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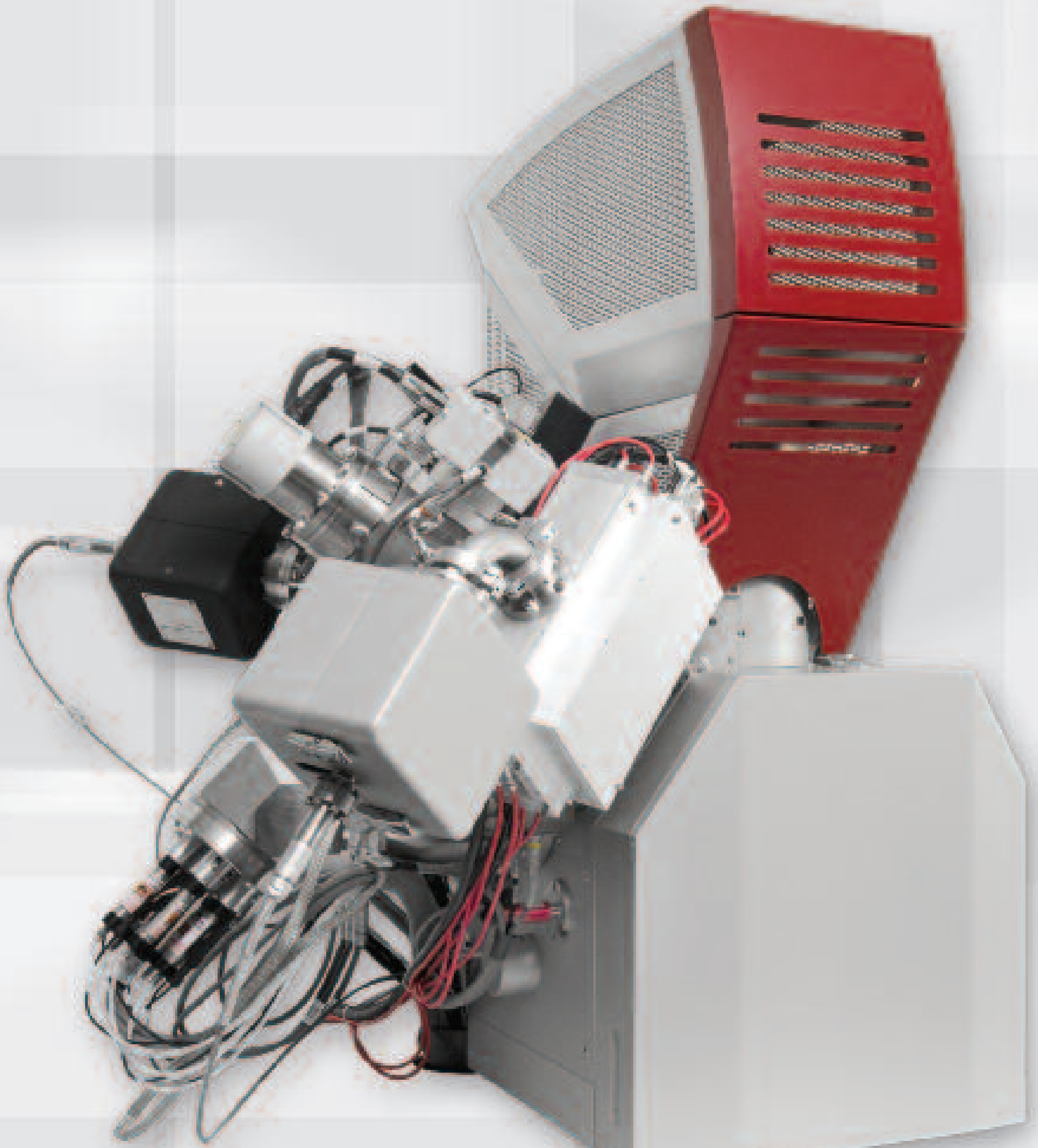

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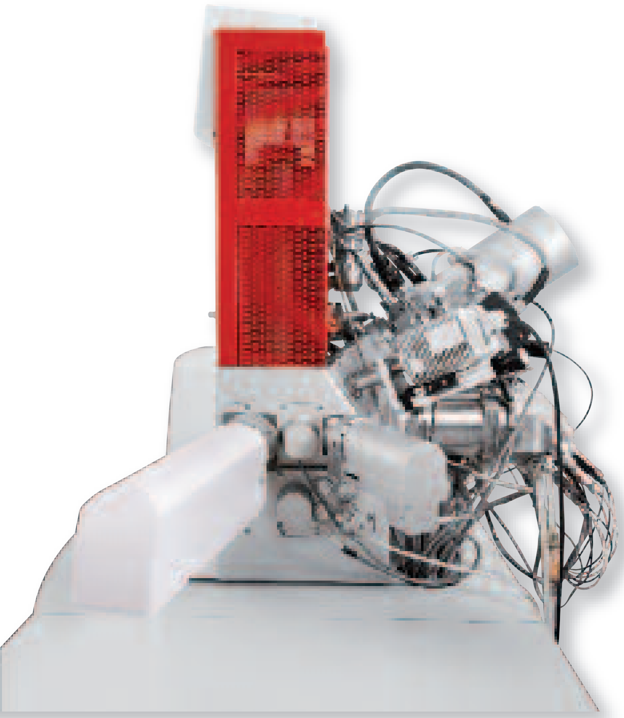


TESCAN Focused Ion Beam Scanning Electron Microscopes

This new generation of field emission scanning electron microscopes provides users with the advantages of the latest technology, such as new improved high-performance electronics for faster image acquisition, an ultra-fast scanning system with compensation for static and dynamic image aberrations or built-in scripting for user-defined applications, all the while maintaining the best price to performance ratio.

