7

How to ‘See’ Electrons

CHAPTER PREVIEW

If we are studying the structure of a material, when all is said and done, all we have to show for learning how to operate our expensive TEM, the many hours spent in specimen preparation, etc., is an image or a DP. These images and DPs, which are just different distributions of electron intensity, have first to be viewed in some manner. After viewing, we have to decide if we want to save the results for future reference, perhaps so we can print out the data for a presentation, technical report, or scientific publication. Since, as we noted in the opening chapter, our eyes are not sensitive to electrons, we have to find ways to translate the electron-intensity distributions generated by the specimen into visible-light distributions, which we can see. This chapter will explain how we ‘see’ electrons.

We’ll break the process down into two parts: first, detection (and display) of the image, and second, recording of the image. Both these areas are undergoing rapid change because of ongoing advances in electronic imaging and storage technology, and so this chapter will undoubtedly contain anachronisms by the time you read it. In particular, numbers are favored over photographic data; how can we quantitatively compare two photographs? Comparing two sets of numbers is routine.

7.1 ELECTRON DETECTION AND DISPLAY

As we saw back in Figure 2.1, images and DPs are different kinds of two-dimensional, electron-density distributions which are produced when a thin specimen scatters electrons. We detect and display them in different ways depending on whether we are using a TEM or STEM, as we’ll explain in Chapter 9. In a conventional TEM, the images and DPs are static, because the incident beam is fixed, and so we can easily project them onto a viewing screen within the microscope column. TEM images, for example, are analog images of electron-density variations in the image plane of the objective lens. We cannot manipulate the image or its contrast in any way between the electrons leaving the image plane and being projected onto the viewing screen. So we will briefly discuss the properties of the viewing screen. The manufacturer controls the choice of screen materials so you might think there’s not much need to understand this aspect in any depth. You might be surprised by the limitations you don’t need to accept or the improvements which could be made.

When we operate our TEM as a STEM, or we use a dedicated STEM, the image is not static; it is built up over time as the small probe is scanned across the area of interest. Under these circumstances, we can detect the electron signals in several ways. If we are seeking secondary electron (SE) or backscattered electron (BSE) signals, then these detectors sit in the specimen stage area. If we are seeking the same forward-scattered electrons that we view on the TEM screen, the detectors are in the viewing chamber of the TEM. After we’ve detected any one of these signals, it is usually digitized and the digital scanning image is presented on a fluorescent screen as an analog image. You may hear this fluorescent screen referred to as the CRT, which are the initials for cathode-ray tube and a relic from the early days of electron physics. It is becoming much more common for the image or DP to be displayed on a flat-panel screen beside the main TEM column (or even on a plasma or LCD screen on the wall of the EM lab) controlled by the TEM’s computer.

We should point out that the sequential or serial nature of the scanning image makes it ideal for on-line image enhancement, image processing, and subsequent image analysis. The signal from any electronic detector can be digitized and electronically manipulated prior to display on the CRT or computer screen, in a way that is impossible with analog images. We can adjust the digital signal to enhance the contrast or to reduce the noise. Alternatively, we can store the digital information and process it mathematically. The availability of cheap memory and...
fast computers permits on-line image processing and the rapid extraction of quantitative data from the scanning image; we discuss all this and more in Chapter 31. Because of developments in computer technology, there is great interest in recording analog TEM images via a TV camera in order to digitize them; charge-coupled device (CCD) cameras are readily available for on-line viewing and processing, particularly of HRTEM images. CCD technology is advancing rapidly, driven largely by the digital-camera market and microscopists will continue to benefit from the availability of ever-larger CCD detectors. So we’ll spend part of this chapter on CCDs which you’ll have now worked out are equally sensitive to visible light and high-energy electrons.

In attempting to compare the properties of detection and recording devices we often use the concept of the ‘detection quantum efficiency’ or DQE. If a detector is linear in its response then the DQE is defined simply as

\[
\text{DQE} = \left( \frac{S_{\text{out}}}{\text{out}} \right)^2 \left( \frac{S_{\text{in}}}{\text{in}} \right)^2
\]

where \( S/N \) is the signal-to-noise ratio of the output or input signal. So a perfect detector has a DQE of 1 and all practical detectors have a DQE < 1.

Note on terminology: We use several different terms, often imprecisely, to describe how we ‘see’ electrons. Since our eyes can’t in fact see electrons, we have to resort to the phenomenon of cathodoluminescence (CL) (which we introduced back in Section 4.4) in order to provide an interface between electrons and our eyes. Any electron display system that we look at relies on CL at some point. The CL process converts the energy of the electrons (cathode rays) to produce light (luminescence). As a result, any electron display screen emits light in proportion to the intensity of electrons falling on it. A few definitions are in order

- **Light emission** caused by ionizing radiation is *scintillation*.
- The process of *fluorescence* implies *rapid emission*.
- **Phosphorescence** implies that the wavelength and the *delay time* are longer than for fluorescence.

All these terms are used in electron microscopy (interchangeably and often inaccurately) because the ‘fluorescent’ screen is coated with a long-delay phosphor (see Chapter 9).

### 7.2 VIEWING SCREENS

The viewing screen in a TEM is coated with a material such as ZnS, which emits light with a wavelength of ~450 nm. The ZnS is usually modified (doped) to give off green light at closer to 550 nm; hence you’ll see screens of different shades of green which, being in the middle of the visible spectrum, is most relaxing for your eyes. As long as sufficient light is emitted, the main requirement of the viewing screen is that the ZnS particle (grain) size be small enough so that your eye cannot resolve individual grains. This means that grain sizes < 100 µm are acceptable (although you can see the grain size if you look at the screen through the auxiliary focusing binoculars). Typical screen coatings are made with a ZnS grain size of ~50 µm, although they may be as small as 10 µm for the highest-resolution screens.

As we’ve seen in Chapter 4, the cross section for inelastic interactions (and hence the emission intensity of most signals, including CL) decreases with increasing beam voltage. You would thus expect the light intensity to degrade at higher voltages, but this is offset by the increase in gun brightness. In some HVEMs the support for the small focusing screen is made of a heavy metal such as Pt to enhance backscatter and increase screen intensity. Of course, this backscattering will broaden the volume where light is generated and blur the image, so we don’t gain very much. In fact most TEMs have very similar screens. Other signals are also given off by the viewing screen, such as X-rays, and whenever you look at the screen you are protected from this lethal radiation flux by lead glass, which is carefully selected to reduce transmitted radiation to levels at or below ambient background. In HVEMs this can amount to several tens of millimeters of glass and, invariably, the optical transmission capabilities are degraded as the glass gets thicker, but obviously we have no alternative if we want to view the screen directly.

**A FEW WORDS OF CAUTION ABOUT YOUR SCREEN**

There isn’t much you can do about choosing the best material for the viewing screen since the manufacturer selects it for you, but you can extend its life substantially by taking care to minimize overexposure. The greatest source of screen damage is the intense direct beam that comes through thin specimens and constitutes the central spot in DPs. Using what you’ll learn about operations of the TEM in Chapter 9, you can minimize burning of the screen by (a) only going to diffraction mode with the selected-area aperture inserted, (b) only going to diffraction mode with the C2 lens overfocused, and (c) if the spot appears exceptionally intense despite these precautions, then insert the beam stop while you’re observing the pattern on the screen (but not when recording it).