XEIA3

1.4 nm at 1 keV

IN-BEAM DETECTORS

i-FIB Xe

TESCAN

PERFORMANCE IN NANOSPACE

Whether your applications demand extremely powerful and ultra-fast micro-/nano- FIB machining, an outstanding image resolution at low beam energies, ultra-fast and reliable microanalysis or 3D analytical reconstructions, XEIA3 stands out as the ideal turnkey solution that offers all these capabilities in one single and unique instrument with ultimate performance.

KEY FEATURES

- **Powerful ultra-high resolution SEM column** equipped with a high brightness Schottky emitter for high currents, low-noise and extraordinary imaging
- **In-Beam detectors** for excellent imaging at low energies and very short working distances
- **Ultra-fast xenon plasma ion source FIB -** high beam currents for outstanding milling speeds and an excellent performance in sputtering large volumes of material, and low beam currents for smooth polishing.
- **Less implantation, doping or degradation** of insulator deposition, a valuable feature for semiconductor industry
- **Simultaneous SEM imaging during FIB milling** or deposition (the whole process could be observed directly)
- **Unique and advanced TESCAN's technologies** in terms of automated operations such as the In-Flight Beam Tracing™ designed to accurately compute and adjust all the optimal parameters for high resolution imaging
- **Advanced patterning and 3D characterisations** capabilities powered by DrawBeam, a pattern editing tool that also provides real-time visualization during milling or lithographic processes
- **High-performance electronics for faster image acquisition** up to 20 ns/pxl, an excellent deposition rate and ultra-fast scanning
- **Novel solution for fast 3D microanalysis** such as 3D EDX and EBSD reconstructions
- **12'', 8" and 6" wafer inspection** by means of an extended chamber; an exclusive feature of TESCAN
- **Unique integration with TOF-SIMS**
- **Gas Injection System (GIS)** for enhancing your FIB applications
- **Powerful turbomolecular and dry fore vacuum pump** for keeping the chamber clean. Electron gun pumping by ion getter pump in ultra-high vacuum.

Specific solutions for specific needs

With the launch of XEIA3, TESCAN not only delivers an instrument top of its class but also fulfils its commitment to continue helping researchers to push science and development forward. This is also reflected in the careful customisation of every system in order to meet specific needs of every customer. From materials science to life sciences or from engineering to semiconductor industry, TESCAN is delivering systems without any compromise in performance.

- **Extremely powerful FIB column**
  Take advantage of the xenon plasma ion source that assures an efficient and simplified high quality milling process capable to turn - once - a 40-hour milling-polishing task into astonishing 30 minutes. XEIA3 with Xe plasma ion source can be more than 50 times faster than any conventional Ga ion source FIB. When it comes to stability, XEIA3 plasma ion source produces an ion flux which is constant in time with excellent spatial uniformity.
- **Superb resolution at low accelerating voltages and high currents**
  As far as imaging is concerned, XEIA3 is specially aimed at low accelerating electron voltages operations. Therefore, it represents a concrete solution for imaging sensitive components in IC for FA/inspection purposes in the semiconductor industry. It also allows for the imaging of non-conductive samples as well as the imaging of biological samples in their natural state, a highly appreciated feature in life sciences.
- **Fast microanalytical capabilities**
  The Xe plasma ion source is the ideal solution for high throughput in sample microanalysis. The high milling rates capabilities allow for ultra-fast data acquisition which in turn enables the analysis of large volumes of the sample in short periods of time; XEIA3 turns 3D EDX and large-scale 3D EBSD reconstructions into routine applications. Furthermore, high yield of secondary ions, no interference in the mass spectrum and enhanced detection limits are the advantages that Xe plasma ion source offers for precise TOF-SIMS analysis.

Behind superb resolution is a 60° single-pole objective lens

The SEM column in XEIA3 is equipped with a unique design of a 60 degree single-pole immersion lens that allows for about three times better resolution at low landing electron energy imaging than a conventional double-pole objective lens. The objective lens is narrower than conventional lens, the feature of which provides more space available for handling the samples and it is also advantageous for different analytical techniques and FIB operations.
The specimen is fully immersed in the induced strong magnetic field produced by the lens coils and as a result the optical aberrations decrease dramatically compared to a conventional lens. The column is also equipped with a second objective lens which is of a conventional double-pole type. This lens is located above the single-pole objective lens and it is used alternatively to enable a field-free imaging mode for samples which are sensitive to magnetic fields. The excellent resolution at low accelerating voltages offered by XEIA3 is significant advance in the examination of tiny surfaces, nanolayers and various types of nanostructures reducing significantly the risk of damaging the specimens. Indeed, XEIA3 enables a detailed and complete inspection or failure analysis (FA) of semiconductor devices in a non-destructive way, which allows for the investigation of points of interest that are not easily reached by other conventional techniques that are usually much more time-consuming. The outstanding performance at low accelerating voltages of the electron column in XEIA3 also allows for observing non-conducting samples as well as the imaging of biological samples in their natural state without the need of using conducting coatings.

XEIA3 delivers an unbeatable solution in terms of sputtering speeds for large volume sample preparation and analysis in semiconductors and precise TEM sample preparation.

Tailored system for fulfilling specific needs

Your best choice for a complete and ultimate failure analysis/ inspection in the semiconductor industry

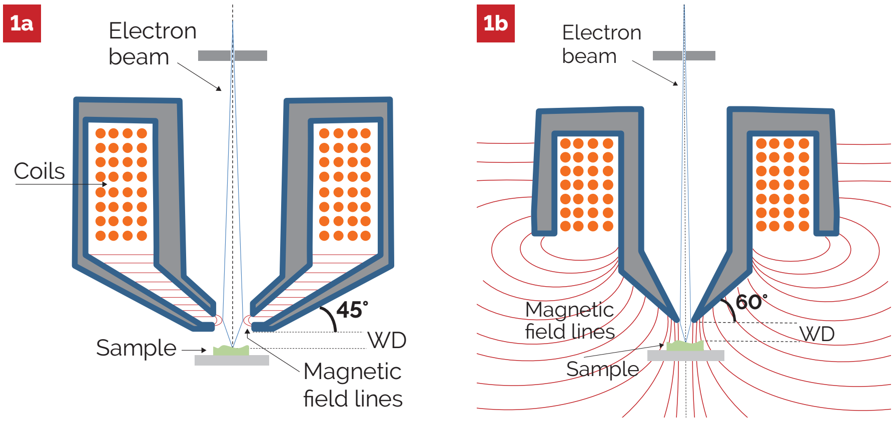

Fig. 1: a) Conventional double-pole lens. **b)** Unique XEIA3 60 degree single-pole immersion lens. The specimen is immerse in the magnetic field produced by the coils and the resolution is improved.

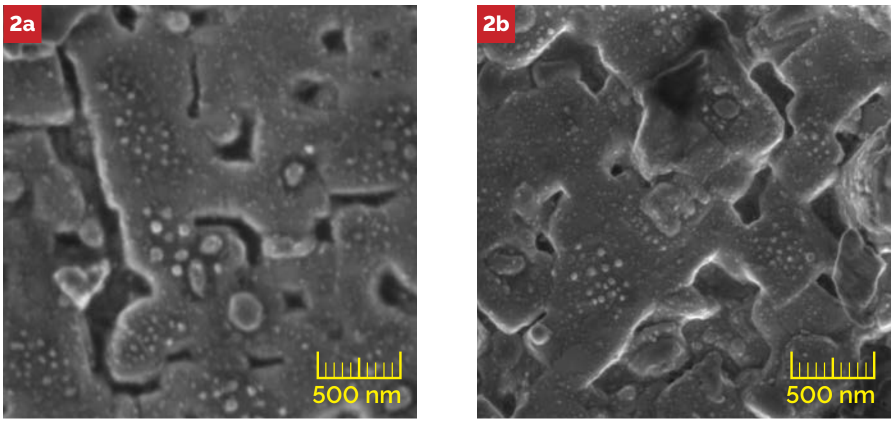

Fig. 2: Comparison of the imaging of a **(a)** conventional double-pole lens with **(b)** a single-pole lens imaging at low accelerating voltage. The sample consists of a semiconductor imaged at 1 keV with the In-Beam detector. The resolution power of a single-pole lens is almost double than of a conventional double-pole lens.

Why Xenon Plasma Ion Source?

Most conventional FIB systems use liquid metals ion source (LMIS) such as gallium (Ga). Ga beams can deliver a small spot size. Their performance, however, decreases at high currents (> 10 nA), see figure 2; the beam size rapidly increases and thus the spherical aberration becomes significant to the point of dominating the size of the focused beam. These unwanted features make gallium ion sources unsuitable for large volume milling tasks; the milling rate on silicon at 10 nA and 30 keV is 2.7 µm³/s whereby at that rate, milling volumes of the order of 10^6 µm³ can take more than a day to be accomplished. The semiconductor industry commonly requires large volumes of material to be removed for the purposes of failure analysis or inspection. XEIA3 Xe plasma ion source stands as the concrete solution to overcome the limitations of LMIS in this regard. Its angular intensity is three ranks of magnitude larger than LMIS, hence the production of high current ion beams is more achievable. XEIA3 excels in terms of life-time and current stability.

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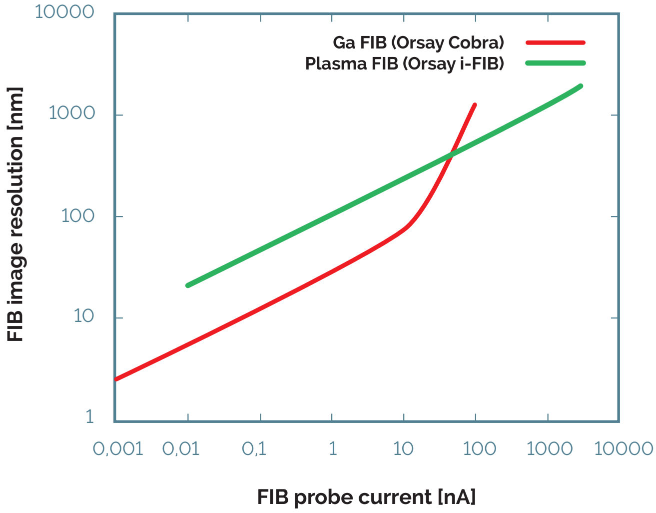

Fig. 3: Resolution as function of probe current in FIB.

