Recent Developments in CrossBeam® Technology

A. Thesen, H. Hoffmeister, M. Schumann, P. Gnauck
Carl Zeiss SMT Oberkochen, Germany
a.thesen@zeiss.de

Recent developments in nano- and semiconductor technology have substantially increased the demand for accurate and efficient site specific cross-sectioning of specimens and preparation of TEM samples. Moreover, nano-research is facing new challenges for manipulation, observation, and modification of devices on a submicron scale. At the same time in materials science a new focus on analytical nanoscale investigations—not only of specimen surfaces and cross sections—but on sample volumes is emerging.

These demanding requirements can be met if a focused ion beam (FIB) column for nanoscale structuring is combined with a high resolution SEM that is used to monitor the FIB milling and deposition process on a nanometer scale. Such an integrated CrossBeam® system enables the high resolution observation and direct control of the FIB milling process in real time. Using this concept it is possible to prepare site specific TEM samples and cross sections with nano-scale accuracy. Such a system can be complemented with a gas injection system (GIS), for deposition and enhanced etching of specific materials, as well as, *in-situ* micro manipulation systems, and analytical detectors such as EDX and EBSP systems [1].

Recently a new CrossBeam® system, the NVision 40, has been introduced. This is comprised of the accelerating objective lens technology zeta ion column, a Gemini® SEM column, and a mass flow controlled single injector multi channel gas injection system (GIS). This article will discuss both the unique ion and electron optical design of these components and the benefits of combining them into one system.

Accelerating Objective Lens Ion Beam Technology

One major bottleneck for most FIB application, like high throughput TEM sample preparation, is the speed of the ion milling process. As the milling speed is directly related to the current density of the ion beam, time to create a sample can be significantly decreased by employing advanced ion optical designs optimized for high current densities and improved probe profiles.

As in any optical system, beam properties can be characterized by adding up the contributions to the probe resulting from the apparent virtual source size, the chromatic aberration and the spherical aberration disks. Due to the high mass of the gallium ions used in FIB optics the diffraction error can be neglected and the probe size can be computed according to

$$D = \sqrt{(Md_v)^2 + \left(\frac{1}{2}C_s\alpha^3\right)^2 + \left(C_c\alpha\frac{\Delta E}{E}\right)^2}.$$

Here E denotes the acceleration energy of the ion beam, ΔE the energy spread, α the beam half angle at the image plane, M the magnification of the source, d_v the virtual source size, C_s the spherical aberration coefficient, and C_c the chromatic aberration coefficient. Apparently the contribution of the spherical aberration dominates especially for large apertures, which are required for large milling currents, while chromatic aberration dominates the beam properties for the small aperture currents used for imaging (fig. 1). To improve the ion optical properties of an ion column both C_s and C_c should be reduced to increase the beam current densities and to reduce the spot sizes.

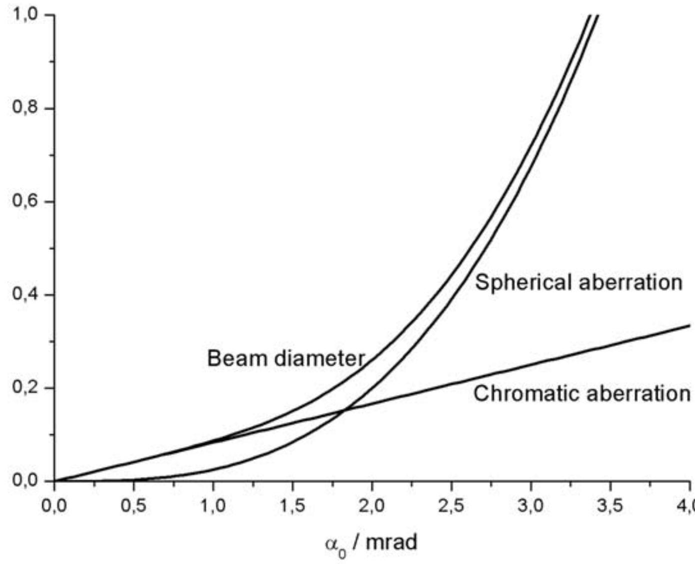

Fig 1.: *FIB beam diameter (arbitrary units) versus beam half angle including the contributions due to spherical and chromatic aberration. Unlike the well known analogous curve for electrons, there is no minimum because of the negligible diffraction term due to the high mass of the ions. Spherical aberration dominates the probe size for high coarse milling currents, while chromatic aberration becomes significant for the small imaging currents.*

