

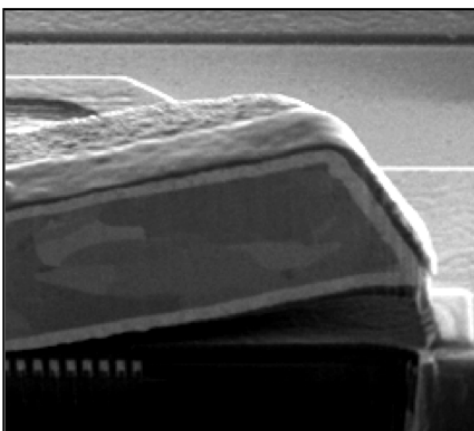
Characterizing New Materials with Electron Microscopy

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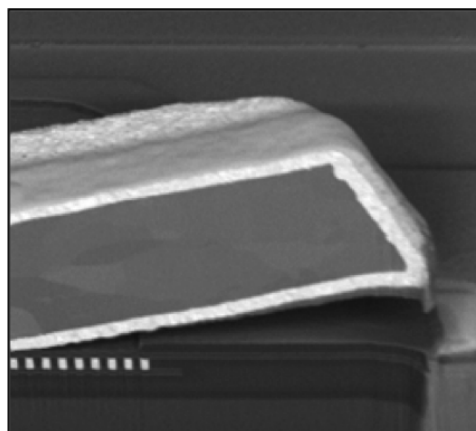
The Scanning Electron Microscope (SEM) continues to be one of the most powerful and versatile instruments used in research, development and manufacturing environments. The SEM has the ability to image a wide variety of sample types and sizes, often with minimal sample preparation, and is capable of generating multiple analysis signals, providing high-resolution information about the composition, phase, electrical, optical, and other properties of a sample.

In this paper[1], we'll look at the capabilities that enable SEMs to play such a key role, illustrated with a variety of examples taken from semiconductor and materials samples.

By way of introduction, *Figures 1* and *2* show a brief overview of SEM capabilities that we will return to later in the white paper. *Figures 1a* and *1b* show complementary contrast using secondary electron and backscatter electron modes to look at a section through a bond pad. In addition, the SEM can be used in a transmission mode (*Figure 1d*). Analytical capabilities are illustrated by an electron backscatter diffraction map of copper lines (*Figure 2a*) and examples of x-ray analysis on a bulk sample and on a thinned sample (*Figure 2b,c*).



1a

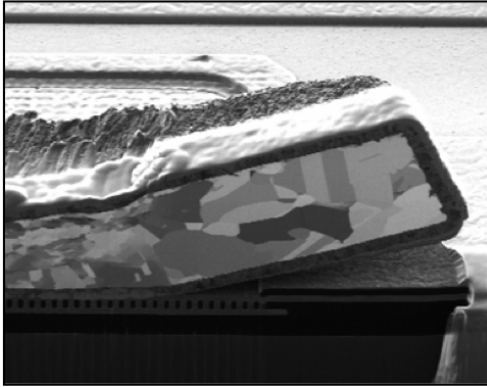


1b

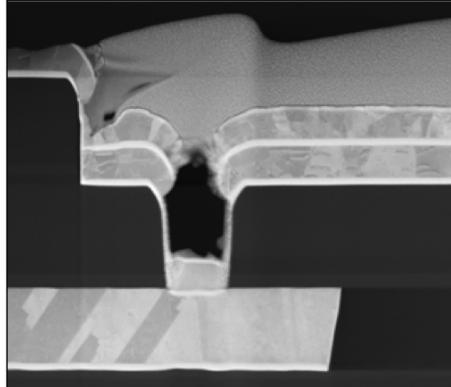
Figures 1a and 1b – Complementary contrast using secondary and backscatter electron mode through a bond pad.

Combining the SEM with a focused ion beam (FIB) column adds the capability of highly site-specific preparation from within a dual-beam system[2]. Dual-beam sample preparation is also a powerful technique for other analytical tools, such

as transmission electron microscopes, atom probes, auger, and SIMS tools. The ion beam also provides another complementary imaging technique, as shown in *Figure 1c*.