The LYRA3 series was designed with respect to a wide range of FIB-SEM applications and needs in today's research and industry. Its excellent resolution at high beam currents has proved to be advantageous for analytical applications such as EDX, WDX, EBSD, 3D tomography, etc. The powerful software turns this TESCAN FIB-SEM into excellent tool for other applications, such as e.g. electron/ion lithography, TEM sample preparation, etc.

LYRA3 is manufactured in configurations with XM and GM chambers.

Modern Optics

- A unique **Wide Field Optics**™ design with a proprietary Intermediate Lens (IML) offering a variety of working and displaying modes, for instance with enhanced field of view or depth of focus, etc.
- Real time **In-Flight Beam Tracing**™ for performance and beam optimization, integrated with the well-established software Electron Optical Design. It also includes direct and continuous control of the beam spot size and beam current.
- Fully automated electron optics set-up and alignment
- Fast imaging rate
- Unique live stereoscopic imaging using advanced **3D Beam Technology** opens up the micro and nano-world for an amazing 3D experience and 3D navigation.

High Performance Ion Optics

- Sophisticated high performance CANION FIB system for fast and precise cross-sectioning and TEM sample preparation
- Optional ultra-high resolution COBRA-FIB column represents the highest level of technology in terms of resolution both for imaging and milling. This is one of the most precise FIB instruments for nano-engineering in the world.

Analytical Potential

- All of the various chamber models provide superior specimen handling using a full 5-axis motorized compucentric stage and ideal geometry for EDX and EBSD.
- Option of extra-large XM and GM chambers with robust stage able to accommodate large samples
- Numerous interface ports with optimized analytical geometry for EDX, WDX and EBSD as well as for attaching many other detectors
- First-class YAG scintillator-based detectors
- Selection of optional detectors and accessories
- Full operating vacuum can be obtained quickly and easily.
- Investigation of non-conductive samples in variable pressure mode versions, favorable conditions for the investigation of magnetic samples, non-distorted EBSD pattern compared to immersion magnetic lenses
- Integrated active vibration isolation ensures effective reduction of ambient vibrations in the laboratory.

User-Friendly Software

- Multi-user environment is localized in many languages.
- Image management and report creation
- Built-in self-diagnostics for system readiness checks
- Network operations and remote access/diagnostics

Software Tools

- Modular software architecture enables several extensions to be attached.
- Basic set of Software modules, such as highly automated ion beam control; DrawBeam Basic pattern generator; Simultaneous FIB/SEM imaging; Predefined FIB working profiles available as standard
- Several optional modules or dedicated applications optimized for automatic sample examination procedures, such as Particles Basic/Advanced or 3D surface reconstruction, etc.
- DrawBeam software module turns the focused ion beam provided scanning electron microscope into a potent instrument not only for electron beam lithography, but also for electron beam deposition and electron beam etching as well as for ion beam deposition and ion beam milling.
- 3D Tomography software option provides fully automated procedure of serial SEM imaging of FIB-prepared cross-sections and subsequent 3D reconstruction and visualization.

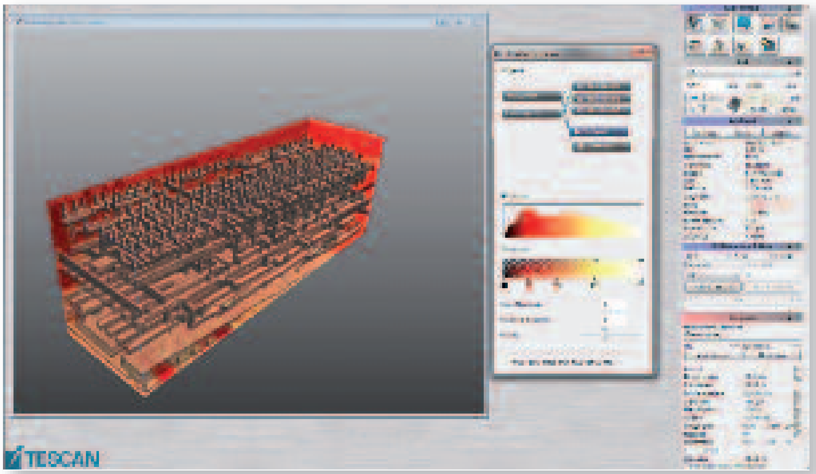


Fig. Screenshot showing 3D Tomography module (displayed volume and visualization settings)

Rapid Maintenance

Keeping the microscope in peak condition is now easy and requires a minimum of microscope downtime. Every detail has been carefully designed to maximize microscope performance and minimize operator's effort.

Automated Procedures

Automatic set-up of the microscope and many other automated operations are characteristic features of the equipment. There are many other automated procedures which reduce the operator's tune-up time significantly, enable automated manipulator navigation and automated analyses. SharkSEM remote control interface enables access to most microscope features, including microscope vacuum control, optics control, stage control, image acquisition, etc. The compact Python scripting library offers all these features.

