FIB and DualBeam Theory and Applications

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What is FIB and What it can do?

- **FIB is a scanning ion microscope.** As the primary beam rasterst on the sample surface, the signal from the sputtered ions or secondary electrons is collected by detector to form a secondary ion image or secondary electron image.

- **FIB is a milling machine.** The milling is site specific. The Gallium (Ga+) primary ion beam strikes the sample surface removing material through the physical sputting of sample material.

- **FIB can deposit metals and chemical enhanced etching.** By injecting special gases, an ion beam is able to deposit materials with submicron precision. Gases can interact with the primary Gallium beam to provide assisted chemical etching or for selective milling.

Comparing Electrons and Ga+ Ions

Ions are positively charged atoms with one or more electrons missing from their valence electron shell. The mass of the ionized atom, along with its high energy and momentum (360 times electron), provide unique capabilities for milling, imaging and micro-depositions.

For the same Beam Energy there are big differences in other critical parameters:

- **Mass:** Ga+ Ion = 128,000 times heavier than Electron
- **Velocity:** Ga+ Ion = 1/360 of Electron
- **Momentum:** Ga+ Ion = 360 times Electron

200 electrons/ions on target of Al with different energy

<table>
<thead>
<tr>
<th>Energy</th>
<th>Penetration depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 keV</td>
<td>Stop Range</td>
</tr>
<tr>
<td>1 keV</td>
<td>Stop Range</td>
</tr>
</tbody>
</table>

30 keV electron

1 keV electron
What a FIB does that a SEM does not

- Removes/Adds Material
- Secondary Ion imaging shows material contrasts
- Channeling Contrasts
- Prepares samples in situ
- Combines high magnification imaging and sample modification
- Ion beam has smaller interaction volume at the target comparing with Ebeam, typically 5 nm to 40 nm for energies in 30 kV range

Comparisons of Electron column and Ion column

- The ion column is somewhat self-cleaning and is not as susceptible to contaminations as the SEM column. The ion beam within column annihilates all but the most stubborn particles or debris. It will probably not require internal cleaning blow the extractor through out the lifetime.

- The LMIS functions by cold-field emission, so no filament heat is used except to periodically “re-wet” the tip with Ga. The LMIS has life time, and it is generally turned off when not in use.

- All electric static deflector and focus elements are high voltage and low current controlled. So, there is little heat generated in the column.

- The aperture strip is subject to wear off from ion beam and require periodic replacement.

Liquid metal field ionisation sources

<table>
<thead>
<tr>
<th>Material</th>
<th>Form</th>
<th>Colour</th>
<th>Odour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ga</td>
<td>Solid</td>
<td>Silver-colour</td>
<td>Odourless</td>
</tr>
<tr>
<td>Sn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Au</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AuSi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AuGe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AuCo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CoGe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CoY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuGe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuMg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AlGe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GaIn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AuCoGe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AuCoY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AuSiPr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AuSiBe</td>
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<td></td>
</tr>
<tr>
<td>AuCoPr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AuCoSi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AuErSi</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Until now, the following LMIS have been produced and studied: Ga, Sn, In, Au, AuSi, AuGe, AuCo, CoGe, CoY, Cu, CuGe, CuMg, AlGe, GaIn, AuCoGe, AuCoY, AuSiPr, AuSiBe, AuCoPr, AuCoSi, AuErSi. The most commonly used ion is Gallium since it has the longest liquid range of any metal (from 29.8°C to 2175°C) providing room temperature operation and yields a long lifetime source. Gallium can be focused to a very fine probe size (< 10 nm in diameter). Liquid metal Gallium is high vacuum compatible and Gallium is large ions for physical sputtering. Below the melting point Gallium is a soft, silver white metal that is stable in both air and water.
**Liquid Metal Ion Source**

The tungsten is wetted with gallium which is held in the spiral by surface tension. The vapour pressure is about $10^{-7}$ mbar.

Frozen-in shape LMIS showing 45° half angle. The field emission area is a 2-5nm across giving current densities >10⁸ Acm⁻².

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**Source heating/Manual heating: Old Stories**

The V/I slop value gets larger as the source becomes depleted.

For a given change extraction current $V$, the change in emission current, $I$ is smaller for a depleted source than for a new source.

