New Developments in GEMINI® FESEM Technology

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Introduction

The Field Emission SEM was introduced to improve imaging resolution available with conventional SEMs with a tungsten source. Thermal assisted or Schottky Field Emission SEMs were introduced in the nineties by a number of companies as a stable source to overcome the beam instability of the cold FESEMs introduced earlier. The GEMINI® based Field Emission SEM launched by ZEISS 12 years ago has been designed from the beginning as a high stability FESEM with a relatively large multi-ported chamber. The drive to develop GEMINI® technology was the need for a FESEM capable of ultra-high resolution performance over the entire accelerating voltage range that also possessed the flexibility needed for a wide range of analytical applications.

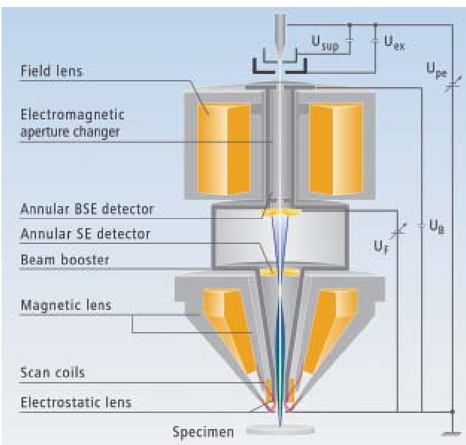

Fig. 1: Cross section of the GEMINI® electron optical column utilised in the ULTRA FESEM.

Uex = extractor voltage of first anode

UPE = primary beam voltage

UB = booster voltage

UF = EsB filtering grid voltage

GEMINI® technology has been designed to overcome the main limiting factors of SEM resolution:

- Probe diameter at the sample surface – the smaller the probe size, the better the resolution, hence the need for a FESEM column
- Thermal assisted FE source – no flashing needed and gives stability for X-ray mapping and EBSD
- Depth of penetration of the electron beam into the specimen surface – deeper penetration yields a larger interaction volume and degrades resolution: ultra low voltage capability is the solution
- Probe current – higher probe currents give better signal to noise ratio: high current module
- Detector efficiency – higher efficiency give better contrast and higher signal to noise ratio: In-column detectors to improve resolution

The GEMINI® column integrates a number of innovations like the integrated beam booster, the magnetic / electrostatic objective and annular in-column detectors. It has imaging capabilities comparable with in-lens FESEMs without specimen size limitations. The name GEMINI® has been derived from Castor and Pollux, the astronomical "twins" of Gemini, in this case the twin end lens end the electrons travelling down to the specimen and up to the detector.

GEMINI® FESEM Column Design

The Schottky FE source used in the GEMINI® column achieves a similar low energy spread compared to a cold field emission source, but with a much higher emission current and much higher beam stability. Regeneration of the beam tip (flashing) is not required. The GEMINI® column features the innovative integrated beam booster to keep a relatively high accelerating voltage in the column. Furthermore the electron beam path is designed without any cross over between electron sources.

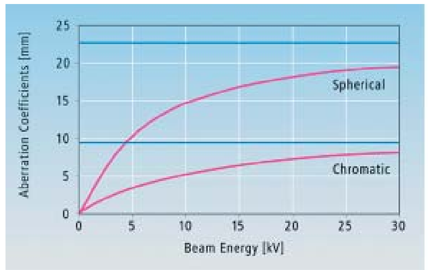

Fig. 2. GEMINI®'s decreasing spherical and chromatic aberrations with decreasing landing energy

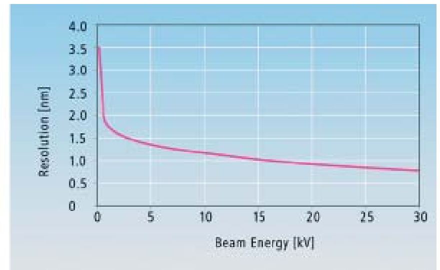

Fig.3. GEMINI®'s guaranteed resolution depending on landing energy.

