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# Failure Analysis and Defect Review for the 45 nm Node Using Extended Accuracy of the CrossBeam Technology

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As we look forward to the 65 nm and 45 nm technology nodes, challenges arise in virtually every aspect of the semiconductor industry. The push to smaller dimensions puts demands on lithography and mask making, as well as etching processes. The push for new materials to increased frequencies creates challenges with deposition, patterning, integration and inspection, as well as packaging. Fab automation continues to be important, not only in terms of optimizing yield and fab efficiency, but also in terms of supply chain management. Equipment and materials suppliers, and their own suppliers of components and subsystems, are developing tools to meet these challenges.

Without a doubt, process control is a major metrology obstacle facing those considering technology requirements for work at the 45 nm node. One of the most important means of controlling that process is precision. When design engineers contemplate work in dimensions below 50 nm, they must deal with tolerances in the range of ~5 nm.

These requirements put a high demand on the inspection tools with regard to accuracy and resolution. The resolution of single-beam focused ion beam (FIB) instruments [1] is not sufficient anymore to deal with the necessary accuracy. To overcome this problem, the FIB tool must be combined with a high-resolution SEM that is used to monitor the FIB work on a nanometer scale. These integrated CrossBeam® tools enable the observation and direct control of the FIB operation in real time. In addition to the improved accuracy and resolution, the electron beam adds analytical capabilities, such as STEM, EDS and EBSP, to the instruments.

## System Layout

The CrossBeam tools combine the imaging and analytical capabilities of a high-resolution field emission SEM (FESEM) with a high-performance FIB column into one integrated instrument (*Figure 1*). In the case of the CrossBeam tool, the final lens of the FESEM is designed as a magnetic/electrostatic compound lens. This layout has the advantage of no magnetic field interfering with the ion beam, and the FESEM can be operated at nanometer resolution during the ion milling process. This layout allows full control over the total process and gives an excellent endpoint detection and cut localization for defect review and failure analysis.

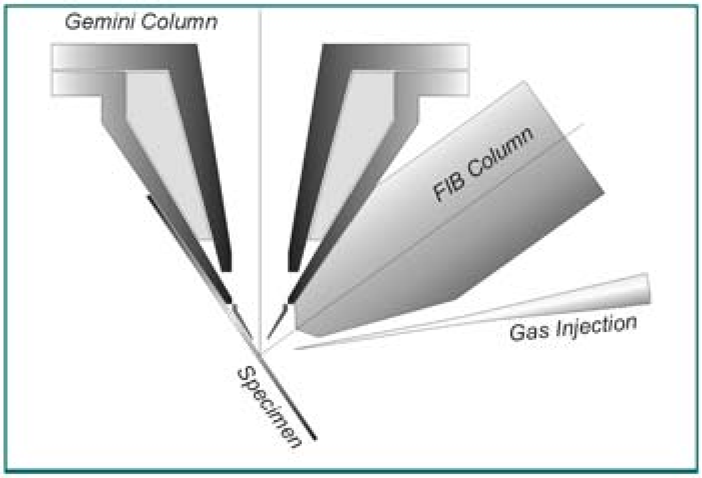

***Figure 1.*** *Schematic layout of Zeiss CrossBeam tool. The electron and ion beam coincide at 5 mm below the final lens of FESEM.*

Together with a multichannel gas injection system for metal and insulator deposition and for enhanced and selective etching, the CrossBeam workstation is a very powerful analytical and imaging tool for a wide range of applications within the semiconductor industry.

## SEM Cross Sections

Cross sectioning in a standard FIB workstation is basically a blind process. The sample surface is imaged with the FIB before cutting to determine the area of interest. Afterward, the sample is milled and polished with a predefined milling pattern. Without the possibility of monitoring the milling process directly, the area of interest can easily be destroyed.

The unique capability of the CrossBeam tools to image the sample in real time at high resolution during the ion milling process gives the operator a direct interactive control to the ion milling process (*Figure 2*). This results in an extended accuracy on site-specific cross sections. The milling and polishing process can be directly imaged and stopped exactly at the detail of interest (*Figure 3*). Especially in the case of TEM sample preparation, the danger of destroying the fine lamella is reduced to a minimum.

