Imaging of Shallow Surface Topography by the Low-Loss Electron (LLE) Method in the Scanning Electron Microscope

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The low-loss electron (LLE) method in the scanning electron microscope (SEM) was proposed by Dennis McMullan in 1953: "...the beam from the specimen could be restricted to the electrons which have lost only small amounts of energy and which have therefore travelled only short distances through the specimen." (1)

Subsequent studies showed that the LLE method gives different image contrasts from the more familiar secondary electron (SE) method: (i) it is less affected by specimen charging; (ii) has a shallower information depth for a given beam energy; (iii) shows less serious penetration effects at sharp edges; (iv) shows stronger channeling contrast; and (v) is better for showing shallow surface topography. These features can be shown (usually to the advantage of both methods) by taking comparison pairs of SE and LLE images.

Figure 1 shows three sorts of energy filters that have been used for the collection of LLE: (a) Retarding-field energy filter with the sample tilted by between 45 and 60 degrees (2). (b) Similar but for the sample tilted by 0-20 degrees (3). (c) Magnetically filtered LLE detector in which a nonmagnetic sample is mounted in the manner of the transmission electron microscope (TEM) in the high-field region between the polepieces of a magnetic immersion lens (4).

In all cases, the LLE signal is weaker than the SE signal and typically the image integration time for the same beam current must be four times greater in that case. The LLE image is directional with a high degree of sensitivity (for example) for scratches that are at right angles to the direction of the detector. In some cases it may be desirable to rotate the sample, while in the system proposed for the examination of integrated circuit wafers for shallow surface topography shown in Figure 5, it is proposed to put a number of magnetically filtered LLE detectors around the incident electron beam to give a series of images with different apparent directions of illumination.

Figure 2(b) shows the earliest successful LLE image that was obtained by Conrad Bremer during a study of aluminum films that had been damaged by electromigration (2,5). It can be compared with the SE image shown in Figure 2(a).
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which at this beam energy corresponds to a maximum penetration distance of 120 nm in the specimen. The most probable interaction involves a single wide-angle Rutherford scattering event and for such a scattering event of a few tens of nm. The SE image involves the scattering of the primary electrons at depths down to about half of the total penetration path.

(Another situation in which the image contrasts arise from a wide-angle Rutherford scattering event in the initial stages of penetration into a solid specimen is in the formation of either electron channeling patterns (ECP) or electron backscattering patterns (EBSP) where the probability of such an event is modulated jointly by the incoming and outgoing channeling conditions(6,7).)

Figure 3 shows a comparison pair between the SE and LLE images of uncoated greenhouse-grown maize(8) at a beam energy chosen to minimise charging (1.7 keV). The improved imaging of surface topography is quite clear in this case. In general the LLE method works best with samples of this kind where essentially the whole surface is in line-of-sight from the detector.

An application to integrated circuit technology is shown in Figure 4, which shows an uncoated pattern in photoresist(9) examined with a beam energy of 2.5 keV. The SE image shows serious charging, and tests with the energy filter showed that this complete destruction of the SE image can be caused by a charge potential of about 10 volts on the specimen (voltage contrast). Even a charge potential of a volt or so can seriously degrade the SE image. The LLE image (with an energy window of 300 eV) shows the surface clearly whenever there is an unobstructed path to the LLE collector.

The sensitivity of the LLE image towards the direction of the LLE detector has led to the proposal shown in Figure 5 to review a (nonmagnetic) integrated circuit wafer for shallow surface topography by means of the magnetically filtered LLE method. In this approach, the wafer is at a right angle to the incident electron beam and a number of LLE detectors are put around the beam to provide images simultaneously with the same field of view but with different apparent directions of illumination.

The above examples were chosen to illustrate how the usefulness of both the SE and LLE methods can be increased by comparing the corresponding micrographs from the same area. The proposed system shown in Figure 5 poses the question of whether the immersion magnetic lens, which has been used with great success in the TEM for about 50 years can also be applied in this proposed way to the review of (nonmagnetic) silicon integrated circuit wafers for shallow surface topography by the LLE method.

REFERENCES

(1) McMullan, D., (1953), 'An improved scanning electron microscope for opaque specimens,' Proc. IEE 100, 245-259
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