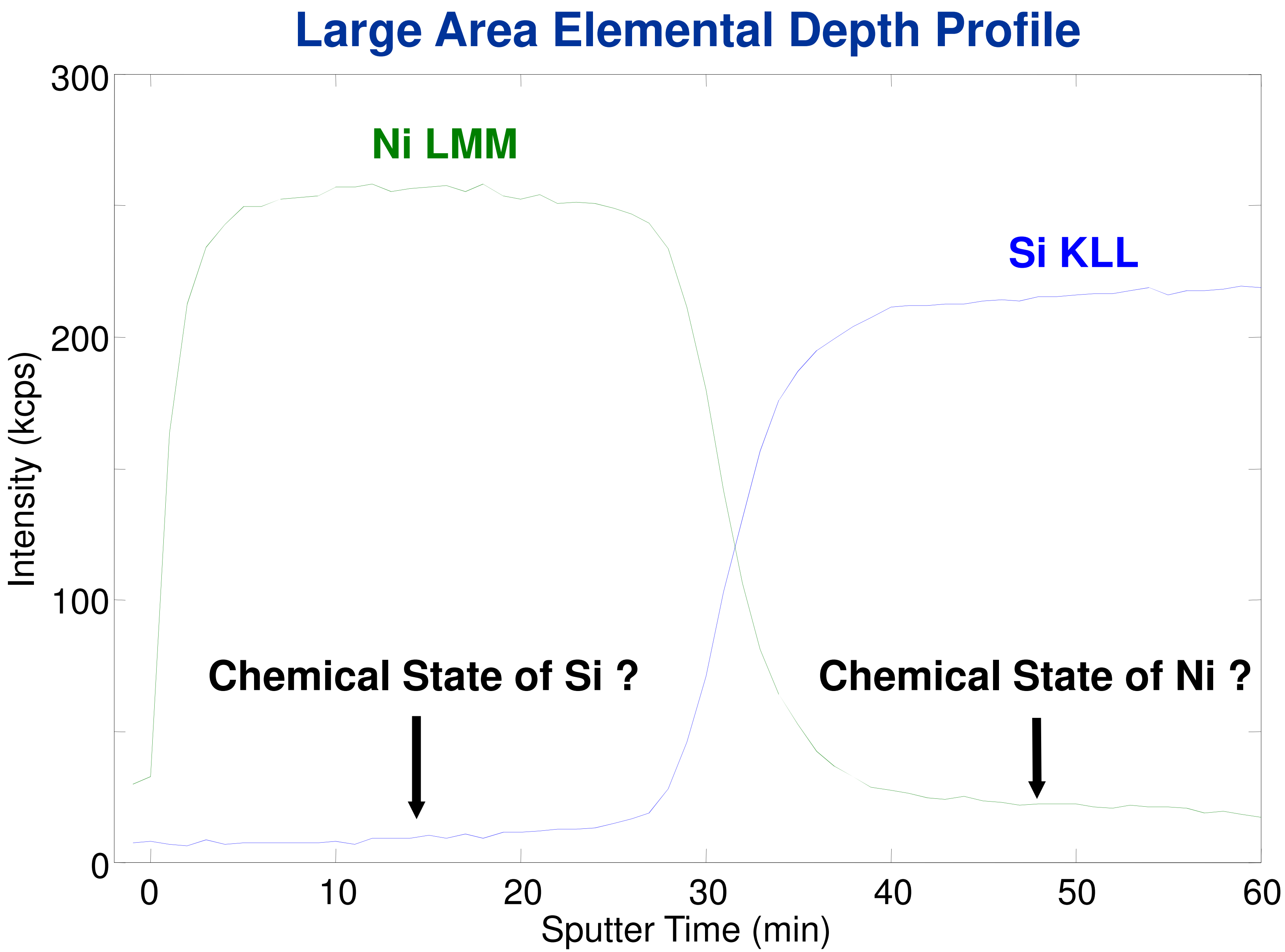


With Rotation



Without Rotation

PHI *710*: Chemical State Depth Profiling



Sample:
Ni deposited on Si substrate
Annealed at 425°C

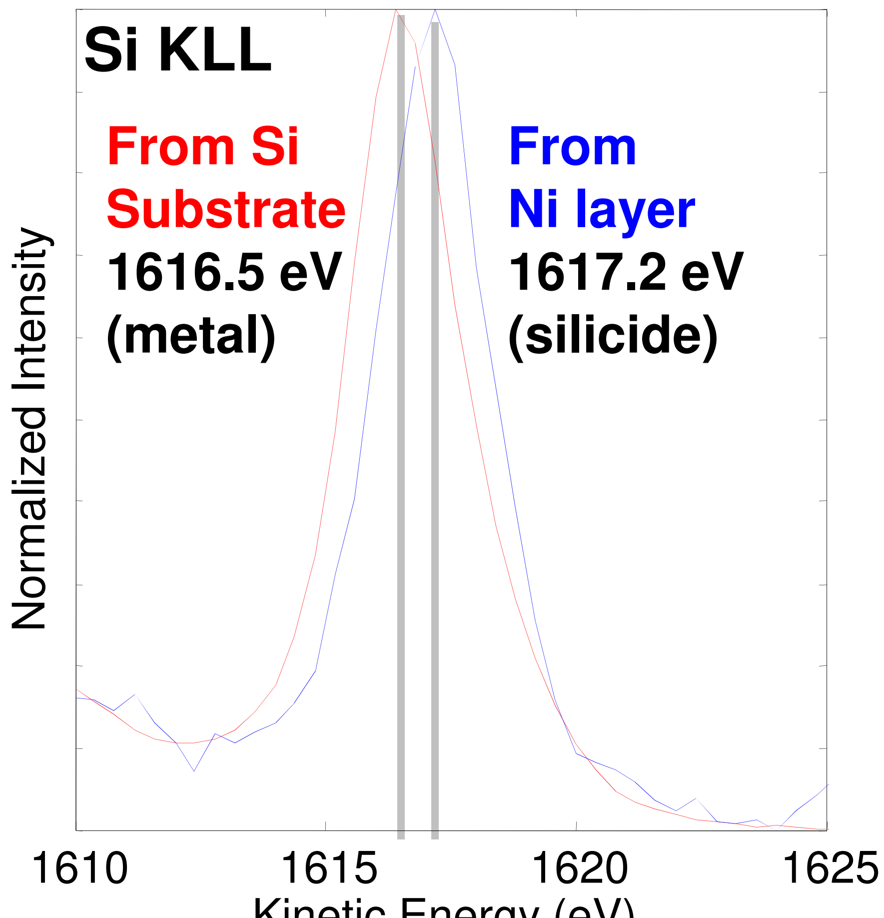
Analysis Conditions:
