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).

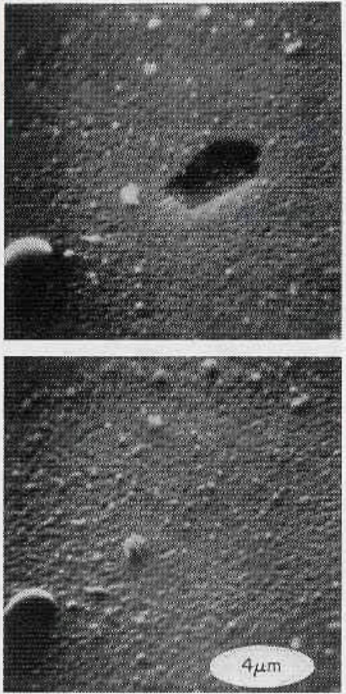

Figure 2. Aluminum films damaged by electromigration(2,5): (a) SE image. (b) LLE image. Energy window = 400 eV. (Field of view measures 13 micrometers left to right; micrographs were taken by Conrad Bremer.)

In the case of the retarding-field energy filters shown in Figures 1(a) and 1(b) the second (filter) grid is set to a small positive potential relative to ground to detect SE and to a few hundred volts (up to 1.5 kV) positive to the SEM cathode potential to give the "energy window" for LLE. The scintillator is at +12 kV relative to ground potential for SE or relative to the SEM cathode potential for LLE. In the case of magnetic energy filtering as shown in Figure 1(c) the detector is a scintillator, knife-edge or similar device that is positioned at a short distance inside the limiting surface at which the fastest (zero-loss) electrons from the specimen are returned towards the lens axis by the lens field.

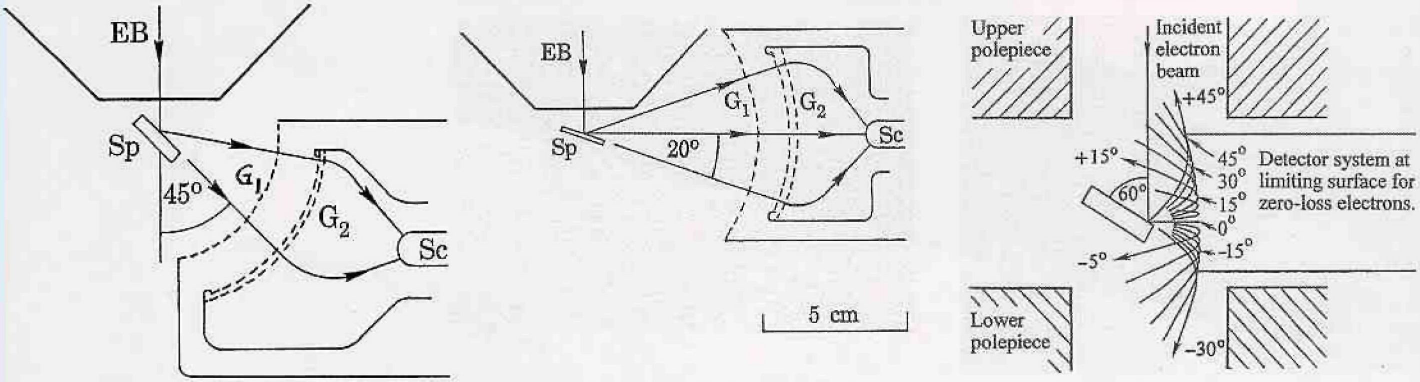

Figure 1. Energy filters used for collecting LLE: (a) based on the use of a retarding-field energy filter with 45-60 deg. specimen tilt(2) and (b) with zero to 20 deg. tilt(3). Sp = specimen. Sc = scintillator optically coupled to a photomultiplier. (c) Magnetically filtered LLE detector as used with a non-magnetic sample in 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 to 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