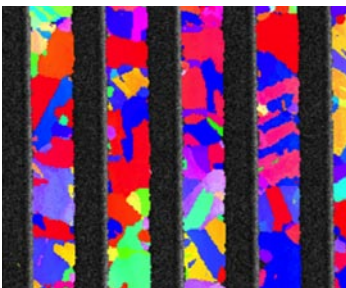
1c



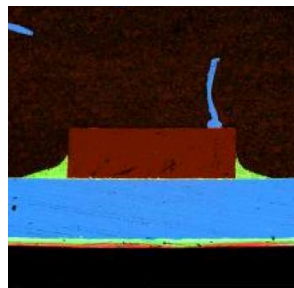
1d

Figure 1c – Complementary imaging with an ion beam. Grain contrast in the metal layer is particularly pronounced due to the channeling contrast with the ion beam.

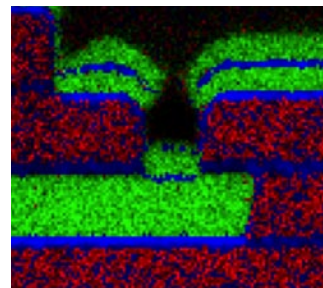
Figure 1d – Transmission mode image of an IC interconnect.



2a



2b



2c

Figure 2a – Electron backscatter map on copper.

Figure 2b and 2c – Examples of x-ray analysis on a bulk sample and on a thinned sample.

Using the SEM as an Analytical Platform

A key reason why the SEM is such a powerful tool is the wide variety of capabilities that can be added on to the basic imaging system. Multiple ports are typically provided so that options such as x-ray and electron backscatter detectors can be mounted together. Combining analytical techniques speeds data collection by enabling the simultaneous collection of different types of data. It also enables more complete data analysis by allowing direct comparison of the data on a pixel-by-pixel basis.

When adding multiple detectors to the tool, it can be important to leave room in the chamber for probe stages and other stage-mounted accessories. Such probe stages enable four or even eight needles to be brought down into a minute area of the sample. Using modern probe stages, individual needles can be positioned at 100 nm or better, enabling multiple needles to contact individual transistors in microprocessors or memory arrays (*Figure 3*).

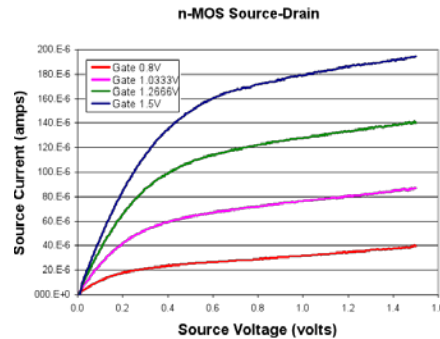
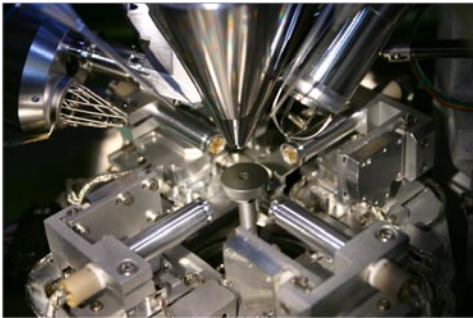


Figure 3 – Electrical probe stage mounted into SEM along with example of electrical probing data from a transistor.

Stages that can cool or heat the sample or apply forces such as tensile stress allow the observation of real-time material changes under high resolution (Figure 4). Such movies enable an investigation of both the macroscopic overview of the melting process, as well as a higher magnification view into the microstructural changes that occur.