Software Tools

Image Processing	●
Object Area	●
Hardness	●
Tolerance	●
Multi Image Calibrator	●
Switch-Off Timer	●
3D Scanning	●
X-Positioner	●
Live Video	●
Histogram	●
Analysis & Measurement	●
EasySEM™	●
Particles Basic	○
Particles Advanced	○
Image Snapper	○
DrawBeam Basic	●
DrawBeam Advanced	○
3D Tomography	○
3D Tomography Advanced	○
Sample Observer	○
3D Metrology (MeX) *	○
Input Director	○
Cell Counter	○
TESCAN TRACE GSR	○
System Examiner	○
AutoSlicer	○
Coral	○
SYNOPSYS Client	○

● standard, ○ option,
* third party dedicated software by Alicona Imaging GmbH

LYRA3

Electron Optics

Resolution	
In high-vacuum mode SE	1.2 nm at 30 kV 2.5 nm at 3 kV
In high-vacuum mode In-Beam SE	1.0 nm at 30 kV 1.8 nm at 3 kV
In high-vacuum BDM (Beam Deceleration Mode)	3.5 nm at 200 V
In low-vacuum mode LVSTD	1.5 nm at 30 kV
In low-vacuum mode BSE	2 nm at 30 kV
STEM Detector	0.9 nm at 30 kV
Electron optics working modes	
High-vacuum mode	Resolution, Depth, Field, Wide Field, Channelling
Low-vacuum mode	Resolution, Depth
Magnification	Continuous from 1x to 1,000,000x
Field of view	6.0 mm at WD $_{analytical}$ 9 mm 17 mm at WD 30 mm
Accelerating voltage	200 V to 30 kV / 50 V to 30 kV with BDT (Beam Deceleration Technology) option
Electron Gun	High Brightness Schottky Emitter
Probe current	2 pA to 200 nA

Ion Optics

Ion column	Canion / Cobra
Resolution	< 5 nm at 30 kV / < 2.5 nm at 30 kV (at SEM-FIB coincidence point)
Magnification	Minimum 150x at coincidence point and 10 kV (corresponding to 1 mm view field), maximum 1,000,000x
Accelerating Voltage	0.5 kV to 30 kV
Ion Gun	Ga Liquid Metal Ion Source
Probe Current	1 pA to 40 nA / 1 pA to 50 nA
SEM-FIB Coincidence at	WD 9 mm for SEM – WD 12 mm for FIB; Automatic set up of the coincidence point of the electron and ion beam
SEM-FIB angle	55°

Vacuum System

System pressure:	
Chamber - High-vacuum mode	$< 9 \times 10^{-3}$ Pa*
Chamber - Low-vacuum mode	7-500 Pa**
Electron Gun	$< 3 \times 10^{-7}$ Pa
FIB Gun	$< 5 \times 10^{-6}$ Pa
	* pressure $< 5 \times 10^{-4}$ Pa reachable ** with low vacuum aperture inserted
Microscope control	All microscope functions are PC-controlled using trackball, mouse and keyboard via the program LyraTC using the Windows™ platform.
Scanning speed	From 20 ns to 10 ms per pixel adjustable in steps or continuously
Scanning features	Focus Window, Dynamic focus, Point & Line scan, Image rotation, Image shift, Tilt compensation, 3D Beam, Live Stereoscopic Imaging (SEM), Other scanning shapes available through DrawBeam Software

Image size	16,384 x 16,384 pixels***, adjustable separately for live image(in 3 steps) and for stored images (11 steps), selectable square or 4:3 or 2:1 rectangle **** Temporarily not available for software modules EasyEDX, 3D Metrology and TESCAN TRACE GSR.*
Automatic procedures	In-Flight Beam Tracing™ beam optimization, Spot Size and Beam Current Continual, WD (focus) & Stigmator, Contrast & Brightness, Scanning Speed (according to Signal-Noise Ratio), Gun Centering, Column Centering, Vacuum Control, Compensation for kV, Look Up Table, Auto-diagnostics, Gun Heating, Setup of FIB-SEM intersection point, Automated FIB emission start
Remote control	Via TCP/ IP, open protocol

Requirements

Installation requirements	Power 230 V/50 Hz or 120 V/60 Hz, 2300 VA No water cooling Compressed dry nitrogen for venting: 150 – 500 kPa Compressed air: 600 – 800 kPa
Environmental requirements	Environment Temperature: 17 – 24 °C Relative humidity: < 65 % Acoustic noise: < 60 dBC Active vibration isolation: < 10 µm/s below 30 Hz; < 20 µm/s above 30 Hz Background magnetic field: synchronous < 2 x 10^{-7} T; asynchronous < 1 x 10^{-7} T Room for installation: 3.5 m x 3 m minimum, minimum door width 1.0 m

LYRA3

FIB-SEM Configurations

The XM and GM configurations provide the capability to perform fine sample surface observation and modification even with extra-large specimens.

Besides the ability to investigate the sample surface with extra-large specimens, the GM chamber extends the features of LYRA3 FIB-SEMs with the option of attaching many other detectors and accessories to the chamber from the outside (additional SE, BSE, LVSTD, EDX, EBSD, TOF-SIMS) but also with the capability of accommodating various additional instruments, e.g. AFM/STM, inside the chamber.

LYRA3 XMH/GMH

A high vacuum model is suitable for a wide range of applications where large/ extra large conductive samples are investigated.

LYRA3 XM/GMU

A variable pressure variant that supplements all the advantages of the high vacuum model with extended facility for low vacuum operations.