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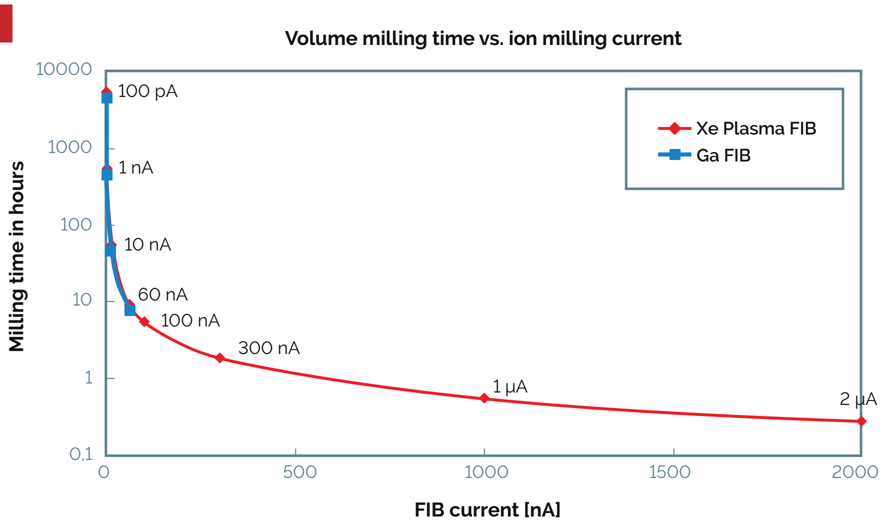


Fig. 4: The milling time in hours is plotted as a function of FIB current, the curve corresponds to the expected milling time in 100 µm³ of copper.

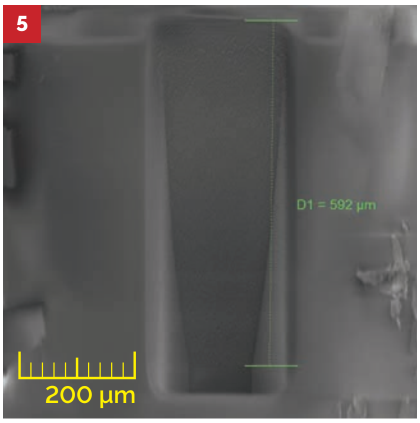


Fig. 5: Milling into a glass layer for reaching the IC board. Probe window: 200 x 200 x 592 µm³. Milling time with Xe plasma ion at 2 uA: 14 hours. Milling time with Ga LMIS at 65 nA: more than 20 days.

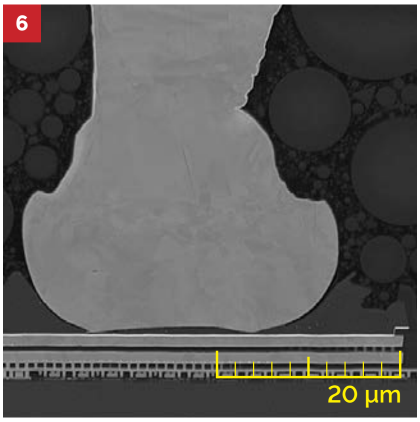
Xenon plasma ion source, the solution for coping with the highly demanding semiconductor industry

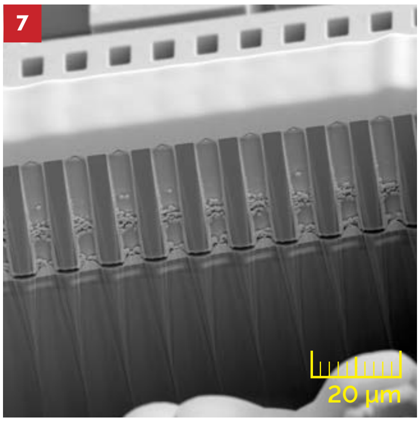
The more massive the ions, the higher the sputter yield; xenon (Xe) is therefore the inert gas of choice in XEIA3 for ultra-fast milling applications. Furthermore, compared to other inert gases, Xe plasma source offers greater source brightness, less energy spread and lower first ionisation energy. This results in a higher plasma density that in turn results in a higher ion current density. In terms of implantation, as opposed to gallium, xenon does not form intermetallic compounds that might interfere with the analysis of the sample. Furthermore, the depth of implantation of Xe ions is twice as less than Ga ions and as a result the milled surface is less prone to become amorphous.

Extend the capabilities in all your FIB applications with Xe plasma ion source

XEIA3 combines the capabilities of an outstandingly fast and powerful xenon plasma ion source with an ultra-high resolution electron column. Such synergy allows for carrying out the most challenging large volume removal applications in beating times which have – up until now – never been achievable before. The highest precision, that only a sub-2 nm resolution of the electron column can guarantee, opens new possibilities in a wider range of applications in both research or the high-tech industry.

Ion current beam	Features	Applications
High: **1 µA – 2 µA**	• High speed milling rates • Large spot size • Not suitable for imaging	• Rough milling, suitable for large etching volumes • > 1 × 10^5 µm³ • TSV, IC inspection and failure analysis and circuit modification
Medium ~ **100 nA**	• Fast speed milling rates • Medium spot size	• Polishing of rough cross sections and other FIB-created objects such as lamellae polishing • Small spot size also allows for short term imaging at low magnifications • Reducing the curtaining effect in cross sections
Low ~ **100 pA**	• Smallest possible spot size • Very low etching speed	• Creation of very small objects • Imaging at higher magnification with minimum destructive effects





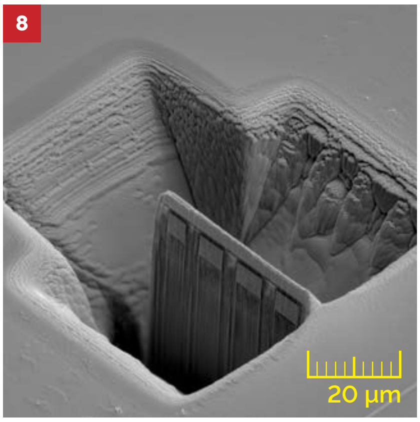
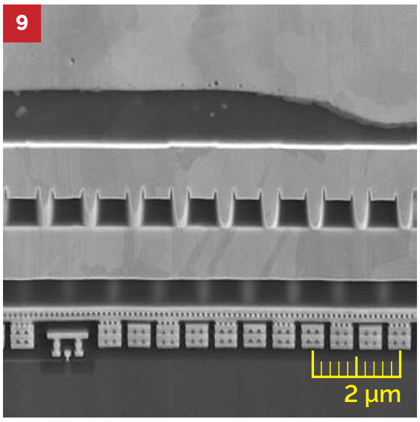


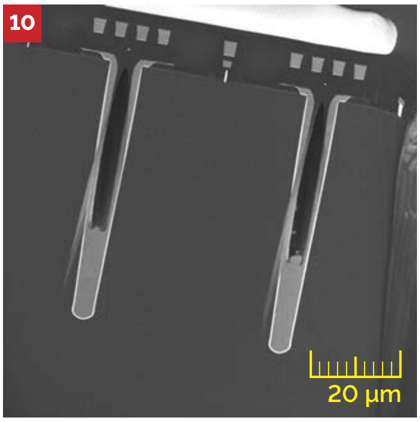
Fig. 6: Detail of a cross-section of an IC imaged at 10 keV with the In-Beam SE detector.

Fig. 7: Cross-sectioning in a MEM, imaged at 10 keV with the SE detector.

Fig. 8: Lamella preparation, imaged at 10 keV with the SE detector.

Ion comparison	Xe+	Ga+
Sputtering rate at 30 keV on silicon (atoms/ion)	3.2	2.4
Sputtering rate at 30 keV on silicon (µm³/nC)	0.4	0.28
Maximum probe current	2 µA	50 nA





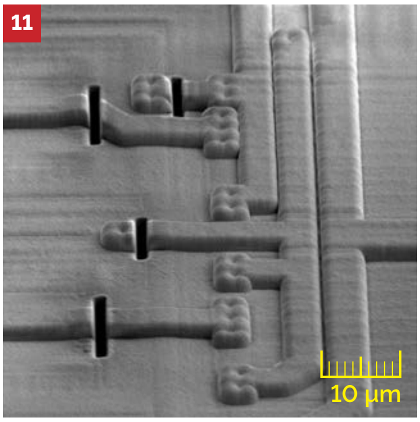


Fig. 9: Detail of a cross-section in a solder bump imaged at 10 keV with the BSE detector.

Fig. 10: Cross-section through a TSV device, image taken at 10 keV with the In-Beam detector.

Fig. 11: Modifying a circuit with FIB, image taken at 1 keV.

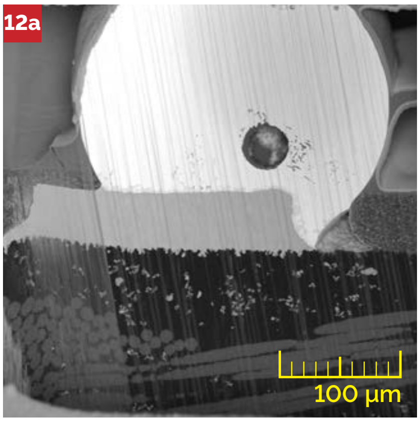
Rocking Stage: for speeding up cross-sectioning tasks with impeccable finishing

While on the one hand a Xe plasma ion column delivers high sputtering rates which are ideal for milling large volumes in short period of times, on the other hand surfaces milled with high current plasma FIBs are more prone to curtaining effects. This fact makes it imperative to have a good strategy for milling applications and the Rocking Stage is an essential tool to optimise such strategies.

The Rocking Stage is a novel patented multi-tilt sample stage which also allows for real-time SEM imaging during FIB operations. It greatly simplifies FIB operations and significantly reduces curtaining effects.

Cross-sectioning and lamellae preparation for TEM analysis are the most important FIB applications in the semiconductor industry. High quality surface finishing is crucial to detect small structures and to determine possible failures in integrated circuits. Artifacts such as the curtaining effect and other surface damages undermine the smoothness of the surface at the cross section and therefore interfere with the inspection process. As far as lamellae preparation is concerned, their surfaces need to be as smooth as possible in order to avoid unwanted topographical effects that reduce the ratio of transmitted electrons.

