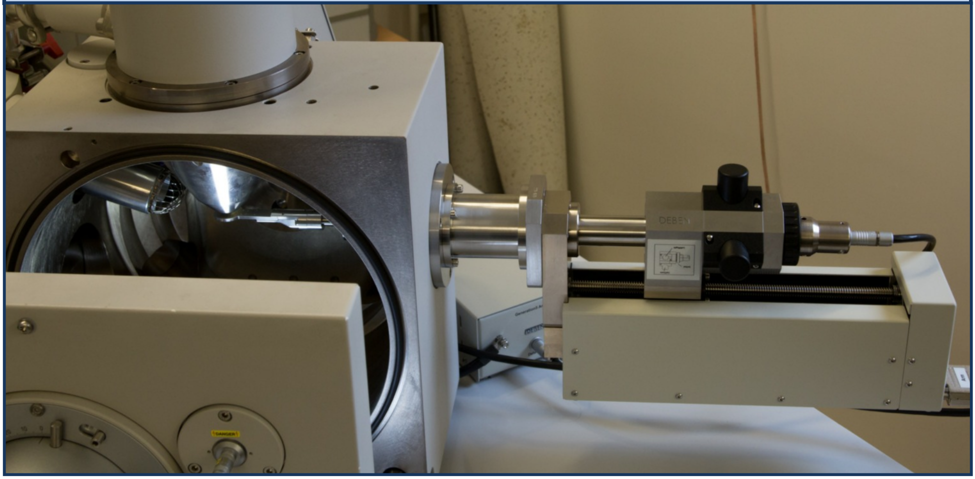
SEM Diaries - 9

The Backscattered Electron Detector is Installed!

Jeremy Poole



The backscattered electron detector (arrowed) in place under the final aperture, with its advancing mechanism outside the chamber to the right.

At the end of Diaries - 8 I left readers with a bit of a cliff-hanger. Would my backscattered electron detector (BSED) ever be installed? Would it work? And anyhow, what is a BSED, or even a BSE?

Well, the title and picture above give away the answer to at least the first of those questions, and I can confirm that it works well. To give a sensible answer to the last two questions, however, requires delving into the subject of beam-specimen interactions.

When I was younger (well, up to about three years ago) I naïvely assumed that an SEM image was produced when the electron beam was reflected from the surface of the specimen that it was scanning. Fortunately for science, the situation is significantly more complicated than that! Having said that, however, those not wanting a headache are welcome to jump to the results section on Page 4.

Figure 2 attempts to indicate some of what goes on when the electron beam strikes the surface of an extended (in width and depth) specimen.

Secondary Electrons

When the electron beam strikes the surface of the specimen some electrons are dislodged from within a very shallow depth from the surface of the specimen. These are shown in red in Figure 2. They are of low energy compared with the energy in

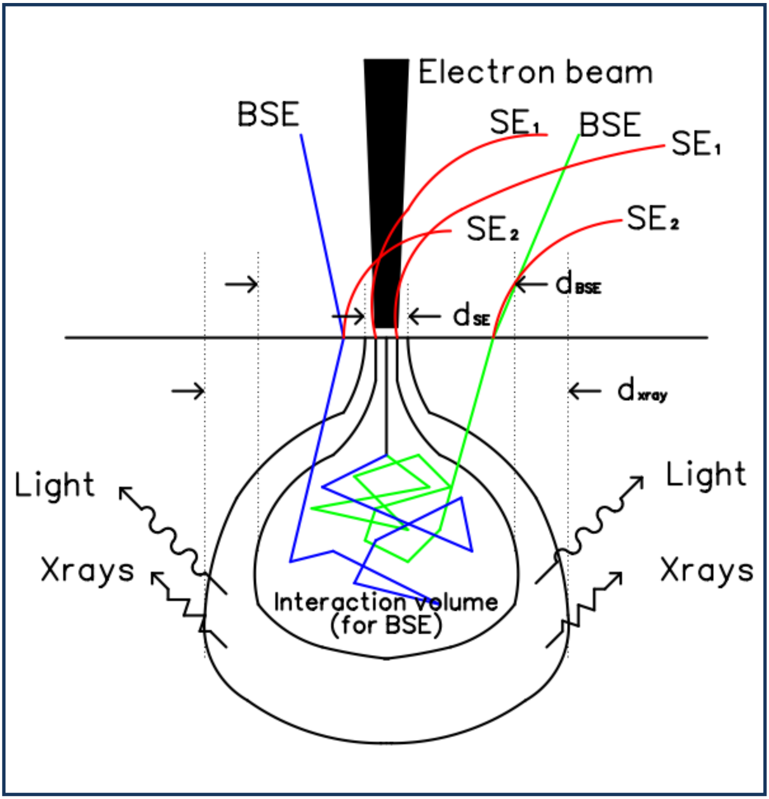


Fig. 2: Illustrating the interactions between the electron beam and an extended specimen