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**Ion Source: Energy Spread**

The energy distribution (FWHM) of Ga LMIS over the current range 3 nA –10 uA. Three different radius emitters were used over different ranges (Bell AE., Rao K., Schwind GA., Swanson LW., J Vac Sci Technol., B6(3), 1988).

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**Ray diagrams: FIB Magnum and a SEM SFEG**

Ray diagrams of a FIB Magnum and a SEM SFEG.
### Magnum vs Sidewinder

<table>
<thead>
<tr>
<th>Feature</th>
<th>Magnum</th>
<th>Sidewinder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest beam current</td>
<td>1 pA</td>
<td>1.5 pA</td>
</tr>
<tr>
<td>Highest beam current</td>
<td>20,000 pA</td>
<td>20,000 pA</td>
</tr>
<tr>
<td>Spot roundness</td>
<td>+ (&gt;60%)</td>
<td>++ (&gt;85%)</td>
</tr>
<tr>
<td>Cross-sectioning</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Low voltage performance</td>
<td>not possible</td>
<td>possible (should make low voltage alignment easier)</td>
</tr>
<tr>
<td>Mid column steering</td>
<td>not possible</td>
<td>possible (should increase low voltage performance)</td>
</tr>
<tr>
<td>Bipolar power supply</td>
<td>12 kV</td>
<td>9 of 9.5 kV</td>
</tr>
<tr>
<td>Extractor</td>
<td>2.2 uA</td>
<td>1.8 – 2.2 uA</td>
</tr>
<tr>
<td>Emission current</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sidewinder: Improving low kV performance and reducing the cross-section time.

### Magnum vs Sidewinder at Large Current

**Two ways to look at the improvements:**

- **36% reduction in spot size at same current**
- **78% more current into the same spot size**

**Sidewinder ion column**

- Improved beam profile
- Better signal-to-noise ratio
- Using same aperture system, Sidewinder generates 78% more current at same spot size
- Lower operating keV

**Therefore:**

- Speed – faster milling and TEM prep
- Better resolution and imaging across entire voltage range
- Easier TEM prep by allowing use of higher currents with minimized concern for sample damage and redeposition

**Ion beam currents and spot sizes**

- 140x60x30 um deep cross-section.
- Magnum mill time: 4 hours
- Sidewinder mill time: 42 min.

**Beam size data from FEI technical notes**
Obtaining the smallest beam diameter

1. Use the minimal working distance (L2 to sample surface). For example, Strata 205, decrease WD from 18 mm to 15 mm, the 1 pA spot will be 45% smaller than 18 mm (based on my testing).

2. Switch to smallest aperture: This limit acceptance angle from the source and minimizes the spherical aberration and the tails of the beam.

3. Use highest kV possible; smallest beam diameters are limited by chromatic aberration, which is proportional to the energy spread of the beam divided by the total beam energy, \( \Delta E/E \).

4. Reduce the emission current to 1 \( \mu \)A. A reduction of emission current will result in a lower energy spreading, \( \Delta E \) and so reduce the chromatic aberration.

Ion-Solid Incidence Angle

<table>
<thead>
<tr>
<th>Ion Energy</th>
<th>0°</th>
<th>89°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion incident angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target material</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sputter Yield in Si as a function of angle and E

<table>
<thead>
<tr>
<th>Ion Energy</th>
<th>0°</th>
<th>1 keV</th>
<th>2 keV</th>
<th>5 keV</th>
<th>30 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sputter yield (atoms/ion)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>incidence angle (degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Melting point

<table>
<thead>
<tr>
<th>Element</th>
<th>Melting point</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>0.01 K</td>
</tr>
<tr>
<td>Li</td>
<td>1.63 K</td>
</tr>
<tr>
<td>Na</td>
<td>977 K</td>
</tr>
<tr>
<td>K</td>
<td>776 K</td>
</tr>
<tr>
<td>Ca</td>
<td>1260 K</td>
</tr>
<tr>
<td>Sr</td>
<td>1440 K</td>
</tr>
<tr>
<td>Ba</td>
<td>1480 K</td>
</tr>
<tr>
<td>Ra</td>
<td>1500 K</td>
</tr>
<tr>
<td>B</td>
<td>2500 K</td>
</tr>
<tr>
<td>C</td>
<td>3500 K</td>
</tr>
<tr>
<td>N</td>
<td>3590 K</td>
</tr>
</tbody>
</table>
...
**Sputter Yield and target materials**

- Materials have different sputter yields.

