Scanning Electron Microscopy (SEM) and Focused Ion Beams (FIB) in Materials Research

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The higher resolution and depth of focus available with the SEM are clearly observed. The SEM also provides a very wide, easily adjustable range of magnifications. For most imaging applications minimal or no sample preparation is required.

The high resolution attainable (very small probe size) is due to very low mass and short wavelength of energetic electrons (0.007nm @30kV). The combination of high brightness sources of electrons and electron optics allows the formation and manipulation of very finely focused electron beams to probe the sample surface for imaging and analysis.


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SEM - Exceptionally High depth of Focus

2,200X original magnification

“This rat’s hair” psilomolene (Mn, Ba oxide natural mineral sample)

100,000X original magnification

Carbon Nanotube
SEM - Extremely Wide Range of Magnifications

12X original magnification

Miniature Sensor Device - Calorimeter

500,000X original magnification

Sputtered Au-Pd on Magnetic Tape
What does the SEM do?

Many Applications:

One of most widely employed microscopy techniques other than optical microscopy.

Surface topography / morphology
Composition analysis
Crystallography (electron diffraction and channeling techniques)
Optical/Electronic properties (cathodoluminescence, EBIC)
Many other more specialized applications

- A Scanning Electron Microscope is an instrument for observing and analyzing the surface microstructure of a bulk sample using a finely focused beam of energetic electrons.
- An electron-optical system is used to form the electron probe which may be scanned across the surface of the sample in a raster pattern.
- Various signals are generated through the interaction of this beam with the sample. These signals may be collected or analyzed with the application of appropriate detectors.
- For imaging, the signal amplitude obtained at each position in the raster pattern may be assembled to form an image.

Animation from A Guide to X-Ray Microanalysis, Oxford Microanalytical Instruments
Sequential Image Acquisition in SEM

- The scan of the electron beam and the digitization of the image pixel value are synchronized with intensity proportional to the collected signal.
- Typically electrons emitted from the sample are detected to assemble the image.
- Magnification is given by the ratio of the length of the line on display device to length scanned on the real sample.

\[ M = \frac{L_{\text{display}}}{L_{\text{specimen}}} \]

Caution: Instrument magnification value is based on reference image size which may vary.


Figure from *Scanning Electron Microscopy and X-Ray Microanalysis*, Joseph I. Goldstein et al. Plenum Press
Generalized Construction of an SEM

- Vacuum System
- Electron Source and Accelerating Voltage
- Electron Lenses (electromagnetic)
  - Condenser Lens(es)
  - Objective Lens
    - Stigmator Coils
- Beam Deflectors (electromagnetic)
  - Alignment
  - Scanning (raster)
- Objective Aperture
- Multi-Axis Specimen Stage
- Detectors
  - Imaging detectors
  - Analytical detectors
- Operating / Display Systems
Four electron beam parameters define the probe:

- Probe diameter – $d_p$
- Probe current – $I_p$
- Probe convergence angle – $\alpha_p$
- Accelerating Voltage – $V_o$

These interdependent parameters must be balanced by the operator to optimize the probe conditions depending on needs:

- Resolution
- Depth of Focus
- Image Quality (S/N ratio)
- Analytical Performance

Electron optical brightness, $\beta$, of the probe is essentially equal to the brightness of the source, thus is a very important electron source parameter.

$$\beta = \frac{\text{current}}{\text{area}\cdot\text{solid angle}} = \frac{i_p}{\left(\frac{\pi d_p^2}{4}\right)\cdot \pi \alpha_p^2} = \frac{4i_p}{\pi^2 d_p^2 \alpha_p^2}.$$
Tungsten Filament

LaB$_6$

**Major Advantages:**
- Very high probe currents obtainable
- Stable probe, especially W
- Less complex vacuum system
- Lowest overall cost / easy to maintain

**Disadvantages:**
- Lower brightness
- Relatively short lifetimes

Schematic of a generalized thermionic electron source for electron microscopy.


http://www.a-p-tech.com/lab6.htm
Electron Sources - Cold Field Emission

Sharp Single Crystal (310) Tungsten Tip

Major Advantages:
• Highest brightness SEM source available
• Very long potential source lifetime – many years

Disadvantages:
• Lowest maximum probe current
• Poor short and long term probe current stability
• Requires ultra-high vacuum in gun area
• Cost (initial)
Electron Sources - Thermal-Field (Schottky) Emission