the beam (say <50 eV compared with up to 30 keV for the beam electrons, where eV refers to electron volts). These "secondary" electrons, designated SE_1, are shown following an arc as if they were being attracted to the positive potential of the cage round the secondary electron detector. Thus the resolution obtained by detecting SE_1 electrons (d_{se}) is similar to the diameter of the electron beam at the point of contact. Also, as the specimen is tilted away from the horizontal (or normal to the beam) then the area irradiated by the beam, and hence the number of secondary electrons dislodged, increases. The relationship is given by:

$\delta(\theta) = \delta_0 \sec \theta$

… where δ is known as the secondary electron coefficient.

This relationship between the number of secondary electrons emitted and the angle (or slope) of the specimen under the electron beam gives rise to the light and shade in the image that reproduces the surface topography; the more the surface slopes, the greater the number of electrons that are displaced and the brighter the image. SE_2 secondary electrons are described briefly later.

Backscattered Electrons

As the beam penetrates the specimen more deeply the electrons of the beam interact with the electric fields in the atoms within the specimen and are deflected along a new trajectory. This is known as elastic scattering, as the kinetic energy of the electron is maintained (think snooker). Multiple scattering events can take place before the scattered electrons either emerge again from the surface of the specimen as "backscattered electrons" or eventually lose their energy through "inelastic" scattering, which also takes place. This whole process is horrendously complicated (to me) so rather than attempt to describe it further it is worth just recording a few facts and outcomes:

- Emerging backscattered electrons (BSE) have significantly higher energy than secondary electrons.
- As the BSEs escape from the specimen they may dislodge secondary electrons, designated SE_2. The proportion of SE_2 to SE_1 is low for organic material, and I shall ignore their effect.
- The BSE emerge from an area significantly greater than the cross sectional area of the electron beam and hence the resolution (d_{BSE}) is lower than with SE_1.
- The scattering takes place within an "interaction volume" designated by the inner pear-shaped space on Figure 2.
- The size of the interaction volume increases with beam energy.
- The linear dimensions of the interaction volume decrease with increasing atomic number at a fixed beam energy. (The atomic number is the number of protons in the nucleus of an atom.) This means that for materials of high atomic number the electron beam penetration is less than with lower atomic number materials, and the backscattering is stronger.
- As the angle of tilt of the specimen surface increases the interaction volume becomes smaller and asymmetric, allowing more BSE to escape. This provides the modelling of the surface topography in a similar, but less marked, way to secondary electrons.

Other Interactions

For completeness it is worth recording the other products of electron beam interaction. These are shown on Figure 2 and include X-rays and photons (light). These can be detected by dedicated sensors and produce yet more information about the material of the specimen, but since I do not (yet) have these detectors I shall not say any more about these mechanisms for now.

The Backscattered Electron Detector

The detector system that I had installed was supplied by Deben, who manufacture "third party" accessories for SEMs and also supply equipment direct to the manufacturers.

Their unit comprises a four quadrant diode detector fitted to an arm that can be advanced or retracted by a mechanism fitted to a port in the specimen chamber (see Figure 1). There is also an external high gain amplifier unit, and a power supply and control unit. Positioning (in either the operating position, a parked position or retracted) is achieved by a simple keypad. There is a software interface that permits setting of brightness and contrast and also selecting which of the four segments of the detector are used, and which polarity each detector operates with. A combination of segments and polarities can give subtle and effective differences in the final image.

When Don first arrived to fit the BSED I was concerned that the retraction mechanism would take up the port on the right hand side of the chamber that is the location for a cryogenic system, should one be required. I had expected that the detector would simply clip on to the final aperture and would be connected to the "outside world" via a port with a sealed cable connector. A cryogenic system is on my wish-list, so "stealing" its port would be a big deal. Don listened to my concerns

Fig. 3: Showing the BSED located under the final aperture in its operating position, the SE detector with its cage on the left, and a Deben “Chamberscope” camera in the background.

and returned with a smaller, clip-on detector. Sadly, this required a different final aperture assembly that was incompatible with the clip on apertures required for my Low Vacuum mode. This would have led to complications when switching between modes. Furthermore, the central aperture in that detector was so small that it restricted the angle available for the scan, and hence the minimum magnification available with the BSED. Thus Don, with the patience of a saint, returned a third time finally to install the system of Figure 1.