**Beam profiles and Incidence Angle on SY**

- Asperities on a surface will be FIB milled at different rates due to topographic effects on milling.
- The topographic effects will grow and exacerbate as FIB milling continues.
- **This is why surfaces are “never” FIB milled from top-down, but rather, are created by FIB milling at high incident angles.**

**Materials Have Different Sputter Yields**

- The incident angle affects the sputtering yield of different materials.

**DualBeam Concept: Eucentric Height**

- The eucentric height is a stage Z-height, which means that the height of the specimen at which its image does not move laterally (side movement of the imaging) as a function of stage tilting.
- All aligned:
  - Gas injectors
  - SEM coincident
  - Tilt axis
  - Beams pre-focused
  - Optical microscope
  - Charge neutralizer
Primary Ion Beam - Sample Interactions

- Reflection: sputtering, SIMS
- Emission: Electron emission, ion emission
- Absorption: Ion implantation

CDEM Detectors

Electron multipliers
- Continuous dynode Electron Multiplier (CEM)

Positioned above sample and biased to collect secondaries.

Take care with your CDEM

1. Always condition the new detector after installation.
2. The better the chamber vacuum the better for the detector. “Vac OK” is not means you can start imaging because it is not healthy for the detector. Waiting the chamber vacuum back to the 10^-4 mbar before start to scan.
3. Never use AUTO contrast.
4. Avoid unnecessary low beam current imaging. The general guessing is if you view 50 nm features using 10 pA; if your feature is 50 nm, then using 50 pA for imaging would be good enough. Low beam currents are not always help due to the low S/N ratio.
5. When you want to replace the sample, Please switch off HV (the contrast will be automatically drop to 5%) and wait for 5 min (let the CDEM cool down) then open the chamber door; this will help the CDEM cool down before it open to atmosphere.
6. If you used water or XeF₂ or EE for your job, pleases wait until chamber vacuum back to at least 5x10^-5 mbar before open the door.
7. Avoid unnecessary low current secondary ion imaging.

ISE Image and ISI Image

Secondary Electron Image

Since the primary ion beam is positively charged, insulators will charge positively, and will show low secondary electron yield. Therefore, the insulators will show dark on the images, while conducting materials will show bright and the current caused by the primary beam will can flow away.

Secondary Ion Image

The ion yield is much lower than electron yield. For this reason ISE images are often clearer than ion images, larger scan times or larger beam currents are some times requires for high quality SI images.
The primary Ga\(^+\) ion beam is positively charged, so that insulators will charge positively, and will show low secondary electron yield. For conducting materials, the charge caused by the primary beam can dissipate. Therefore, the non-conducting materials will show dark compared with conducting materials showing bright on FIB images. Those basic imaging properties can localise defects by voltage contrast.

Tilted FIB images showing the embedded inclusion. If the contrast changes with tilting angle it must be a crystalline materials exhibiting tunneling contrast (crystallography contrast). If it is always dark it means it is an insulative oxide showing voltage contrast (dark means no-conducting materials).

(a) 25°  (b) 35°  (c) 45°
When an ion beam is incident parallel to a low index crystallographic direction, they can interact with only small angular deflections at each collision. These ions can travel a short distance through the crystal before stopping and are described as channelled.

Channelling reduces the electron yield. As a result, that grain will appear dark due to a decrease in the number of secondary electrons that are emitted from the surface.

The grain boundaries are located by changes in ion introduced secondary electron image (ISE) contrast between neighbouring grains. This contrast differential can be maximised by combining several images taken of the same grains at different tilt angles.

**Channelling Contrast**

- **Ion:**
  - Channeling
  - Non-channeling

- **Secondary electrons:**
  - Escape & are detected

The Image on the left was generated without charge neutralization. The image on the right was generated with charge neutralization.

**Charge Neutralization: For Optimum FIB Performance**

The image on the left was generated without charge neutralization. The image on the right was generated with charge neutralization.

**Milling: vector scan, beam steps**

For a digital scanning scheme that consists of a beam of diameter $d$, and step size $s$ scanned over an area of length $L$ and width $w$. The software determines the step size by specifying the beam overlap $OL$, which determines the percentage of beam overlap between adjacent pixels in a digital scan of the sample.
Changing pattern parameters: what can you get?

