
Failure analysis and defect review

Accuracy of the CrossBeam Technology

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The use of the focused ion beam (FIB) systems has increased to a high level in recent years [1]. The imaging, milling, and deposition capabilities of the FIB make it the ideal instrument for, e. g., site-specific failure analysis, specimen preparation and nano-machining. Ion channeling contrast allows for selective imaging of polycrystalline and poly-phase microstructures. In addition, the FIB and CrossBeam instruments are unique stand-alone analytical tools. Their vast capabilities have enabled numerous applications into the semiconductor and materials sciences applications. 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 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 (Fig.1). In the case of the CrossBeam tool, the final lens of the SEM is designed as a magnetic / electrostatic compound lens. This layout has the advantage that no magnetic field interferes with the ion beam and the SEM can be operated at nm 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. Together with a multi-channel 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.

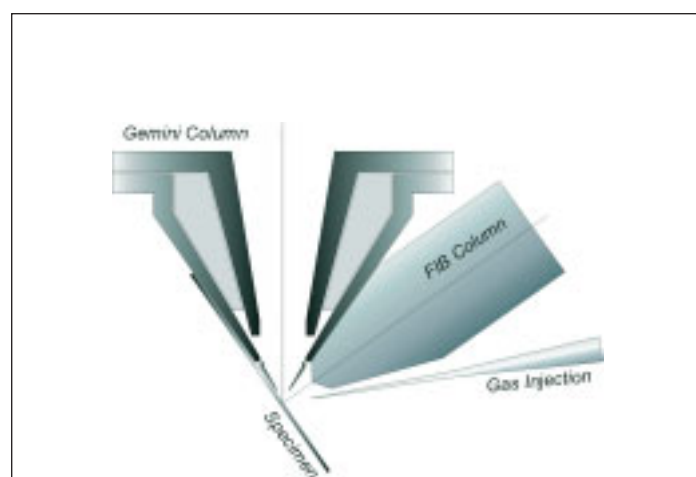


Fig. 1: Schematic layout of a CrossBeam tool. The electron and the ion beam coincide at a point 5mm below the final lens of the SEM.

(Source: Carl Zeiss NTS)

Vacuum system

To ensure a safe and reliable operation of the instrument, a dedicated vacuum system is needed. This type of instrument combines a high resolution field emission SEM with UHV requirements in the emitter area, a focused ion beam (FIB) column with high vacuum requirements in the total column and a gas injection system that can increase the pressure in the vacuum chamber of the instrument up to 10^{-3} mbar even with aggressive gases. Therefore the vacuum system of the instrument has to satisfy the following requirements:

1. The pumping system must be free of vibrations to ensure the high-resolution capability in the sub nm range of the SEM.
2. The vacuum system must be oil free to avoid sample contamination during SEM imaging.
3. The vacuum system must be able to handle aggressive gases at relatively high pressures when the GIS is used.

The vacuum system of the CrossBeam tool is illustrated in Fig. 2.

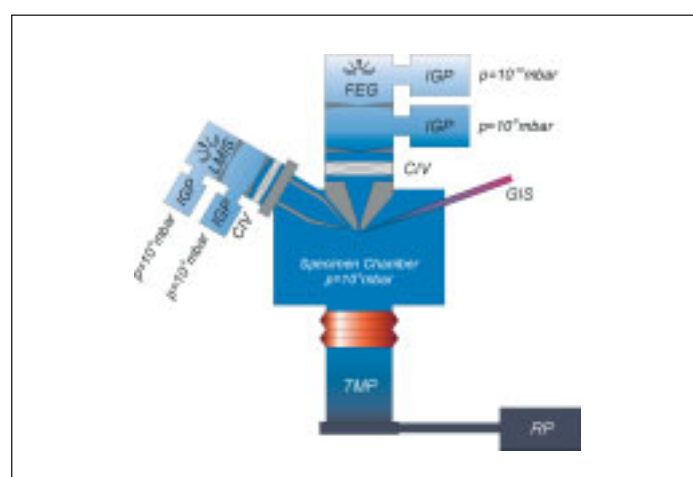


Fig. 2: Vacuum system of a CrossBeam tool. The vacuum in the specimen chamber is generated by a turbomolecular pump (TMP) while the vacuum in the two columns is maintained by two ion getter pumps (IGP) per column.