Results

Rather than simply dive into using the BSED to make micrographs of insects and spiders I decided to experiment using grids. Figure 4a shows a titanium grid, captured using the BSED. The low contrast is normal for images taken with a BSED, although my particular model permits adjustment of the brightness and contrast “on screen” prior to making the micrograph. Figure 4b shows the “levels” window in Photoshop illustrating the tonal range of Figure 4a, which occupies the central third of the possible tones from

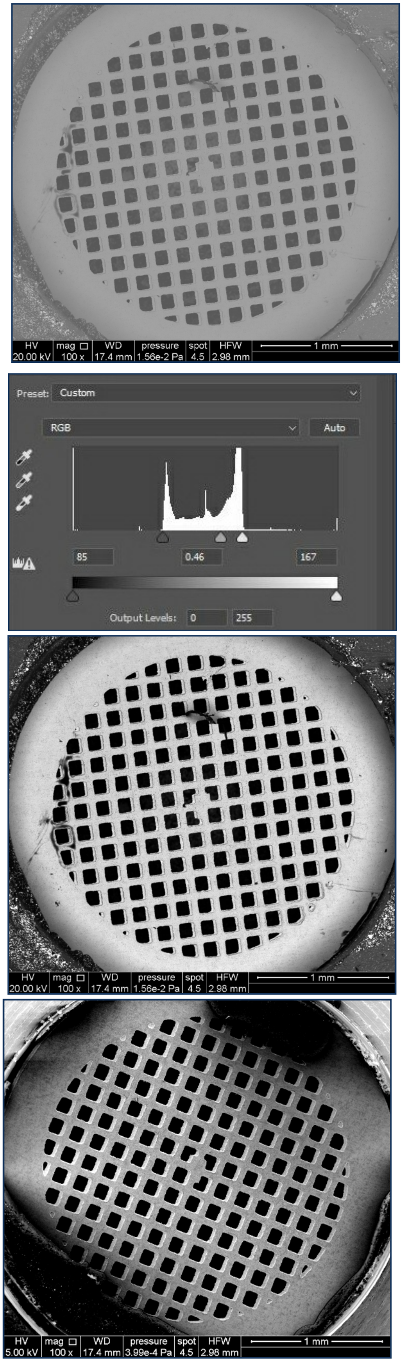


Figure 4 a to d, from top to bottom. See text for descriptions.

black (left) to white. Figure 4c shows the same micrograph with the tonal range stretched in Photoshop to cover the entire range.

For comparison, Figure 4d shows the same grid, imaged using the Secondary Electron Detector (SED). One consequence of the way the SED operates is that although the brightness of individual parts of the image is a function of the angle of the surface from the horizontal, there is also an overall effect that makes the image appear as though it were viewed along the axis of the electron beam, but “illuminated” by a lamp in the position of the SED. In other words, parts of the image can cause what appear to be shadows. Hopefully this subtle modelling effect can be observed in Figure 4d.

I mentioned the atomic number dependence of backscattered electrons. To demonstrate this I made a test stub containing a platinum aperture (atomic number 78), a titanium grid (22) and a copper grid (29), all mounted on a carbon substrate (6). The resulting image is shown in Figure 5. It can clearly be seen that the higher the atomic number, the lighter a shade of grey the material appears.

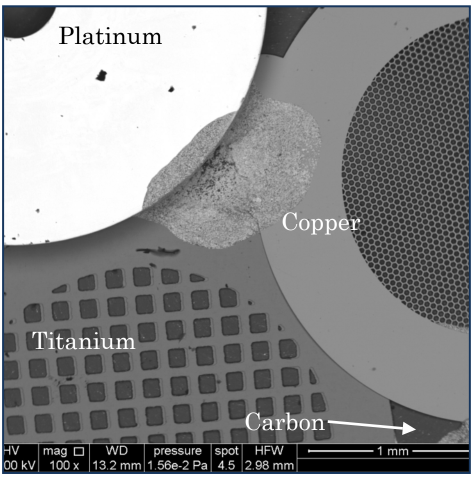


Fig. 5: Tonal differences based on atomic number

A down side of the “modelling” effect of the SE detector can be that subject matter at the side of the specimen distant from the SE detector can appear to be in shadow when this is not desired. An example of this is shown in Figure 6a. This shows the head of a queen wasp (*Vespula germanica*). Despite the image having been post-processed to some extent in Adobe Lightroom, the top of the head remains excessively light, while the mouthparts are in shadow and of low contrast. By comparison, Figure 6b, captured using the BSED and again post-processed in Lightroom, is in my view a more interesting and informative image.