Beam overlapping: general rules

The distribution of the charge from the beam is a tricky issue. In general, the optimum coverage for imaging is in 50% overlaps. Based on this, the normal milling overlap was also 50%. This provides smooth coverage of the surface without taking too much time to scan.

To get in memory of large patterns, in general use OL of -50%. Overlap would be positive for milling and negative for deposition purpose.

If you don’t mind the milling quality of the high current rough milling, using -100% or more for the Overlap.

With gas enhancement etching, 0% overlap is recommended. There is a pixel column (voxel - volume pixel) on the surface, so you don’t want any more charge around then just on that pixel.

Beam parameters with GIS: general rules

EE:
- Large enhancement: Si, Al, GaAs (x 20 times to x 30 times); Low enhancement: Oxides, SiO₂, Al₂O₃ (close to 1); Silicon Nitride (Si₃N₄): also faster (x5 to x7 times);
- Scan parameters: Overlap: 0%, Dwell: 0.2 – 1 µs, large area reduce pixel dwell time: 0.2 µs, small via: 1 µs to 10 µs.

IEE
- SiO₂, Si₃N₄: faster (up to x20 times); Si: faster (up to x20 times); Al: No (up to x4 times);
- Scan parameter is critical: Overlap: 0 to ~99%, dwell: 0.1 to 0.5 µs, large area reduce pixel to 0.1 µs, small via between 1 to 10 µs.

General rules: Pixel dwell and loops

Pixel dwell and loops:
- If a relatively large area is being scanned, the enhancement can often be increased by reducing the pixel dwell time (such as 0.2 µs) while reduce the loop time. For small size pattern, such as those used in drilling Vias, there is less gain form a short dwell time. So a 1 µs to 10 µs is appropriate.

- Pattern loop time is the time it takes from the beam to return to any given pixel in the pattern. If the pattern is small the loops is short and do not allow enough time for the gas to re-absorbed before the beam return the same pixel on the next loop. So less beam current must be used if a large enhancement is required.
Multi-needle approach enables rapid switching between gases
- Gas pressure doesn’t have to be high when delivered close to sample – gas is concentrated where used
- No pressured gases

Z height, H distance

Gas Injection system

The GIS or Gas Injection system is what enables the FIB to perform these deposition and preferential milling operations.

- Deposition chemistries, metal or insulator
- Etching chemistries, normally enhance one or more materials over another to give beneficial effects
- The effects of all chemistries can be further enhanced by adaptive or selective area patterning which is available on all platforms
- There are now a total of 26 chemistries available, but not all are on every tool. The basic set is listed here.

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>PT Dep</th>
<th>Wt dep</th>
<th>Beam (MB)</th>
<th>EE</th>
<th>EEx</th>
<th>Del E</th>
<th>SCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td>Working Temp</td>
<td>90°C</td>
<td>90°C</td>
<td>90°C</td>
<td>90°C</td>
<td>90°C</td>
<td>90°C</td>
<td>90°C</td>
</tr>
<tr>
<td>Exposure Time</td>
<td>500 min</td>
<td>500 min</td>
<td>500 min</td>
<td>500 min</td>
<td>500 min</td>
<td>500 min</td>
<td>500 min</td>
</tr>
<tr>
<td>Apparatus</td>
<td>DC</td>
<td>DC</td>
<td>DC</td>
<td>DC</td>
<td>DC</td>
<td>DC</td>
<td>DC</td>
</tr>
<tr>
<td>Needles</td>
<td>Precision</td>
<td>Precision</td>
<td>Precision</td>
<td>Precision</td>
<td>Precision</td>
<td>Precision</td>
<td>Precision</td>
</tr>
</tbody>
</table>
Deposition: Metal and Insulation

Ion beam activates gas to leave a protective platinum layer.