Conventional 5-axis eucentric stages allow for tilting the sample only about the perpendicular axis to the SEM and FIB columns. This represents a limitation for imaging the milling process in real time with the SEM column, making FIB cross-sectioning applications ineffective and time consuming. The Rocking Stage is the essential tool to optimise FIB applications on a wide variety of samples in order to obtain the highest throughputs.



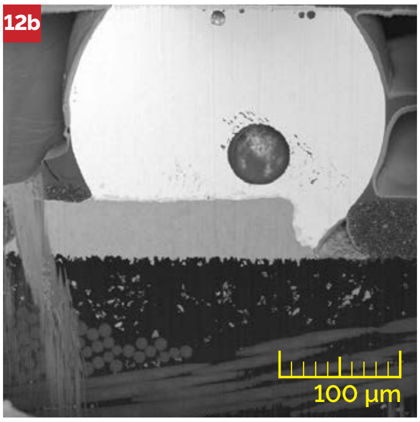


Fig. 12: **a)** A solder bump cross-sectioned with a wrong milling strategy; the curtaining effects are clearly visible. **b)** Surface after polishing in different directions using Rocking Stage. As it can be seen, the curtaining effects have been significantly reduced.

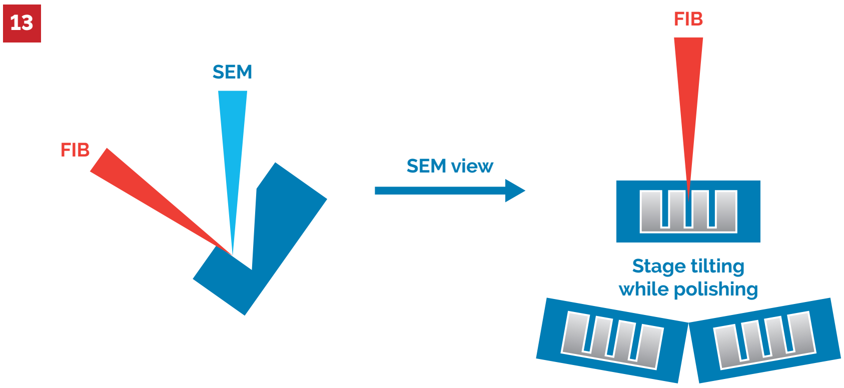


Fig. 13: An illustration of how the Rocking Stage tilts the sample during polishing a TSV.

Highlights of the Rocking Stage

- **Unique multi-tilt sample stage.** The Rocking Stage allows for tilting the sample about an axis perpendicular to the cross section plane up to a maximum of ± 10° in all directions. A pivot is created at any location on the sub-stage in the SEM and FIB view.
- **Piezo-drives for enabling 6-axis precise movements**
- **Multi-direction surface milling.** The additional tilting allows for milling the cross section from different directions.
- **Absolute control of the entire cross-sectioning process in real time by SEM imaging**
- **Significant reduction of the curtaining effect.**
- **Reliable end-point detection** which is achieved with the assistance of SEM imaging at all times during milling operations.
- **Wizard** for guiding the user in setting up the Rocking Stage
- **Integration with DrawBeam.** Rocking Stage is fully integrated with DrawBeam for ultimate milling application automation.

Enhance your imaging and FIB applications with the latest technology: low-energy BSE down to 200 eV acceleration voltage - without beam deceleration

■ TESCAN In-Beam Detectors

The magnetic field induced by the single-pole objective lens drives the secondary electrons (SE) into the electron column in the direction along the optical axis of the column. The **In-Beam SE** detector then enables high SE signal which results in images with excellent resolution, especially at low voltages and short working distances. The **In-Beam BSE** detector is based on the high quality scintillator. The images can be taken at very short working distances and the space under the objective is free for other detectors. Both, low-angle (standard BSE) and high-angle (In-Beam BSE) backscattered electrons detectors can be used at the same time for excellent imaging. Imaging at energies as low as 200 eV is possible with the low energy BSE detector, which is capable of working in the whole range of accelerating voltages: 0.2 to 30 keV. The In-Beam detectors can be combined with the **Beam Deceleration Technology (BDT)**, a solution for ultra-high resolution imaging at ultra-low landing electron voltages.

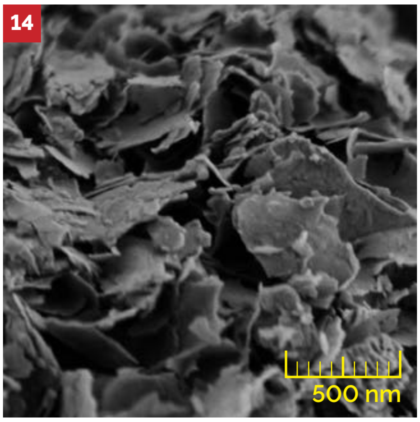


Fig. 14: Image at 1 keV using the SE (BDM) detector.

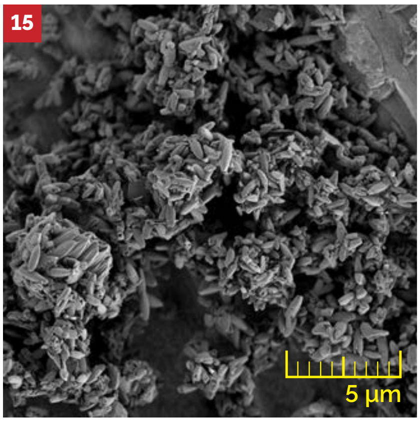


Fig. 15: Aragonite imaged at 1 keV using the SE (BDM) detector.

■ TESCAN Automatic Load Lock

The Load Lock is an optional accessory for TESCAN's SEMs. It allows for quick sample exchange without the necessity of venting the chamber. The Load Lock developed by TESCAN is fully integrated in the automatic vacuum system of the microscope. The main SEM chamber remains pumped during the Load Lock manipulation. The Load Lock is used for demanding applications where the time of sample exchange should be as low as possible, or where no significant vacuum loss during specimen exchange is required. The samples are exchangeable in a retractable cabinet gate which is subsequently evacuated within 15 seconds.

■ Highlights

- The design of the loading chamber provides the user with the possibility to exchange up to 7 samples at once and up to 95 mm in size.
- Suitable for demanding applications where the time of sample exchange should be kept as little as possible
- Ideal for applications in which minimal vacuum loss during specimen exchange is of the utmost importance (e.g. FIB-SEM).

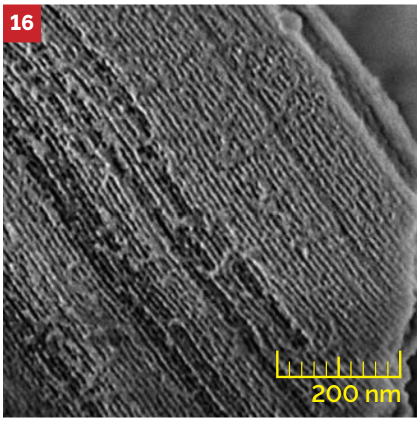


Fig. 16: Silicon powder imaged at 1.2 keV with the SE (BDM) detector.

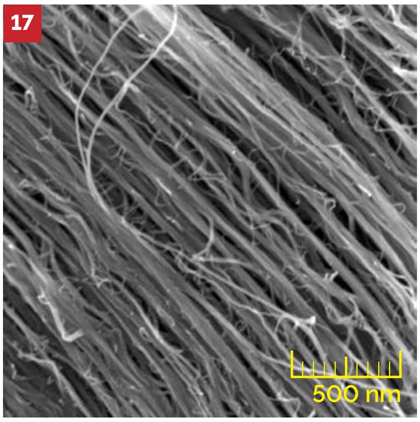


Fig. 17: Carbon nanotubes imaged at 2.5 keV with the In-Beam detector.

Fig. 18: TESCAN Automatic Load Lock.

Flood Gun for charge compensation

When the sample is non-conductive such as glass, ceramics or polymers, a low energy electron Flood Gun can be used to provide positively charge neutralisation. In non-conductive specimens, the ion beam creates a build-up of positive charge on the sample surface during the milling. The amount of charge build-up and the period of time this charge remains on the sample is a complex process that depends on the ion beam current and the electric properties of the sample surface, etc. Charging effects can cause severe damage on the sample surface and the charge build-up can also deflect the ion beam leading to the misplacement of the ion beam during milling process thus spoiling the entire etching task. The Flood Gun assures a stable electron current during FIB imaging and machining for highly insulating materials. The Flood Gun provides the solution to successfully overcome all these complications.

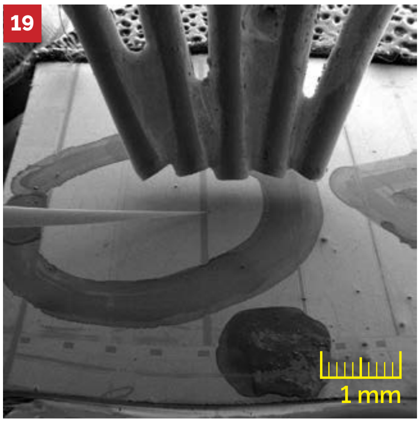


Fig. 19: The Gas Injection System at work.

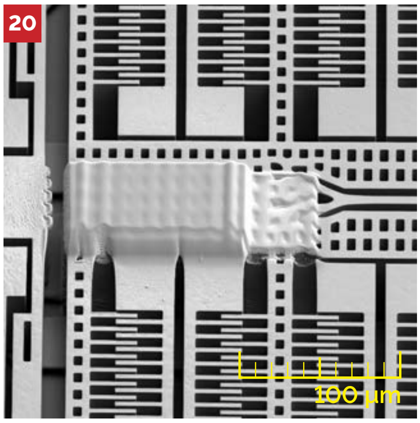


Fig. 20: Platinum deposition on MEMs.

