EsB Detection Low Voltage – BSE Imaging

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Nanotechnology has become a very active and highly charged discipline in science and technology, growing rapidly in industrial sectors and is part of almost every field of research and engineering. The intense interest in nanotechnology is being driven by visions of a stream of new nanotech commercial applications that will dominate future industrial appearance. Our latest FESEM technology enables, not only routine inspection and failure analysis, but also ultra high resolution imaging including the complete variety of state-of-the-art analytical features essential in nanotechnology research.

Fig. 1: The ULTRA FESEM

The GEMINI® Column

Zeiss´ Field Emission Scanning Electron Microscopes are all based on the GEMINI® principle. In order to reduce aberrations and sensitivity to interfering strayfields the electron optical column possesses a positively biased booster that shifts the energy of the primary electrons. The incident beam is focussed by a combination of a magnetic lens with an axial gap that avoids field leakage to the specimen and an electrostatic retarding lens formed by the beam booster, together with the grounded pole piece cap. Shortly before the electrons hit the specimen they are decelerated to the desired primary energy. A suitable explanation for the reduction of spherical and chromatic aberrations is that the electron beam is focussed by the objective lens at higher energies and smaller electron beam diameters. The GEMINI® concept has overcome the problem with classical objective lens designs, which immerse the specimen in the magnetic field prohibiting imaging of magnetic samples.

Detection System

GEMINI® FESEMs microscopes enable a large variety of detector types (Fig. 3) to analyse all scattering products emerging from the specimen: Secondary electrons (SEs) used mostly to resolve topographic and charging information, backscattered electrons (BSEs) to enhance compositional contrast and crystal orientation, as well as photons to visualise lattice structures or to show luminescence effects.

Beside the already mentioned benefits of highest resolution and beam stability, the beam booster is also advantageous for secondary electron collection. SEs emerging from the sample surface are attracted and accelerated by the positively biased electrode of the beam booster and are collected with the SE In-lens detector. An additional Everhart-Thornley chamber detector (ETD) collects remaining SEs that are not captured by the beam booster (especially at large working distances) or second generation secondary electrons, SE3 type, which are produced by BSE interaction with the objective lens.

The ETD typically depicts compositionally enhanced contrast combined with some surface information. Correct BSE detection is rather complicated and needs several detectors covering the whole solid angle depending on the primary energy of the initial electrons. A retractable quadrant diode detector installed beneath the objective lens collects BSEs scattered under very low angle (almost parallel to the sample surface) and produces high quality material contrast images.

Low Voltage BSE Imaging – EsB Detection

In order to detect high angle BSEs (almost perpendicular to the sample surface) backing up through the lens, a new detector has been developed and introduced in the new ULTRA FESEM (Fig. 1).

To understand the basic principle of this new detection system a closer examination of the energy spectra as well as the take-off angle distributions of the released electrons and their trajectories through the electron column is necessary. Fig. 4 illustrates a schematic energy

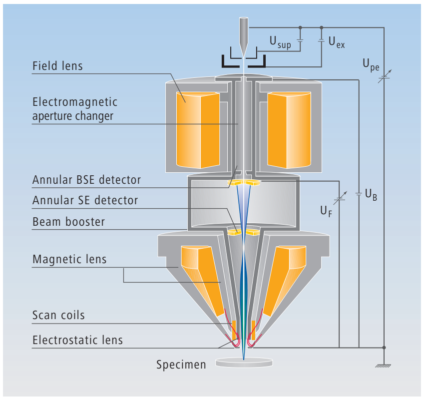

Fig. 2: GEMINI® bias concept

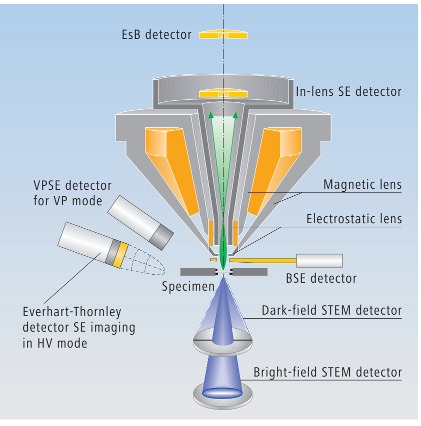

Fig. 3: GEMINI® detectors

spectrum of electrons escaping from the specimen. Secondary electrons (green), possessing very low energies by definition, are released near the surface and produce a signal rich in topographic information, where as backscattered electrons (blue), which have undergone at least one large angle scattering, originate from larger depths and possess compositional information.