Deposition example: Platinum

(methyl(cyclopentadienyl)trimethyl platinum, C<sub>9</sub>H<sub>16</sub>Pt)
Solid at room temperature
Operating Temperature 38-42 degrees C.
About 10 minute warm-up period.
User refillable (use fume hood)
Very hard: tougher for probing and thermal cycling.
Chemically resistant

Deposition example Pt

These gases form non-volatile compounds
Deposition is a delicate balance between decomposing the adsorbed gas and sputtering.
• Platinum
• Tungsten
• Insulator

Something need to know while dealing with GIS

Depositions:

• Parameters: Needle position (Height-H and Distance-L), needle diameter, and crucible temperature; Beam current, scan area and scan speed (dwell time and overlap);
  Absorbed gas to produce deposits, sputtering from the surface
  Net deposition rate = deposition rate – sputtering rate

• Current density for depositions:
  • Pt: 2 – 6 pA/µm<sup>2</sup> (below 1 nA, for 1 µm Pt should be around 5 to 8 mins, for above 1 nA using 2 pA/µm<sup>2</sup>);
  • W: 80 – 150 pA/µm<sup>2</sup> (most time using lower density parts);
  • Carbon: 1 to 10 pA/µm²
  • Insulator deposition: 1 – 10 pA/µm² (1.2 pA/µm² for deposition pads, such as 28 µm x 28 µm using 1nA).
### Something need to know while dealing with GIS

<table>
<thead>
<tr>
<th>Chamber pressure</th>
<th>Current density into the pattern</th>
<th>Resistivity</th>
<th>OL and t_D</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>70 to 100 pA/µm²</td>
<td>CE: 10 pA/µm²</td>
<td>0.15 µm/nC</td>
</tr>
<tr>
<td>Pt</td>
<td>2 to 6 pA/µm²</td>
<td>CE: 10 pA/µm²</td>
<td>0.5 µm/nC</td>
</tr>
<tr>
<td>SiOx</td>
<td>1 to 10 pA/µm²</td>
<td>CE: 10 pA/µm²</td>
<td>0.3 µm/nC</td>
</tr>
</tbody>
</table>

### EBID - Electron beam induced deposition

**Examples of electron beam deposited patterns**

Ebeam deposition for TEM specimen preparation
Pt deposited for 300 s at 2 kV, spot size 5 with t_D= 20 µs and OL = 0%

### Comparing: IBAD and EBAD

**IBAD: Ion Beam Assisted Deposition**

**EBAD: Electron Beam Assisted Deposition**

For metal deposition, the effect of Ga+ implantation is not so critical, and we know (J Vac Sci. Technol. B19(6) Nov/Dec 2001) by Auger analysis (wt%), the deposited Pt is 46%Pt, 24% C, 28%Ga, 2%O, and W is 75%W, 10%C, 10%Ga, 5%O. However, for Insulator deposition (SiO₂), Ga+ implantation will increase conductivity. So, IBAD is desirable if the metal impurity is not important and the growth rate is important.

Paper published by Harvard University (Rev. Sci.Instru., 73 (11) 3901, (2002)) indicated that the compositions difference between IBAD and EBAD of insulators, which deposited by FEI DB235, is obvious. The WDX analysis showed IBAD insulation has atomic percent of 33Ga:16Si:51O. However, EBAD is always Si₃O₂ₓ.

### Insulator Deposition

**Material is TEOS in liquid form at room temperature**

Mixed with H₂O in needle to improve reaction

Operate at room temperature

Goes in a standard design crucible and gas injector.

In via structure, 1 Gohms resistance, 20 V breakdown Deposition rate for coatings is about 1 micron/20 minutes
Iodine Enhanced Etch (EE)

- Solid at room temperature.
- Operate at 32 degrees C.
- Allow 10 minute warm-up period.
- User refillable (use fume hood).
- Metal selective etch ~5-10:1.
- Mills Al about 15x than sputtering.
- Mills Oxides about 1-3x than sputtering.

Insulator Enhanced Etching (XeF2)

- The Insulator Enhanced Etch (IEE) allows rapid etch of many insulating materials with the assistance of a halogen compound, Xenon Difluoride (XeF2). IEE preferentially removes insulating materials, leaving the conductor. The IEE process removes material faster than normal ion milling.
- The IEE process is particularly useful when removing passivation from a circuit area containing several metal layers.

Selective Carbon Milling (SCM)

- Selective Carbon Mill (SCM) uses water vapor to increase the removal rate of carbon-containing materials such as polyamide, PMMA (polymethyl methacrylate), and other resistive materials by a factor of 20 relative to normal FIB sputtering rates, and that of diamond by a factor 10. In addition, SCM decreases the removal of other materials (e.g., Si and Al). This effectively increases the etching of polymers over these other materials.