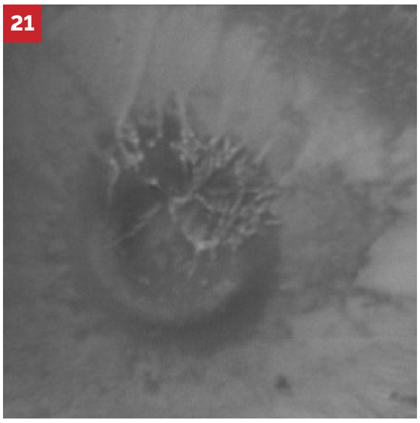


Fig. 21: Charging effects can severely damage the sample during FIB operations.

Fig. 22: The Flood Gun effectively compensates for sample charging. FIB milling carried out with no charge compensation.

Gas Injections System (GIS)

GIS is a tool which is used to enhance and optimise a wide range of FIB and SEM applications.

Highlights

- Deposition for protecting the sample and reducing charging effects during FIB milling and TEM lamellae preparation (W, Pt, SiO_x)
- Speeding up milling process (XeF_2 used in Si)
- The reduction of curtaining artifacts in some materials
- Nano-patterning and complementing lithographic techniques
- Enhanced or selective etching for milling multi-layers samples (Si, SiO_2, Si_3N_4, H_2O)

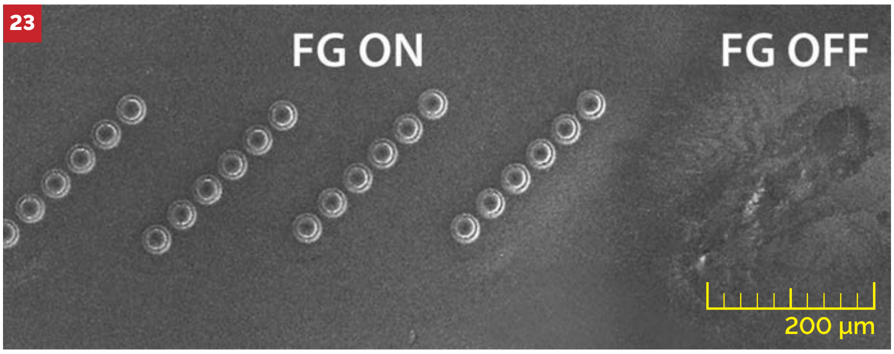


Fig. 23: SEM image of a set of circles milled into a glass sample using 2 µA FIB current. The Flood Gun (FG) was set to 50 eV electron energy and the emission currents were varied from 40 µA to 10 µA. With FG on, the sample charging was fully compensated. After the FG was turned off, the charging of the sample caused the total destruction of the milled structures.

Make the most of the SEM/FIB beams in all your applications

Make the most of your FIB-SEM system by enhancing the capabilities of the electron and ion beam and by having full control over all your applications. TESCAN software modules are aimed at helping to conduct advanced applications in an easy and simplified way as well as allowing for automation of different processes in your applications.

DrawBeam

DrawBeam is a powerful software module specially designed for enabling advanced patterning capabilities in electron/ion beam lithography, multi-layer setting for processing of sample, creating various defined structures on specimen surfaces at nanoscale as well as live-imaging during the milling process. It allows for creating and editing different designs and objects. Moreover, these objects can be created in different layers, each with their own parameters and required setting for exposition, etching, and deposition. In the basic DrawBeam version the scanning speed is 80 ns/ pixel. The advanced version has a minimum dwelling time of 20 ns/pixel and additionally the options for multiple write fields, stage navigation, and proximity effect correction are available.

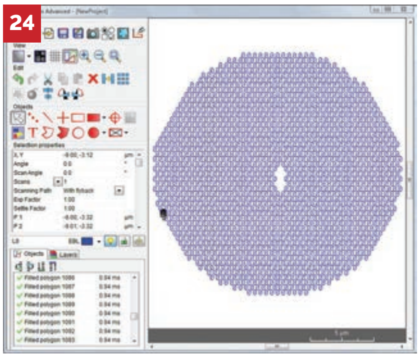


Fig. 24: Electron Beam Lithography patterning of a photonic crystal.

Synopsys Client

Synopsys is a correlative microscopy module for semiconductor applications which includes the Camelot software tool for CAD navigation, circuit edit and failure analysis in semiconductors. The Camelot software system is a CAD navigation software tool capable of reading and displaying the physical schematics and layout of a device such as an integrated circuit or a lithographic pattern. The CAD layout is displayed on top of the SEM/FIB image using the DrawBeam software as interface. In this way, Camelot is used for the correlation of electronic semiconductor design data with a physical semiconductor device. Camelot is an indispensable tool for electron/ion lithography applications and for all FIB applications such as modification of the sample either for the purposes of prototyping and circuit editing or failure analysis in semiconductor industry and in fab. Camelot provides more than 50 different types of predefined analyses; therefore, it optimises all resources in semiconductor failure analysis applications.

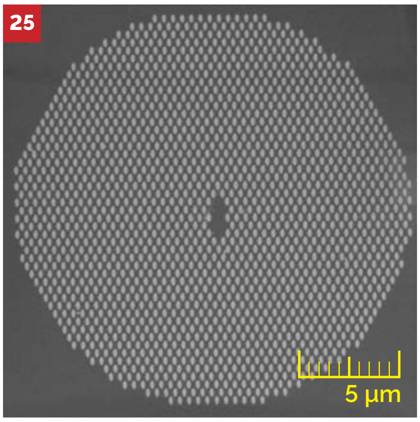


Fig. 25: SEM imaging of a photonic crystal.

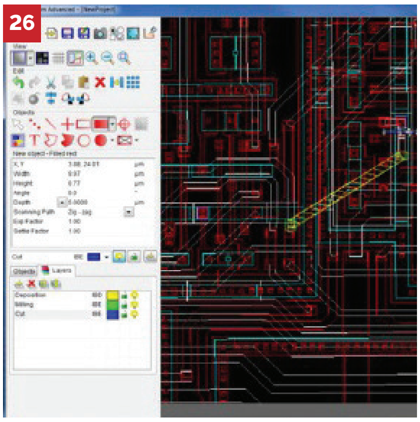


Fig. 26: CAD layout in the DrawBeam software.

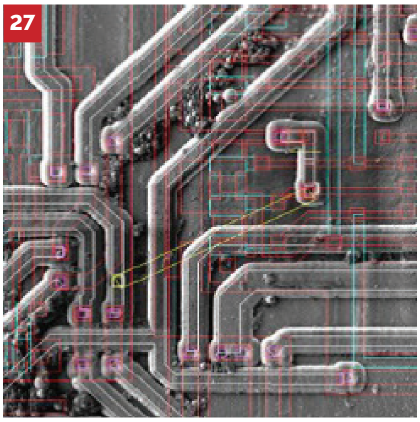


Fig. 27: Design data superimposed on top of FIB image for circuit editing.

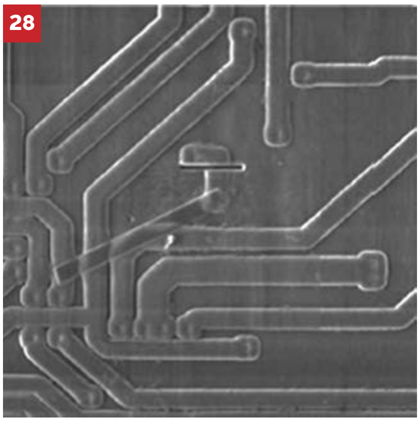


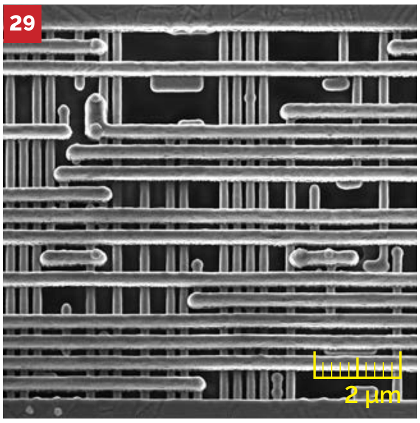
Fig. 28: Finished circuit editing.

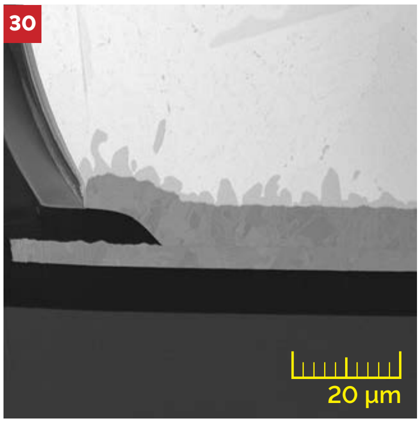
Applications

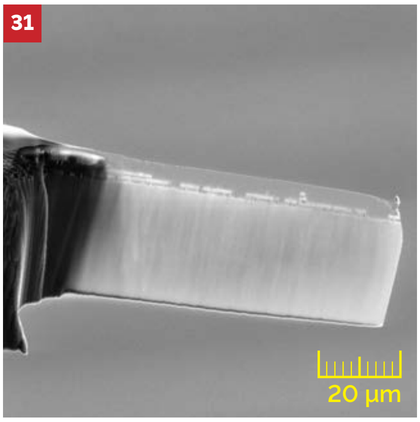
- **Semiconductors and Microelectronics**

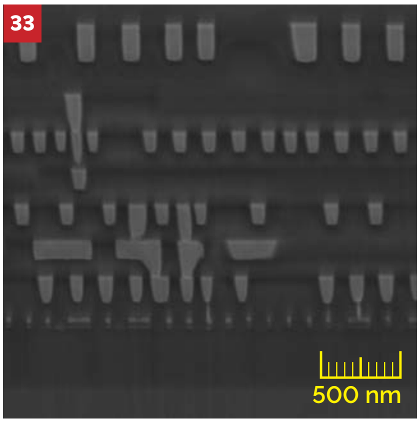
The powerful Xe plasma ion column makes XEIA3 the system of choice for the semiconductor and microelectronic industry. High currents for rough milling, ideal for lamellae preparation or large cross sectioning; medium current for polishing and reducing surface artifacts (curtaining effect); small current for fine polishing of cross sections and lamellae.

