# SEM Diaries - 3

## How an SEM works

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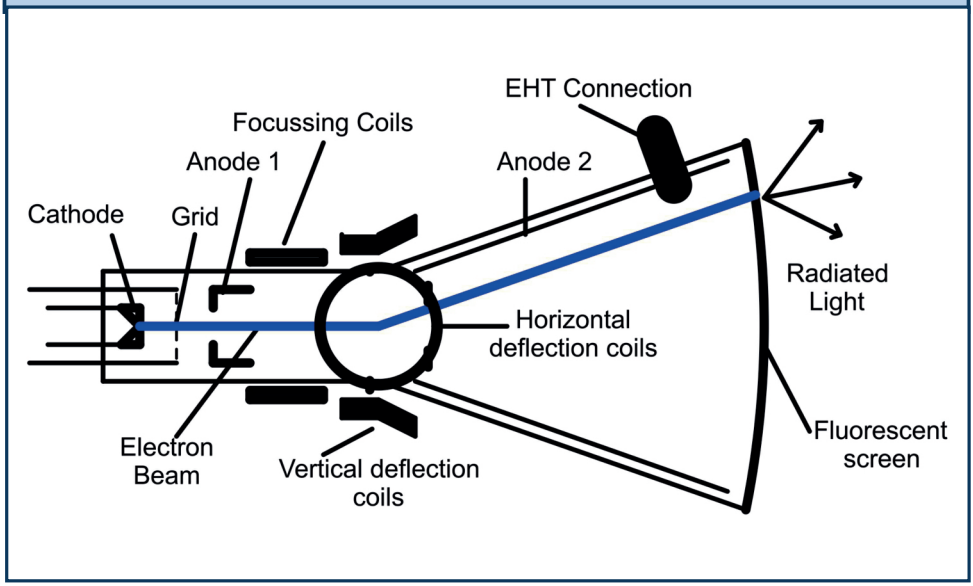


Fig. 1: The main components of a standard television cathode ray tube

Since the last three months have been largely spent with the erection of the laboratory - or more like three weeks with the erection of the building and the rest of the time with waiting for things to happen, I thought this would be a good opportunity to remind readers how an SEM functions and what some of its advantages are over a conventional optical microscope.

### Basic Electron Optics

Rather than launch straight into a description of the electron optics of an SEM, I though it might make life easier if we first reminded ourselves of how the cathode ray tube (CRT) used in older monochrome television sets works.

At the left of Figure 1 is a cathode. This is a sheath of metal surrounding a filament. The filament is heated by an electric current and this causes the sheath to emit electrons. The electrons are attracted by anode 1, which has a positive voltage (relative to the cathode) applied to it, passing through the grid in the process. The grid is an electrode with a wire mesh across it, through which electrons can pass. A negative voltage applied to this controls the intensity of the electron beam.

Having been accelerated towards anode 1, the electrons pass through a hole in the anode and enter a magnetic field from coils wrapped round the outside of the neck of the CRT. This has the effect of concentrating the electrons into something resembling a narrow beam. This electron beam next passes through two orthogonal magnetic fields from the vertical and horizontal scanning coils. At any instant the combination of the current in the horizontal and vertical scanning coils will cause the beam to be deflected away from the centre, in each of the vertical and horizontal planes. A second anode, normally a conducting coating on the inside of the glass envelope, is subjected to a high positive voltage and further accelerates the electron beam towards the screen. At the point where the beam impinges on the screen, the phosphor on the screen emits light.

Other than the focusing and scanning coils, the components of the CRT are contained in a high vacuum (of about $10^{-7}$ atmospheres) within the glass envelope, to avoid the problem of the electron beam being scattered by air molecules.

A television picture is created by the beam scanning rapidly in the horizontal direction in a raster pattern of a series of horizontal lines moving down the screen under the control of the vertical scanning coils. At the end of each horizontal line the horizontal scanning coils deflect the beam rapidly back to the side of the screen where the scan started and repeats the process with a new line, displaced vertically by the vertical scanning coils. See Figure 2. The brightness of the light emitted by the phosphor at any instant is controlled by a video signal synchronised with waveforms in the scanning coils that is applied to the grid.

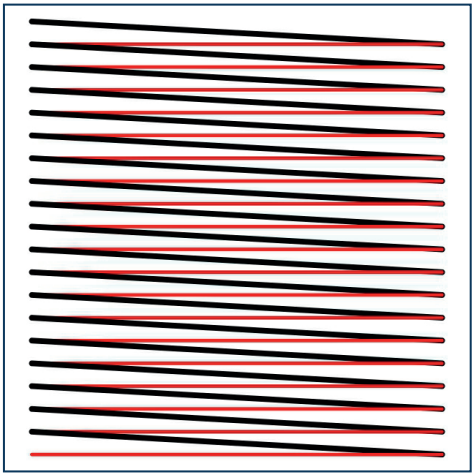

Fig. 2: A raster scan. The sloping black lines represent the picture information, the red lines are the flyback.

