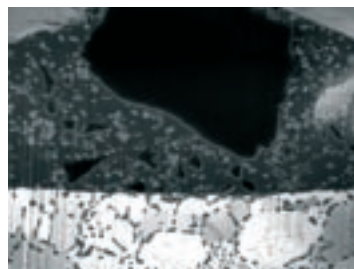
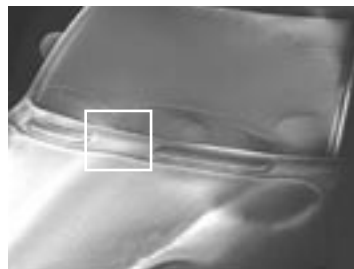


Introducing the first truly 3 Dimensional Scanning Electron Microscope

Any sample, all data, any dimension



SEM (Scanning Electron Microscope) is now a truly 3 dimensional front-line investigative tool, that is fully independent of the samples' materials properties, shape, surface characteristics, chemical nature, mechanical preparation history or electrical conductivity. Even highly diverse composite materials are as trivial to analyse in three dimensions as a polished SEM stub.

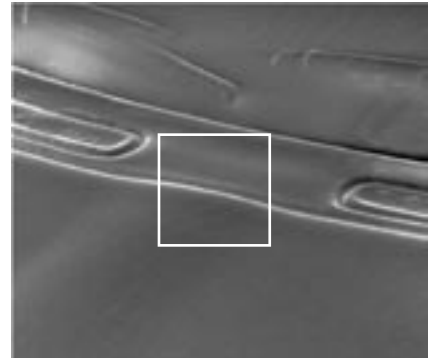
SEM users have learned to tolerate only being able to capture images of the surface of samples with all the inherent preparation limitations the standard SEM technique has, but no longer; now samples can be sectioned exactly at the point of interest in real time for immediate 3D and chemical information without any form of mechanical sample preparation required.



Toy die cast 'Mini' car* – 5.5 cm long



Selected area between wind screen wiper blades is the area to be analysed.



Front view of the Mini. This is a minimum magnification image of the front of the Mini taken with the Quanta™ 3D microscope in low vac mode. The same area between the wipers is selected.

How is this possible?

By integrating FIB (Focused Ion Beam) technology into our ESEM family platforms. This is FEI's pioneering DualBeam™ technology and system architecture.

Focused Ion Beam technology provides an artefact-free method of site specific real-time micro-cross-sectioning at the point of a mouse.

"Next Generation" ion beam optics mean that you can now section through a target feature no larger than 100nm and be certain that you have left the remaining half of the feature undamaged and available for immediate imaging and characterisation.

This exact point-and-shoot cross-sectioning functionality means that you can have your immediately prepared polished surface, ready for imaging or analysis wherever you want - **no mechanical sample prep required.**

Charge neutralisation technology means that even highly insulative materials can be machined as easily as highly conductive ones – **no coating required.**

DualBeam™ coincident beams with sample eucentric system stages mean that all SEM capabilities are fully available to electron or ion beams without repositioning, additional preparation or sample re-alignment.

ESEM technology brings the full capabilities of an SEM to any sample, whatever its charging profile though variable pressure sample handling and patented extended vacuum signal detectors.

Ion beam microscopy is also a field emission high resolution imaging technique in its own right, very similar to an SEM but with higher levels of materials contrast and voltage contrast, so a DualBeam™ really does provide two microscopy techniques on one platform.

Energy Dispersive (EDS) X-Ray Microanalysis

When an electron beam strikes the surface of a material, x-rays are fluoresced from the atoms within the first few microns of that surface. The energy of these x-rays are characteristic of the elements present. Hence if the x-rays are detected and their energies measured then the elements present in a feature can be identified. This method of analysis is known as Energy Dispersive X-ray analysis (EDS). It can be used qualitatively to show what elements are within a feature or quantitatively to show the weight% composition of that feature. EDS can detect trace elements down to approximately 0.1wt% depending on the element measured and the matrix it is in. An area of sample can also be mapped by EDS to show the spatial distribution of elements within a region of interest. The beam is moved over the region of interest and the intensity of a pixel in the map is related to the concentration of the mapped element. Hence bright pixels correspond to higher concentration relative to other pixels in the map.