Sharp Single Crystal (100) Tungsten Tip with ZrO₂ Film

Major Advantages:
- Very high brightness source
- High probe currents obtainable (few hundred nA)
- Long potential source lifetime (few years)
- Excellent short and long term stability

Disadvantages:
- Requires ultra-high vacuum in gun area
- Source heating is continuous, 24/7 (finite life)
- Cost (initial and maintenance)

From Rooks and McCord, SPIE Handbook of Microlithography

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# Comparison of Electron Sources

<table>
<thead>
<tr>
<th>Effective Source Size (nm)</th>
<th>TUNGSTEN</th>
<th>LaB$_6$</th>
<th>SCHOTTKY</th>
<th>COLD FIELD</th>
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<tbody>
<tr>
<td></td>
<td>15,000</td>
<td>5000</td>
<td>15</td>
<td>3</td>
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<table>
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<tr>
<th>Brightness (A/cm$^2$SR)</th>
<th>10$^5$-10$^6$</th>
<th>10$^6$-10$^7$</th>
<th>$&gt;$10$^8$</th>
<th>10$^9$</th>
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<th>Energy Spread (eV)</th>
<th>1.0</th>
<th>1.0</th>
<th>0.5 - 1.0</th>
<th>0.3</th>
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<th>Emission Current</th>
<th>&lt;150µA</th>
<th>&lt;100µA</th>
<th>&lt;150 µA</th>
<th>&lt;20µA</th>
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<tr>
<th>Maximum Probe Current (SEM)</th>
<th>1000+ nA</th>
<th>&lt;1000 nA</th>
<th>10-500 nA</th>
<th>&lt;2.0 nA</th>
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<tr>
<th>SEM resolution (typical specs range)</th>
<th>3.0 - 4.0 nm</th>
<th>2.0 - 3.0 nm</th>
<th>&lt;1.0 – 2.0 nm</th>
<th>&lt;1.0 - 1.5 nm</th>
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<tr>
<th>Probe Current Stability (%/hour)</th>
<th>&lt;1</th>
<th>&lt;2</th>
<th>&lt;1</th>
<th>&gt;10</th>
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<th>Operating Temperature (K)</th>
<th>2800</th>
<th>1850</th>
<th>1800</th>
<th>300</th>
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<th>Operating Vacuum (Pa)</th>
<th>&lt;10$^{-2}$</th>
<th>&lt;10$^{-5}$</th>
<th>&lt;10$^{-7}$</th>
<th>&lt;10$^{-7}$</th>
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<tr>
<th>Typical Service Life</th>
<th>100 hrs</th>
<th>1000 hrs</th>
<th>&gt;&gt;1 year</th>
<th>&gt;&gt;&gt;1 year</th>
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<th>Cost</th>
<th>$</th>
<th>$$</th>
<th>$$$</th>
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**Magnetic Lens**
- Electromagnet coil
- Precision machined soft iron “pole piece”

**Limiting Parameters**
- Spherical Aberration
- Chromatic Aberration
- Astigmatism
- Aperture diffraction

Spherical Aberration

Aperture Diffraction causes a fundamental limit to the achievable probe size.

Optimum aperture angle determined by combined effect of spherical aberration and aperture diffraction.

Chromatic Aberration

Astigmatism is caused by imperfections in the lens or other interference. It can be corrected using additional elements called stigmators contained inside the objective lens.

Magnetostatic quadrupole lens is basis of a stigmator

Octupole lens stigmator


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Function of Condenser Lens(es)

De-magnify the beam extracted from the source to enable a small spot to be obtained on the sample. Multiple lenses may be used in the condenser lens system.