As Received
0.1% Energy Resolution
10 kV-10 nA
20 µm Area Average

Sputter Conditions:
500 V Argon
1 x 0.5 mm raster

No Zalar Rotation
10° Sample Tilt

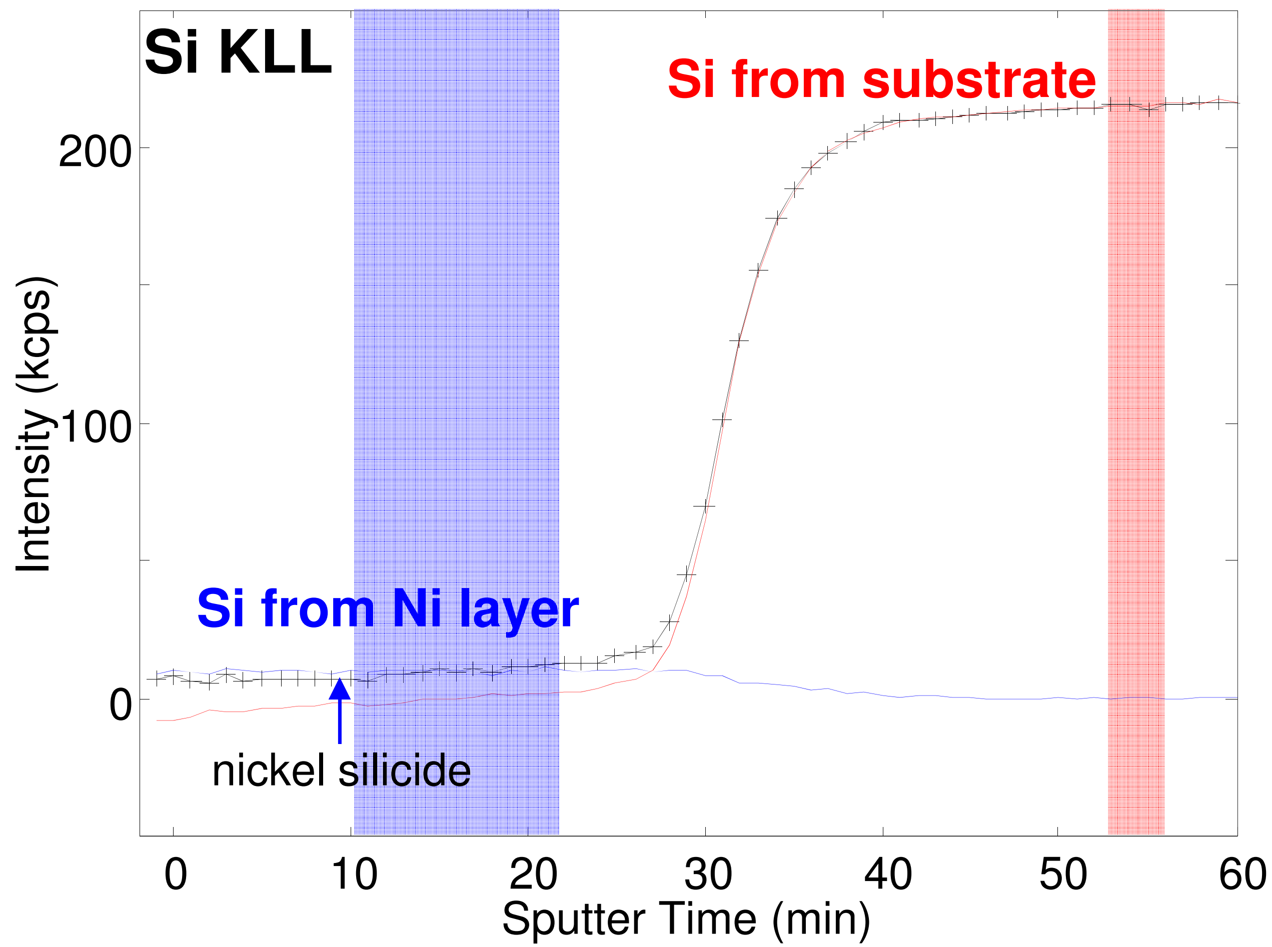
PHI *710*: Chemical State Depth Profiling