(Source: Carl Zeiss NTS)

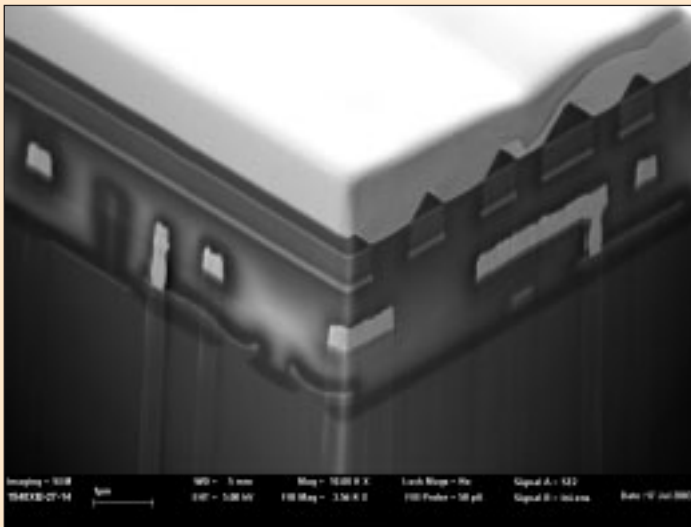


Fig. 3: Three-dimensional analysis of a semiconductor device. The image was taken during ion milling.
(Source: Carl Zeiss NTS)

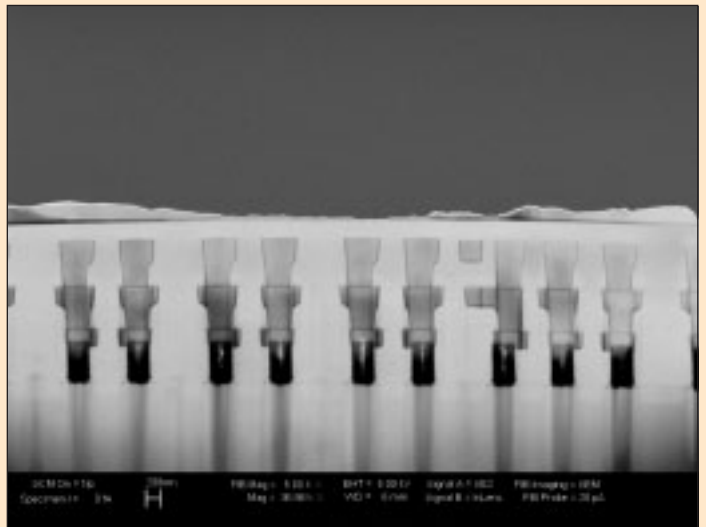


Fig. 6: TEM sample during ion milling. The lamella can be positioned exactly at the area of interest. Note the electron transparency of the thin area.
(Source: Carl Zeiss NTS)

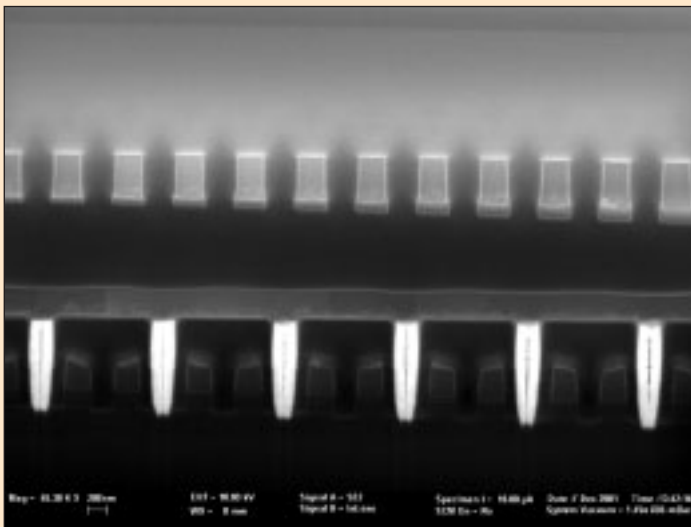


Fig. 4: Cross section through tungsten plugs in a semiconductor device. The image was taken during ion milling. The milling process can be stopped exactly in the centre of the plugs.
(Source: Carl Zeiss NTS)

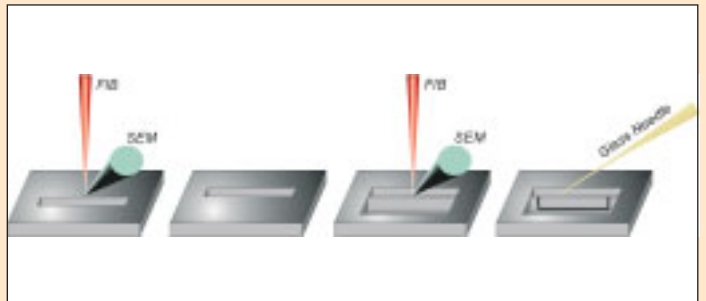


Fig. 7: TEM lift out sample preparation using the CrossBeam technology. After the final polish the lamella is cut out of the substrate by three cuts and is transferred to a TEM grid by use of a micromanipulator and a glass needle.
(Source: Carl Zeiss NTS)

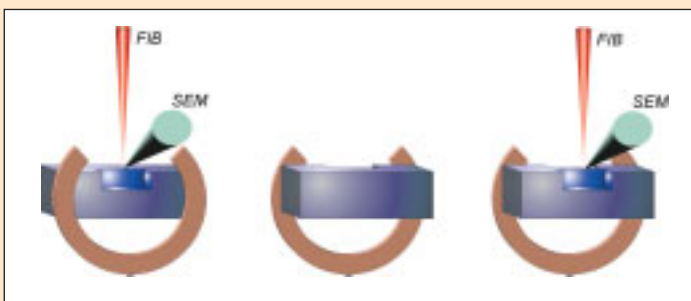


Fig. 5: Steps for a pre-thinned TEM sample preparation using the Cross-Beam technology. In step 1 the sample is milled and polished from the first side under continuous SEM control. In the second step the sample is rotated by 180° and the backside of the sample is milled and polished under continuous SEM control until the desired thickness is achieved.
(Source: Carl Zeiss NTS)