**Weak Lens**
- Longer focal length, Small $\alpha_1$, Larger $d_1$
- More beam accepted into objective aperture
- Higher probe current at specimen
- Larger focal spot at specimen
- Lower resolution
- Higher Signal Levels

**Strong Lens**
- Short focal length, Larger $\alpha_1$, Smaller $d_1$
- Less beam accepted into objective aperture
- Lower probe current at specimen
- Smaller focal spot at specimen
- Higher Resolution
- Lower Signal Levels

\[ \frac{1}{u} + \frac{1}{v} = \frac{1}{f} ; \quad M = \frac{v}{u} \]
Objective Lens / Working Distance

- **Focus** the electron beam on the specimen with minimal lens aberrations, astigmatism is corrected

- Short Focal Lengths ($W_1$) 
  -> smaller $d_2$, larger $\alpha_2$ -> better resolution, poorer depth of focus

- Longer Focal Lengths ($W_2$) 
  -> larger $d_2$, smaller $\alpha_2$ -> better depth of focus, poorer resolution

- Smaller Apertures 
  -> smaller $d_2$, smaller $\alpha_2$ -> better resolution & better depth of focus, limited by aperture diffraction or S/N

Secondary and Backscattered Electrons

Secondary electrons are low energy electrons (<50eV) ejected from the specimen atoms by the energetic primary beam.

Backscattered electrons are primary beam electrons scattered back out of the sample. There is a purely elastic peak and a continuum of BSE that have lost energy.
Monte-Carlo simulations of electron scattering

PMMA @ 20kV
Everhart et.al. (1972)

- Determine effective lateral or depth resolution for a particular signal in a defined sample.
- Simulate X-ray generation / X-ray spectra in a defined sample.
- Simulate image contrast/images.

Simulations are very useful for testing if a measurement is possible or interpreting results.

Animation from A Guide to X-Ray Microanalysis, Oxford Microanalytical Instruments

Monte Carlo Calculations, CASINO
Effect of Beam Energy on SE Imaging

15 kV
Au particles and plates on filter paper

5.0 kV

3.0 kV

1.0 kV

Sample courtesy Tom Bassett (P. Kenis group)
Electron Beam / Specimen Interactions

**Incident Beam** $I_b$, $E = 0.5-30$ keV, $\alpha = 0.2-1^\circ$

- **Secondary electrons (SE)** $\delta I_b$
- **Backscattered electrons (BSE)** $\eta I_b$
- **Auger electrons**
- **Bremsstrahlung X-rays**
- **Characteristic X-rays**
- **UV/Visible/IR Light**
- **CL**
- **EDS/WDS**

**Imaging**

**EDS/WDS Imaging**

**Specimen Current** $I_{sc, EBIC}$

$$I_{sc} = I_b - \eta I_b - \delta I_b = I_b \left(1-(\eta+\delta)\right)$$

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“Secondary Electron Detector” / Imaging

- Faraday Cage (collector) is usually biased a few hundred volts positive (for collection efficiency).
- Scintillator is biased +10kV to accelerate electrons to sufficient energy to efficiently excite scintillating material.
- Amplified output level is directly used to set brightness (offset) and contrast (gain) in corresponding pixel in image.

Contrast results from **topographical dependence** of the secondary electron yield, other detected electrons (BSE), edge effects, and geometrical collection effects.

**Electrodeposited Gold Dendritic Structure**
Secondary Electron Yield

SE yield is strongly dependent with (local) angle of incidence of the beam with the sample surface.

Geometrically the volume of material from which secondary electrons escape increases proportionally with the secant of the tilt angle.

Note: There is also some material (atomic number) dependence of SE yield.
Edge Brightening Effect on Contrast

“Excess” SE’s generated when interaction volume intersects an edge.

30 kV Beam

1 kV Beam

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Sources of Electrons Detected By E-T Detector

Geometrical Effects
- Direct BSE’s need “line of sight” trajectory
- SE detection efficiency may vary with topography and sample surface / detector geometry

Backscattered electrons are also directly and indirectly detected (image is not pure SE)

λ - mean free path <10nm
Analogy to Oblique and Diffuse Optical Illumination

These dependencies on electron yield and detection in combination with the high depth of focus of the SEM, gives the familiar SEM images with a good perceptive sense of surface topography.
Through The Lens Detector

Highest Resolution SEM’s use a semi-immersion type objective lens to improve resolution, especially at low beam energies and short WD.

Low voltage performance can be further improved along with extremely low “landing energies” made accessible by biasing sample ($V_{\text{landing}} = V_{\text{beam}} - V_{\text{bias}}$).

Arrangement of biased electrodes and BSE conversion plates to provide selection or filtering of detected energy range:
- Detect only SE’s to only Low Angle BSE’s to various mixtures.