Ultra low voltage imaging capabilities

One of the most important features of the GEMINI® column is the decreasing aberrations manifested with decreasing beam energy–assuring superb resolution even at ultra-low voltages, see fig. 2. The magnetic / electrostatic lens combination increases the incident beam aperture angle at the specimen, which improves both the signal to noise ratio and the resolution, see fig. 3. The GEMINI® lens is shaped to minimize the magnetic field at the specimen. Therefore, high resolution imaging of dia-, para-, or ferromagnetic materials is possible with very short working distances. The specimen is not emerged in a strong magnetic field like with other designs.

GEMINI® High Current Module

A further development of the GEMINI® column has resulted in the recently developed high current mode that allows for doubling the beam current compared to standard operating parameters. The high current in a smaller beam diameter gives a virtually parallel illumination at the sample, see fig.4, which greatly increases depth of focus, see fig 5a/b. The advantages for analytical applications like EBSD are that smaller crystals in the region of 20-50 nm can be detected and classified.

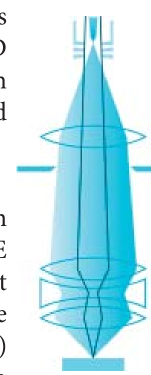

Fig. 4: Beam profile comparison, virtual parallel illumination with high current mode (narrow beam)

In-column Detectors

The GEMINI® column design includes an integrated In-lens SE detector. The weak magnetic field at the specimen surface intercepts the low energy secondary electrons (SE) at the point of impact. They are then accelerated in the booster column and focused on the In-lens above the objective lens. The recently introduced, high-efficiency, 3rd generation In-lens detector boosts signal to noise ratio by a factor of 2-3, improves dynamic range, and does not suffer from ageing.

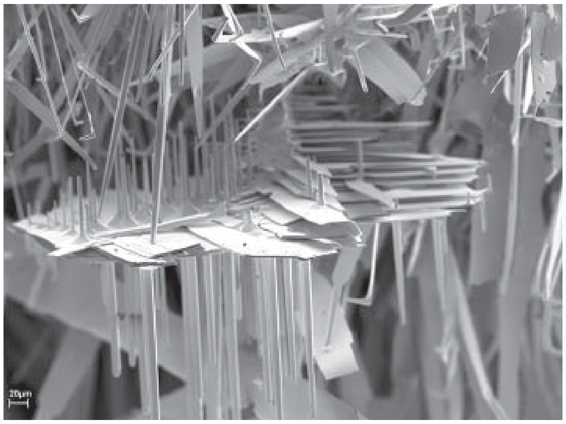

Fig. 5a: Normal imaging on high topography sample. The sample is 4mm high and was acquired at 4mm working distance and 1.2kV. Although the GEMINI® column is still superior to other systems under these conditions, the limited depth of field is noticeable.

Fig. 5b: Using the HC/DoF module gives a dramatic improvement of the depth of field under the same conditions as in Fig. 5a. Even with a height of 4mm the complete sample is in focus.

New GEMINI® based FESEM: ULTRA

The ULTRA FESEM, introduced last year, is based on the SUPRA™ series of FESEMs and features a second In-column detector enabling simultaneous detection of backscattered electrons (BSE) with the newly developed EsB detector. The **E**nergy and angle **s**elective **B**ack-scatter detector is positioned directly above the In-lens SE detector. The difference in energy and emerging angle at the specimen surface of the SE and the BSE allows for effective separation in the GEMINI® column precisely at the plane of the In-lens SE detector, see fig. 6. The BSE pass the central aperture and are then projected on the EsB detector, see fig.7. To avoid any unwanted overlay with SE electrons, a filtering grid is installed in front of the EsB detector to repel any SE that may have passed through the In-lens aperture. Adjustment in the range from 0 to minus 3000 volts enables real-time mixing and simultaneous observation of surface, voltage and material contrast, without interfering with the primary beam.