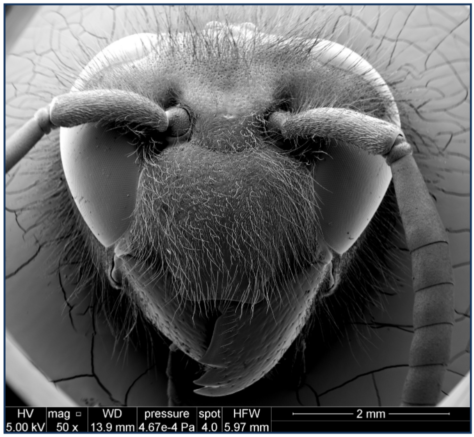


Fig. 6a: Head of wasp, captured using the secondary electron detector

Fig. 6b: The same wasp head, captured with the BSED

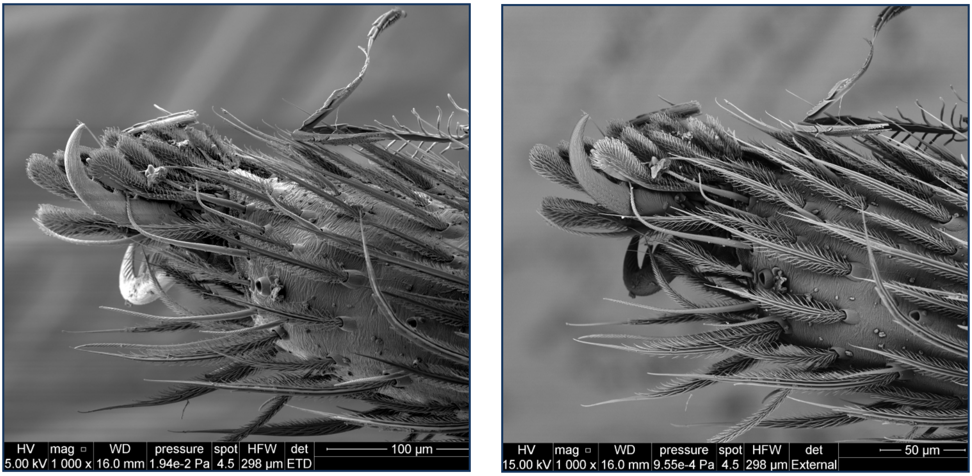


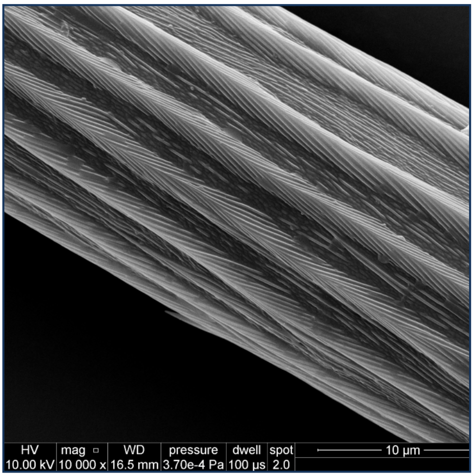
Fig. 7: Two micrographs of the tarsal claw and scopulae of a *Philodromus sp.* spider. Left, imaged with the Secondary Electron Detector, showing signs of charging. Right, imaged with the BSED.

Those of you with excellent eyesight might manage to read the data bar at the bottom of each micrograph. This identifies, among other parameters, the accelerating voltage used for the micrograph. You will notice that micrographs captured with the SED had an accelerating voltage of 5 kV, while those imaged with the BSED used 15 kV or 20 kV. These voltages are selected to achieve a reasonably low background noise level with each type of detector.

Despite the BSED requiring a higher accelerating voltage, however, the effects of charging are generally less noticeable with the BSED than with the SED. This is illustrated in Figure 7, where the image taken with the SED shows streaks emanating from the tips of hairs (of which there are many with this sort of subject) compared with that taken using the BSED, where the effect is hardly discernable, even on a large screen.

Well, I apologise if you have found this issue of SEM Diaries heavy going. If its any consolation I found it difficult to write, given the complexity of the subject of backscattered electrons and specimen / beam interactions in general. So, on a lighter note I include a micrograph (below) and leave you with the question "What is it?"

The answer will appear in SEM Diaries 10.



The Mystery Micrograph