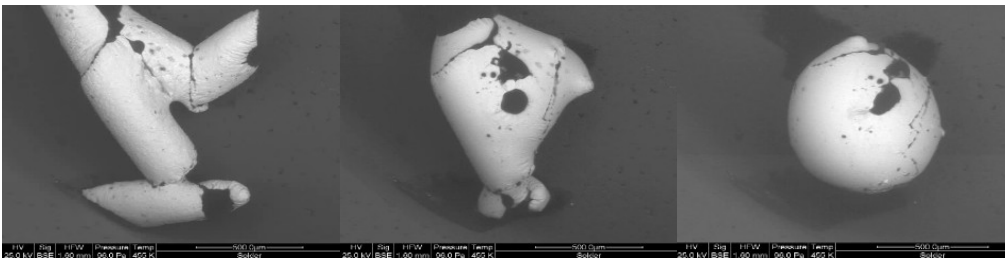


Figure 4 – Stills from a movie of solder being melted in a SEM.

Low Vacuum for Charge Control without Coating

One challenge that comes from working with an electrically charged particle beam in a vacuum is that insulating samples can get charged up by the electron beam.

One way to control charging is by operating at a particular beam voltage—for example, the point where the yield of electrons from the sample matches the incoming electron flux. But with chemical analysis like energy dispersive X-ray spectroscopy (EDS), where it is important to have enough electron beam energy to create the x-ray photons of interest, going to a lower voltage to achieve a charge balance may limit the data available.

Another approach is to coat the sample with some sort of conductive layer. However, this technique may obscure information of interest, particularly when performing multiple types of analysis in the SEM or in other instruments.

An effective way to control charge without coating is to use low-vacuum mode. Water vapor or similar gas is introduced into the sample chamber, and the

ionization of the water bleeds off any charge from the sample. Secondary electron detectors have also been designed that use the local water vapor to amplify the detected signal.

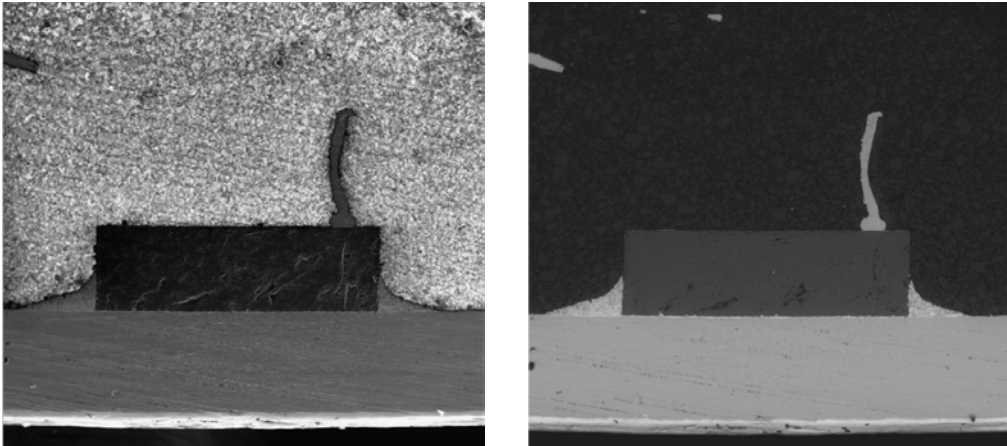


Figure 5 – Low magnification view of a packaged part, where severe charging of the packaging material would have prevented a clear image in under high-vacuum conditions. The left image uses secondary electrons, while the right one uses backscattered ones, showing the different contrast obtainable using the electron beam.

Complementary contrast gives an operator quite a bit of information about the materials present. To learn more, x-ray analysis can be performed. When charging is eliminated, it is possible to run the experiment at the appropriate voltage for EDS (Figure 6). In this case, the experiment was run at around 15 kV in order to obtain a full series of x-ray peaks.