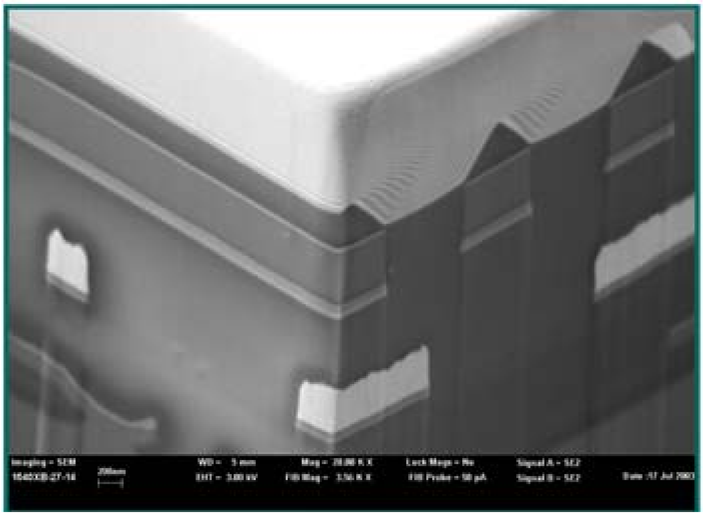

***Figure 2.*** *Three-dimensional analysis of a semiconductor device. The image was taken during ion milling.*

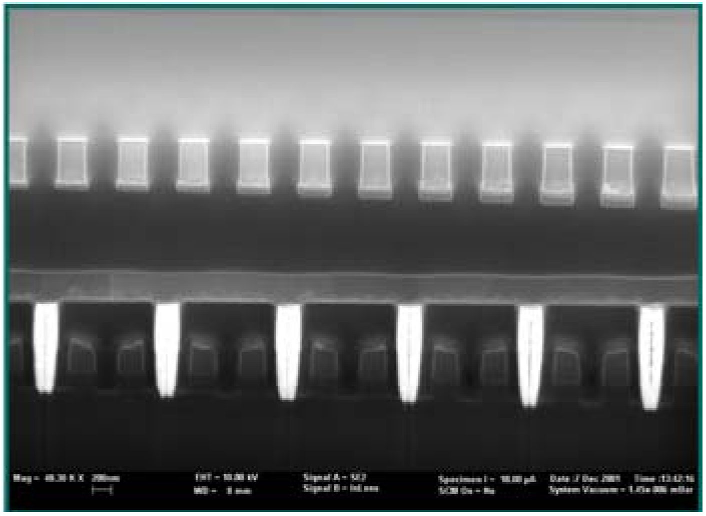

***Figure 3.*** *Cross section through tungsten plugs in a semiconductor device. The image was taken during ion milling. The milling process can be stopped exactly in the center of the plugs.*

Another advantage of the CrossBeam technology is the time-saving cut-and-see operation—the sample is imaged during or immediately after the polishing. This results in extremely short inspection times for each cross section. In addition, digital video, recorded during the cutting process, can be used for three-dimensional reconstruction of the sample.

## TEM Sample Preparation

Several TEM sample preparation techniques using FIB, such as prethinning (*Figure 4*) and lift-out techniques (*Figures 5* and *6*) have been published [2-4]. The FIB lift-out technique allows thin membranes to be extracted from bulk material, which saves a lot of sample prethinning time and is very successful in the preparation of site-specific cross sections and planar samples. Although TEM sample preparation can be automated by using scripts and macros, the best accuracy is achieved if the milling is done manually with direct SEM observation. (Keep in mind that an automated process is a blind process.) In a first step, the sample is milled and polished from the front side under continuous SEM control until the detail of interest is visible. In the second step, the sample is rotated by 180°, and the backside of the sample is milled and polished under continuous SEM control until the desired thickness is achieved (*Figure 4*).

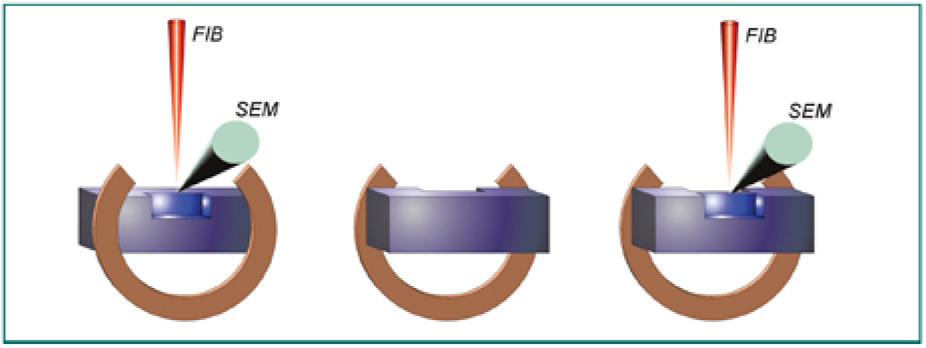

***Figure 4.*** *Steps for prethinned TEM sample preparation using CrossBeam technology.*

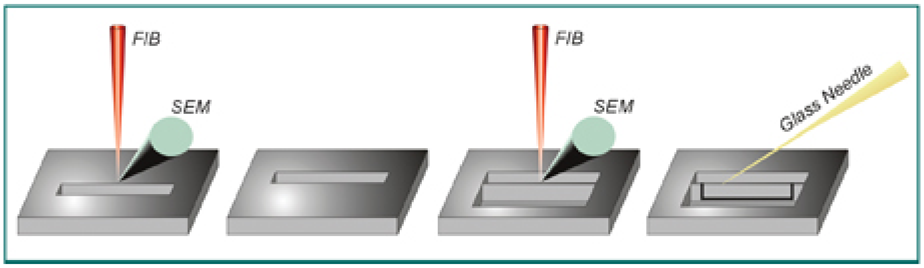

***Figure 5.*** *TEM lift-out sample preparation using CrossBeam technology. After the final polish, the lamella is cut out of the substrate by three cuts and is transferred to a TEM grid by use of a micromanipulator and a glass needle.*