System integration (mechanical, electrical, electromagnetic, chemical, software) means that both these microscopy techniques and all additional functions resident on the tool (EDX, EBSP, STEM, Cryo etc) are simple point and click operations which are uncompromised by this significant advance in technology and the new system architecture.

* Images printed with the kind permission of BMW.

So how does it work?

There is an 9 step process.

STEP 1

Load the sample – no need for polishing or coating or mechanical preparation of any kind. This is a significant time advantage over conventional SEM.

TIME: 3 MINUTES

STEP 2

Use the SEM to locate the feature of interest – normal modes are available like SE or BSE, not only in high-vacuum but also in low-vacuum and even in extended low-vacuum allowing humidity control (ESEM).

TIME: 5 MINUTES

STEP 3

Once you have the feature, use the ion beam in high-vacuum to coat it with a thin layer of Platinum (about 1 micron)– but only within the field of view, the rest of the sample remains untouched. This provides a more planar surface and protects the point of interest from possible re-deposition, thermal effects, charge effects or accidental beam damage. This uses FEI's 'one click' gas injection systems.

TIME: 5 MINUTES

STEP 4

Section the point of interest. This is dependant on the size and depth of the feature, and so time can vary. This part is available for automation so can be done real time for modest features or overnight for larger features.

TIME: 5 MINUTES

(to several days! You decide.)

Sectioning is done by changing the ion beam from a low current, gentle hi-res imaging technique to a high current density milling spot and then scanning it over the area of the sample that is to be removed.

This highly focused milling spot ionises the material within a very specific area without touching even immediately neighbouring material on the sample.

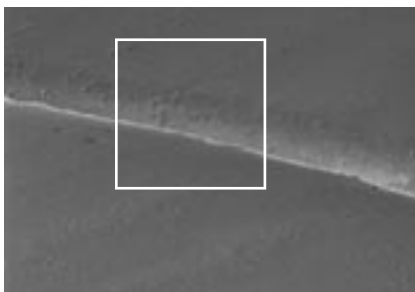
The milling beam remains strictly within the pattern defined by the user to create the section and leaves the rest of the sample untouched.

As an example the high current density and excellent beam profile mean that this cutting is so precise that it is possible to entirely sputter a gold island from an SEM resolution sample without even changing the appearance of the gold balls immediately adjacent to it.

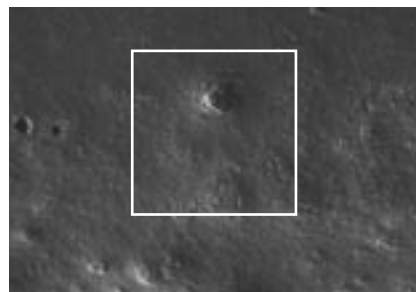
Sputtered material diffuses into the vacuum chamber to be pumped away, or can be chemically reacted during milling using in-situ etchant gases delivered at the point of beam incidence (through a gas injection system) to enhance the ion beam etching process and reduce re-deposition effects.

The removed material leaves a 'staircase' structure milled into the sample, with the deepest point (bottom step) being at the foot of the newly created vertical wall which is directly through the feature of interest.

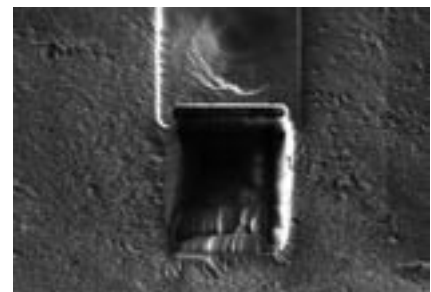
This vertical face may be further polished with the ion beam to produce a truly artefact free section for imaging.