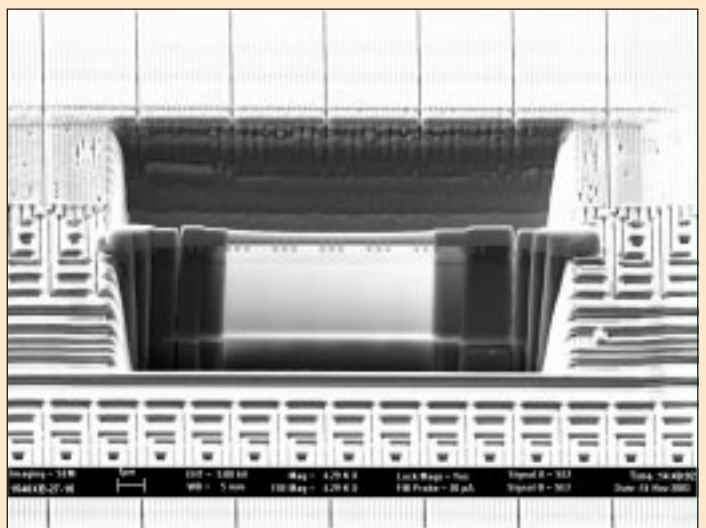


Fig. 8: TEM lift out sample after milling and polishing. The sample is cut out of the substrate and is ready for lift out. Note the electron transparency of the thin area.
(Source: Carl Zeiss NTS)

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. Afterwards 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 (Fig. 3). 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 (Fig. 4).

Especially in the case of TEM sample preparation, the danger of destroying the fine lamella is reduced to a minimum.

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 AVI movies that are recorded during the cutting process can be used for three-dimensional reconstructions of the sample.

TEM sample preparation

Several TEM sample preparation techniques using FIB, such as pre-thinning (Fig. 5) and lift-out techniques (Fig. 7, 8) 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 pre-thinning time and is very successful in the preparation of site-specific cross sections and planar samples. While TEM sample preparation can be automated 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 reverse side of the sample is milled and polished under continuous SEM control until the desired thickness is achieved (Fig. 6).

By imaging the TEM sample in the SEM the danger of destroying the TEM lamella due to drift etc. 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 (Fig. 6).

The best result concerning time and accuracy is achieved if different samples are pre-thinned automatically overnight to a thickness of about $1\ \mu\text{m}$ and then polished manually under high resolution SEM observation.

STEM imaging

The insertion of a multimode STEM-detector into the instrument allows analysis on a sub nm level. Together with the real time imaging capabilities, extremely accurate and site-specific cross sections can be performed and analyzed at a sub μm level. Fig. 9 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.

References:

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- [4] T. L. Shofner, J. L. Drown, S. R. Brown, B. B. Rossie, M. A. Decker, Y. S. Obeng, F. A. Stevie, *ISTFA*, p. 45 (2000).



Peter Gnauck studied physics at the University of Tübingen, Germany, where he gained his PhD in 2000. From 1995 to 1999 he was a research scientist at NMI, Reutlingen, Germany, before becoming Project Manager in the R+D department of LEO Electron Microscopy Group. In 2001 he moved Carl Zeiss NTS, where he is currently Product Manager for CrossBeam Systems.

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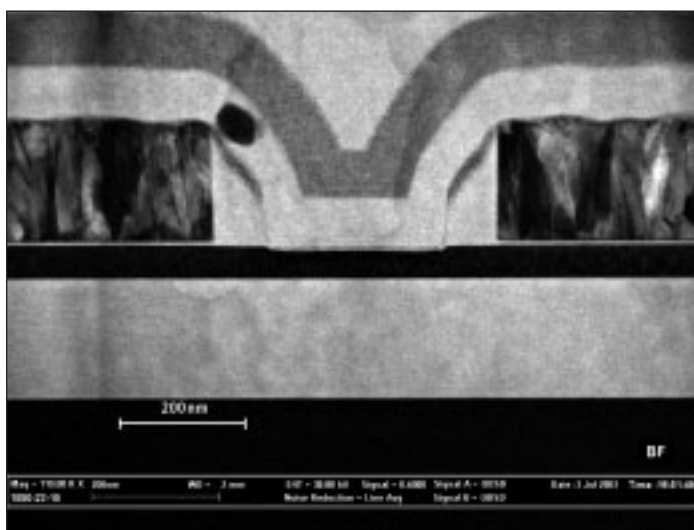


Fig. 9: 30kV bright field STEM image of a Semiconductor structure. A very small defect was exactly hit in the centre.

(Source: Carl Zeiss NTS)