

Beam Deceleration Imaging with ZEISS EVO



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EVO conventional scanning electron microscope has a new sample bias module that enables beam deceleration imaging. This, combined with the ZEISS HD BSE detector, produces high quality images with enhanced surface contrast and topographical detail. This technique is particularly beneficial to low kV imaging and life science specimens. This paper explains the technique and how it can enhance low kV imaging.

Introduction

Scanning electron microscopy (SEM) obtains an image by rastering a beam of electrons over the surface of a sample. See figure 1. The interaction of the electron beam with the sample generates secondary electrons (SE) and backscattered electrons (BSE) which are collected by electron detectors. The intensity of the collected electrons at each scanning position is used to produce the image.

The interaction of the primary electron beam with the sample produces electrons from a small volume close to the surface. This region is known as the interaction volume and its size and depth is highly dependent on the energy of the primary beam. Since electrons from the interaction volume form the image, it determines which features on the sample can be observed. A high energy primary beam (commonly called 'high kV') penetrates typically more than a micron deep into the sample. Therefore, surface detail located only a few nanometers on the surface becomes invisible. See figure 2.

When it is required to image surface detail, the energy of the primary beam and therefore the interaction volume are kept as small as possible so that secondary electrons are emitted from an area a few nanometres below the surface. This is achieved by using a low kV. See figure 3.

The primary beam will also generate BSEs from the interaction between the beam and the atomic nucleus, to produce an image which displays atomic number contrast.

However, low kV BSEs cannot usually be detected with semiconductor type BSE detectors since the 'dead layer' on the surface of the semiconductor diode blocks the transmission of low kV BSEs. This means that atomic number contrast images usually require a high kV primary beam.

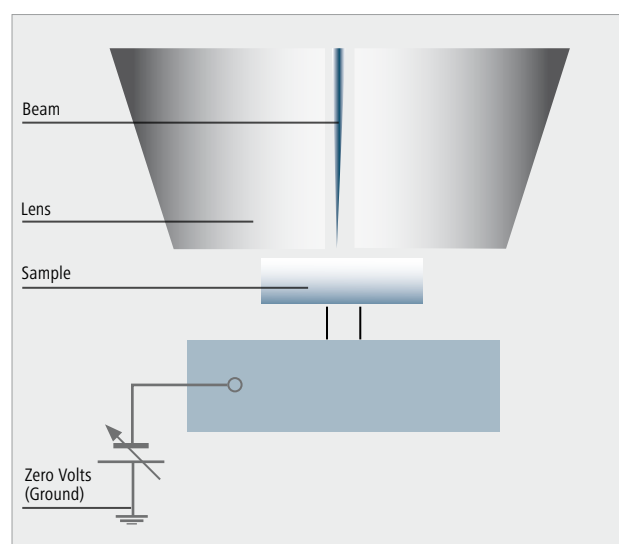


Figure 1

Beam deceleration

An alternative method to increase the quality of low kV imaging is to negatively bias the sample which in turn decelerates the primary beam. See figure 4. The principle of this technique is to use a high kV primary beam whilst maintaining a small interaction volume in order to capture surface detail.

Sample biasing applies a negative field to the sample which reduces the energy of the electrons approaching from the primary beam. Hence, the landing energy of the electrons reaching the sample is reduced, resulting in reduced penetration, a smaller interaction volume and enhanced surface detail.

The landing energy can be calculated by:

$$\text{Landing energy} = \text{Primary beam accelerating voltage} - \text{Beam deceleration voltage}$$

After interacting with the surface, secondary and backscattered electrons are produced from the interaction volume. When these electrons leave the surface, they gain energy as they are repelled away by the stage bias. The stage bias increases the energy of both SE and BSE which can now be detected by solid state BSE detectors. This enables low kV BSEs to be detected and atomic number contrast from a small interaction volume becomes visible.

The energy gained by electrons are:

$$\text{Energy of SE} = \text{Nominal SE voltage} + \text{Beam deceleration voltage}$$

(typically less than 50 eV)

$$\text{Energy of BSE} = \text{Landing energy} + \text{Beam deceleration voltage}$$

$$= \text{Primary beam accelerating voltage}$$

With additional energy from the stage bias, both SE and BSE can now be detected by the solid state BSE detector because the energy gained by both the SE and BSE enables them to overcome the 'dead layer' of the BSE diode. Additionally, the BSE detector which is mounted on the final lens becomes a very efficient SE detector due to its large solid detection angle and its proximity with the sample. Furthermore, acutely scattered electrons are deflected towards the BSE diode by the beam deceleration field thereby increasing the signal. See figure 5.