Chamber	XM	GM
Internal size	285 mm (width) x 340 mm (depth)	340 mm (width) x 315 mm (depth)
Door	285 mm (width) x 320 mm (height)	340 mm (width) x 320 mm (height)
Number of ports	12+	20+
Chamber suspension	Integrated active vibration isolation system	

Specimen Stage	XM	GM
Type	compucentric	
Movements	5-axis fully motorized X = 130 mm, Y = 130 mm, Z = 100 mm Rotation = 360° continuous	
Tilt	-30° to +90°	-60° to +90°
Specimen height	maximum 139 mm	

Detectors	XMH GMH	XMU GMU
SE Detector	●	●
Motorized retractable BSE Detector	●	●
Beam Deceleration Technology (BDT)	○	○
In-Beam SE Detector	○	○
In-Beam BSE Detector	○	○
Low Vacuum Secondary Electron TESCAN Detector (LVSTD)	–	○
STEM Detector *	○	○
Motorized CL Detector **	○	○
Motorized Rainbow CL Detector **	○	○
Compact CL	○	○
Rainbow CL (Compact)	○	○
Secondary Ion TESCAN Detector (SITD)	○	○
EBIC	○	○
EDX ***	○	○
WDX ***	○	○
EBSD ***	○	○
TOF Mass Spectrometer***	–/○	–/○
SPM***	○	○

Accessories		
Probe current measurement	●	●
Touch alarm	●	●
Chamber view camera	●	●
Peltier cooling stage	○	○
Beam blanker for SEM column	○	○
Control panel	○	○
Load Lock	○	○
Optical Stage Navigation	○	○
Nanomanipulators	○	○

Other Options		
Gas Injection System for 5 gases	○	○
Gas Injection System for 1 gas	○	○
Decontaminator/plasma cleaner***	○	○
Flood gun for FIB charge compensation	○	○

● standard, ○ option, – not available, * motorized mechanics as an option, ** compact version as an option, *** third-party products

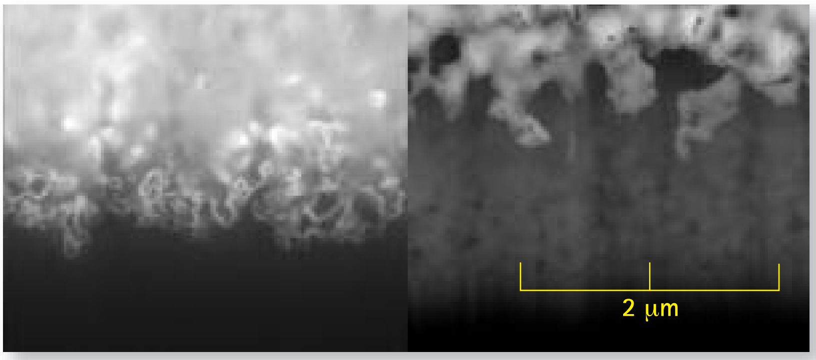


Fig. FIB cross section of nano-structured solar cell. Same image using EBIC detector signal (left) and BSE (right).

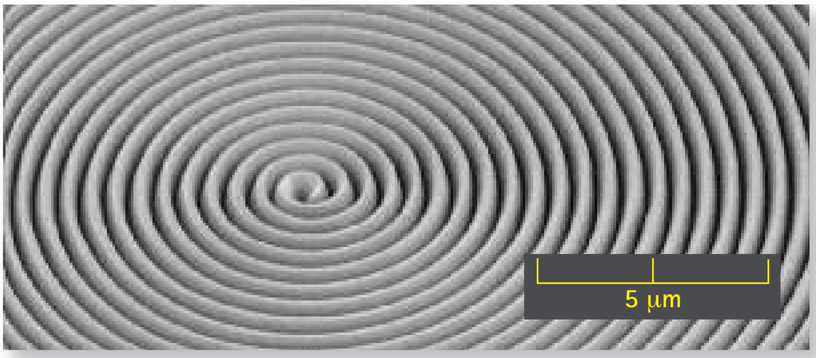


Fig. Milling recipe according a mathematical function of spiral.

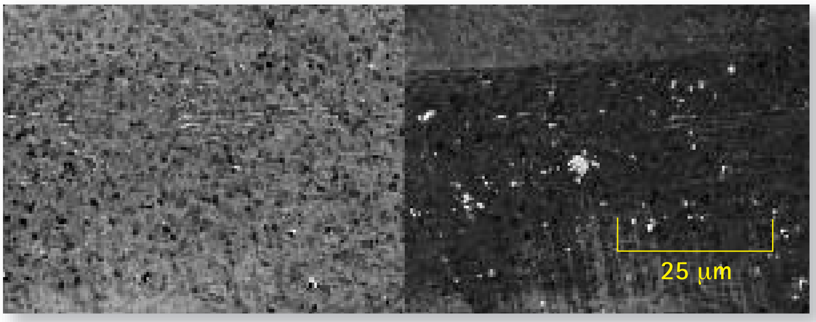


Fig. Alumina inclusions visualization comparing SE (left) to SITD (Secondary Ion TESCAN Detector – right) which is extremely sensitive to ultra-thin surface oxides - bright.

Common FIB-SEM Applications

Materials Science

Materials characterization of metals, ceramics, polymers, composites, coatings, metallurgy, metallography, fracture analysis, degradation processes, morphological analysis, steel cleanliness analysis, microanalysis, texture analysis, ferromagnetic materials, etc. using automated 3D EBSD analysis, 3D reconstruction and visualization, TEM lamellas preparation.

Research

Mineralogy, geology, paleontology, archeology, chemistry, environmental studies, particle analysis, applied physics, nanotechnology, nanoprototyping.