## SEM Optics

The comparison between a CRT and an SEM can easily be made by referring to Figure 3. The filament of the SEM, raised to white heat, provides the source of electrons. The simple grid of the CRT is replaced by something called the "Wehnelt Cylinder", which is used to help focus and shape the beam as well as to control the emission of electrons. There is only one anode, which is in the same location as anode 1 in the CRT. The positive side of the high voltage supply (the accelerating voltage) is connected to earth, which means that the filament and grid can be at a potential of as high (in the negative direction) as -30kV.

The "condensers" are magnetic lenses, which take the place of the focusing coil in the CRT. The scanning coils are shown located inside a final (objective) lens, although they can also be located before that lens, which is used finally to shape the electron beam. (It is probably worth pointing out that, although overall the SEM is capable of much higher resolution than a light microscope, relatively speaking the quality of the magnetic lenses is much lower than of the equivalent lenses in light microscopy. It is much more difficult to correct for chromatic aberration or

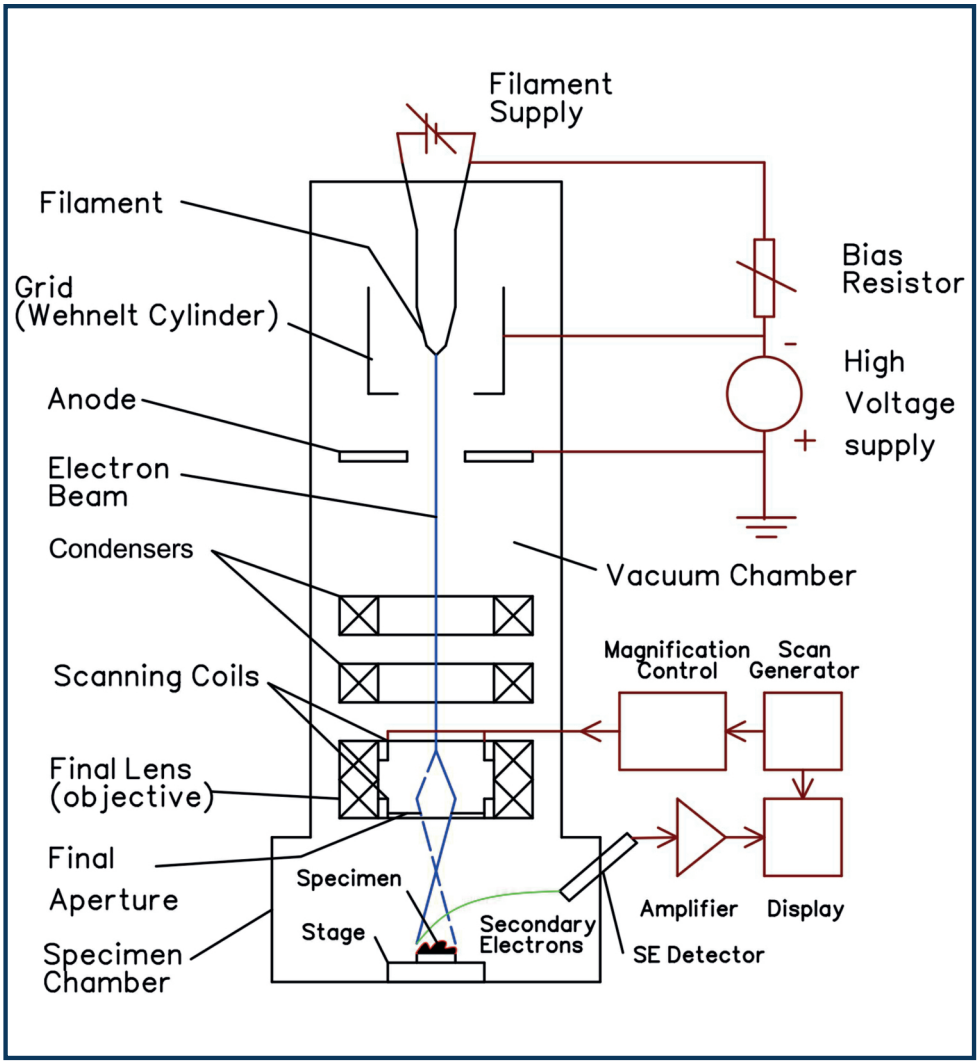


Fig. 3: Electron optics and control circuitry of a simple SEM

astigmatism in magnetic lenses, than it is for optical lenses.)

The scan generator produces the line and frame waveforms for the scanning coils, and the magnification control determines the extent of the surface area of the specimen that is scanned. The smaller the area scanned, the higher the magnification.

The specimen takes the place of the phosphor on the inside of the CRT screen, and instead of emitting light, the specimen produces "secondary" electrons back into the chamber, in this example. The stream of secondary electrons is collected by a detector, to provide a waveform, synchronised with the scan generator, which is not unlike the waveform used to modulate the

grid of the CRT. This waveform is applied to a display device, synchronised to the scan generator, to provide an image of the specimen.