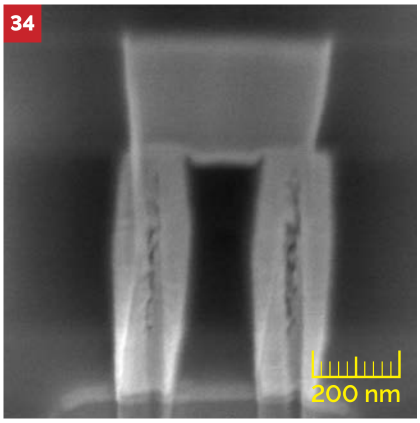
- **Trough-Silicon-Vias (TSV) analysis**
- **Integrate Circuits (IC) and Microelectromechanical Systems (MEMS) and Failure Analysis**
- **IC inspection and editing**
- **3D Tomography of Integrated Circuits**
- **Solar cells inspection and efficiency analysis**
- **Electron and Ion Beam Lithography**
- **Nano-prototyping**
- **In-situ lamellae imaging with the STEM detector**

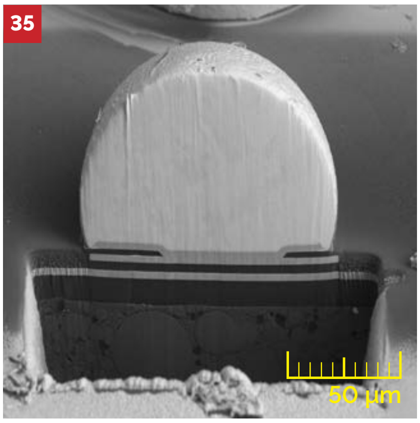












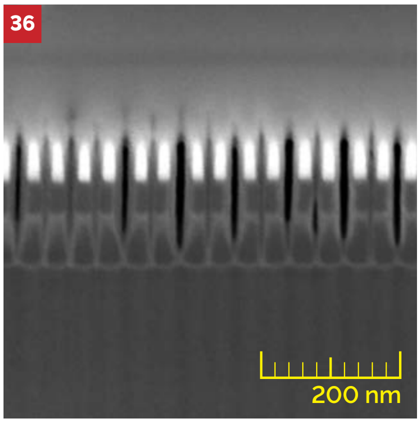


Fig. 29: Metal deposition for circuit editing, image taken at 5 keV with the In-Beam detector.

Fig. 30: Detail of the cross-section in a solder bump connection for inspection purposes. The image was taken at 10 keV with the In-Beam BSE detector.

Fig. 31: Large TEM lamella prepared with Xe plasma FIB and the Rocking Stage, imaged at 10 keV with the SE detector.

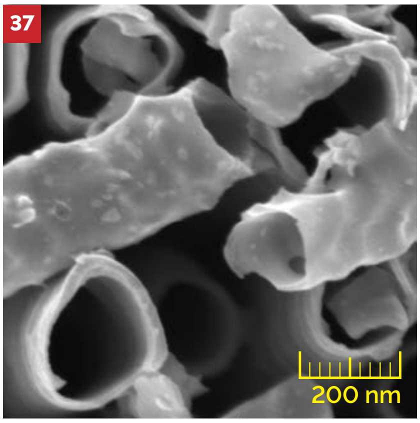
Fig. 32: Cross-section of TSV imaged at 3 keV with the In-Beam detector.

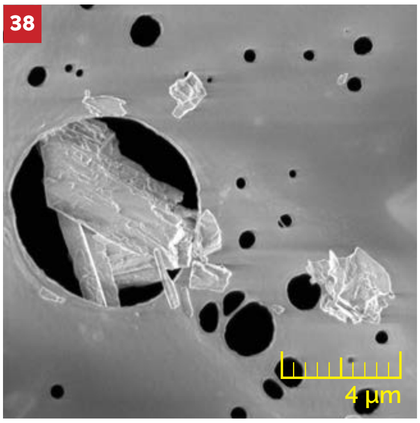
Fig. 33: Detail of the cross-section in an IC device imaged at 2 keV with the In-Beam detector.

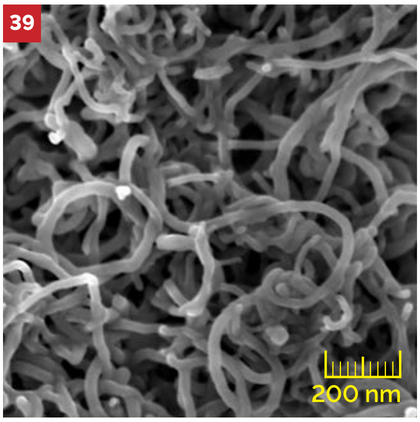
Fig. 34: Detail of a cross-section of an IC imaged at 5 keV with the In-Beam SE detector.

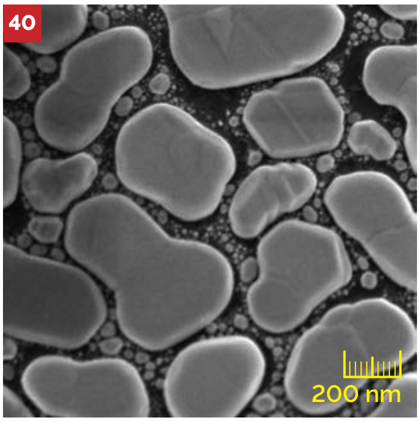
Fig. 35: Cross-section of a solder bump imaged at 10 keV with the BSE detector.

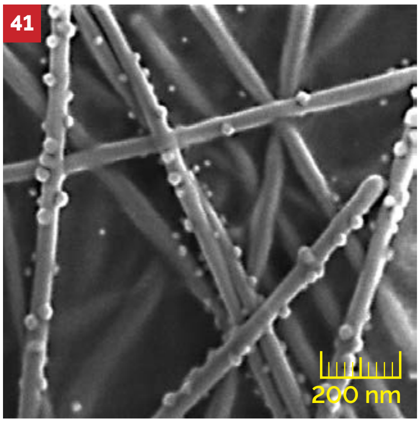
Fig. 36: Cross-section of a storage device component imaged at 5 keV with the In-Beam detector.

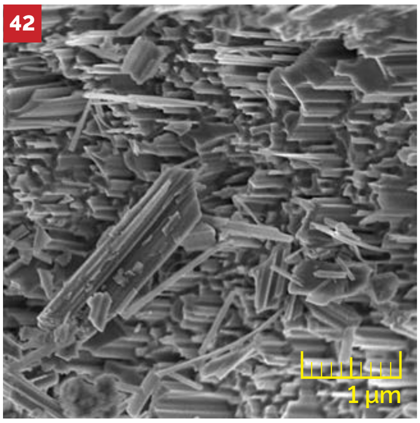


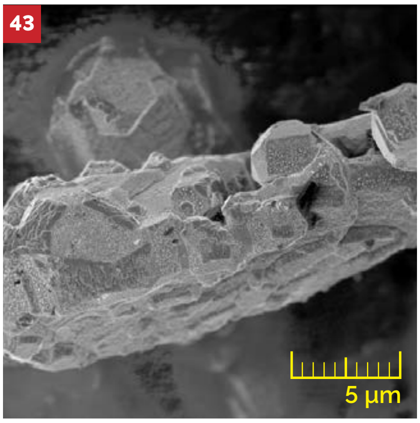


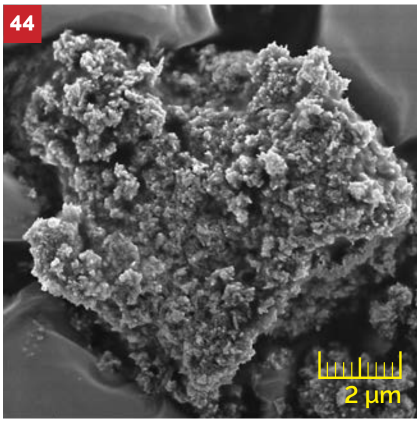












Materials Science

Xe plasma source provides great advantages for making the most of chemical and compositional analytical techniques such as energy and wavelength dispersive X-ray spectroscopy, large scale 3D EDX and 3D EBSD reconstructions as well as full integration with TOF-SIMS for achieving superior resolution in surface analysis. XEIA3 is an extraordinary robust analytical platform with far reaching research potential in materials science.

- **Research in new materials and their characterisation**
- **Study of non-conductive materials such as crystals, ceramics and polymers**
- **Patterning of complex nanostructures**

A series of different materials science samples imaged at low accelerating voltages. Some of the samples have high topography, so they are not suitable to be observed with the BDM.

Fig. 37: TiO_2 nanotubes imaged at 1 keV with the SE (BDM) detector.

Fig. 38: Fullerene imaged at 1 keV with the In-Beam detector.

Fig. 39: Carbon nanotubes imaged at 2 keV with the SE (BDM) detector.

Fig. 40: Golden grains on carbon imaged at 1 keV with the SE (BDM) detector.

Fig. 41: Ag wires imaged at 1 keV with the In-Beam detector.

Fig. 42: Cross-section surface on silicon imaged at 2 keV with the SE (BDM) detector.

Fig. 43: Ag electrode imaged at 2 keV with the In-Beam detector.

Fig. 44: Hydroxyapatite biomaterial imaged at 5 keV with the In-Beam detector.

- **Fast compositional 3D analysis**
  The high performance Xe plasma ion source allows for rapid data acquisition which in turn, enables to analyse large volumes of the sample in short period of times. The XEIA3 equipped with an EDX spectrometer and an EBSD analyser delivers fast large-scale 3D EDX and EBSD reconstructions for investigating the elemental compositional aspects as well as crystallographic information of the sample. The results from 3D EDX and 3D EBSD of samples such as solder bumps or TSV respectively show that by using the XE plasma FIB it is possible to perform high quality 3D sample tomographies along with important analytical information such as elemental distribution in composition and crystal orientation in a feasible and competitive times.
- **TOF-SIMS**
  Time-of-Flight Secondary Ion Mass Spectrometry is a technique that allows for a high precision compositional surface analysis. The interaction volume of secondary ions created by the ion column is smaller than that of X-rays generated by the electron beam. This results into a better resolution capability compared to other chemical characterisation techniques such as EDX and WDX. The analytical resolution in TOF-SIMS allows for the detection of light elements (e.g. Li, B, Be can be detected at concentrations of few ppm), isotopes and the distribution of individual elements in the analysed volume. Depth profiles can be also achieved to determine the distribution of different chemical species as a function of the depth of the surface. Xe plasma ion source provides significant advantages for TOF-SIMS, such as high yield of secondary ions, no interference in the mass spectrum and enhanced detection limits. TOF-SIMS can be fully integrated with XEIA3 for 3D chemical mapping, a high sensitivity analysis, distinguishing of isotopes, without the need of additional ion sources.