Life Sciences

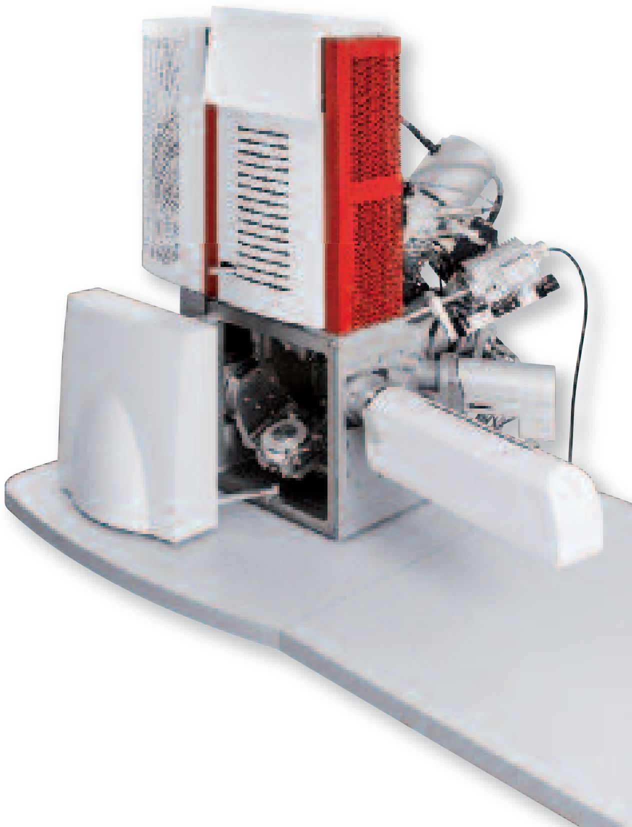
Structural research of biological samples, preparation of biological samples for various analytical microscopy techniques, 3D studies of biological samples.

Forensic Investigations

Bullet and cartridge investigation, analysis of hairs, fibres, textiles and papers, paints, ink and print characterization, line crossings, examination of counterfeit documents.

Electrotechnical Engineering

Electron and Ion Beam Lithography, TEM lamellas preparation.



EXCELLENCE IN INVESTIGATION

The combination of FIB and SEM is one of the most versatile instruments available for the examination and analysis of the micro and nano characteristics of solid objects. The main advantage of this state-of-the-art technique is the capability to analyze defects, microstructure, phases or interfaces in a specific region of interest.

The preparation of samples for other analytical techniques is another important application for the semiconductor or storage media industry as well as in materials research. The preparation of lamella for transmission electron microscopy (TEM) is rapid (about 30 minutes) and can be automated for maximum productivity.

FORENSIC APPLICATIONS

There are many cases in modern Forensic Science where conventional methods of investigation are not always sufficient. Sometimes, only nano analysis can give us the relevant information to solve a crime.

Forensic Research of Crime Scene Particles

There are several types of particles formed during the rapid cooling of vapourized elements after high-temperature burning. Such particles are for example the result of firing a gun, an explosion or drilling into a safe. The quantity, morphological and structural information on the particles at a given crime scene objects are studied and evaluated. The FIB-SEM instrument offers the capability of investigating the morphology and/or inner structure of a particle.

Counterfeit Document Investigation

One such forensic application is determining the authenticity of various commercial documents such as blank bills, agreements, contracts and the like. This is usually done by visual-optical and correlation methods with a stereoscopic microscope and video spectral comparator.

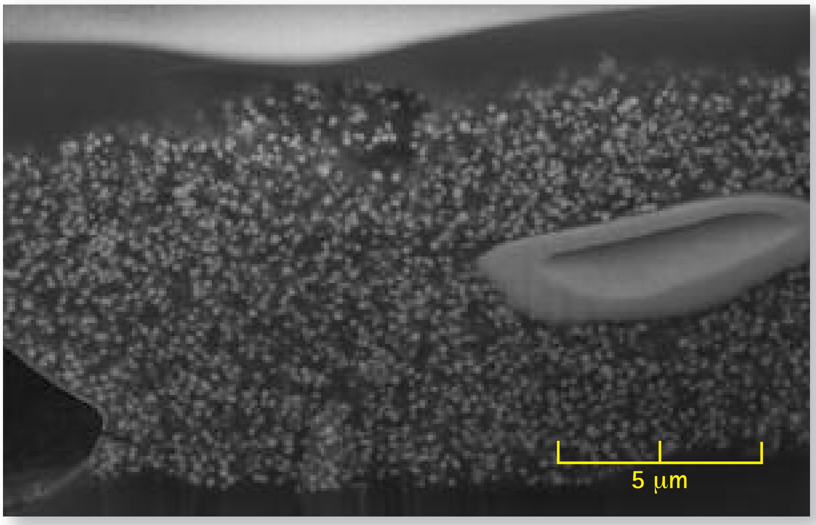


Fig. Cross section of cross lines showing layer of pen lead on printer ink layer.

Nevertheless, neither of the above-mentioned methods are able to provide definite proof of a document being counterfeit or authentic. This is where the FIB-SEM plays a vital role. Its capability of creating a micro cross-section of predefined areas allows the user to investigate the positions of each layer. This resolves whether it is pen on ink or ink on pen, as in the case of a counterfeit document. FIB-SEM is beyond doubt capable of providing precise conclusions in the shortest possible time.

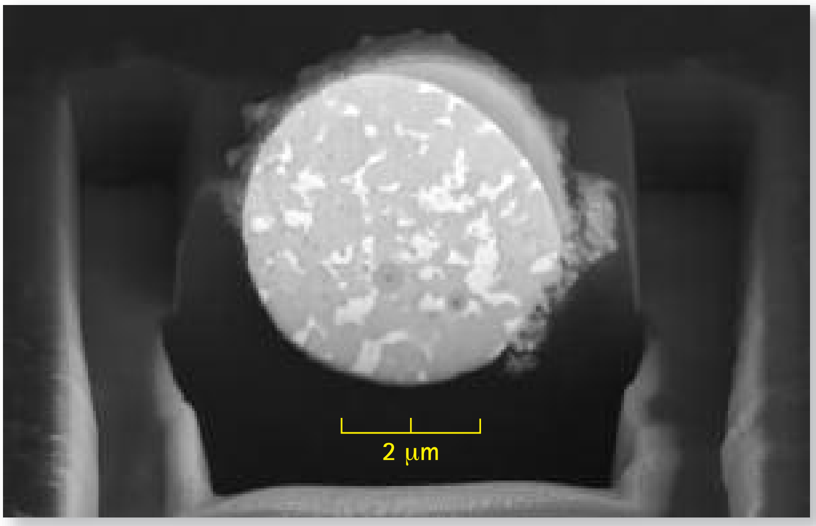


Fig. Cross section of Gunshot Residue particle exposing different phases in the structure.