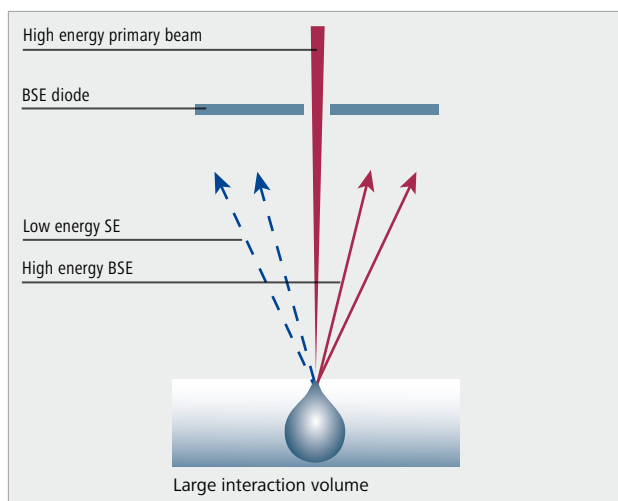


Figure 2 Imaging at high acceleration voltages. Red represents high kV and blue represents low kV. Secondary electrons have low energy and backscattered electrons have approximately the same energy as the primary beam.

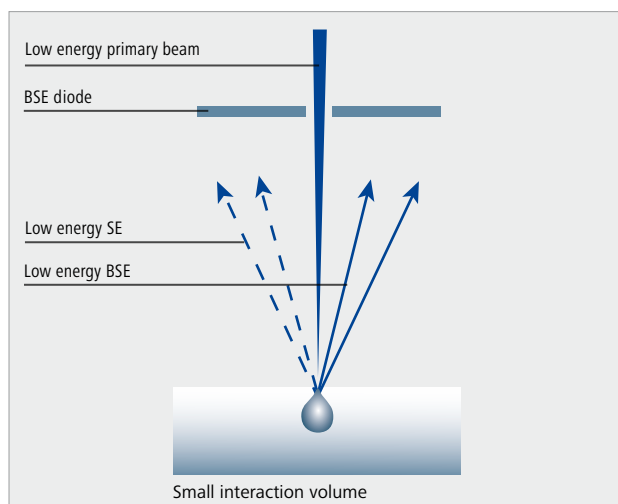


Figure 3 Imaging at low acceleration voltages. Since the primary beam is at low kV, both SEs and BSEs have low kV.

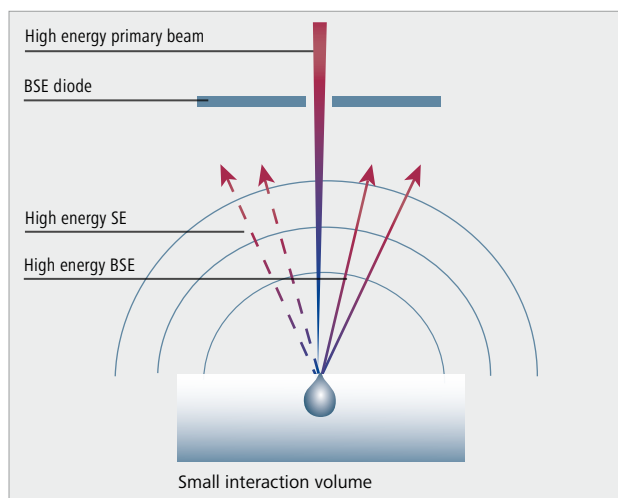


Figure 4 Imaging with beam deceleration. The primary beam energy is reduced when it approaches the sample because it is decelerated by the stage bias. When the electrons leave the surface, both SE and BSE are now accelerated away by the stage bias thereby gaining energy.

The beam deceleration voltage can be varied from 0 to 5000 V to select an appropriate landing energy and adjust the ratio between topographical and compositional information.