Si basis spectra extracted from depth profile data set



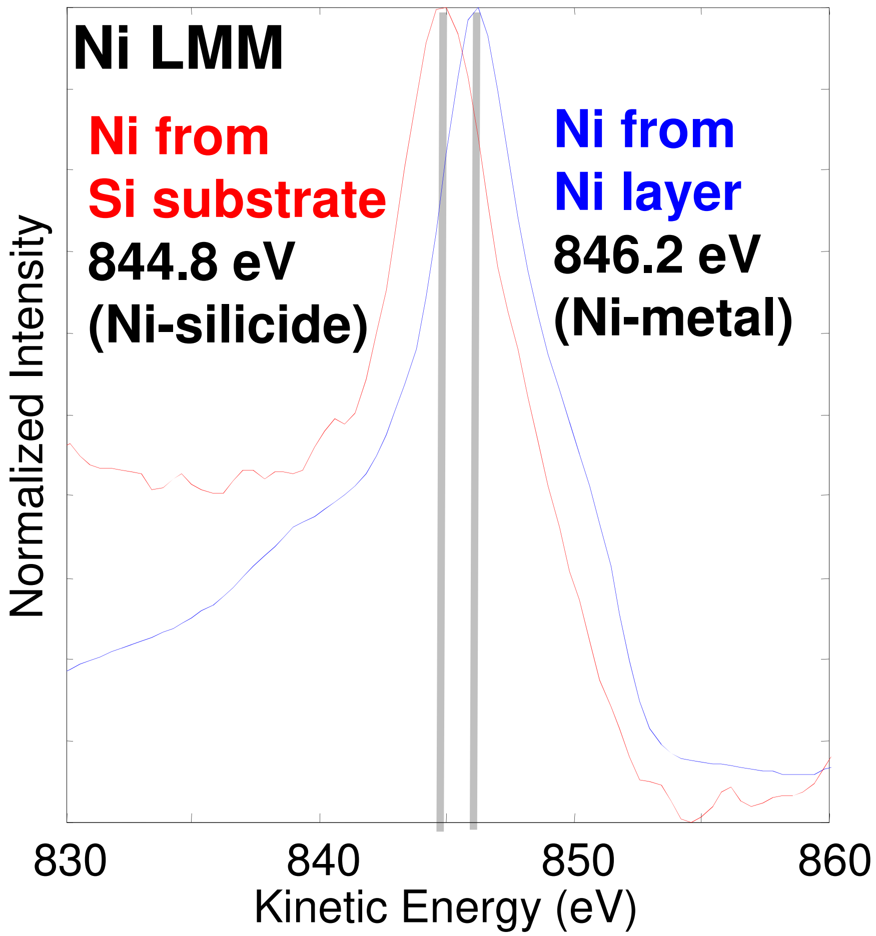
0.1% Energy Resolution

Large area Si chemical state depth profiles created with Linear Least Squares (LLS) fitting