- LOSS of Oblique Illumination effect

In-chamber E-T detector can still detect direct and indirect BSE’s → signal mixing with through-the-lens-detector

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Backscattered Electron Detectors and Yield

- Solid State (often 4 quadrant) Backscattered Electron detector placed annularly to bottom of objective lens (electron sensitive large area photodiode).
- Scintillator/PMT type detectors are also available.
- **Composition image** – electronically sum signal from all 4 quadrants.
- BSE **topographic images** – differencing various detector quadrants.
- Also can provide electron channeling (crystallographic orientation) contrast in suitable samples.

Backscattered Compositional Contrast

• Compositional mode imaging most useful on multi-phase samples
• Sensitivity can be as low as 0.01 average Z differences
• Flat-polished specimens preferable for best sensitivity in compositional mode

La, Mn, Ca, Al oxides - mixed phases
• A solution to specimen charging of un-coated non-conductive samples is to introduce a gas (air, etc.) into the specimen chamber.

• The high energy electrons ionize the gas, thus positive ions are available to dynamically neutralize any charge on the sample.

• Available in both Schottky FEG and Thermionic (Tungsten) instruments.

Uncoated Dysprosium Niobium Oxide Ceramic

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Stereo-microscopy (Qualitative/Quantitative)

Qualitative (Visual)
- Anaglyph (shown here in freeware software)
- Other Methods (same as in movies, TV, scientific visualization Labs)
- Stereo Image pair is very easy to obtain and make anaglyph (essentially any SEM, image mode)

Anaglyph Freeware: http://www.stereoeye.jp/software/index_e.html

Quantitative Height Maps/Profiles
Geometrical assessment of parallax shifts in eucentrically tilted image pair, triplet, etc. to reconstruct a height map.

Manually – possible for limited number of points
Automated – software*
* now several commercial software solutions available

For a review and assessment of the technique see:
• Energy-Dispersive Spectroscopy (EDS) – solid state detector simultaneously measures all energies of X-ray photons.

• Wavelength Dispersive Spectroscopy (WDS) – sequentially measures intensity vs X-ray wavelength (energy). Superior energy resolution and detection limits (P/B ratio).

• Electron Backscattered Diffraction (EBSD) – acquires electron diffraction information from surface of highly tilted bulk sample with lateral resolution of low 10’s of nm.

• Cathodoluminescence (CL) – optical emission spectrometer and imaging system for 300-1,700nm. Liquid He cooled stage module.

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Characteristic X-ray Generation

- A scattering event kicks out an electron from K, L, M, or N shell of an atom in the specimen.
- An electron from an outer shell falls to fill in the vacancy.
- Energy difference results in release of an X-ray of characteristic energy/wavelength or an Auger electron.

Mechanism of X-ray Energy Determination

- X-ray loses energy through inelastic scattering events creating electron / hole pairs
- High voltage bias keeps generated pairs from re-combining
- Charge sensitive amplifier “counts” pairs generated by X-ray
- Spectrometer calibration effectively multiplies by energy/pair (3.8 eV) to determine X-ray energy


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Energy Dispersive X-ray Detector: Si(Li)

Other technologies now available: Si drift (SDD) and microcalorimeter detectors


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X-ray EDS Microanalysis in the SEM

- Fast Parallel Detection
- Qualitative elemental analysis
  - From Beryllium up on periodic table
  - Sensitivities to <0.1 wt.% depending on matrix and composition
- Quantitative analysis
  - Many requirements / Limitations
- Digital elemental distribution imaging and line-scans, full spectrum imaging
- Analysis of small volumes, from order of \( \mu \text{m}^3 \) to \(< < 1 \ \mu \text{m}^3 \) depending on accelerating voltage, element analyzed, and matrix
- \(~130 \text{ eV Mn K-alpha resolution typical for Si(Li) detector\)
A full X-ray spectrum collected for each pixel. X-ray elemental maps, phase maps, spectra, and quantitative analysis extracted from full spectrum images.