Applications

Low kV imaging benefits greatly from beam deceleration. It is difficult to obtain high quality images at low kVs because the primary beam is distorted by aberrations and other physical and electrostatic interactions. By keeping the primary beam energy high, the distortions are reduced. Beam deceleration allows the primary beam energy to be kept high and still benefit from low landing energy interaction. This improves the resolution whilst maintaining a small interaction volume. This ability is desirable in life sciences, where the low landing energy reduces beam penetration and reduces beam damage.

Biasing the stage also helps to compensate for charge. Materials that are poor conductors can charge up under the beam. With beam deceleration, minor charging artefacts can be avoided because a smaller interaction volume enables more electrons to be emitted from the surface. So, the charge arriving from the primary beam can be balanced with the charge emitted from the sample. See figure 6 and 7.

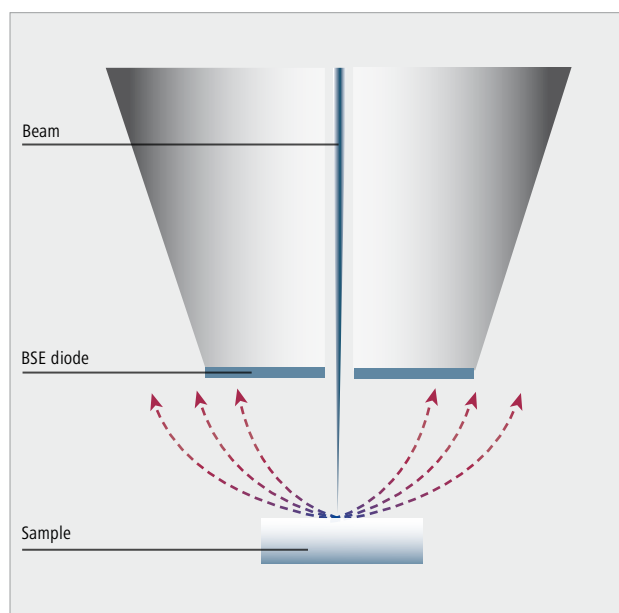


Figure 5 The trajectories of the secondary electrons are deflected towards the BSD diode.

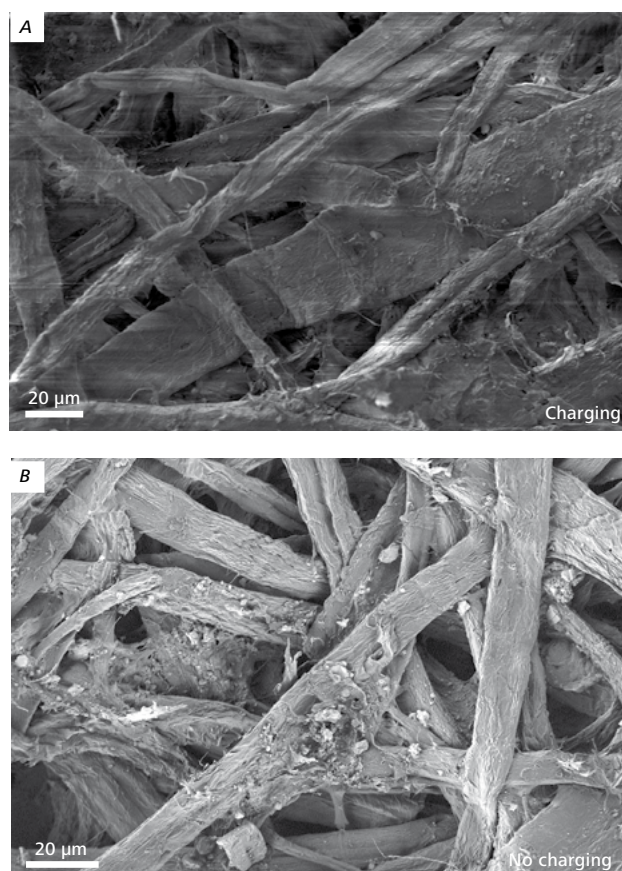


Figure 6 Image A) shows paper fibres imaged at 1 kV accelerating voltage without beam deceleration at high vacuum. The image is charging up and a good image cannot be obtained. In image B) paper fibres were imaged at 5 kV acceleration voltage and 4 kV beam deceleration to give 1 kV landing energy. Charging effects are minimised.