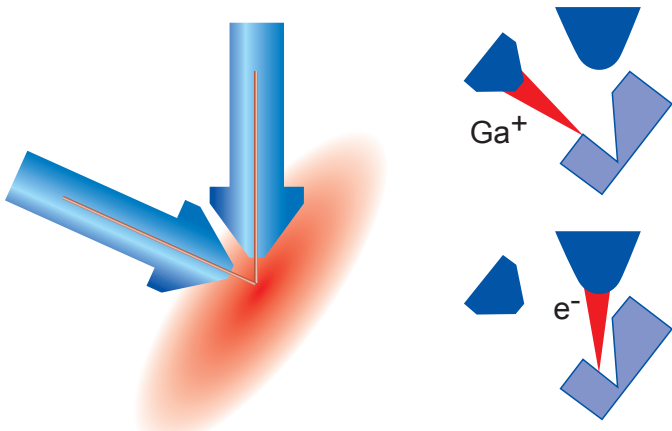
A first image of the front of the Mini – SEM image low vac.



A further zoom in of the selected area, the paint roughness is now becoming evident. SEM image low vac.



A further zoom in image – this time with the ion beam normal to the surface of the car, a large paint defect in the selected region is at the centre of the field of view.

**STEP 5****Image the interior of the selected feature**

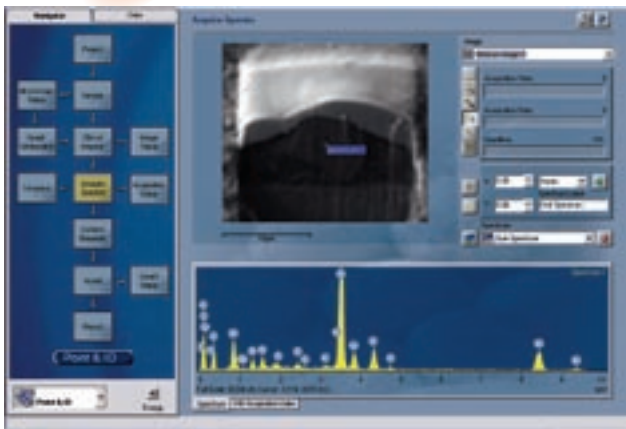
It is not even necessary to tilt the sample to the electron beam as the system columns are separated by 52 degrees of tilt. Immediately use metrology SE, BSE, ion beam SE, ESEM or any other technique that you have available to extract the data you need from this feature. This is referred to as 2 1/2D imaging. A single vertical plane through a 3D structure is exposed and made available for immediate imaging.

TIME: 5 MINUTES

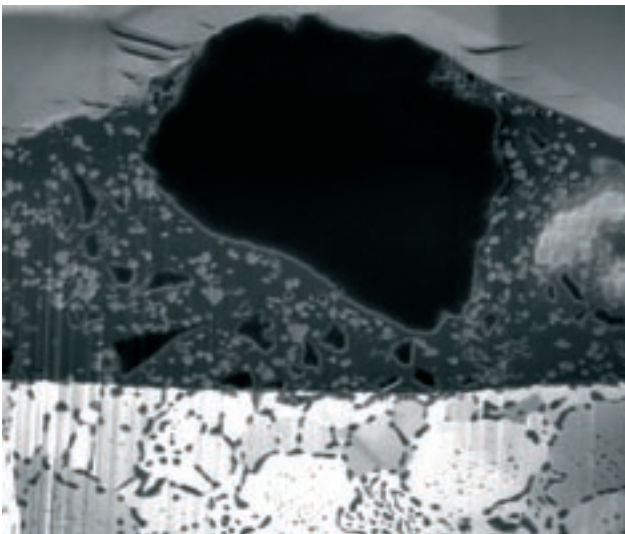
STEP 6**Analyse the Feature by EDS**

The newly cross sectioned face is immediately available for EDS analysis. Using the Point and ID Navigator, images can be acquired and used as a reference for selecting the region for EDS analysis. By simply clicking on the image, a spectrum is acquired from a point, quickly identifying the internal chemistry of a feature. Auto-ID immediately identifies the elements present so that the feature can be characterised

