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EAG Laboratories



Dual Beam Focused Ion Beam (FIB)-Scanning Electron Microscopy (SEM)

The dual beam is a versatile instrument that combines a focused ion beam (FIB) with a scanning electron microscope (SEM).

The FIB is used to controllably modify samples with nanometer scale precision, while the SEM is used to non-destructively analyze samples as well as locate and monitor the FIB modifications.

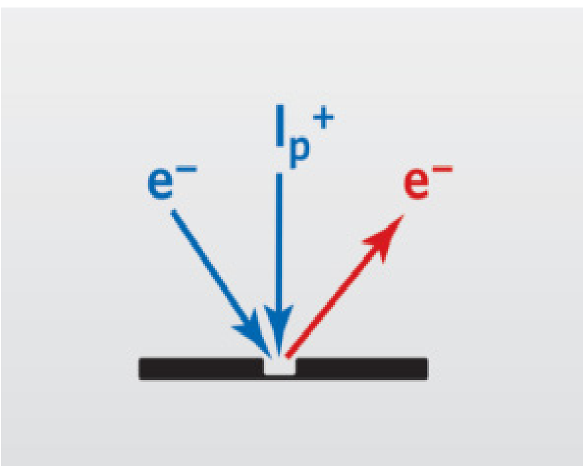

Figure 1: General schematic of how Dual Beam FIB works.

It is most often used to create site-specific cross-sections (XS), delayering of heterogeneous samples, and is the industry standard for creation of electron-transparent samples suitable for (S) TEM analysis. Both the FIB and the SEM form images by rastering a highly focused beam of ions or electrons across a sample surface while typically monitoring either the secondary (SE) or backscattered (BSE) electrons that are ejected from the sample.

The secondary electrons originate from the top 5-10 nm of the sample and provide information on the topography and, to a lesser extent, on the elemental variation in the sample. Backscattered electrons escape from deeper within the sample and provide information chiefly related to the average atomic number of the sample.

Secondary electrons and ions produced by the FIB create unique images that can help to highlight grain structure due to ion channeling effects. Both the FIB and the SEM can also be used to deposit metals or insulators on the sample using an in-chamber gas injection system (GIS). This allows site-specific sample protection for XS preparation as well as complex circuit editing. The dual beam FIB-SEM is a versatile tool that can be used to study the surface and interior of almost any materials system including but not limited to semiconductors, polymers, metals, and ceramics.

Strengths

- High precision material removal and deposition
- Rapid, high-resolution imaging
- Excellent depth of field
- Versatile platform that supports many other tools

Limitations

- Vacuum compatibility typically required
- SEM may spoil sample for subsequent analyses
- Ultimate resolution is a strong function of the sample and preparation Insulating samples may need to be coated
- Gallium FIB cross-section size limited to ~100 microns wide by 20 µm deep

Common Applications

- Failure analysis of integrated circuits
- SEM and (S)TEM sample preparation
- Exposing buried defects
- Process development of submicron films and features for optics, photovoltaic, semiconductor, biotechnology and other industries
- Characterization of metal corrosion
- Investigation of interfacial layers, oxidization and contamination
- Delayering and circuit editing

Industry Sectors and Technologies

- Semiconductors
- Displays
- Electronics
- Energy storage and batteries; Photovoltaics
- Medical devices

Case Study: FIB Cross-Section and SEM Imaging of an Integrated Circuit

A dual beam FIB-SEM is used to expose the interior of an integrated circuit at a precise location. The FIB cuts a small cross-section into the sample as the location of interest, and the SEM is used to image the sub-micron features within the chip cross-section. The different layers of semiconductors, metals, and dielectrics are clearly visible in the cross-sectional view (figure 2).