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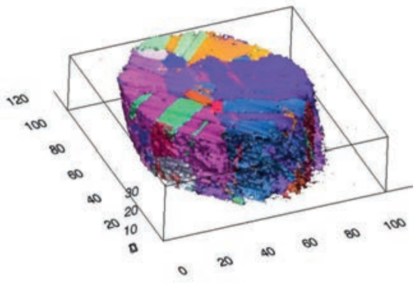

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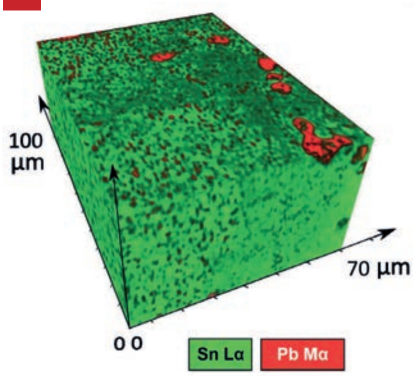

Fig. 45: 3D EBSD reconstruction of a Copper wire used in microelectronics. The volume 100 × 100 × 30 µm³ was analysed within 2.5 hours using the XEIA3 Xe Plasma FIB-SEM . Crystal orientation was mapped using a colour coded inverse pole figure (IPF-Z). All scales in µm.

Fig. 46: EBSD reconstruction of a copper TSV showing no preferred orientation.

Fig. 47: 3D EDS reconstruction of a solder structure by the XEIA3 Xe Plasma FIB-SEM. The volume of 100 × 70 × 45 µm³ was analysed and all data were acquired in about 2.3 hours. Reconstruction of a composite 3D elemental map using SnL_α and PbM_α.

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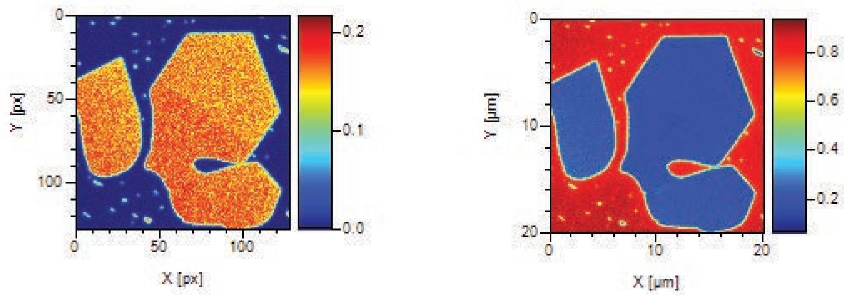

Fig. 48: BeAl alloy: $^{9}Be^{+}$ (left) and $^{27}Al^{+}$ (right) distribution maps.

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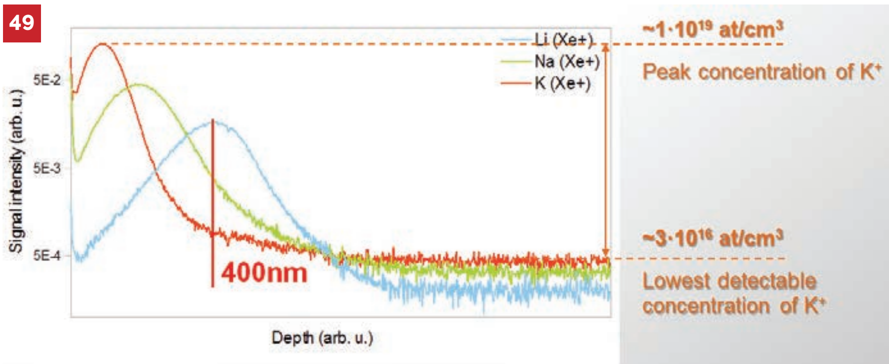
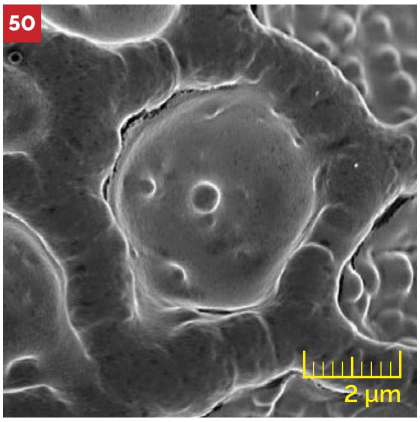
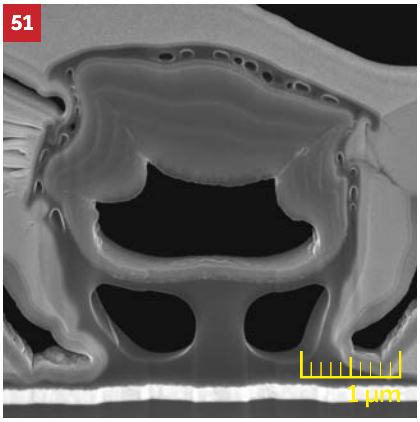
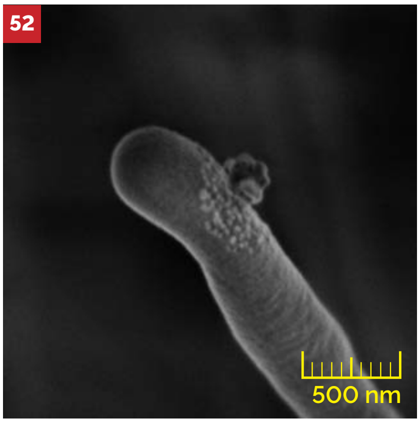
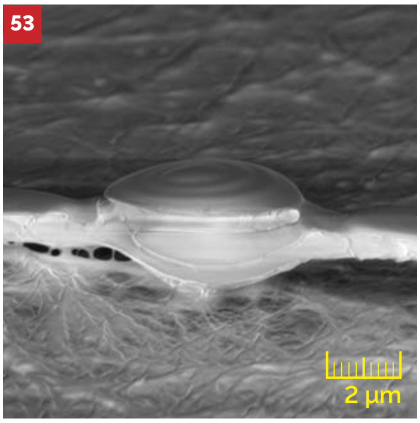


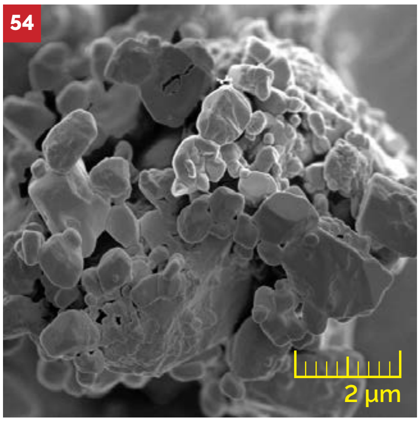
Fig. 49: TOF-SIMS detection limit with Xe⁺ beam. The detection limit for Li, Na and K less than 1×10^{17} at/cm³ which is 2 ppm atomic obtained without any additional method for yield enhancement.

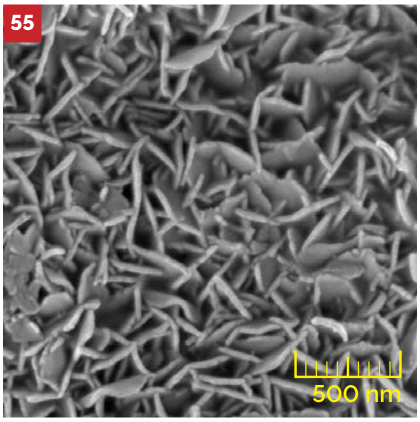


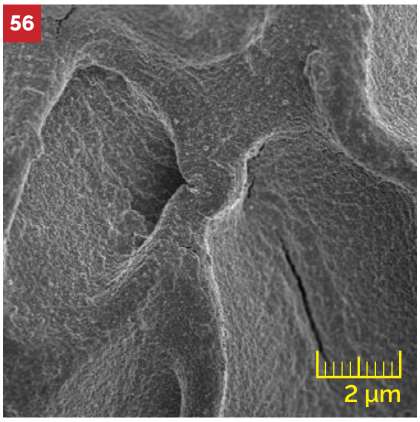


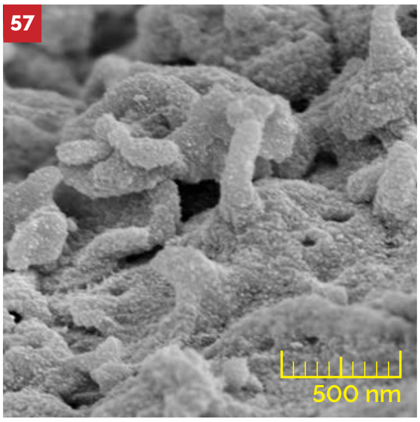












Life Sciences

XEIA3 superb imaging capability is designed for imaging a wide variety of sensitive biological samples in their natural state. This represents a great advantage as no coatings or chemical fixing of these types of samples are needed, which makes the whole analysis process much simpler.

- Microbiology
- Biomedical engineering
- Cell and tissue biology
- Cellular analysis
- Pharmaceutics
  - **Study of dynamic processes** such as crystallization or dissolution of substance
  - **Study of particle properties** such as the particle size, porosity, structure and contaminants

Images of biological samples at low accelerating voltage (with no BDM). The samples were observed without any coatings. The surface topography of some of these samples is not suitable for BDM, as this technology works best on flat samples and normal to the lens. The resolution power of the single-pole objective lens makes possible their observation at low voltages.

Fig. 50: Pollen imaged at 2 keV with the In-Beam detector.

Fig. 51: Lamella from a peptide imaged at 5 keV with the In-Beam detector.

Fig. 52: Mold fiber imaged at 800 eV with the In-Beam detector.

Fig. 53: Peptide imaged at 700 eV with the In-Beam detector.

Fig. 54: Pharmaceutical powder imaged at 2 keV with the In-Beam detector.

Fig. 55: Crop imaged at 2 keV with the In-Beam detector.

Fig. 56: Biomaterial imaged at 2 keV with the In-Beam detector.