Cumulative Spectra and Quantitative Analysis for each extracted phase (ex. Phase 1)

<table>
<thead>
<tr>
<th>Element</th>
<th>Line</th>
<th>Weight %</th>
<th>Weight % Error</th>
</tr>
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<tbody>
<tr>
<td>O</td>
<td>K</td>
<td>22.13</td>
<td>---</td>
</tr>
<tr>
<td>Al</td>
<td>K</td>
<td>3.81</td>
<td>+/- 0.02</td>
</tr>
<tr>
<td>Ca</td>
<td>K</td>
<td>10.26</td>
<td>+/- 0.04</td>
</tr>
<tr>
<td>Mn</td>
<td>K</td>
<td>30.57</td>
<td>+/- 0.07</td>
</tr>
<tr>
<td>La</td>
<td>L</td>
<td>33.23</td>
<td>+/- 0.09</td>
</tr>
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</table>

Thermo Instr.: Noran System Six
Hybrid X-ray optics containing both a polycapillary optics (up to ~12 keV) and a paraboloidal grazing incidence optics (up to ~ 2.3 keV).

Comparison of EDS (SiLi) to Parallel Beam WDS (Thermo Instruments MaxRay)

Expl.: Identification of sub-micron W Particle on Si
Electron Backscattered Diffraction in the SEM (EBSD)

Microscope

EBSP camera/detector

Electron beam

Phosphor Screen

Sample

Tilt axis

Silicon

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EBSD of GaAs Wafer
Microtexture in Al-Li Alloys for Future Aerospace Applications

Investigation of crystallographic aspects grain morphology and delaminations.

True Grain ID, Size and Shape Determination

Complimentary to XRD texture determination
- gives **local texture** & **misorientations**
Phase Discrimination by EBSD

Forward Scatter image
Z-projected Inverse Pole Figure Image
Phase Image (Stainless Steel)
Red = FCC iron
Blue = BCC iron
Cathodoluminescence (CL)

Emission of light from a material during irradiation by an energetic beam of electrons.

Collection of emitted light
Paraboloidal mirror placed immediately above sample (sample surface at focal point)

Wavelength (nm)
Collection optic in position between OL lens and sample

Aperture for electron beam
Cathodoluminescence Imaging and Spectroscopy

- **Optical spectroscopy from 300 to 1700 nm**
- **Panchromatic and monochromatic imaging** (spatial resolution - 0.1 to 1 micrometer)
- **Parallel Spectroscopy** (CCD) and full spectrum imaging
- **Enhanced spectroscopy and/or imaging with cooled samples** (liq. He)
- **Applications include:**
  - Semiconductor bulk materials
  - Semiconductor epitaxial layers
  - Quantum wells, dots, wires
  - Opto-electronic materials
  - Phosphors
  - Diamond and diamond films
  - Ceramics
  - Geological materials
  - Biological applications
  - Plasmonic Structures
Defects (dislocations) are observed as points or lines of reduced emission; act as e-h pair traps with non-radiative recombination.
Monochromatic CL imaging of GaN Pyramids

The strongest yellow emission comes from the apices of the elongated hexagonal structure.

Results courtesy of Xiuling Li, Paul W. Bohn, and J. J. Coleman, UIUC
Summary: Scanning Electron Microscopy

- Remarkable depth of focus
- Imaging from millimeters to a sub-nanometer
- Chemical composition with 0.1-1 μm resolution
- Crystallography using electron EBSD
- Optical properties on a micrometer scale (via CL)
The FEI Dual-Beam DB-235 Focused Ion Beam and FEG-SEM has a high resolution imaging (7nm) \textit{Ga}^+ \textit{ion column} for site-specific cross-sectioning, TEM sample preparation, and nano-fabrication. The \textit{Scanning Electron Microscope (SEM) column} provides high resolution (2.5 nm) imaging prior to, during, and after milling with the ion beam. The instrument is equipped with beam activated Pt, C deposition and H$_2$O plus 2 \textit{in-situ} nano-manipulators: \textit{Omniprobe} for TEM sample preparation and \textit{Zyvex} for multiprobe experiments.

- site –specific cross-sectioning and imaging
  * Serial sections and 3-D reconstruction are an extension of this method
- site –specific preparation of specimens for Transmission Electron Microscopy (TEM)
- site –specific preparation of specimens for EBSD
- nano-fabrication (micro-machining and beam-induced deposition)
- modification of electrical routing on semiconductor devices
- failure analysis
- mask repair

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FEI DB235 - FIB Specimen Chamber

FIB Column

Electron Column

Pt Injection Needle

Specimen Stage (chamber door open)