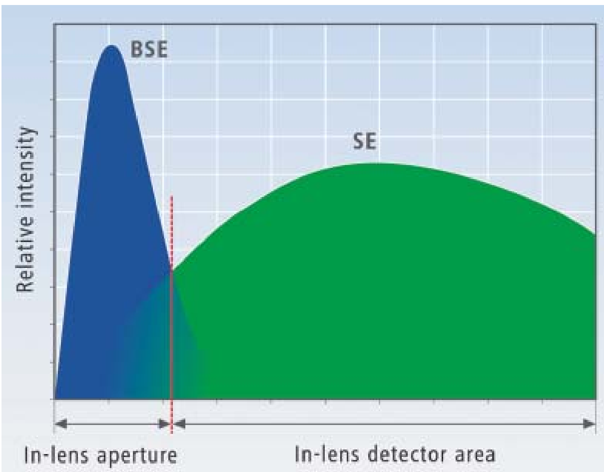

Fig. 6: Radial distribution of BSE and SE in the In-lens detector plane. Clearly visible is the separation of the electrons at the In-lens SE detector plane and the high detection efficiency of both detectors.

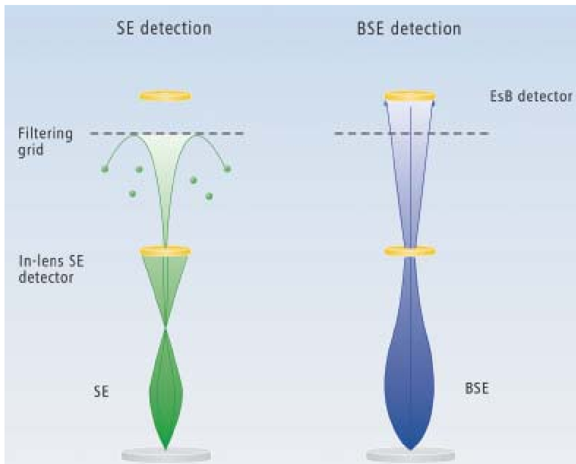

Fig. 7: The SEs (green) are projected onto the high efficiency In-lens detector and the BSEs (blue) are guided onto the integrated EsB detector.

Conclusion

The ULTRA FESEM with the dual In-column detectors enables precise and clear simultaneous ultra high resolution imaging with secondary and backscattered electrons at voltage as low as 100V and working distances down to 1mm. Low voltage BSE imaging with the EsB detector allows for advanced metrology and suppresses charging effects on non-conducting samples (Fig. 8, 9 and 10). Application fields for this new type of FESEM are as diverse as magnetic specimens, barrier layers in semiconductor material, compositional imaging, particle analysis and immuno-gold labelling. ■

References:

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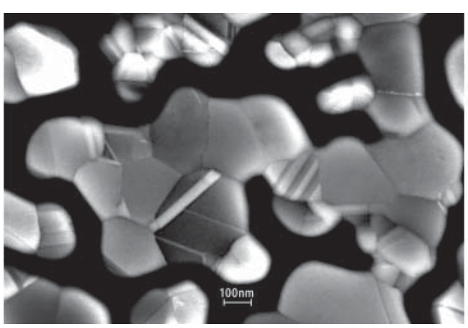

Fig. 8: Evaporated Au particles on carbon with clearly visible twins (BSE)

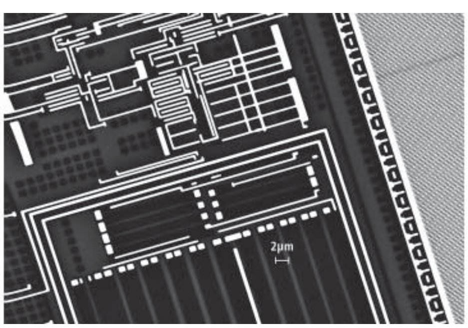

Fig. 9: Compositional contrast on semiconductor device (BSE)

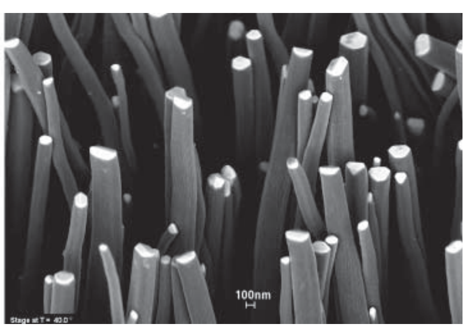

Fig. 10: Carbon-Nanotubes with Ni-particles (SE/BSE mix)