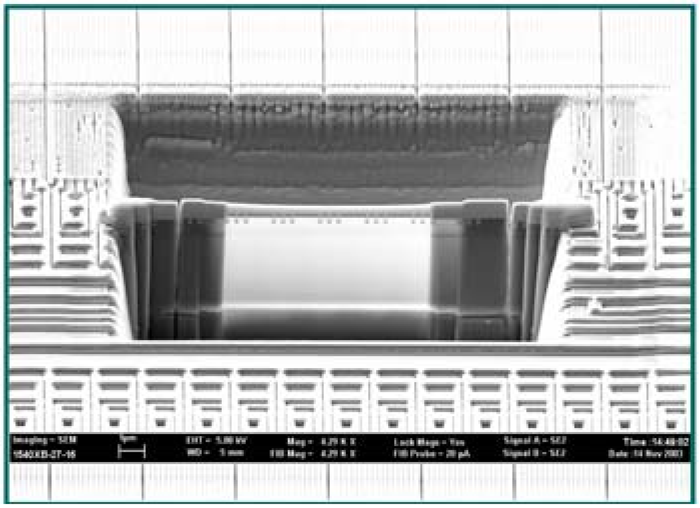

***Figure 6.*** *TEM lift-out sample after milling and polishing. The sample is cut out of the substrate and is ready for lift-out. Note the electron transparency of the thin area.*

By imaging the TEM sample in the SEM, the danger of destroying the TEM lamella due to drift and so on is minimized. Another opportunity of the direct

SEM imaging is a very straight control of the specimen thickness and electron transparency during the ion milling process (*Figure 7*).

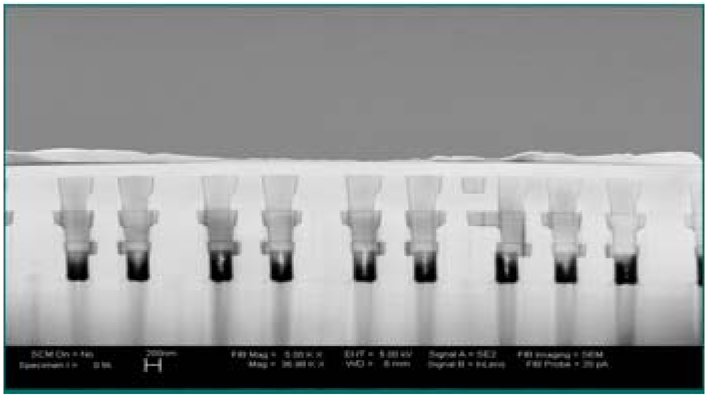

***Figure 7.*** *TEM sample during ion milling. The lamella can be positioned exactly at the area of interest. Note the electron transparency of the thin area.*

The best result concerning time and accuracy is achieved if different samples are prethinned automatically overnight to a thickness of about 1 µm and then polished manually under high-resolution SEM observation.

## STEM Imaging

By inserting a multimode STEM detector into the instrument, analysis on a subnanometer level is possible. Together with the real-time imaging capabilities, extremely accurate and site-specific cross sections can be performed and analyzed at a sub nm level. *Figure 8* shows an example of a sub-µm defect in a semiconductor sample that could be located by using the live imaging possibilities of the CrossBeam. The image was taken using the STEM mode of the CrossBeam system.

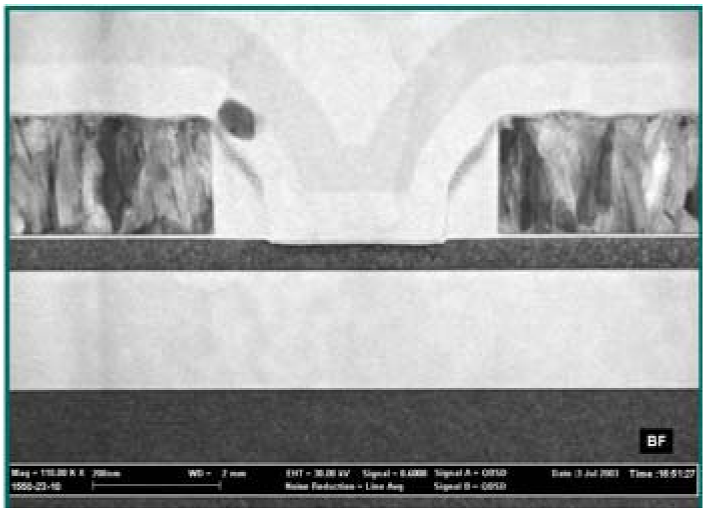

***Figure 8.*** *30 kV bright field STEM image of a semiconductor structure. A very small defect was hit exactly in the center.*

## References

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