Fig. 57: Mouse brain tissue imaged at 3.1 keV with the In-Beam detector.

XeF_2 injection for ultrafast large-area polishing using Xe plasma FIB

Milling with a high current ion beam can cause in some cases surface artifacs. One method to deal with this situation is to use an optimised FIB scanning strategy in combination with the novel TESCAN Rocking Stage. The Rocking stage allows for tilting the sample during the milling process so that the direction of the ion beam can be changed, a strategy which has been proven to be effective for reducing curtaining effects on the milled surfaces. Alternatively, another promising way for removing surface artifacs has been found. It consists of injecting xenon difluoride (XeF_2) precursor – by using a Gas Injection System (GIS) - during the FIB polishing process.

Introduction

Fast milling rates and high quality artifact-free surfaces are two essential and desired elements when preparing cross-sections in samples for the purposes of failure analysis. When compared to conventional Ga ion sources the Xe plasma ion source reduces dramatically the time for cross-sectioning from tens of hours or even days to a matter of hours. However, this comes with a price; the high milling rates achievable with plasma sources can, in some cases, lead to the appearance of unwanted curtaining effects which are even more significant than those produced with Ga ion sources. A low current (1 nA – 10 nA) FIB polishing can be performed for removing surface artifacts, however, this turns out to be an extremely time-consuming process when one of the sides of the cross section area exceeds 100 µm.

An efficient and fast technique for removing these artifacts is by FIB polishing at medium currents (100 nA – 300 nA) from two different directions. This is achievable by using the novel multi-axis Rocking Stage developed by TESCAN. Furthermore, another way of getting rid of curtaining effects has been recently developed. Such a method is based on the use of gas-assisted FIB-inducing etching. This procedure allows for achieving excellent surface, which is crucial for keeping the total time of analysis short. The total processing time of a 100 µm wide cross-section in copper can be reduced to 15 minutes without the necessity of rocking the sample.

Experimental details

TESCAN Xe plasma ion FIB-SEM XEIA3 system was used in combination with a xenon difluoride precursor gas injection system. Halogen-based reactive gases (e.g. I_2, XeF_2, Cl_2) are used in combination with FIB for enhancing etching rates up to 15 times and in some cases, such as XeF_2 on a silicon substrate the enhancement can be up to 1000 times. This is because of the spontaneous reactivity of the gas with Si which enables drilling of access trenches even through full-thickness silicon devices - a common practice in circuit-edit applications. Furthermore, it has also been found that the use of XeF_2 injection during plasma FIB polishing results in significant reduction in curtaining artifacts on micro-machined surfaces.

Results and discussion

Copper

Figure 58 shows the results of top-down ion milling on a copper sample with and without the assistance of XeF_2 gas. A cubic volume of 100 µm^3 was milled in 9 minutes using an ion beam current of 2 µA at 30 keV, the exposition pitch parameter was set to 700 nm, while the FIB dwelling time to 0.2 µs in both cases. Figure 58(a) shows the result obtained after milling without the assistance of any gas. It exhibits significant over-milling of the surface close to the milled area caused by the exponential tail of the the walls of the cube. It also shows a huge surface roughness which is the result of either different sputtering rate during the milling process, or, different copper grain orientation. Figure 58(b) shows the same task performed with the assistance of XeF_2. The difference is clearly visible; there is minimal over-milling of the sample surface and as a result, the edge of the structure is much better defined and additionally, the trench walls are smoother with almost no grain orientation milling selectivity.

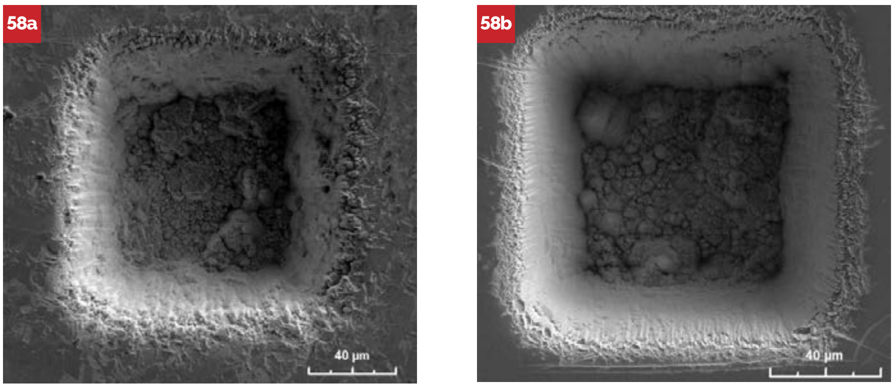


Fig. 58: Comparison of surface damage and trench shape after top-down ion milling of a Copper sample. A cubic volume of 100 µm^3 was milled in 9 minutes using an ion beam current of 2 µA. The exposition pitch was set to 700 nm while dwelling time 0.2 µs. **(a)** Milling without gas assistance. **(b)** Milling with XeF_2 injection.

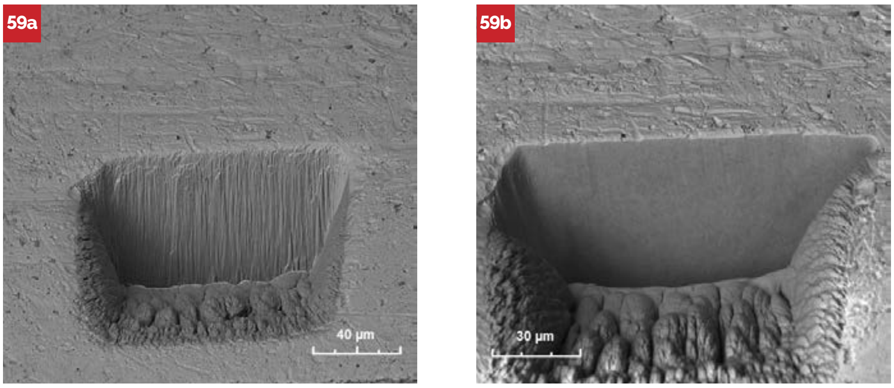


Fig. 59: Comparison of duplex steel surface quality after polishing using an ion beam current of 100 nA, exposition pitch 150 nm, dwell time 0.2 µs. **(a)** Polishing without gas assistance **(b)** Polishing with XeF_2 injection.

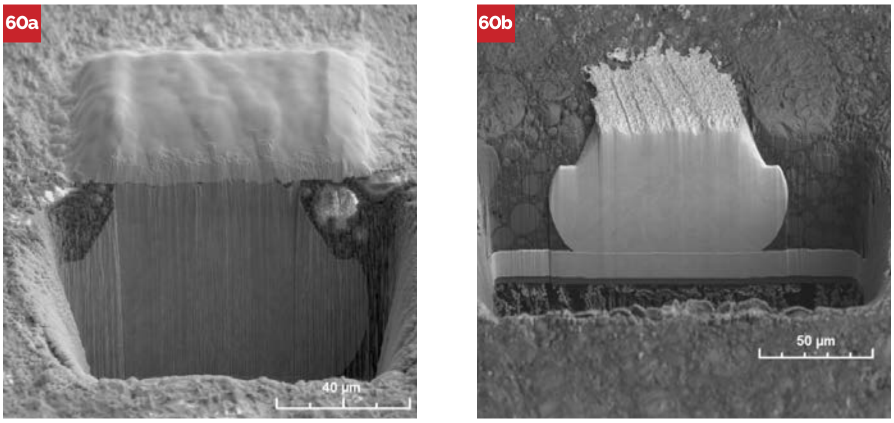


Fig. 60: Comparison of polishing quality of sample with combined materials (solder, mold compound, copper, silicon.) **(a)** Polishing without gas assistance. **(b)** Polishing with XeF_2 injection.

Duplex steel

A standard cross section (110 × 80 × 60 µm^3) was prepared in a duplex steel sample. The process consisted of rough milling for 10 minutes at ion beam current of 1 µA, followed by 100 nA polishing for 15 minutes. The resulting cross section –see figure 59(a) - shows curtaining effects. This is because zones with different grain orientation have different sputtering rate, and these effects are also caused by the non-homogeneity of the sample surface. XeF_2 gas assisted polishing is effective for removing not only the curtaining effects but also surface damage caused by the exponential beam tail so that surface non-homogeneity transition into cross section is neglected. Figure 59(b) shows the effect of XeF_2 gas injection-assisted polishing at ion current of 100 nA and exposition pitch of 150 nm and the dwelling time of 0.2 µs. The final surface is of very high quality and artifact-free, and as a result, the contrast due to grain orientation is clearly visible.

Solder ball in mold compound

The last example is a typical application for Plasma FIB in the semiconductor industry – a solder ball embedded in mold compound on a silicon substrate. A modern mold compound contains about 20 raw materials which are filled with 90 percent of fused silica. Due to the large variety of materials there is some material selectivity and a visible curtaining effect on the cross section (figure 60(a)), which is the result of different sputtering rates. The sample has undergone the following process. Firstly, a 10 µm thick layer of platinum was deposited on the sample surface in order to supress the surface topography. Subsequently, a trench of the dimensions of 110 x 120 x 90 µm^3 was milled with an ion beam current of 2 µA for 10 minutes. Lastly, final polishing by using ion beam currents of 300 nA and 100 nA was carried out. Figure 60(b) shows the final surface quality after 10 minutes of additional polishing with XeF_2 injection and an ion beam current of 100 nA. The metallic parts of the cross section were nicely polished, however, other parts of the sample contained at least some amount of silicon and due to the XeF_2 (due to its enhanced milling effect on silicon) such parts were milled selectively and essentially became decorated in the large scale.

Conclusion

The effect of XeF_2 injection during Plasma FIB polishing process was investigated using different materials and samples. The quality of metallic surfaces after polishing was significantly improved even when using medium beam currents. This can be helpful for automated slicing and viewing techniques such as 3D tomography and 3D EBSD where the slices are being milled only from one direction or when the rocking procedure is not suitable for such applications, see figure 61.