The vacuum chamber (including the specimen chamber) is evacuated to an even higher vacuum than a CRT. My SEM will operate typically at 5 x $10^{-4}$ Pa, or 5 x $10^{-9}$ atmospheres.

## Characteristics of SEM Images

There are many different uses of an SEM, with different combinations of accelerating voltage, beam size and so on, along with various detectors making use of different emissions from the beam/specimen interaction. In addition to secondary electrons already mentioned, one can detect "backscattered electrons" and even X-rays.

An SEM is capable of providing much better resolution and useable magnification than a light microscope. For example, my Inspect S50 claims a resolution of 3 nm at 30kV, and a magnification of up to x1,000,000. However, the two characteristics of SEM images that are most evident to the layman, and the reasons I embarked on this project in the first place, are the life-like three-dimensional effect, coupled with a large depth of field.

As mentioned earlier, when the beam strikes the specimen, secondary electrons are emitted from its surface (along with other radiations that do not concern us right now). These are attracted towards the secondary electron detector, as illustrated in Figure 3, by means of a positively charged cage surrounding the detector. However, the electrons that are in direct line of sight of the detector, and whose trajectory is in the general direction of the detector are the most likely to reach the detector. Electrons that are emitted from a part of the specimen that is not in line of sight of the detector may "get lost" or be neutralised before reaching the detector.

The result is an image that appears to be viewed from the direction of the electron beam (ie straight down the column) but illuminated by a "light" source at the location of the secondary electron detector.

This effect can be seen clearly in Figure 4.

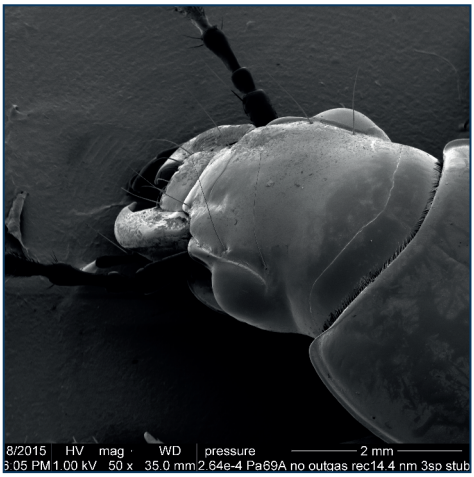


Fig. 4: Showing highlight and shadow areas of a micrograph from my SEM

A distinct shadow can be seen below the beetle's head, but highlights are visible towards the top of the picture. These indicate that the detector is at the far side of the beetle and slightly above the specimen. This "lighting" provides modelling that gives some "depth" to the image, but of course it is not three-dimensional in the conventional use of the term.

The depth of field achievable depends on the set-up of the instrument. The shape of the electron beam leaving the final lens is conical. If the distance between the final aperture and the specimen (the working distance) is long, the focused beam has a shallower angle than with a shorter working distance, providing a relatively greater depth of field. This is illustrated in Figure 5.

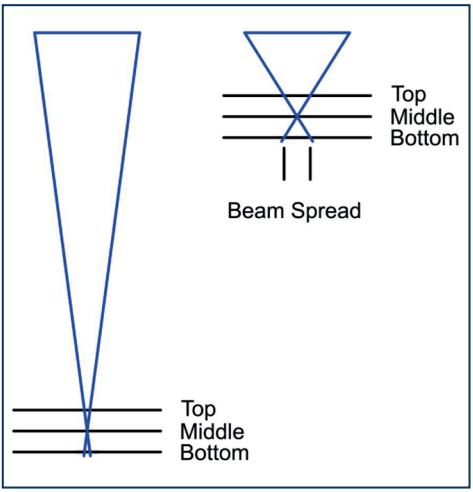


Fig. 5: Illustrating the effect of beam convergence angle (working distance) on three planes of a specimen. The electron beam is focused at the middle plane of the deep specimen. For the long working distance case (left) the extent of the beam spread at the top and bottom of the specimen is significantly smaller than that at a much shorter working distance (right).

## Progress with Building

Despite my grumblings at the start of this piece about the slow progress with the erection of my laboratory, something has happened. I display below three photographs taken at early and later stages of progress to date.

Fig. 6: September 8th - Damp proof membrane covering the insulation for the raft, prior to pouring the concrete. Note the drain pipe on the left, and the shuttering for the extra-deep pedestal under the column.

Fig. 7: October 23rd. At least the lab now has a fine roof, even though it is still waiting for windows and doors.

Fig. 8: December 13th. The lab now has doors and windows, and the dry lining is nearly complete. Also, much of the electrical cabling has been run.

## Recommended Reading

Much of my current knowledge on the scanning electron microscope has been gleaned from the following book:

Goldstein, J. and seven others, Scanning Electron Microscopy and X-Ray Microanalysis, Third Edition, Springer 2003. ISBN: 0-306-47292-9

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