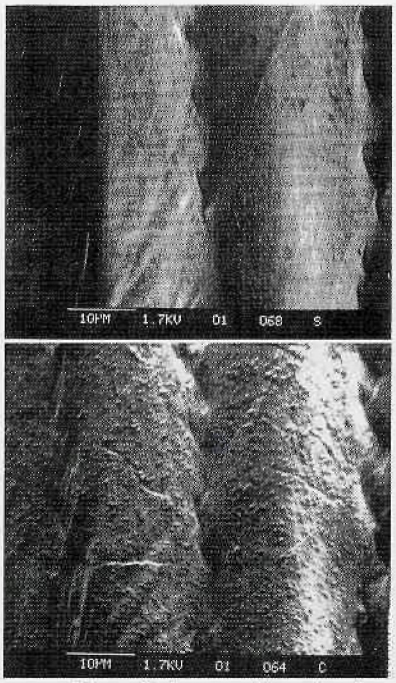

Figure 3. Long epidermal cells of greenhouse-grown maize showing cuticular roughness(8) (Zea mays L., var. Golden Beauty,) fixed in trialdehyde fixative in 0.05M phosphate buffer (pH 7.0), dehydrated in acetone and critical point dried with CO2: (a) SE image. (b) LLE image with 500 eV energy window. (Field of view measures 56 micrometers left to right; micrographs were taken by P.C. Cheng.)

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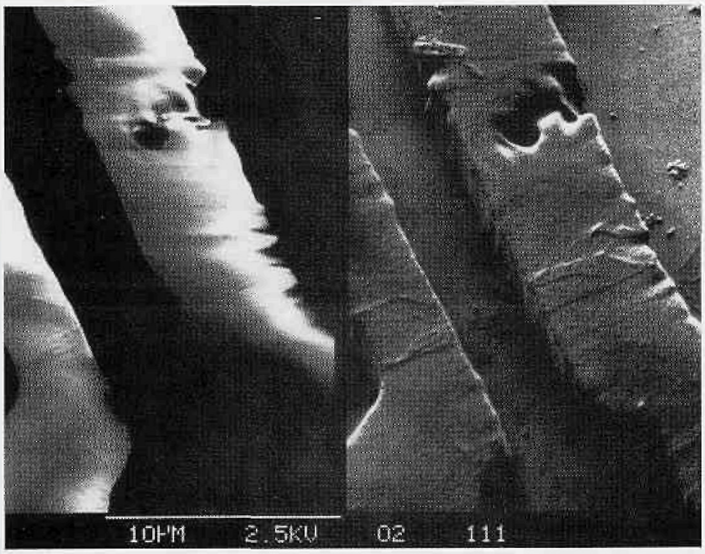

Figure 4. Uncoated pattern in photoresist(9) examined with a beam energy of 2.5 keV: (a) The SE image shows serious charging. (b) The LLE image shows the surface clearly whenever there is an unobstructed path to the LLE collector. (Field of view measures 30 micrometers left to right; specimen is tilted by 60 deg.)

SE image shown in Figure 2(a). The unexpected (well, hoped-for) feature of this comparison pair was the shallow information depth of the LLE image. The energy window of the LLE detector was 400 eV 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 with a low takeoff angle this corresponds to a maximum depth 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.