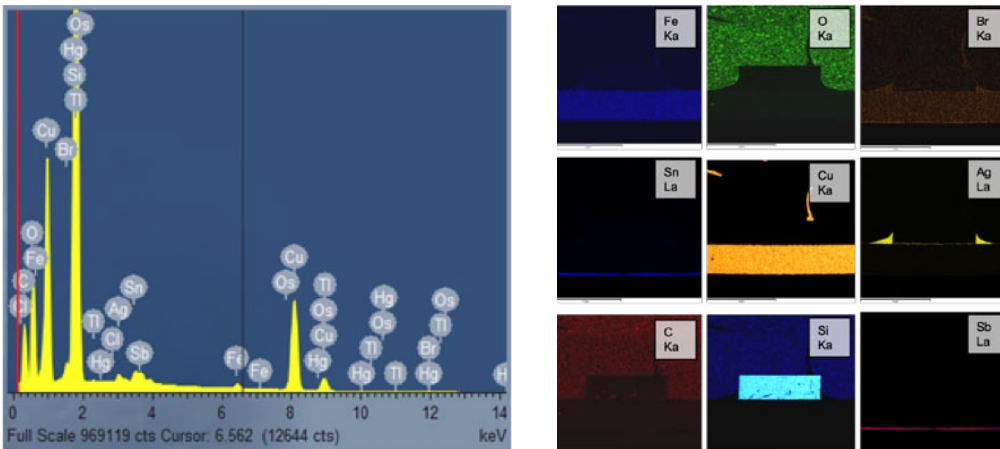


Figure 6 – The large plot shows the spectrum for the device (shown in Figure 5), with the individual maps showing the locations of different materials within the images, based on their characteristic x-rays.

Low-vacuum mode also benefits other techniques such as electron backscatter diffraction. Since obtaining a high-resolution map takes many minutes or even tens of minutes, it's critical to have a stable stage and beam position, and to avoid sample charging (Figure 7).

Low-vacuum mode needs to be used with care. As gas pressure increases, so do beam scattering effects within the gas. These effects need to be balanced to obtain the desired results.

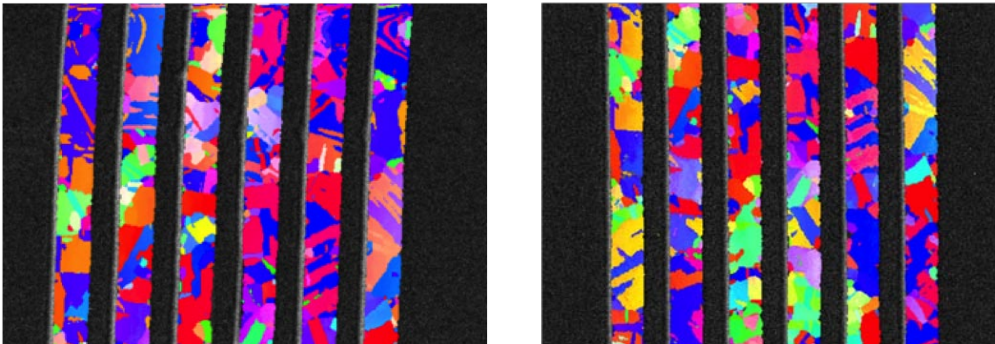


Figure 7 – EBSD maps of a series of copper lines on an insulating substrate in high- and low vacuum modes (left and right images respectively).

In addition to pressure, another key parameter in determining beam resolution is the path length traveled by the electrons through gas in the chamber. A shorter beam path results in improved spatial resolution and signal-to-noise ratio (*Figure 8*). In addition, the additional electron beam scattering from the long beam path excites more x-rays further from the target site, resulting in spurious data from adjacent areas.

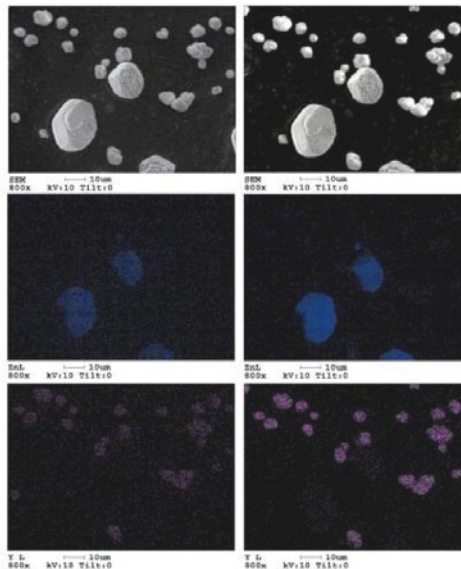


Figure 8 – A secondary electron image and two x-ray maps for the cases of a long and short beam path (left and right images respectively).