MATERIALS SCIENCE APPLICATIONS

The development of new materials requires precise knowledge of their structure and its relationship to mechanical behavior. These FIB-SEM systems enable high-resolution studies of a material's structure, the preparation of FIB cross-sections at selected positions for sub-surface investigations, or the preparation of TEM lamellas.

Oriented TEM Lamella Preparation

The preparation of TEM lamellas by FIB is fast and more accurate than other available techniques. Being able to select the exact position and orientation of the lamella is one of the unique capabilities of the FIB-SEM system.

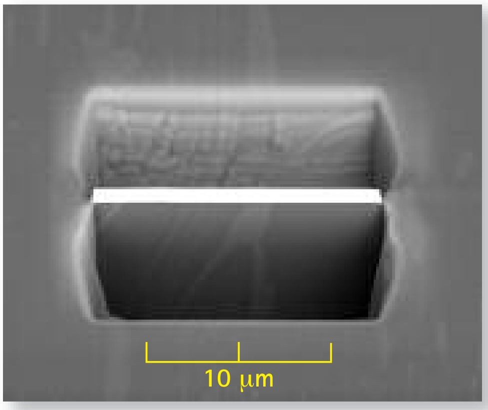


Fig. TEM lamella prepared from TiAl alloy perpendicular to nanolamellar structure.

Micro-Compression Testing

Recent scientific and engineering research is undoubtedly in the realm of nanotechnology. A new powerful set of tools were designed for investigating the mechanical properties of materials in the sub-micrometer range. Preparing thin pillars for micro-compression tests is a recent technique for precise studies of the specific micro-mechanical properties of a material. This technique gives easily interpretable data of material properties in relation with crystal orientation.

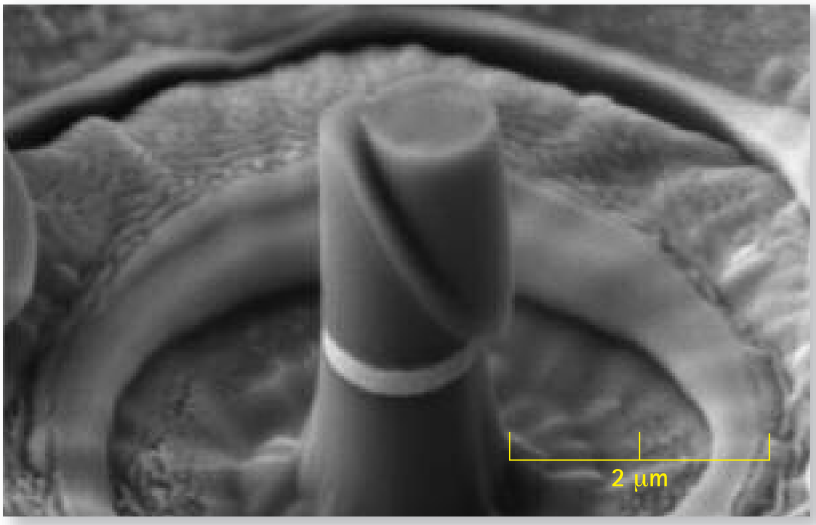


Fig. A micropillar after compression test. Pillar prepared by FIB from single grain of thin polycrystalline Al layer.

Fatigue Damage Investigation in Advanced Materials

The trend towards higher economical and ecological efficiency of consumer products through increased materials performance leads to significant research activity in advanced materials. Alloys and pure metals with grains of submicrometr size are typical examples of such materials. Ultrafine-grained (UFG) materials having grain size in hundreds of nanometers offer higher strength than their conventionally grained (CG) counterparts, but the data on their fatigue performance are very scarce. Moreover, the crack initiation mechanisms are still not fully understood. The combination of FIB and SEM techniques enables to understand crack formation thanks to its unique ability to prepare cross-sections in very specific sites of interest and examine sub-surface regions in nano-scale. The combination of FIB and SEM is therefore an extremely versatile and powerful tool for materials researchers.

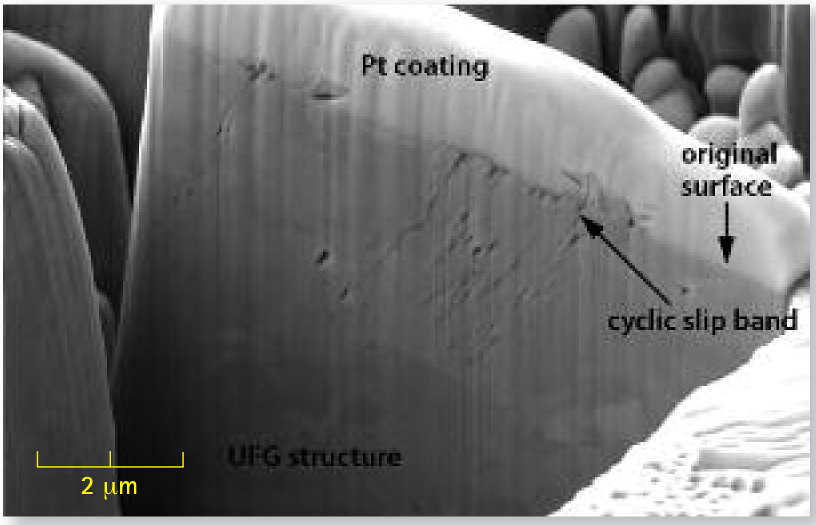


Fig. SE image showing cut through a set of surface slip bands, grain structure and the microcracks