Among other reasons, because gallium naturally occurs in the form of two isotopes, only electrostatic lenses can be used in ion optical systems in order to avoid mass separation of the two isotopes by magnetic fields. Thus, an electrostatic einzel-lens is used as an objective lens for the ion optical system. The einzel lens is comprised of three cylindrical electrodes with the first and last electrode at ground and the second electrode at a different potential V.

In conventional ion optics V is chosen positive such that the ion beam is decelerated inside the objective lens. It has been shown by Orloff [2], however, that both C_s and C_c of the objective lens can be improved by an order of magnitude by choosing V to be negative and thus accelerating the beam inside the objective lens to almost 70 kV before slowing it down to its 30 kV landing energy. This results in up to 20 % more beam current density with respect to conventional optics and an increased ion beam resolution of 4 nm.

This unique accelerating objective lens zeta ion column has been exclusively made available for a CrossBeam® system for the first time with the introduction of the NVision 40 (fig 2).

Gemini® SEM Technology

As discussed in the previous paragraph magnetic fields will cause isotope splitting of the gallium ion beam. Therefore conventional SEM objective lenses, which produce a magnetic field at the sample, have to be turned off during ion beam operation. The Gemini® objective lens, however, does not produce a magnetic field at the sample and therefore ideally complements the ion column, because it enables simultaneous high-resolution SEM imaging of all FIB applications. Additionally, the column includes two complementary inlens detectors for simultaneous SE and BSE imaging.

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

https://doi.org/10.1017/S1551929500051130 Published online by Cambridge University Press

Fig 2.: *The NVision 40 CrossBeam® Workstation. The system is comprised of the Gemini® SEM column, an ion column with accelerating objective lens technology, and a mass flow controlled multi channel GIS. The ion column is located at a 54° angle from the SEM column. The system is also equipped with in-lens SE and BSE detectors, a chamber SE detector, and two infrared chamber scopes. There are additional ports for STEM, 4QBSE, EDS, and EBSD detectors as well as sample manipulation tools.*

becomes possible in a very controlled process. Another advantage of the CrossBeam® technology is the time saving cut and see operation: The sample is imaged during cutting and polishing. This results in extremely short inspection times for each cross section.

By using live AVI recording of the high-resolution SEM image during the milling process data for 3D volumetric reconstructions can be conveniently generated.

Single Injector Multi-Channel GIS System

The NVision 40 features a multi channel GIS system for deposition and enhanced etching of specific materials. To allow maximum flexibility for the choice of gas precursors the system can be operated with solid state, liquid, and gaseous precursors. The precursor gases are piped through mass flow controllers for precise dose control into a single injector needle. Because all gas lines converge into a needle, the gases can be mixed, thus allowing implementation of even more complex gas processes.

Conclusion

The combination of Gemini® SEM column with the zeta ion column offers several benefits for advanced and rapid sample preparation and nano-structuring applications. Thanks to accelerating objective lens design of the ion column, which leads to 20 % higher current densities and small beam tails, the sample preparation time can be greatly improved. By operating the ion column as low as 1 kV, efficient removal of sample surface damage for high resolution TEM imaging is possible. The column also allows high resolution FIB imaging at 4 nm.

The milling process can be live monitored by simultaneous high resolution SEM imaging. This not only provides full control for end point detections but also increases speed and depth resolution for 3D acquisition. ■

References

[1] Konrad, Zaefferer, Raabe: *Acta Mater* 54 (2006) 1369.
[2] Orloff, Swanson, *J. Appl. Phys.* 50(4) April (1979) 2494.