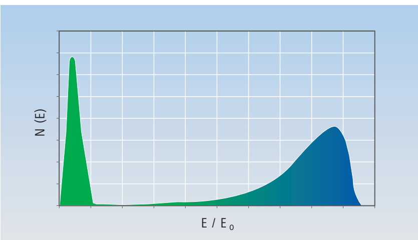

Fig. 4: Electron energy spectrum

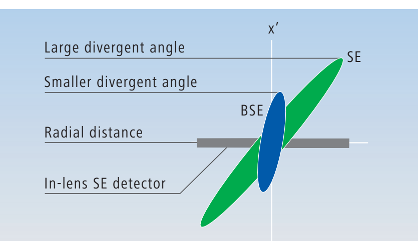

Fig. 5: Phase space comparison

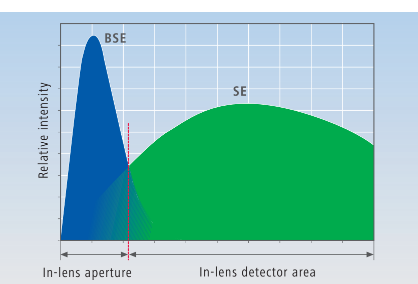

Fig. 6: Radial electron distribution

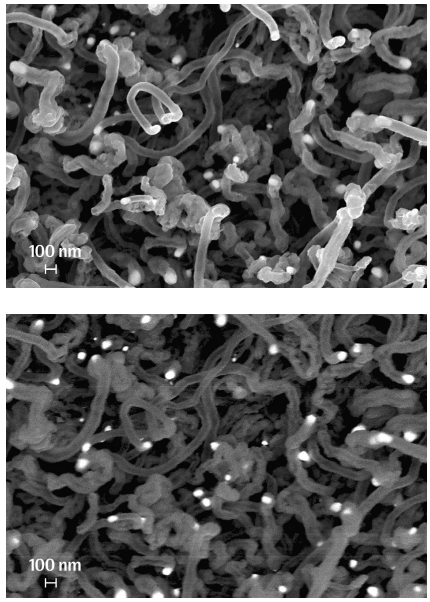

Fig. 7: Nanotube Sample at 4 kV
Top: SE image
Bottom: BSE image taken with EsB detector (filtering voltage 600 V)
Image courtesy of Dr. Heiner Jaksch, Carl Zeiss SMT

Beside electron energy level, both electron types also differ in respect to their take-off angle distribution. While the distribution of secondary electrons orientates perpendicularly to topographic structures, backscattered electrons emerge from the bulk material and are therefore less sensitive to surface topography.
Emerging from the specimen surface most of the electrons are attracted by the beam booster and move upstream into the GEMINI® column. Because of the chromatic aberation of the magnetic lens the electrons are forced on different trajectories depending on their energy when traversing the focussing field. Both, the deflection of the lens and the different take-off angle distribution result in different phase spaces at the position of the lower annular In-lens SE detector (Fig. 5). The green ellipse indicates SEs possessing large divergence and a wide spatial spread, whereas the BSEs emittance is significantly smaller, resulting in an effective separation of secondary and BSEs at the position of the lower SE In-lens detector.

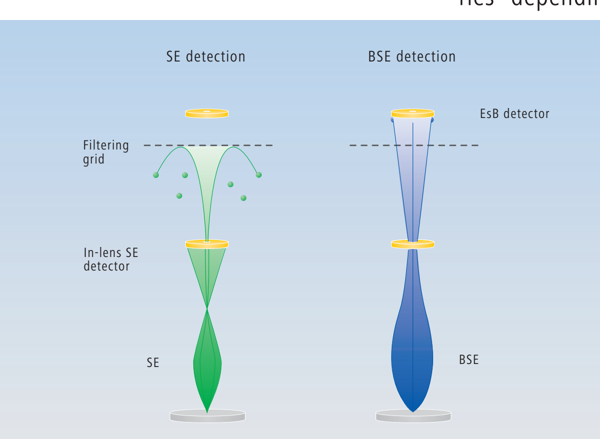

Fig. 8: The SEs (green) are projected onto the lower In-lens detector and the BSEs (blue) are guided onto the upper EsB detector.

As a consequence of different phase spaces, backscattered electrons have a closer radial distance in comparison to SEs and transmit through the central aperture of the In-lens SE detector while secondary electrons land on the In-lens detector and are collected. From Fig. 6, depicting the radial distribution and the dimension of the detector aperture (red line), it is clear that for optimised conditions a filtering efficiency of 90 % may be achieved by applying the method of „**E**nergy and angle **s**elective **B**SE detection". Electrons passing the lower In-lens detector may be collected at the upper EsB detector. These are mainly the so-called „high angle" backscattered electrons, including a small propotion of unwanted secondary electrons inside the phase space volume of the backscattered. The compositional information of the EsB detector is superimposed by an undesirable surface signal. To remove this contribution a negatively biased filtering grid is installed below the EsB detector to repel the secondary electrons. Adjustment of the filtering grid in the range from 0 to minus 3000 volts enables real-time mixing and simultaneous observation of surface, voltage and material contrasts, without interfering with the primary electron beam. Fig. 8 clearly shows the beam shapes of both electron types and the general functioning of EsB detection and filtering mechanism. Fig. 7 depicts the advantages of the new detector arrangement. While the upper image clearly shows topographical and voltage information, the lower micrograph pronounces compositional contrast and suppresses any charging or edge emphasis effects allowing for accurate metrology to be performed.