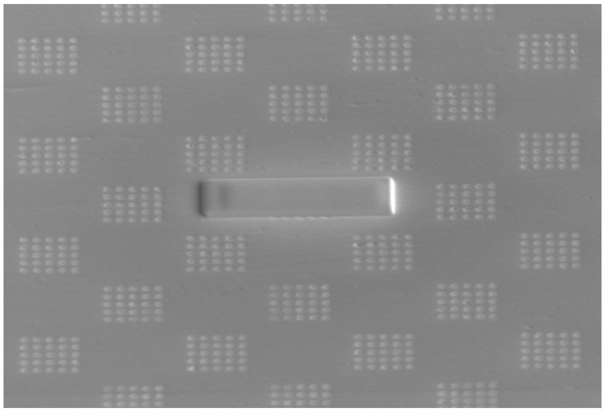

Figure 2a: The ion beam is used to deposit a protective layer of platinum above the cut location. The platinum both marks the cut location and helps to create a smooth cross-section while minimizing further ion beam damage.

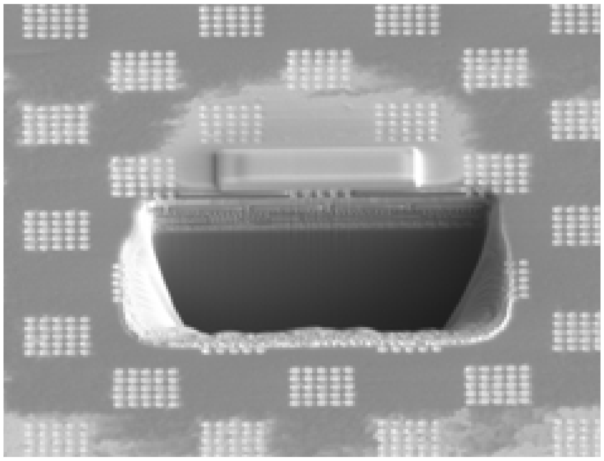

Figure 2b: The FIB is used to open a trench to expose the cross-section face.

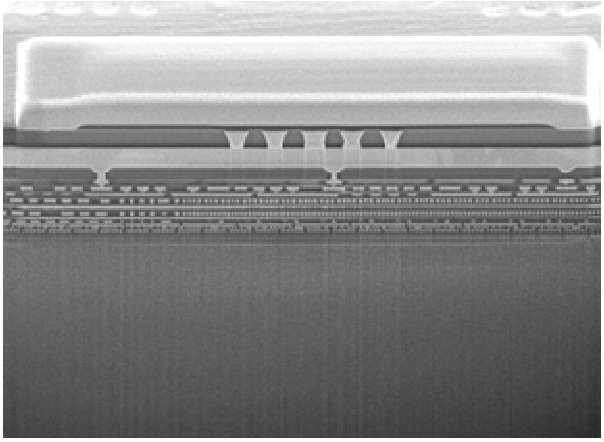

Figure 2c: A finer ion beam current is used to polish the cross-section face for high resolution SEM imaging.

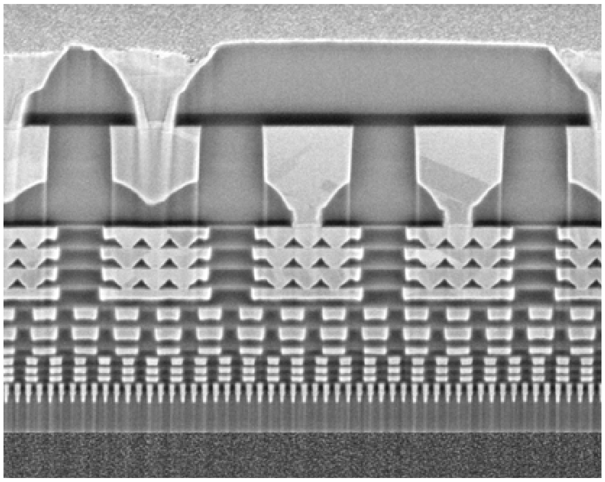

Figure 2d: The SEM is used to collect images showing the stack-up above the silicon substrate. The brighter features are metal layers where the grain structure is clearly visible.