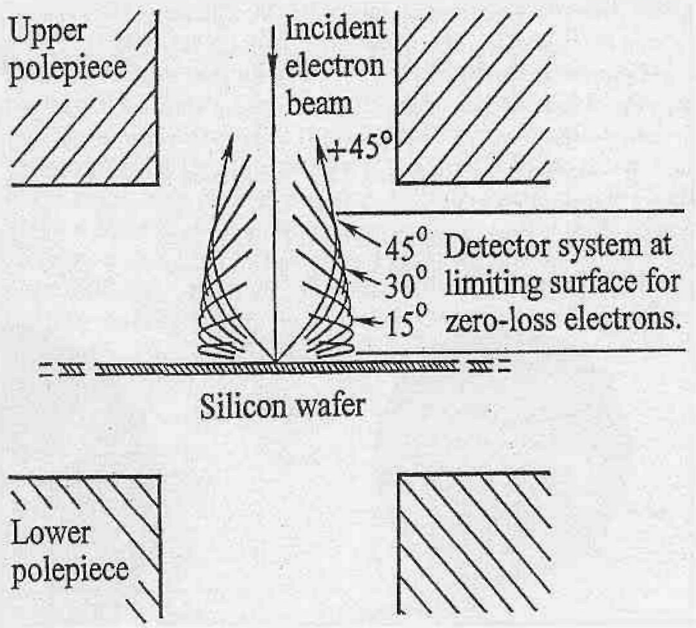

Figure 5. Proposed in-lens system for examining a non-magnetic integrated circuit wafer for shallow surface topography using multiple LLE detectors around the incident electron beam (see text).

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

(2) Wells, O.C., (1971), 'Low-loss image for scanning electron microscope,' Appl. Phys. Lett. 19, 232-235.

(3) Wells, O.C., Rishton, S.A., (1994), 'Studies of poorly conducting samples by the low-loss electron method in the scanning electron microscope,' Proc. 52nd. Ann. Meeting MSA (San Francisco Press), 1022-1023.

(4) Wells, O.C., Legoues, F.K., Hodgson, R.T., (1990), 'Magnetically filtered low-loss scanning electron microscopy,' Appl. Phys. Lett. 56, 2351-2353.

(5) Wells, O.C., Bremer, C.G., (1997), 'High-resolution backscattered electron image and low-loss image for surface scanning electron microscope (SEM), Proc. Sixth Int. Conf. X-Ray Optics and Microanalysis, Osaka, Univ. Tokyo Press, 463-466.

(6) Reimer, L., (1985), 'Scanning Electron Microscopy, Physics of Image Formation and Microanalysis,' Springer Verlag (Springer Series in Optical Sciences vol. 45) 338-341 and 356-361.

(7) Wells, O.C., (1999), 'Comparison of Different Models for the Generation of Electron Backscattering Patterns in the Scanning Electron Microscope,' Scanning 21, 368-371.

(8) Wells, O.C., Cheng, P.C., (1992), 'High-resolution backscattered electron images in the scanning electron microscope,' Proc. 50th. Ann. Meeting EMSA (San Francisco Press), 1608-1609.

(9) Wells, O.C., (1986), 'Low-loss electron images of uncoated photoresist in the scanning electron microscope,' Appl. Phys. Lett. 49, 764-766.

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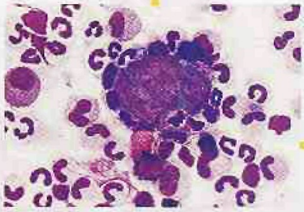

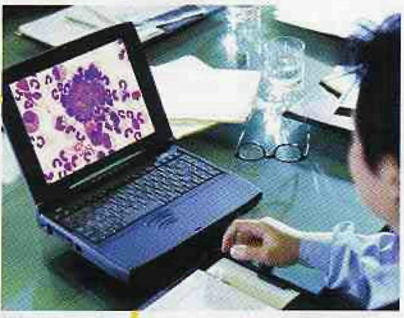

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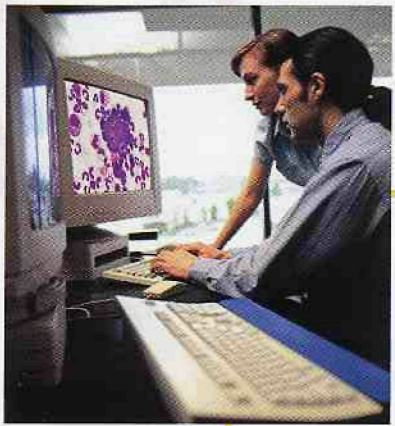

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