CDEM detector

ET & TLD electron detectors
Recent addition - DB-FIB: FEI Helios NanoLab 600i

Tomahawk FIB
2.5nm@30kV, 1pA-65nA
Differential Pumping &TOF

ICE detector
Improved FIB imaging
Secondary I+ or e Contrast

DBS detector
Directional back scatter imaging

150mm high precision piezo stage

Charge Neutralizer

Pt Deposition

600i→Elstar Column
0.9nm @15kV, 1.4nm @1kV

Omniprobe Autoprobe
Advanced sample cleaning
Plasma Cleaner, CryoCleaner

Beam Deceleration

STEM detector
BF,DF,HAADF modes

Standard 16bit scan/pattern engine

iFast Developers Tool Kit
Graphical automation and recipe programming environment

AutoTEM
Auto Slice and View
automation software
ResolveRT 3D reconstruction and Visualization software

+ new features:
- detection / scan strategies
- gas injection processes
- 3D analysis
- integrated CAD prototyping
- cryo

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The gallium ion beam hits the specimen thereby releasing secondary electrons, secondary ions and neutral particles (e.g. milling).

The detector collects secondary electrons or ions to form an image.

For deposition and enhanced etching: gases can be injected to the system.
Ion/Electron Beam Induced Deposition

IBID and EBID

- Precursor molecules adsorb on surface.
- Precursor is decomposed by ion or electron beam impinging on surface.
- Deposited film is left on surface.
- Volatile reaction products are released.

Similarly, reactive gases, can be injected for enhanced etching in milling and improving aspect ratio for milled features.

Pt, W, and Au are common metals SiO_x can be deposited as an insulator.
• Step 1 - Locate the area of interest (site – specific)
• Step 2 - Deposit a protective platinum layer
• Step 3 - Mill initial trenches
  – e-beam view after Step 3
• Step 5 - Perform “frame cuts“ and “weld" manipulator needle to sample
• Step 6 – Mill to release from substrate and transfer to grid
• Step 7 – "Weld" sample to a Cu TEM half-grid and FIB cut manipulator needle free
• Step 8 - FIB ion polish to electron transparency
“Pre-Thinned” TEM Sample prepared by FIB

Diced Wafer with Thin Film

Prethinned Section

Grind to 30 Microns
Dice to 2.5 mm

Prethinned TEM Sample on Half Grid

Pt Protection Layer

Ion Beam Direction

Half Grid

TEM Direction

After Thinning

TEM Direction

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“Pre-Thinned” TEM Sample prepared by FIB

Drawing of typical “pre-thinned” specimen for FIB TEM sample preparation
Precisely controlled etching and deposition

Etched or deposited structures using grey-scale bitmaps or pattern object scripting.

30 nm Pt dot array

500 nm
• Site –specific cross-sectioning imaging and EBSD sample preparation
  – Serial sections and 3-D reconstruction are an extension of this method
• Site –specific preparation of specimens for transmission electron microscopy (TEM)
• Nano-fabrication (micro/nano-machining and beam-induced deposition)
• Modification of the electrical routing on semiconductor devices
References

• *Energy Dispersive X-ray Analysis in the Electron Microscope* (Microscopy Handbooks) by DC Bell (Paperback - Jan 1, 2003)
• *Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM* by Ray F. Egerton (Hardcover - April 25, 2008)
• *Monte Carlo Modeling for Electron Microscopy and Microanalysis* (Oxford Series in Optical and Imaging Sciences) by David C. Joy (Hardcover - April 13, 1995)
• *Electron Backscatter Diffraction in Materials Science* by Adam J. Schwartz, Mukul Kumar, David P. Field, and Brent L. Adams (Hardcover - Sep 30, 2000)
• *Introduction to Texture Analysis: Macrotexture, Microtexture and Orientation Mapping* by Valerie Randle and Olaf Engler (Hardcover - Aug 7, 2000)
• *Electron backscattered diffraction: an EBSD system added to an SEM is a valuable new tool in the materials characterization arsenal: An article from: Advanced Materials & Processes* by Tim Maitland (Jul 31, 2005)
• *Cathodoluminescence Microscopy of Inorganic Solids* by B.G. Yacobi and D.B. Holt (Hardcover - Feb 28, 1990)
• *Introduction to Focused Ion Beams: Instrumentation, Theory, Techniques and Practice* by Lucille A. Giannuzzi and Fred A. Stevie (Hardcover - Nov 19, 2004)
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