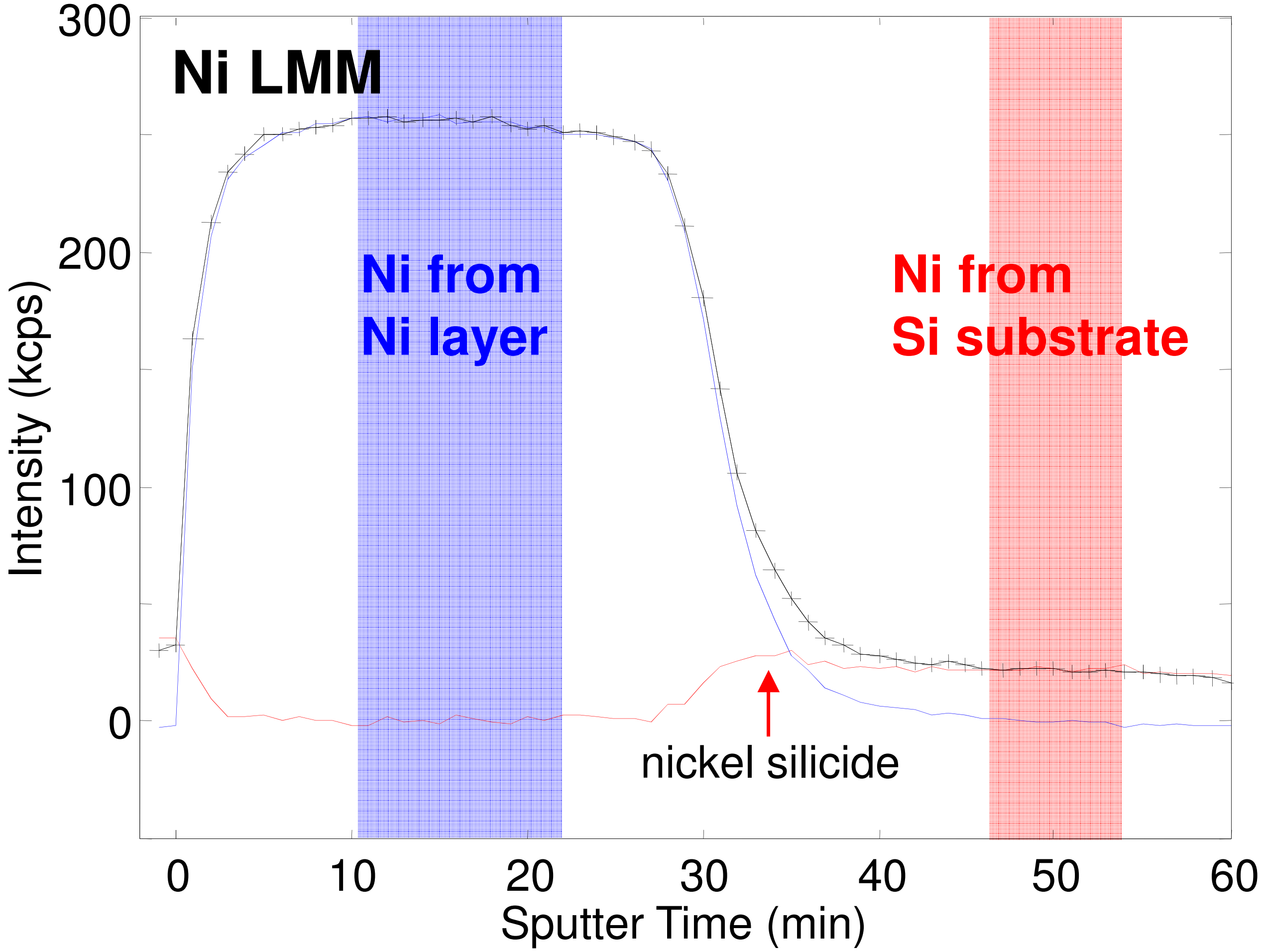
PHI *710*: Chemical State Depth Profiling

