# Depth Information Available from the Backscattered Electron Signal

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Although the secondary electron (SE) signal is still the most commonly used signal in scanning electron microscopes (SEMs), the backscattered electron (BSE) signal is now in wide use. Imaging both atomic number and surface topography have been the major applications of BSE detectors, with some applications in channelling, magnetic contrast and similar specialized applications. Over the last few years, low voltage BSE imaging has been used for imaging surface features to a depth of a few nm. But the BSE signal contains much more information and new techniques are being developed to take advantage of its versatility.

The BSE signal has a wide energy distribution, with electrons having energies from a few hundred eV to the beam energy. Detecting those on an energy distribution basis, can yield significantly different information. One of these first applications was the low loss technique developed by O. Wells [Appl. Phys. Letters, **19** (1971) 232], which could image just the surface layer even though the accelerating voltage was 20 - 30 kV and total beam penetration was many microns. For a long time it has been known that depth information could be achieved by detecting BSEs at different energies. For example, when multi layered specimens such as integrated circuits (ICs) were examined in the SEM, the electron beam passed through several layers and the specimen yielded images which showed those layers superimposed upon each other. However, determining which layers are upper and which are lower, is not easy for most specimens. Yet, if the energy spread of the BSEs could be separated, it would be possible to image the separate layers at different energies which would reflect the different energies of the emerging BSEs. Doing this essentially requires a BSE energy filter, i.e., a backscattered electron spectrometer. In the past, suitable techniques were not easy to develop.

Several different principles have been employed to construct energy filter BSE detectors. Recently, some results obtained by S. Likharev et al., [Proc. Ann. MSA Meeting, **52** (1994) 488] using curved electrostatic surfaces, showed some promise. Since then this work has been extended by E. Rau and colleagues [Izves. Acad. n, Phys. **52** (1995) 87 (In Russian)] - work performed with the author and supported by ETP Semra Pty Ltd. This work shows considerable promise of being able to image individual sub-surface layers. Energy resolution of 1 % of the beam energy has been achieved, enabling the separation of energies with a resolution better than 1 keV. This type of resolution gives significant improvements in image quality, as the following images indicate.

Figure 1, micrographs of an integrated circuit, shows some typical results obtained with a new spectrometer design. 1A shows the secondary electron image, 30 keV beam energy, and illustrates the many layers which are visible, superimposed upon each other. Determining the depths of these various layers is not easy if the structure is not known. However, using an energy filter and imaging at different energies, the results in 1B (28 kV), 1C (25 kV) and 1D (20 kV), clearly indicate the arrangement of the layers. From 1B, it is easily seen that there are two different layers on the top surface, the difference being essentially transparent to the SE signal. Some detail of the structure just below the surface is seen, particularly in the darker region. The 25 kV image shows significant differences in the composition of the lower layer, while the 20 kV signal shows major differences, completely seeing past the surface differences observed with the electrons which had only lost 2 kV energy. These images show the integrated circuit in a completely different perspective from the standard SE image. The magnification marker represents 10 µm, showing that high quality images can be obtained at magnifications of several thousand times.

This ability to positively identify layers at the different depths of the SEM adds a new dimension to the information that can be obtained from the SEM. As well as possible applications in the semi conductor industry, sub-surface imaging offers the possibility of determining the thickness of surface and some sub-surface layers of a few nm depth. This technique also considerably enhances atomic number contrast and may enable small differences to be more easily iden-

tified. With new information again being achieved from the BSE signal, exciting opportunities to the SEM field are again available. ■

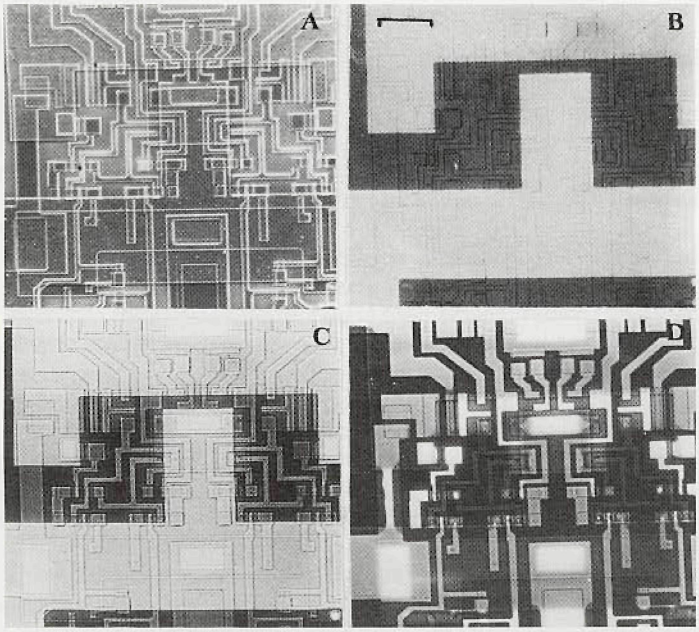

Figure 1: Layer by layer image of a multi level integrated circuit, taken using a backscattered electron energy spectrometer in an SEM, beam voltage of 30 keV. A: secondary electron image, B: BSEs with 28 keV energy, C: BSEs with 25 keV energy, D: BSEs with 20 keV energy. Magnification marker represents 15 µm.

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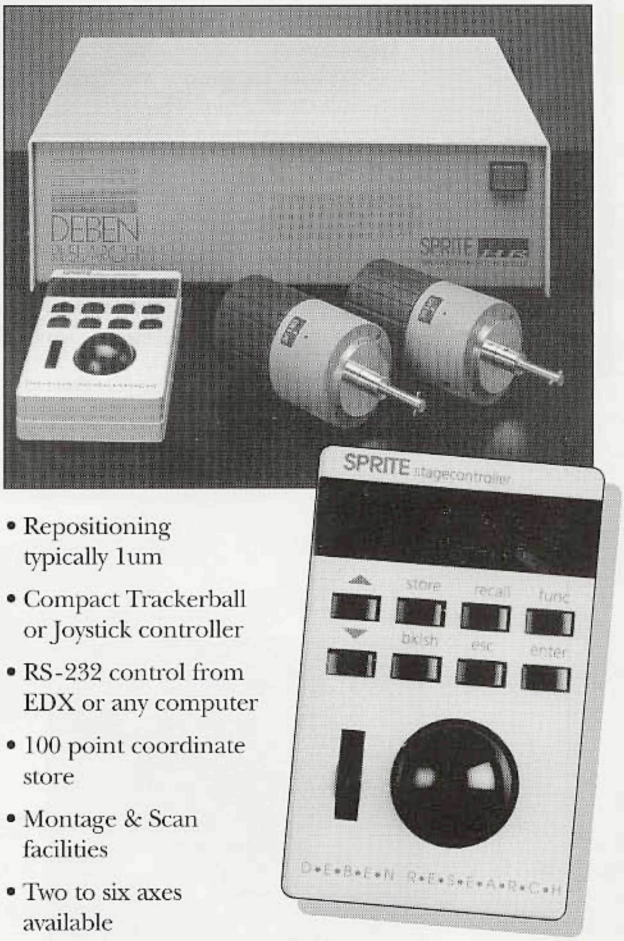

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