NANOTECHNOLOGY AND SEMICONDUCTOR APPLICATIONS

Ion Beam Lithography and Prototyping

Spintronic structures are typically prepared by the sputter deposition of layered structures, consisting of magnetic and non-magnetic metallic or dielectric thin films, with thicknesses typically in the range of 5–50 nm. They can be patterned by FIB lithography into wires, disks, rectangles or pillars with lateral dimensions varying from tens of nanometres to several microns. These structures are then used for studies of domain wall motion in magnetic nanowires, spin-transfer-torque studies in nanopillars and nanowires, magnetization dynamics studies of magnetic vortices and in other applications

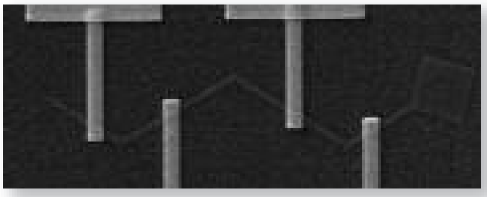


Fig. FIB milled (Permalloy/Cu/Co) nanowire of width 200 nm and length 16 µm with FIB-deposited platinum electric contacts used for the study of domain-wall motion.

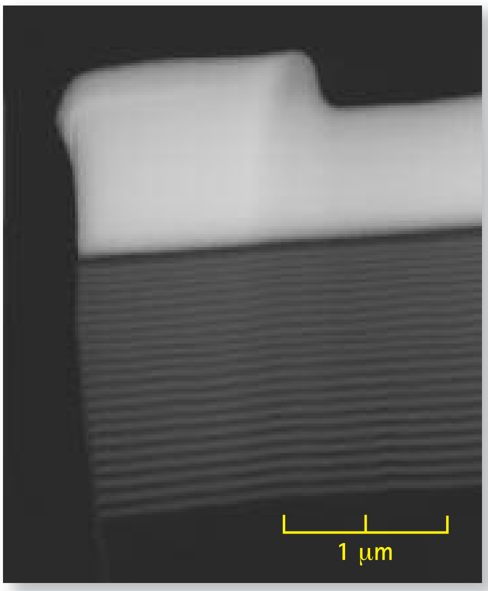


Fig. TEM lamella of optical multilayer

The great potential of FIB-SEM systems is also in ability to combine patterning by FIB with Electron Beam Lithography (EBL). Whilst the FIB is usually used to mill or deposit small specific structures, the benefit of EBL consists in possibility to create much wider patterns in reasonable time. This provides a number of applications in wide range of top research topics like for example spinplasmonics.

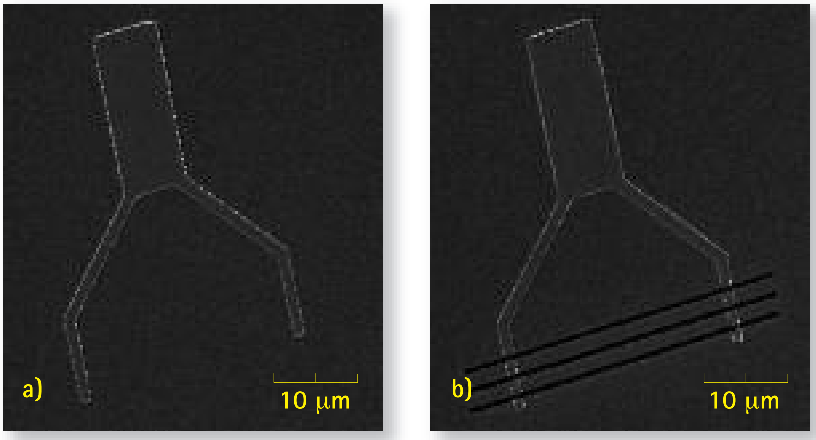


Fig. SEM images of the spinplasmonic Au/Co/Au structure: a) result of the electron beam lithography method, b) the structure modified by FIB milling.

Spinplasmonics is a branch of science concerned with the study of an interaction of electromagnetic waves and free electrons in ferromagnetic structures. Spinplasmonic device can be prepared from layered metal structure with dimensions in tens of micrometers range usually created by EBL. FIB is then used for final structure modification. The obtained knowledge about behavior of electromagnetic wave, trapped at such a specific structures when external magnetic field is applied, can be used for physical interconnection of electronics and photonics for application in high-frequency data transmission.

Failure Analysis of Integrated Circuits

Precise quality control is crucial in the semiconductor industry. When a defect in an IC is located, a high resolution investigation has to be done. An ultra-thin TEM lamella from the located area can be prepared and then observed either using the TE Detector in the SEM or by conventional TEM.

Thin Layer Measurement

This technique is useful for measuring the thickness of thin layers and determining their composition. When dealing with extremely thin layers (at the nanometer scale), it is often difficult to distinguish particular layers due to a lack of contrast in the image. This contrast deficiency is caused by the interaction volume of electrons, which is large compared to the layers' thickness. The preparation of thin lamellas (with thicknesses of approx. 100 nm or less) is the most widespread technique used to decrease the interaction volume. This leads to a much better contrast between each layer in the sample and consequently a more accurate layer thickness determination. It also significantly improves EDX mapping resolution.