Ni basis spectra extracted from depth profile data set



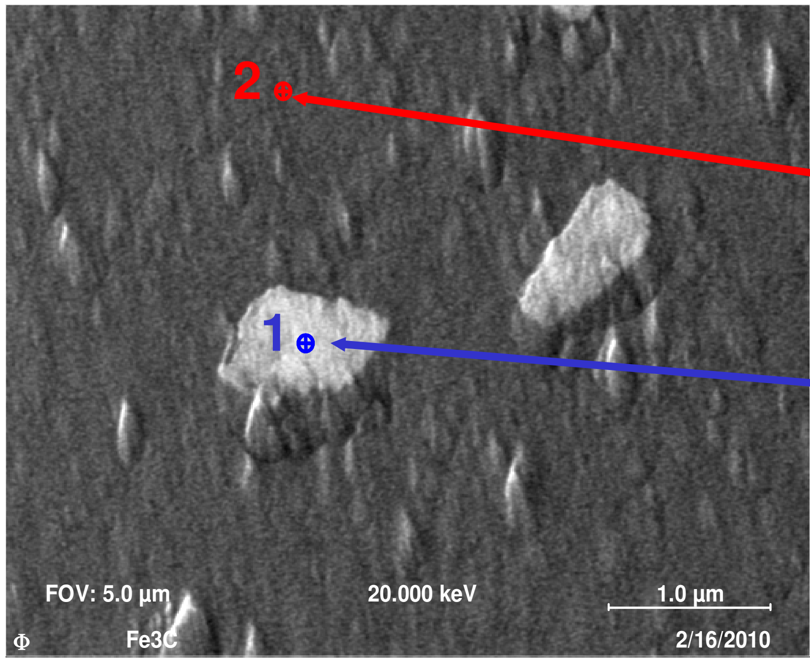
0.1% Energy Resolution

Large area Ni chemical state depth profiles created with LLS fitting



PHI *710*: Chemical State Depth Profiling

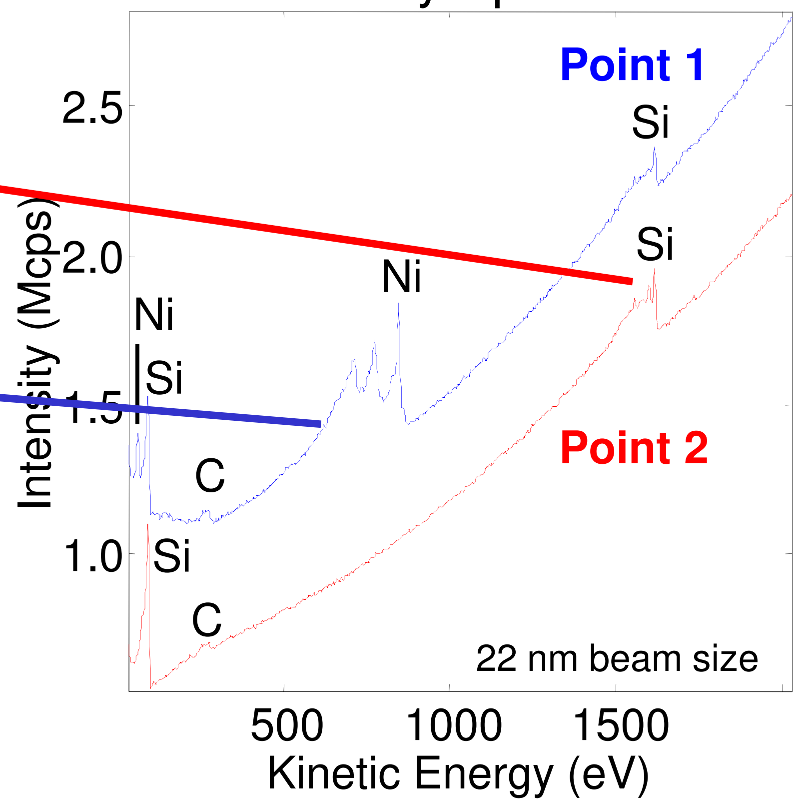
Microstructure observed in SEM image after depth profile



