Nanoscale Structuring and Investigation: Crossbeam Tool with Ultra High Resolution FIB Technology

Nanoscale Structuring and Investigation: Crossbeam Tool with Ultra High Resolution FIB Technology. 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, a new focus on analytical nanoscale investigations – not only of specimen surfaces and cross sections, but on sample volumes – is emerging in materials science.

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 nanoscale accuracy. Such a system can be complemented with a gas injection system (GIS), for deposition and enhanced etching of specific materials, as well insitu micro manipulation systems and analytical detectors such as EDX and EBSP systems [1].

The Crossbeam system NVision 40 (fig. 1) is comprising 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 Objection Lens Ion Beam Technology
One major bottleneck for most FIB applications 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 sample can be significantly increased by employing advanced ion optical designs optimised for high current densities and improved probe profiles. As in any optical system, beam properties can be characterised 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 figure 5. Here $E$ denotes the acceleration energy of the ion beam, $\Delta E$ the energy spread, $\alpha$ the beam half angle at the image plane, $M$ the magnification of the source, $dv$ the virtual source size, $Cs$ the spherical aberration coefficient, and $Cc$ the chromatic aberration coefficient. Apparently the contribution of the spherical aberration dominates especially for large apertures $\alpha$., which are required for larger milling currents, while the chromatic aberration dominates the beam properties for smaller aperture currents used for imaging (fig. 2).

To improve the ion optical properties of an ion column, both $Cs$ and $Cc$ should be reduced to increase the beam current densities and to reduce the spot sizes. Among other reasons, because gallium naturally occurs in 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 of the ion optical system comprising 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 slightly positive such that the ion beam is decelerated inside the objective lens. It has been shown by Orloff [2], however, that both the $Cs$ and $Cc$ 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 the conventional optics and an increased ion beam resolution of 4 nm (fig. 3). Another advantage of the innovative ion optics concept is an unsurpassed low voltage performance of the FIB column (fig. 4). This feature is especially useful to improve the quality of TEM samples with a final polishing step at low kV. 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.

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 to 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 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 life AVI recording of the highresolution 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 one needle, the gases can even 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 life monitored by simultaneous high resolution **SEM** imaging. This does not only provide full control for end point detections but also increases speed and depth resolution for 3D acquisition.

References

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