Case Study: Transmission Electron Microscope (S)TEM Sample Preparation

The dual beam can be used to prepare site specific (S)TEM samples. (S)TEM is necessary to resolve sub-nm features and can be used to obtain atomic resolution images. Figure 3a-f show (S)TEM liftout sample preparation using a dual beam instrument.

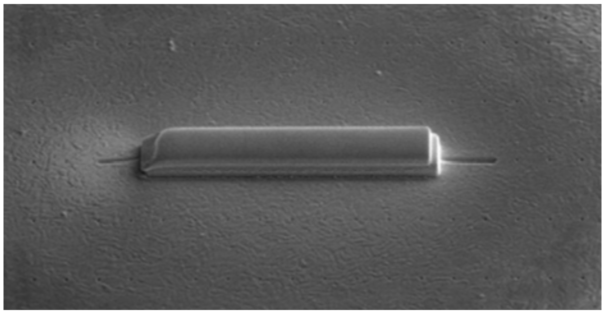

Figure 3a: The region of interest is protected using an electron beam and/or ion beam assisted deposited metal cap (in this case platinum).

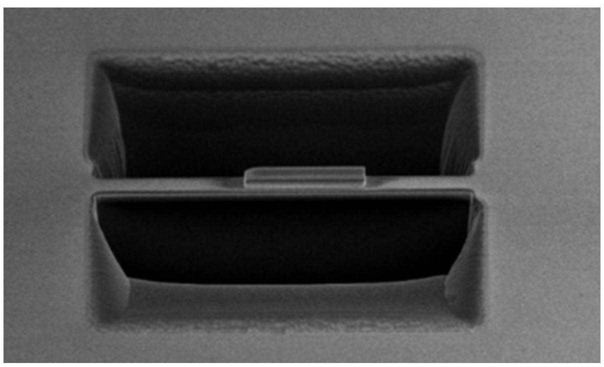

Figure 3b: The FIB is used to cut open a trench around both sides of the region-of-interest (ROI).

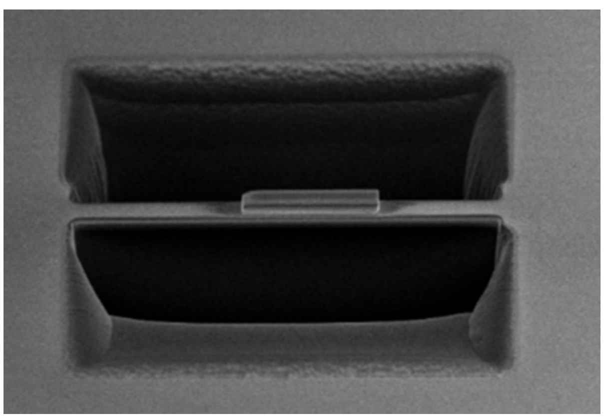

Figure 3c: The FIB is used to cut free 3 sides of the ROI and to attach the sample to a micromanipulator needle within to dual beam.

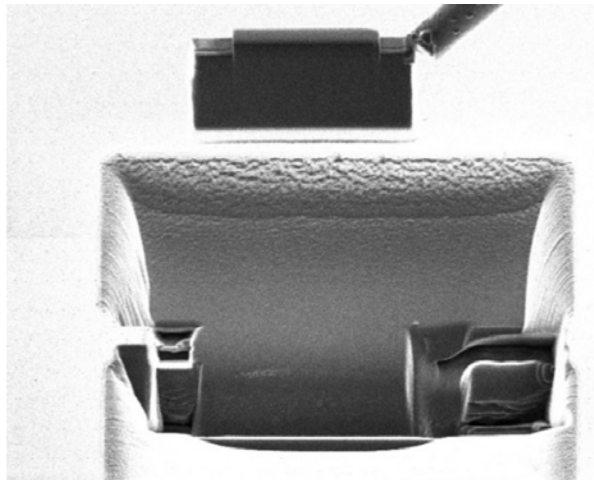

Figure 3d: The ROI is cut free from the bulk sample and lifted out using the needle.