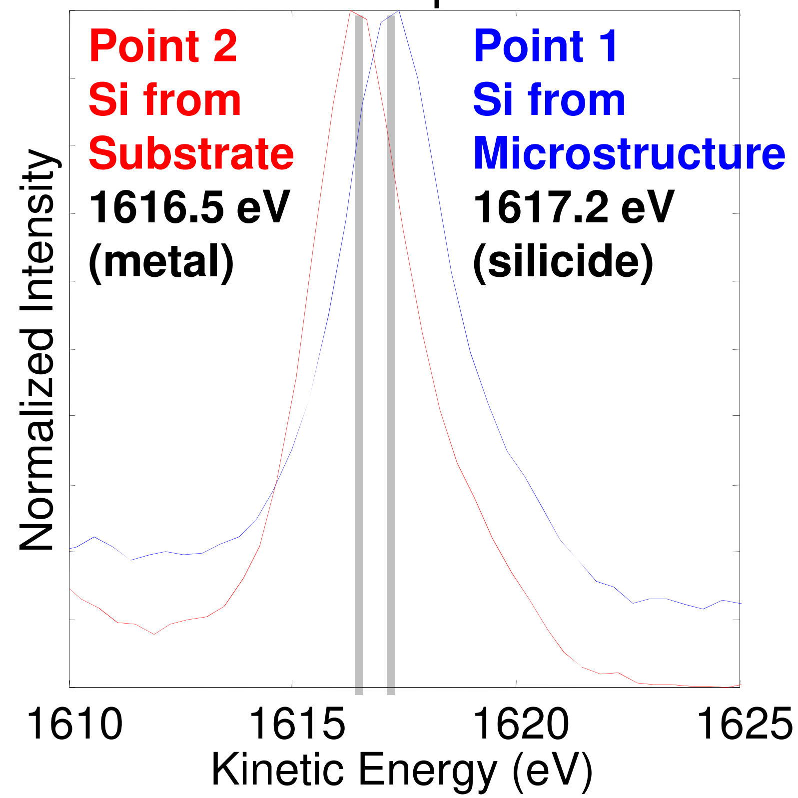
SEM 20kV - 1nA

Nano-area spectra from selected areas showing islands of nickel silicide

Survey Spectra



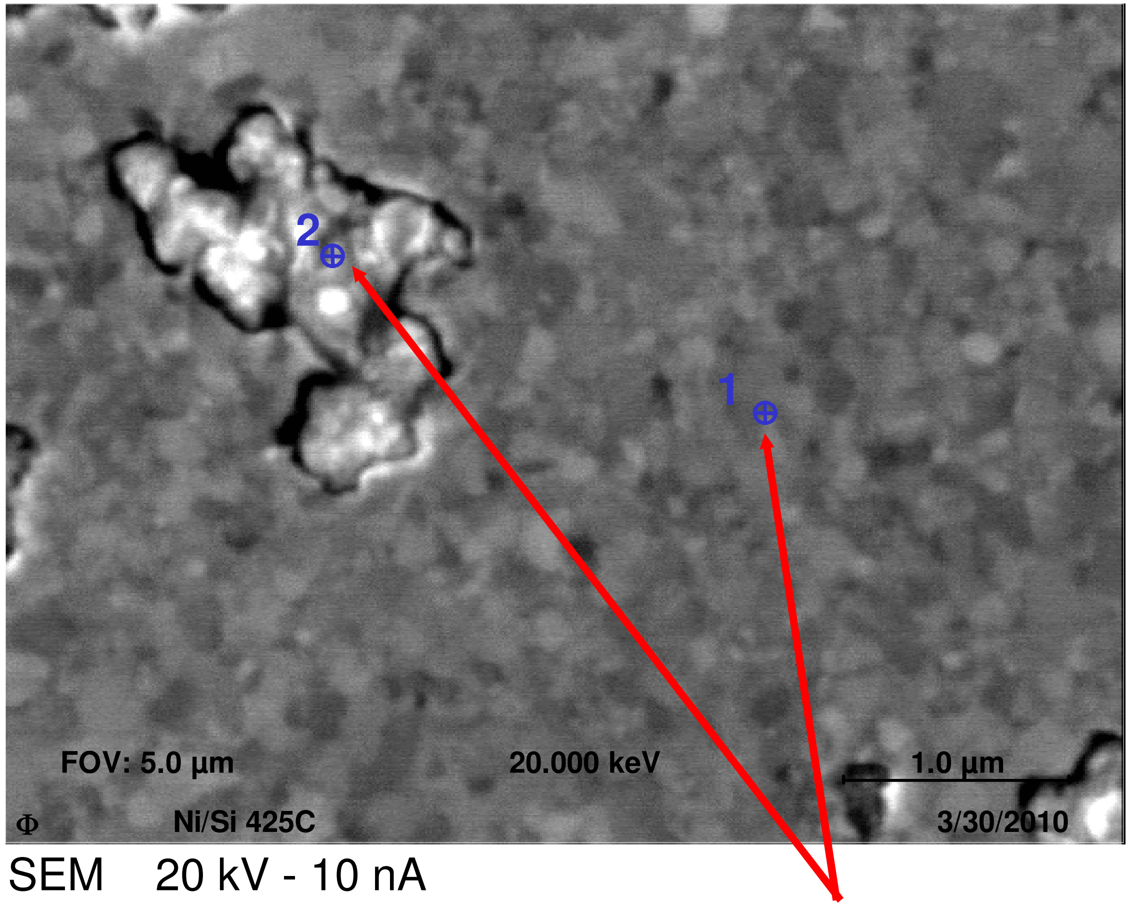
Si KLL Spectra



0.1% Energy Resolution

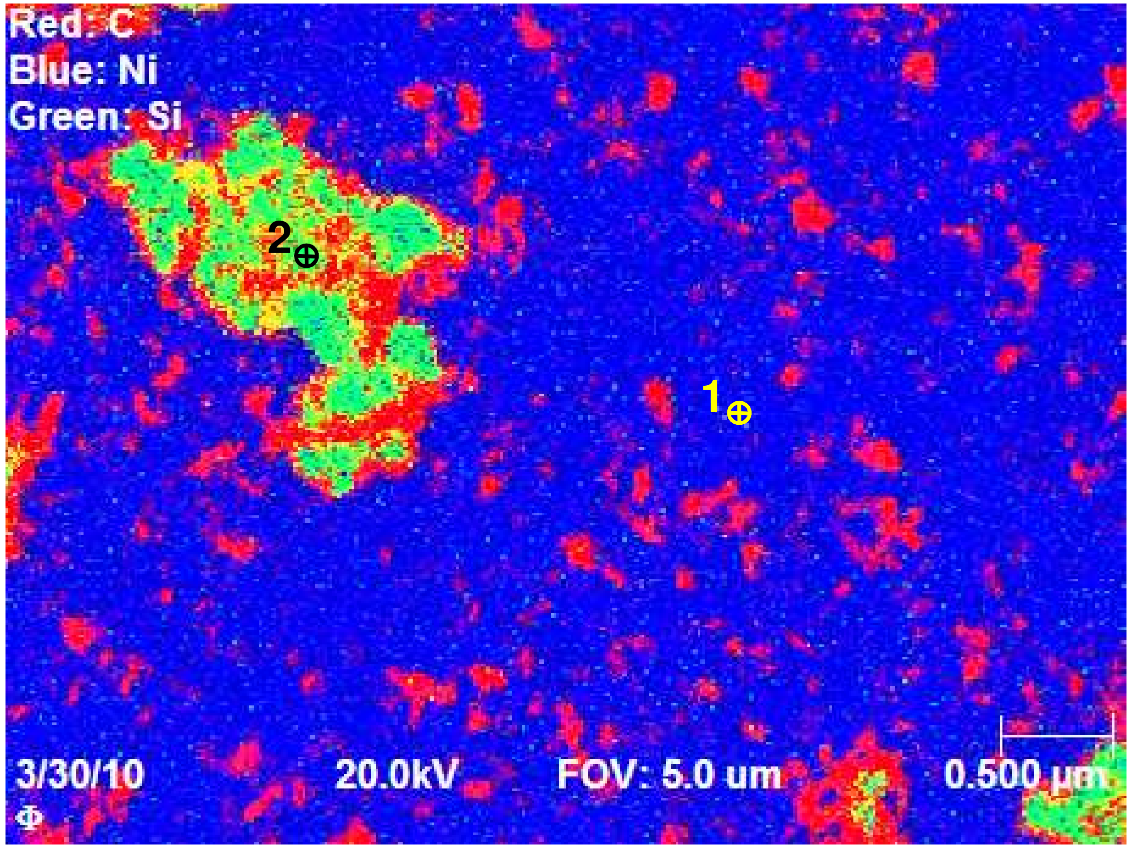
PHI *710*: Chemical State Depth Profiling