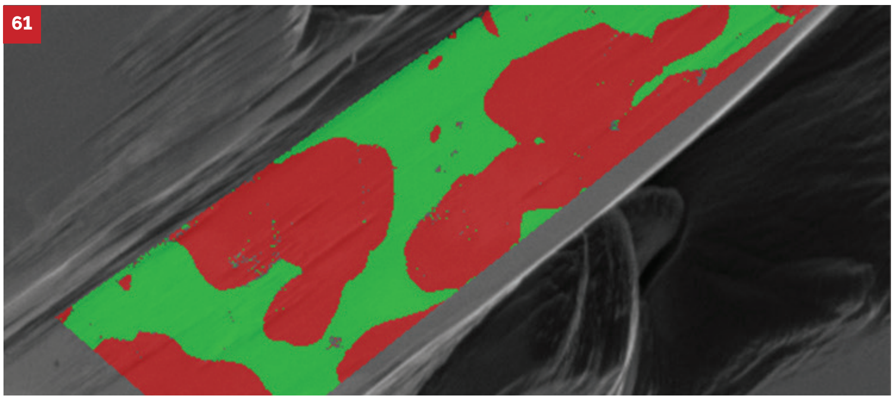


Fig.61: Pillar created in duplex steel for 3D tomography aquisition. One direction FIB slicing (140 µm x 700 µm x 1 µm) at ion beam current 100 nA was performed with XeF_2 gas injection followed by subsequent EBSD mapping of each slice. Image shows phase map of one slice.

Specifications

Electron Optics

Electron Gun	High brightness Schottky emitter
Resolution	
Standard mode In-Beam SE	1.0 nm at 15 keV 1.8 nm at 1 keV
Beam Deceleration Mode	1.4 nm at 1 keV
STEM detector (optional)	0.8 nm at 30 keV
Magnification at 30 keV	4× to 1,000,000×
Accelerating Voltage	200 V to 30 keV/ down to 50 V with BDT option
Probe Current	2 pA to 200 nA
Field of View	4.3 mm at $WD_{analytical}$ 5 mm, 7.7 mm at WD 30 mm
Electron Optics Display Modes	
Resolution:	Ultra-high resolution mode
Depth:	Sets the column up in a high-resolution mode that enhances depth of focus
Field:	Optimizes the column to provide a large non-distorted field of view, free-field mode suitable for magnetic samples

Ion Optics

Ion column	i-FIB
Resolution	25 nm at 30 keV at SEM-FIB coincidence point
Accelerating Voltage	3 keV to 30 keV
Magnification	Minimum 150× at coincidence point and 10 keV (corresponding to 1 mm view field), maximum 1,000,000×
Ion Gun	Xe plasma ion source
Probe Current	1 pA to 2.5 uA
SEM-FIB coincidence point	WD 5 mm for SEM

Gas Injection System

Standard precursors for GIS*	Tungsten metal deposition Platinum metal deposition Insulator SiO_x metal deposition Enhanced etching (H_2O) Enhanced or selective etching of Si, SiO_2, Si_3N_4, W (XeF_2)

*Other precursors available on request (e.g. carbon deposition)

Vacuum system

Chamber vacuum mode	High vacuum: < 9×10^{-3} Pa* Low vacuum: 7 – 500 Pa**
Gun vacuum	< 3×10^{-7} Pa
Pumping time after specimen exchange	< 3 minutes (LM), < 3.5 minutes (XM, GM),

*pressure < 5×10^{-4} Pa can be displayed with an optional WRG vacuum gauge on request
** with low vacuum aperture inserted

Chamber Configuration and Stage

Chamber size

XM	Dimensions	Internal diameter	285 mm (width) × 340 mm (depth)
		Door width	285 mm (width) × 320 mm (height)
		Number of ports	12*
	Stage	Movements	X = 130 mm (- 50 mm to + 80 mm)
			Y = 130 mm (- 65 mm to + 65 mm)
			Z = 90 mm
		Rotation	360° continuous
		Tilt	- 30° to + 90°
	Chamber and column suspension	Standard	Pneumatic
		Optional	Active vibration isolation (integrated)
GM	Dimensions	Internal diameter	340 mm (width) × 315 mm (depth)
		Door width	340 mm (width) × 320 mm (height)
		Number of ports	20*
	Stage	Movements	X = 130 mm (-65 mm to +65 mm)
			Y = 130 mm (-65 mm to +65 mm)
			Z = 90 mm
		Rotation	360° continuous
		Tilt	-60° to +90°
	Chamber and column suspension	Standard	Active vibration isolation (integrated)

* Configuration and number of ports can be modified to meet customer's needs

Scanning

Scanning speed	From 20 ns to 10 ms per pixel adjustable in steps or continuously
Scanning features	Point and Line Scan Focus Window – shape, size and position continuously adjustable Dynamic Focus – in plane of folded plane tilted up to ± 70° Image rotation, Image shift, Tilt compensation 3D Beam – defined tilting scanning axis around XY axis Live Stereoscopic Imaging Other scanning shapes are available through the optional DrawBeam software

Detectors

Standard	Optional+
SE – Secondary electron detector Everhart-Thornley type with scintillation crystal.	**SITD** – Secondary Ion TESCAN Detector; possible simultaneous SE and SI acquisition.
In-Beam SE – Secondary electron detector located inside the column and intended for high resolution and short working distances.	**Beam Deceleration Technology (BDT)** – For high resolution at low electron landing energies and SE detection inside the column. A decontaminator is optional.
Motorised Retractable BSE – Retractable annular backscattered electrons detector of scintillator type with high sensitivity and with an atomic number resolution of 0.1.	**STEM** – Scanning transmission electron microscope detector for Bright and Dark Field imaging and high angular Dark Field.
In-Beam BSE – Backscattered electrons detector with an annular scintillator mounted in-column that enables to obtain BSE images at very short working distances and imaging of the milling process at the highest FIB current.	**R-STEM** – Motorised retractable version of the STEM detector with a standard TEM grids holder and TEM lamellae holder.
IR TV camera – Live chamber view.	**Motorised CL Detector** – Retractable panchromatic Cathodoluminescence detector, two wavelength ranges available: 350 nm – 650 nm and 185 nm – 850 nm.
pA meter – Probe current measurements.	**Rainbow CL** – Retractable Color/Panchromatic Cathodoluminescence detector. RGB image processing is fully integrated in the microscope control software; no external scanning. Wavelength range: 350 nm – 850 nm.
Touch alarm – Alerts when the sample gets in contact with the chamber and stops any movements.	**EBIC** – Electron beam induced current detection.
	TOF-SIMS* - Unique Time-of-Flight Secondary Ion Mass Spectrometry. 3D compositional analysis is possible.
	EDX*,** – Take off angle: 25° at SEM WD 5 mm at coincident point.
	WDX* – Take off angle: 35° at SEM WD 5 mm at coincident point.
	EBSD* – Electron backscattered diffraction, ideally positioned to work at the coincident point.
	Optional Accessories+: Peltier Cooling stage, Beam Blanker for SEM column, Load Lock, Control Panel, Optical Stage Navigation, Nanomanipulators, Decontaminator/plasma cleaner.

+ Combinations of optional detectors and accessories must be discussed with TESCAN product specialists.
* Fully integrated third party products.
** The EDX detector has to be equipped with a shutter.

Software Extensions*

Standard	Optional
Analysis & Measurements	Particles Basic
Histogram	Particles Advanced
Image Processing	Sample Observer
3D Scanning	Image Snapper
Hardness	Input Director
Multi Image Calibrator	TESCAN TRACE GSR
Object Area	3D Metrology (MeX)
Switch-Off Timer	3D Tomography
Tolerance	3D Tomography Advanced
X-Positioner	System Examiner
Live Video	Cell Counter
DrawBeam Advanced	AutoSlicer
EasySEM™	Coral
	SYNOPSYS Client (Correlative microscopy module for semiconductor applications)

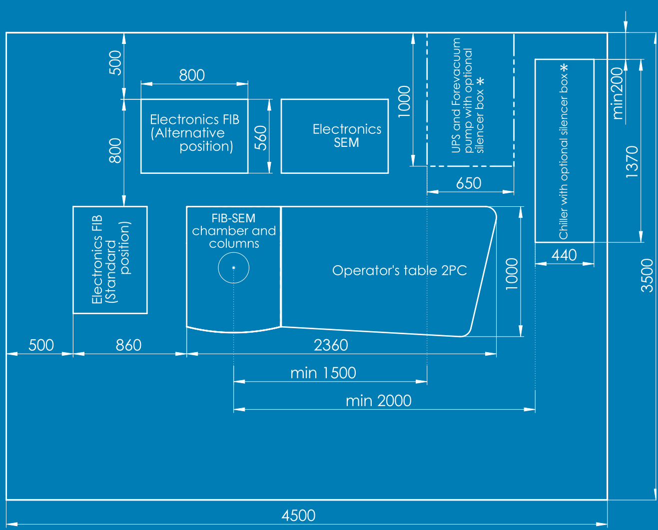
*For more information about software items please consult the Software Extension Modules brochure.

Installation requirements

Power	230 V ± 10% / 50 Hz (or 120 V / 60 Hz – optional) Power 2300 + 1000 VA (basic microscope + chiller)
Water cooling	Closed cooling circuit (no external water supply required)
Compressed air	600 – 800 kPa (6 – 8 Bars)
Compressed N for venting	150 – 500 kPa (1.5 – 5 Bars)
Compressed Xe	300 kPa (3 Bars)
System dimensions	See footprint
Room dimensions for installation	Minimum 4.5 × 3.5 m, minimum door width 1 m
Temperature of environment	17 – 24°C with a stability better than 1°C/hour
Relative humidity	< 65 %
Background magnetic field	Synchronous < 3×10^{-7} T Asynchronous < 1×10^{-7} T
Vibrations for active isolation	< 10 µm/s below 30 Hz < 20 µm/s above 30 Hz
Acoustic noise	< 60 dBc
Altitude	Maximum 3000 m above sea level

Automated Operations

In-Flight Beam Tracing™ beam optimisation for both, the electron and ion beams
Spot size and beam current continual
WD (focus) & Stigmator
Contrast & Brightness
Scanning Speed (according to signal-noise ratio)
Gun heating
Gun centring
Column centring
Vacuum control
Compensation for keV
Look up table
Auto-diagnostics
Setup of the FIB-SEM intersection point
GIS nozzles positioning and temperature control
Automated FIB and SEM emission start



Footprint of the microscope, all dimensions are in mm.

TESCAN
PERFORMANCE IN NANOSPACE

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