Other Imaging Techniques

CHAPTER PREVIEW

Much of what we’ve discussed in the preceding imaging chapters is what we might call ‘classical’ TEM imaging. It began with BF and DF techniques and quickly expanded to include many beams. Diffraction contrast, phase contrast, and to a lesser extent, mass-thickness contrast are the mechanisms we use to characterize our specimens. We control the contrast by inserting the objective aperture, or a STEM detector, and excluding or collecting electrons that have been scattered by the different processes. However, there are variations to the standard ways in which we can extract more information from a TEM image; in this chapter, we’ll present a brief overview of some of them. Most of these operational modes that we’ll discuss here are somewhat esoteric and have rather specialized applications. Nevertheless, you should know that they exist because they may be just what you need to solve your particular problem. There’s no importance to the order in which we go through the various modes, but we’ll cover modifications to conventional parallel-beam TEM imaging as well as those techniques that require STEM and use some of the electron detectors we discussed in Chapter 7. It turns out, however, that the various procedures are often feasible in either TEM or STEM mode.

This is a bit of a potpourri of a chapter but the techniques are not, to our knowledge, gathered together in any other text. The descriptions will, of necessity, be brief but we’ll reference suitable source material so you can follow up if you really want to try the technique for yourself.

29.1 STEREO MICROSCOPY AND TOMOGRAPHY

This section is an excellent example of why we’ve included this catch-all chapter. In the first edition of this textbook, stereo microscopy was an old technique only used by biologists and tomography was used in an MRI. Now tomography fills an entire chapter in the companion text. The principle is, of course, the same as stereo microscopy: record images from more than one direction to give a 3D view of the sample.

You’ve have realized by now that any TEM or STEM image is a two-dimensional projection of a 3D specimen and this is a fundamental limitation. Sometimes we can discern differences in diffraction-contrast images of certain defects, depending on whether the defect is intersecting the top or the bottom of the foil, but generally we lose the depth dimension. To regain this depth information we use stereo microscopy, but only for features showing mass-thickness or diffraction contrast. We cannot use stereo for phase-contrast imaging because the essential experimental step, tilting the specimen, changes the phase contrast and the projected potential of the specimen. So any stereo effect in the image is lost. You may need stereo microscopy if, for example, you want to know whether precipitates have formed on your specimen surface rather than in the interior, or if you want to see how dislocations are interacting with each other.

Stereo imaging works because your brain gauges depth by simultaneously interpreting signals from both your eyes, which view the same scene from slightly different angles (about 5°), giving a parallax shift. So in the TEM, if you take two pictures of the same area but tilted a few degrees relative to each other, then present the two images simultaneously to your brain using a stereo viewer, you’ll see a single image in which the different depths of the features are apparent. In fact, some people are able to see the stereo effect without the aid of a viewer and some people are incapable of discerning the stereo effect at all.

To see in stereo, the two images should be separated by ~60mm, but in practice it’s often sufficient just to move the pictures relative to each other until your eye and brain seize on the effect.
A couple of points are worth noting before we describe the method. First, if the features you want to observe show diffraction contrast, then the only way to maintain contrast is to tilt along a Kikuchi band, keeping both $g$ and $s$ fixed; so tilt while looking at the DP. This procedure almost invariably requires a double-tilt stage and may be difficult, or impossible, if your specimen is heavily deformed. If you just want to measure the foil thickness, any tilt is sufficient and contrast does not have to be maintained. Second, if you want to be pedantic, there is a right way and a wrong way to view the stereo images. You have to present the images in the same way that your eyes would see a scene, that is, the two images have to be correctly positioned, otherwise the brain will interpret depth the wrong way round. If you are trying to perceive the true surface topography (such as with SE images) using SEM or STEM images, then the choice of which image goes into the left eye and which into the right is crucial. (See any SEM text, such as that by Goldstein et al., for more details on stereo viewing.) Of course, for TEM images this difference is irrelevant. TEM applications are reviewed by Hudson and a whole set of related papers appears in that same issue of *Journal of Microscopy*. So if you want to take a stereo pair, follow these steps:

- Select the region of interest, making sure that the specimen is eucentric.
- Record an image (BF, DF, or WBDF, it doesn’t matter, although usually the BF image is used).
- Tilt the specimen by at least 5° (much higher tilts give a larger parallax shift but it’s more difficult to keep the focus and the diffraction contrast constant).
- Ensure that the whole field of view didn’t move while you tilted. If it did, translate it back to its original position (using the beam stop as a point of reference if you wish). All features in the image will be shifted slightly relative to each other: it is this parallax shift which your brain interprets in stereo.
- If the area is now out of focus (it will be if you had to use the second, non-eucentric, tilt axis), refocus using the specimen-height ($z$) control; otherwise you’ll change your image magnification. Obviously, computerized stages will help in this respect.

- Record another image.
- Develop or display the images and observe them under a stereo viewer.

Figure 29.1 shows a pair of BF images showing precipitates. If the images are correctly spaced and you look through a stereo viewer then you should be able to see the relative depth of the precipitates. You can purchase cheap cardboard stereo viewers through any EM supplier. Although a proper stereo viewer is an expensive optical tool, you can use it to calculate the relative depth ($\Delta h$) of a feature in a stereo pair, since

$$
\Delta h = \frac{\Delta p}{2M \sin \phi} \quad (29.1)
$$

where $\Delta p$ is the parallax shift between the same feature in the two images tilted by $\phi$ at a magnification $M$. Be careful how you define $\phi$ because some microscopists define the tilt angle as $\pm \phi$, in which case $\sin \phi/2$ becomes $\sin \phi$. For true depth determination you need to deposit some recognizable feature on the surface, such as gold islands, but that is not usually important in TEM images and relative depth is often sufficient. If you need quantitative stereo measurements, you can either learn about the field of stereology, which is an old established discipline or you can learn the tomography technique.

We will discuss electron tomography in the companion text. This is a very large topic and an emerging activity in TEM. It has been limited until recently by the need for fast computers and large amounts of memory, and specimen holders that allow you to tilt the specimen through nearly the full 360°. Obviously, disk specimens are not ideal for such tilting experiments. The principle involved is just as we’ve described for stereo, but we use about 100 times as many images and a computer is essential to analyze and view the results.

### 29.2 2D MICROSCOPY

This is an example of imaginative terminology in the TEM field. If there are diffraction spots in the SADP which are too close together to give separate DF images, center the objective aperture around them all. Then, if you view two DF images taken at different focus settings through a stereo viewer, you see features at different apparent depths. However, you’re using a pseudo-stereo technique because the ‘depth’ difference is due to a difference...