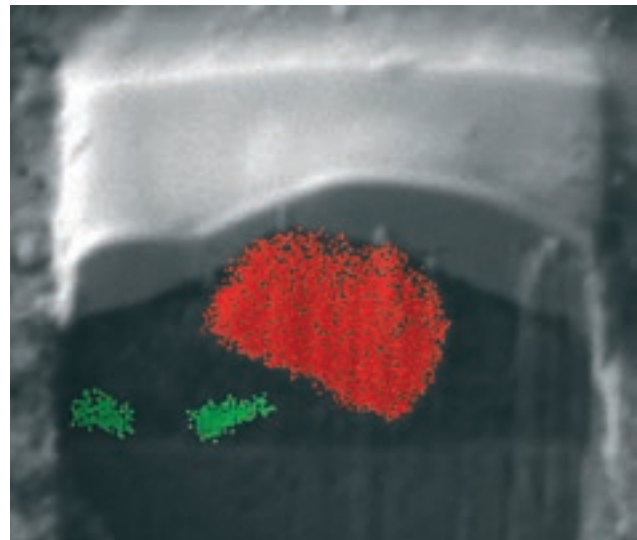
TIME: 2 MINUTES



INCA Point and ID controls the position of the electron beam with reference to an image. The resulting EDS spectrum clearly shows what elements are present in the analysed feature.



This is an image of the cross-section face placed through the centre of the buried defect. This is a high resolution ion beam secondary electron image (tilted to 52 degrees) which clearly shows that the defect was caused by a large particle embedded in the paint layer.



This processing problem can now be traced based on the chemical nature of the unwanted particles.

EDX maps of Ca (red pixels) and Si (green pixels) overlaid on the secondary electron image. The defect seen in the electron images is clearly shown to be rich in Calcium. Other regions are shown to be rich in Silicon.

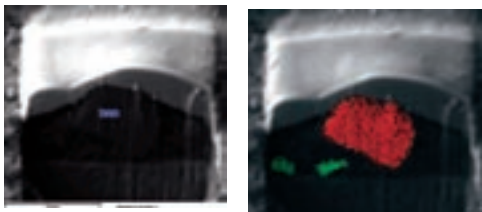
But this is not the final result

A simple section only provides 3D information in a single plane into the sample. To get a true 3D understanding of the feature (surface or sub-surface) you would need many sections through the feature but at incrementally staggered positions.

STEP 7

Acquire a Spectrum Image

The region of interest can be mapped to show spatial distribution of the elements present. Using SmartMap a spectrum is collected at each pixel in the map. X-ray maps can be displayed for any element at any time, during data acquisition or review mapping are during data review. Maps can be overlaid with the electron image to help correlate the elemental distribution with the image



EDS maps of Ca (red pixels) and Si (green pixels) overlaid on the secondary electron image. The defect seen in the electron images is clearly shown to be rich in Calcium. Other regions are shown to be rich in Silicon.

STEP 8

Auto Slice & View™

In order to truly understand a feature in 3D it must be analysed in three dimensions. The user must define a volume of material which is to be analysed with the feature of interest within it.

The will then automatically acquire multiple sections through the feature of interest at user defined spacings.

By providing the instrument with simple parameters like the slice thickness and the depth and extent of the feature of interest, the automated Slice & View™ capability will systematically use the ion beam to shave slices from the face of the micro-cross-section until the feature is fully analysed.

After each slice the SEM will capture an image of your choosing, fully programmable for magnification, detector type, focal length, contrast levels etc. and export these images as a numbered sequence into an image file of your choice. This process is fully automated and so even though each slice may take only a minute to capture, no operator is required. This level of automation ensures that slice thickness remains constant and image settings do not change.

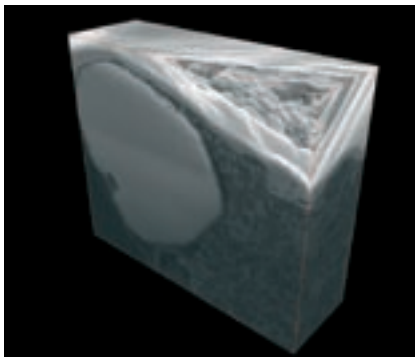
You have now sliced your feature like a loaf of bread and have each slice available for inspection

These images are now available for individual or group metrology, but can also be recompiled into a 'fly through' movie sequence at the touch of a button.