- Very high selectivity of SCM on polyimide over Al was used to remove polyimide passivation and dielectric layers from an integrated circuit.

Selective Carbon Mill (SMC)

- Poly-carbonate (Compact Disc)
Delineation EtchTM

Delineation etch beam chemistry provides variable etch rates on oxides to enhance structural detail. It does not attack Si or poly-Si. It can deal with different oxides. Contrast in a secondary electron images reflects primarily from the presence of topography. Protruding edges allow more secondary electrons to escape, and therefore, appears brighter than recessed edges.

CoppeRx™ for milling Copper

CoppeRx™ is a stand-alone software application that uses tungsten (W) gas and an FEI patent-pending milling process to cleanly remove surface copper from a sample.

The pattern milled with CoppeRx produces a smooth, even box, free of copper debris. In contrast, milling without CoppeRx produces a rough uneven box with considerable copper debris.

DualBeam for Industries Process Control

Cross-section milling and imaging to reveal structures below the surfaces
Cross-Section Overview: Single beam FIB

High beam currents for milling. Staircase pattern is used in making a FIB cross section for bulk removal of material.

Low beam currents for imaging. Stage tilted 45 degrees to allow view the face.

Corrosion/Anti-corrosion layer on steel

Light emitting Polymer

Site-specific location for defect analysis

Below surface Volume Visualization

3D Characterization and Analysis
**EDS below the sample surface: Geometry**

Extra materials need to be removed by FIB to have shadow-free for the X-ray detector.

**EDS analysis below the sample surface**

a) A cross-section image of the Zn-coating on steel acquired by Q3D SSBSE detector, b) A XEDS map mixed with Mg-Al-Zn elements of the cross-section.

**3D Deconstruction**

Dual Beam Slicing and Viewing of the region of interest of an artificial wood sample to reveal water/moisture carrying tubes.

**3D Reconstruction and Visualization**
Site-specific TEM specimen preparation

Sample preparation and High resolution SEM STEM imaging

AutoTEM G2 – Full integration in the User Interface

- Highest success rate
- Less than 20 minutes on Si for a 12x5µm TEM sample, final thickness 100nm

AutoTEM G2 multi locations TEM specimen preparation

Duplicated 5 x 5 matrix Automatic TEM specimen preparation for ex-situ lift out

(a) Rough milled TEM specimen by FEI AutoTEM; (b) Bottom and sides cut and the specimen was ready for in-situ lift out.
In-situ lift out TEM specimen preparation

(a) In-situ lift out micromanipulation probe connected to the specimen by ion beam Pt deposition; (b) The specimen was cut free from the bulk material and in-situ lifted.

(a) The in-situ lifted specimen transferred to a TEM grid without need to break the chamber vacuum; (b) The specimen was connected to the TEM grid by ion beam Pt deposition and the needle was cut free from the specimen. The specimen is ready for final thinning.

Nova 600 NanoLab DB SEM and SETM images

SEM secondary electron images

SEM/STEM BF images

Nova 600 NanoLab DB SEM/STEM

Bright-Field

Dark-Field
A secondary electron image acquired from one of the TEM specimen prepared in EDS mode of the SEM in Nova NanoLab. The XEDS and element maps were acquired on the same area. This TEM specimen was used for the previous TEM work.

DualBeam TEM specimen preparation and SEM/STEM provide rapidly quantification for IC device, data storage and materials science applications. It bridges the gap between SEM and TEM and provides increased productivity for materials characterisations.

The use of the DB/SEM/STEM detection mode with an immersion lens FEGSEM provides a breakthrough for ultra-high resolution imaging and x-ray analysis never before below 30 kV.
FIB Micro-machining: Point laser structures

Point source for laser-light emission produced by milling the circular structure but leaving the spot in the middle intact which then acts as a point source for laser-light emission

70 nm optical transparent SiOx on ZnCdSe and ZnSe

FIB Micro/Nano milling: AFM Diamond Tips

FIB Micro/Nano W-deposition

Intrinsic ferroelectrics single crystal Lithium Nibate (LiNbO3): Using FIB to direct write of metal lone onto the side walls of the LiNbO3

THE END