New area on Ni/Si sample with 12 nm removed – microstructures visible



SEM 20 kV - 10 nA

Nano-areas selected for analysis

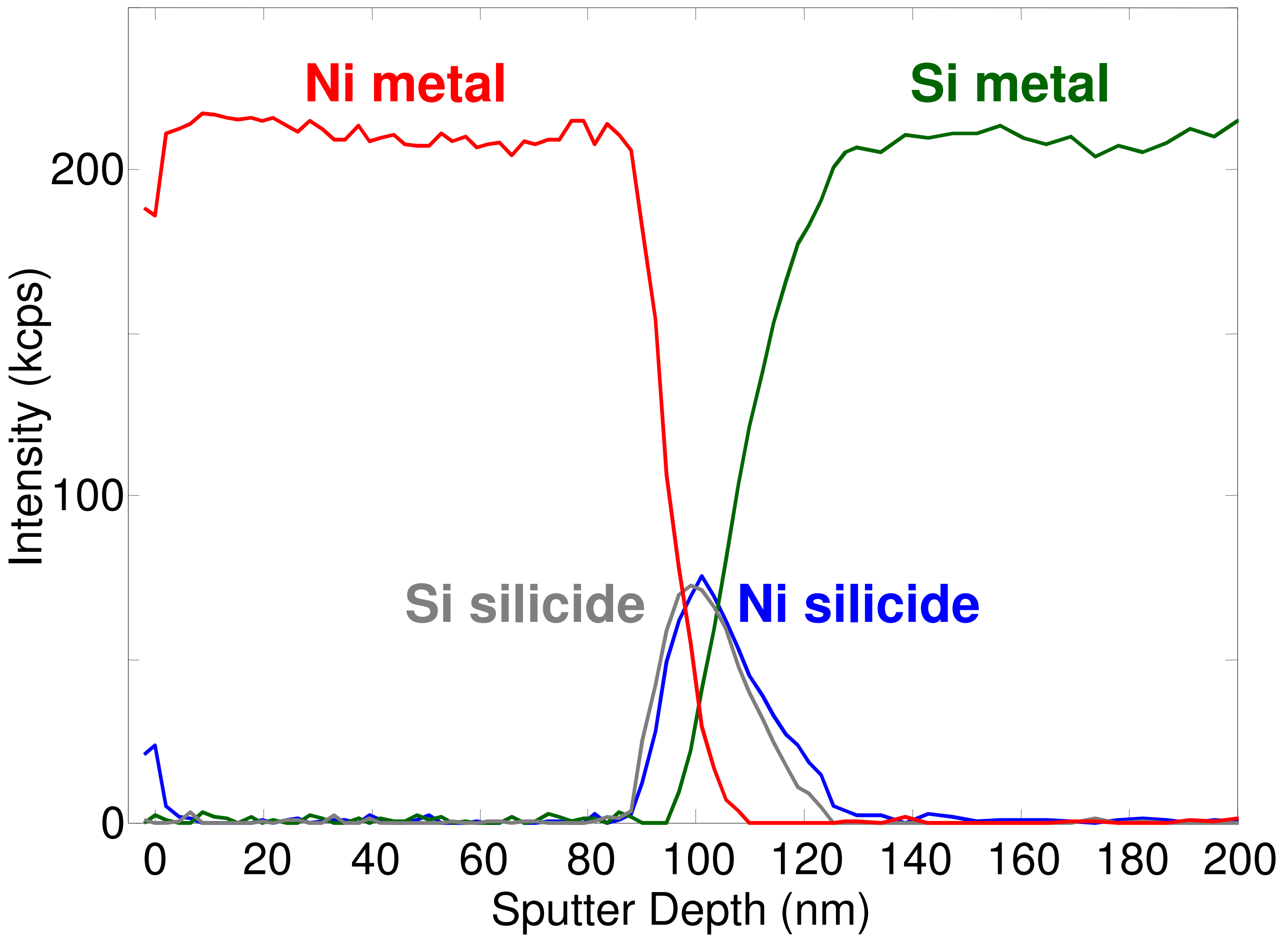


Auger Image Color Overlay 20 kV - 10 nA

Compositional images show presence of silicide microstructures

PHI *710*: Chemical State Depth Profiling

Chemical state depth profile from
point #1 - on film (off microstructure)
Created with LLS fitting in PHI MultiPak