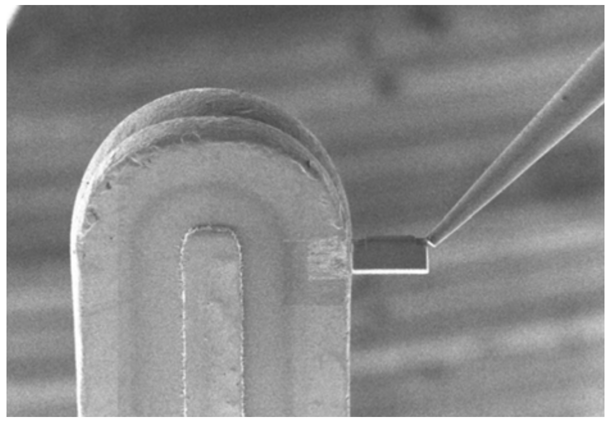

Figure 3e: The sample is welded using ion-beam assisted gas deposition to a TEM grid.

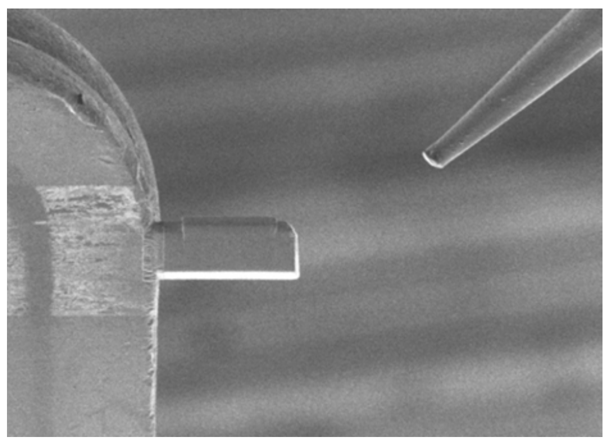

Figure 3f: The sample is cut free from the needle and is securely attached to the TEM grid. The sample will then be thinned to electron transparency (< 100 nm in thickness) for TEM analysis.

Complementary Techniques

Dual beam FIB-SEM is commonly used to prepare electron transparent samples for TEM and scanning TEM (STEM) analysis. TEM and STEM techniques allow for imaging of sub nanometer and atomic level features. STEM energy dispersive spectroscopy (EDS) or electron energy less spectroscopy (EELS) can be used on the dual-beam prepared sample to perform high resolution chemical mapping and analysis. The dual beam can also be used to prepare site-specific samples for atom probe tomography (APT) which produces a near atomic-resolution 3D reconstruction of the small specimen.

Dual beam FIB-SEM is also used in conjunction with hot spot analysis techniques such as OBIRCH, EMMI, LIT, IR, EBIC, and CL. One of these techniques is used to locate the general area where a defect is likely to be present. The dual beam is then used to cut open the suspected area and check for any abnormalities with SEM imaging.

SEM-EDS is another powerful complementary technique for the dual beam FIB-SEM. An SEM-EDS detector can be installed onto the dual beam tool to allow for chemical mapping of the sample surface or of the FIB cross-section. This allows for easy identification of the material stack up or of any foreign materials and defects within the cross-section.

Dual Beam FIB-SEM at EAG

EAG has more than 15 dual beam systems in the network, including: high resolution field emission tools, tools that can accommodate 300 mm wafers, plasma FIB dual beams, and tools equipped with EDS detectors. Besides our extensive hardware collection, EAG has over 25 people who work on dual beams regularly, with experience ranging from Ph.D.'s to FAB process managers, to experts in metallurgy. Our labs service industries such as semiconductor, medical device, optics, energy storage, cell phones, piping and printing. Contact us to learn how we can help you on your next project.