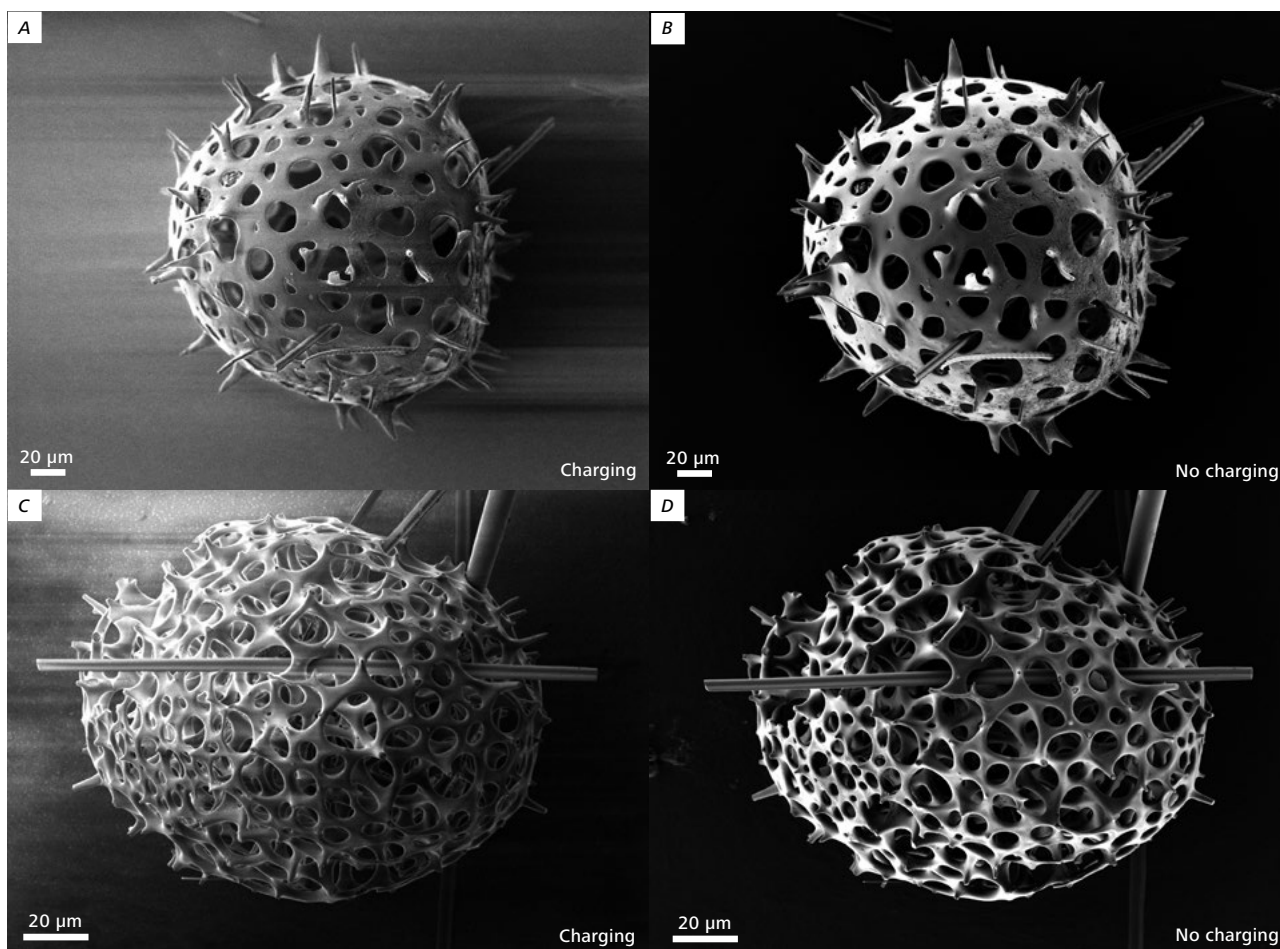


Figure 7 Uncoated Radiolaria was imaged at 1 kV landing energy. Image A) and C) were obtained using 1 kV acceleration voltage without beam deceleration. Image B) and D) (improved surface detail and contrast) were obtained at 5 kV acceleration voltage with 4 kV beam deceleration. The surface detail and contrast have improved using beam deceleration. Additionally, charging artefacts are greatly reduced using beam deceleration.

Summary

The latest generation of EVO provides high resolution low kV images thanks to the ZEISS HD BSD and beam deceleration technology.

Images show

- Increased signal
- Low interaction volume
- Increased surface information
- Charge neutralisation



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