High Contrast, High Resolution STEM Mode

An application for SEM that has recently come to prominence is transmission imaging. When the sample is thinned to roughly 50 to 200 nm, the electron beam passes through the sample and forms an image (*Figures 9, 10*). This is very similar to what happens in a 200–300 kV scanning transmission microscope. At 20 or 30 kV, the images do not have the resolution achievable at higher voltages; but they do show enhanced resolution and contrast compared to imaging on a bulk sample with secondary electrons.

Multi-region detectors are often used so that separate images can be formed with the lightly scattered electrons (the “bright field” signal) and those scattered by larger angles.

Another benefit of the thin sample is improved x-ray spatial resolution due to the small interaction volume of the electron beam with the thinned sample. On a bulk sample, resolutions much below 500 nm are hard to achieve; but on a thin sample, 10-20 nm resolution is possible (figure 2c).

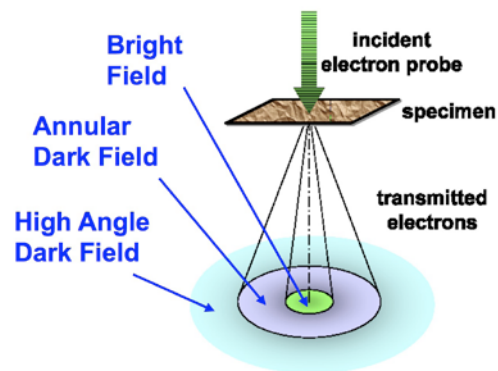


Figure 9 – How STEM mode works.

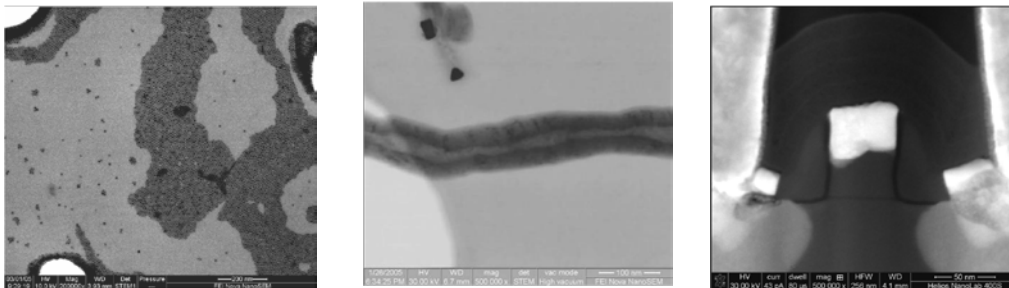


Figure 10 – A variety of samples imaged at high magnification in STEM mode, including magnetic manganese iron oxide particles, carbon nanotubes, and a microprocessor transistor.

The microprocessor transistor sample in *Figure 10* was prepared in a dual-beam FIB/SEM system. The whole process, from the bulk sample to the final site-specific SEM image, was prepared with the same tool. This combination of in-situ preparation and imaging is valuable when targeting small structures or analyzing one-of-a-kind defects. Another advantage of this technique is that the thinned sample is ready to go straight into the high-voltage transmission microscope if further analysis is required.

Closing the Gap Between Optical and SEM Microscopy

Optical microscopes are widely employed for many kinds of inspection roles. With dimensions of interest continuing to shrink, more and more traditional optical applications are now performed in the electron microscope. SEMs can take the place of optical microscopes in both form and function.