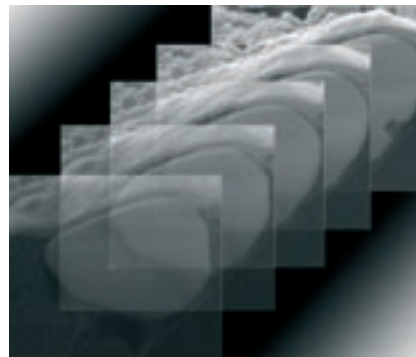
Now the 3D nature of the feature of interest and its relationship to the rest of the sample becomes clear. True 3D information permits the jump to real understanding of the feature properties.

How layer thicknesses change, or voids appear and disappear, or the extent of contamination through a metal grain, are all immediately available.

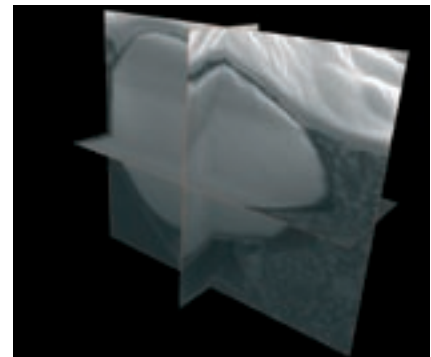
Images provided courtesy of Umicore Research, Development and Innovation, Olen, Belgium.



This is a 3D volume image of a particle embedded in a layer in a complex sample.



A composite image showing how multiple incremental slices can be acquired from a single embedded particle in a complex sample.



A 3 Dimensional representation of the same embedded particle in a complex sample. This image was reconstructed from an automated Slice & View™ data set.

However, there are some limitations to this data set. Each image is still only a 2D plane through a feature. If a void is present in 5 slices of 50, how big is that void? What proportion by volume of the whole feature does it represent? If it is critical to the success of the manufacturing process, when does the size become a risk to production quality? 2D images are still snapshots through 3D structures, even if you have many of them.

STEP 9

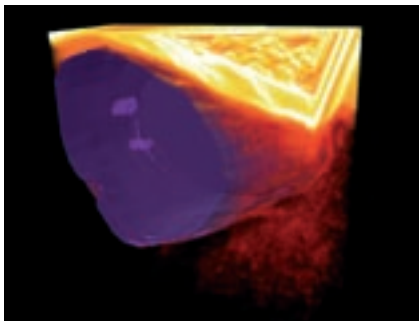
3D Reconstruction

The data set acquired by Auto Slice & View™ is designed for immediate acquisition by FEI's reconstruction software. Slice&View data sets can be imported and reconstructed with user defined data highlighted for export in the reconstructed result.

Now the complete feature that has been analysed and all its structural interactions and volumetric proportions can be understood at a glance.

This 3D data can be displayed in any orientation required for detailed data extraction and can be shared and discussed between colleagues by simply emailing it to them.

The two reconstructions shown here are a grey-scale orthogonal pie-slice and a still image from a fully rotating 3D colour reconstruction in Mpeg format. Both these examples are available for viewing on the Websites of both FEI and its EDX partner.



A full colour 3D reconstruction of a particle embedded in a layer in a complex sample.

This reconstruction was created from a automated Slice & View™ data set provided courtesy of Umicore Research, Development and Innovation, Olen, Belgium.

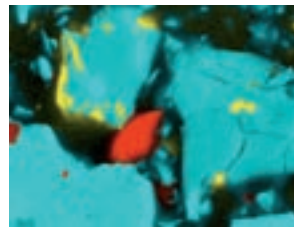
STEP 10

Further Analysis

A data set can be paused during Slice & View™ acquisition for capturing analytical data. This data can then be used to put structural information into context after the series is finished. Additional data is not limited to EDS. Any technique that is compatible with SEM is compatible with 3D ESEM.



A backscattered image of a FIB section through a rock sample.



An EDS map with Red=Sulphur of the same FIB cross section.



The FEI Quanta™ 3D- the first 3D ESEM.

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