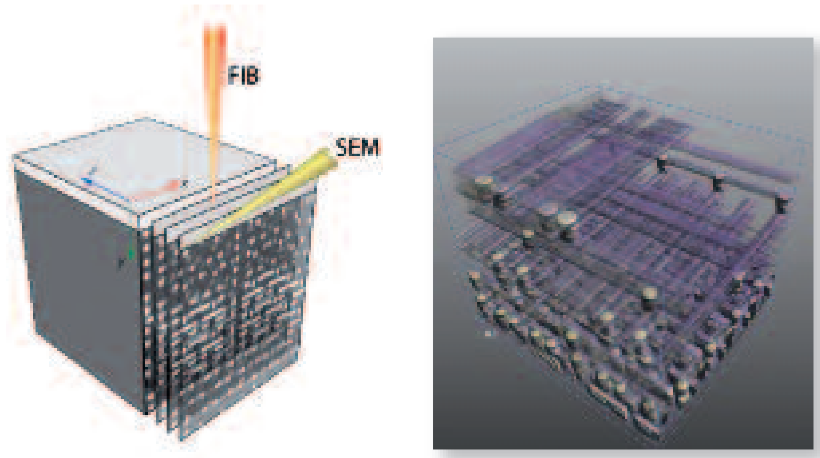


Fig. Direct volume rendering visualization method is less sensitive to noise. A semi-transparent colormap can be applied to highlight different objects.

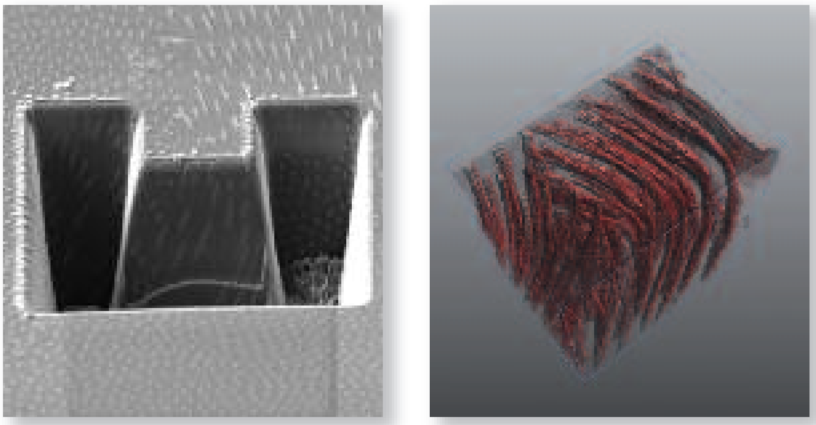


Fig. Reconstruction of volume distribution of eutectic phase of NiAlMo alloy after deformation.

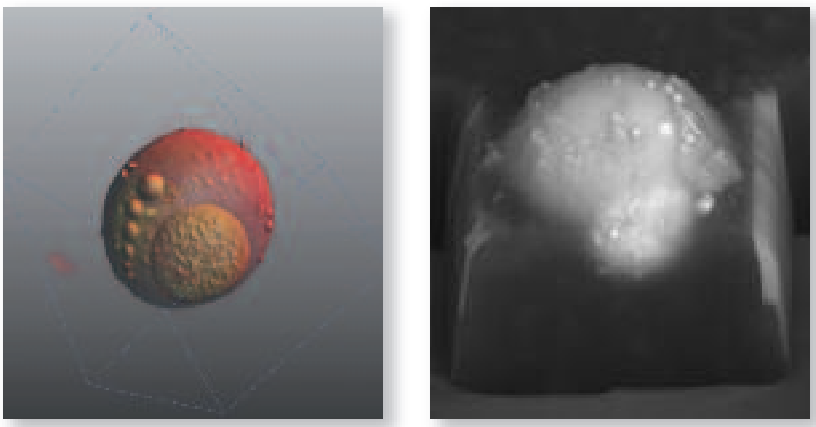


Fig. Reconstruction of volume distribution of Gunshot Residue (GSR) particle.

3D TOMOGRAPHY

The FIB's ability to prepare nano-precise cross sections opens up the possibility of sub-surface analysis. Automated sequential sectioning turns the two dimensional analysis into a 3D volume characterisation. This emerging technique gives a better understanding of the volume distribution, 3D structure and relationship between three-dimensional objects in the specimen.

Intuitive Software module

TESCAN delivers an advanced and fully integrated 3D Tomography software module intended for data collection automation, reconstruction and visualization. A user-friendly wizard guides the operator to set the optimal milling and imaging parameters. Data can be collected with standard FIB-SEM's detectors or in combination with other analytical techniques such as EDS or EBSD.

Excellence Visualization Methods

Various methods for visualization are available. Multiple slices can be displayed, either aligned to a major axis or taken at arbitrary angles. Further, this raw data can be reconstructed into a 3D volumetric dataset. This allows the interesting features throughout the entire stack of data to be highlighted using surface or volume rendering techniques.

Great Analytical Potential

Combining SEM imaging with the microanalytical possibilities of EDS or EBSD transforms SEM into a powerful analytical tool. The TESCAN FIB-SEM chambers have an optimized analytical design that also allows EDS, EBSD data to be acquired during sectioning, without needing to move the sample.

Microtomography Reconstruction of Volume

3D Tomography software is a usefull tool for the acquisition and visualization of FIB-SEM based tomography. This emerging technique gives a better understanding of the volume distribution, 3D microstructure and relationship between three-dimensional objects in the specimen. A fully automated software tool for data acquisition using various detectors can be used for FIB-SEM tomography applications.

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