10 kV – 10 nA   22 nm beam size

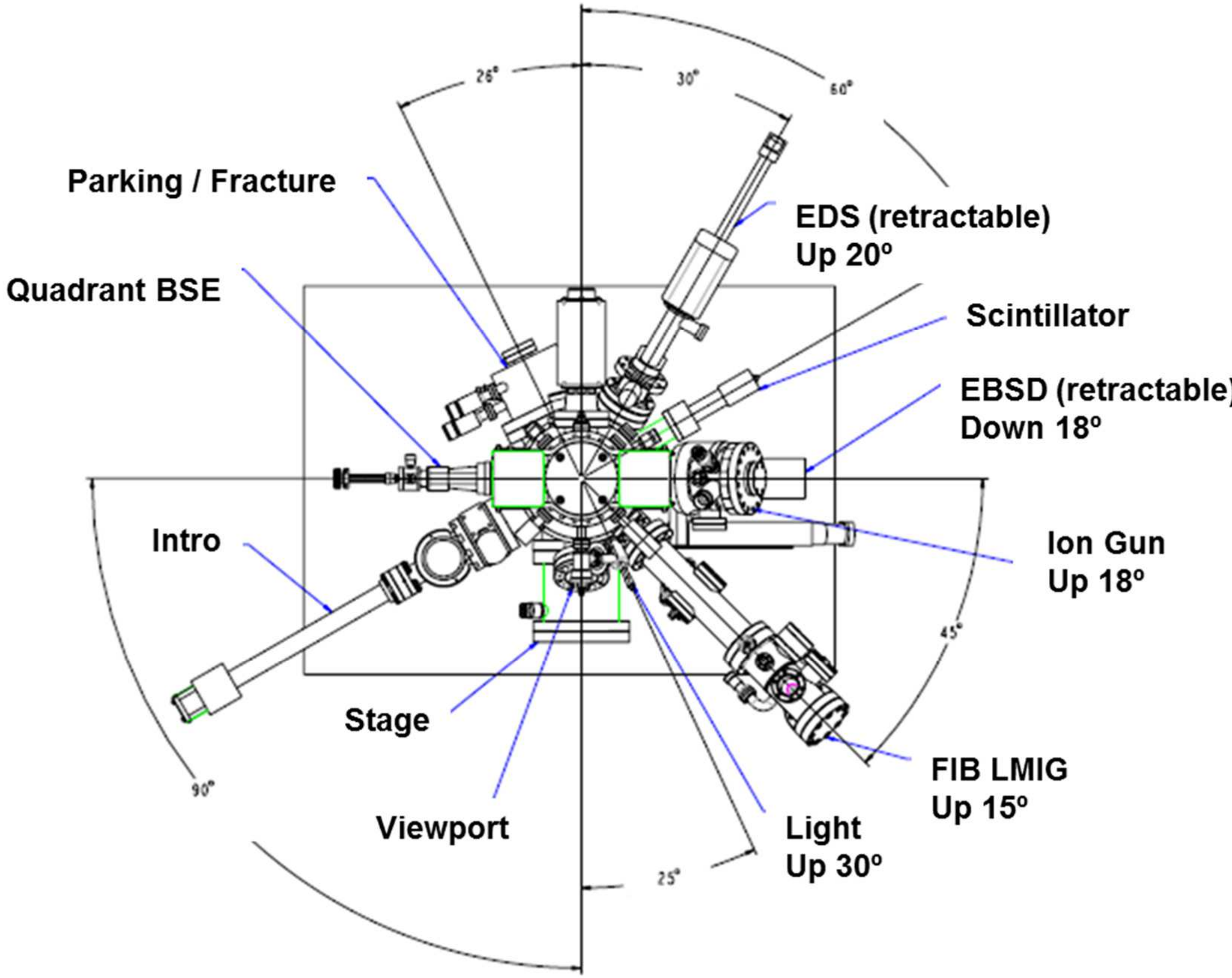
- Ni/Si film chemical state depth profiling summary:
  - The large area depth profiles unknowingly included heterogeneous distributions of nickel silicide microstructures that grew through imperfections in the Ni film
  - The nano-area depth profile on the Ni film (off microstructures) shows nickel silicide only at the nickel / silicon interface

PHI *710* Scanning Auger Nanoprobe

- Multi-Technique options
  - Energy Dispersive Spectroscopy (EDS or EDX)
  - Backscatter Electron Detector (BSE)
  - Electron Backscatter Diffraction (EBSD)
  - Focused Ion Beam (FIB)

The Complete Auger Solution

PHI *710* Chamber Layout for Options



PHI *710* Scanning Auger NanoProbe

Complete Auger Compositional Analysis
for Nanotechnology, Semiconductors,
Advanced Metallurgy and Advanced Materials