One common semiconductor failure analysis application is to strip back an integrated circuit layer by layer to find a particular defect site. SEMs enable you to get the sample in quickly and identify if you are in the right place. If not, then

further polishing can take place and the process can be repeated. Deprocessing is often a “dirty” operation; using a suitable SEM produces images quickly without over-elaborate cleaning or long pump down times.

Figures 11–13 are from a desktop microscope that combines optical and electron microscopy to close the gap between these two techniques.

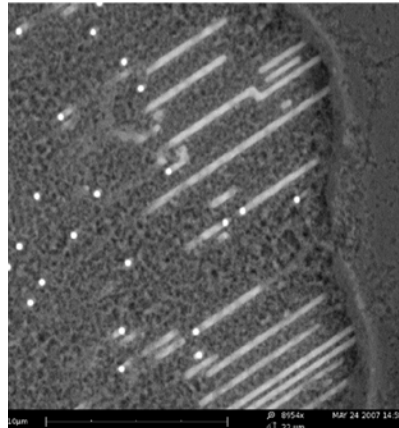


Figure 11 – Two images from a series of increasing magnification, from seeing the whole device with the optical scope down to higher magnification in the SEM.

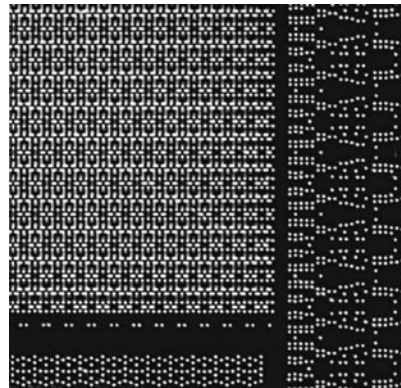


Figure 12 – A similar device to figure 11 that has been deprocessed and is ready for electrical probing, where exposed contacts can be used to probe individual transistors.

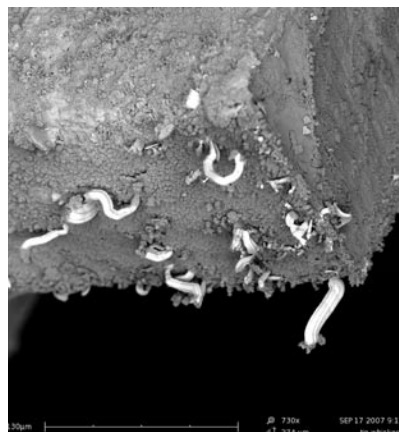
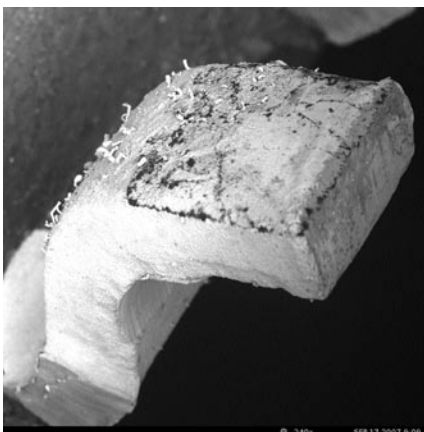


Figure 13 – Overview of a package lead wire. Note the large depth of focus, which makes it easy to understand what’s been looked at. The right image shows a higher magnification view of tin whiskers. If further information of whisker shape or size is needed, the microscope can be zoomed in more.

Summary

Scanning electron microscopy is a powerful and versatile technique for advanced materials research, providing unique and complementary information to other available methods. Therefore, SEMs are finding roles in many product development areas, where a detailed understanding of new materials is crucial. In addition, SEM applications continue to broaden—ranging from optical microscope replacement to fully loaded systems that combine multiple analysis techniques.

Acknowledgements:

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References:

1. This white paper is based on a Webcast presented December 4th, 2007, archived at <http://www.semiconductor.net/webcasts/47486/Supplier+webcasts.html>
2. DualBeam Solutions for Site-Specific 3D Characterization of Semiconductor Devices, Narum et al., Contact FEI at <http://www.fei.com>.

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