SHEET NO. 94

SUBJECT: FEATURES OF A NEW ELECTRON DETECTOR FOR THE S-4700 AND SOME INITIAL APPLICATIONS

INSTRUMENT: THE S-4700 FIELD EMISSION SEM

CONTENTS

1. INTRODUCTION

Semiconductor devices have been moving toward higher integration and density. Similar technological trends are seen in various fields of science and industry. SEMs have been extensively used for process evaluation and failure analysis where image information that allows quick and adequate judgment has been strongly requested. In response to this requirement, we have developed a new and unique electron detector system that allows collection of information from both secondary and backscattered electrons and using them for optimum imaging of samples. Generally secondary electrons are sensitive to sample topography while backscattered electrons are sensitive to sample compositions. This unique electron detector system allows imaging of samples to suit the purpose of observation without changing electron optical conditions such as accelerating voltage, probe current and associated alignment and astigmatism corrections. We report here on the detector and some initial applications.

2. INFORMATION AVAILABLE FROM SECONDARY AND BACKSCATTERED ELECTRONS

Table 1 shows information available from secondary and backscattered electrons (including secondary electrons generated by initial backscattered electrons). Conventional detectors have been designed for collecting all of these electrons and images have been formed using all of them combined. It has been difficult to detect each of them separately with conventional detectors. Therefore, it has been difficult to interpret some of the images where secondary and backscattered electron information is overlapped. Until now, it has been a common technique to operate SEMs at low operating voltages and reduce generation of backscattered electrons at areas deep from the surface or record a separate image using a separate BSE detector and compare both secondary and BSE images for correct interpretation of images.

Table 1 Information available from secondary and backscattered electrons

	Information available from SE	Information available from BSE
Advantages	• Surface sensitive • High spatial resolution • Voltage contrast	• Sensitive to sample compositions • Less sensitive to sample charging • Less sensitive to edge contrast
Disadvantages	• Sensitive to edge contrast • Sensitive to sample charging	• Inner blurred information contained • Less sensitive to surface information

3. A NEW DETECTOR SYSTEM AND ITS FEATURES

Fig. 1 shows the standard upper secondary electron detector of the S-4700. There is an E x B filter, which is composed of electro-static field and magnetic field crossed at right angles. It allows efficient collection of secondary electrons (SE) generated at the sample surface. It also allows imaging of the sample surface at high spatial resolution[1-2]. Fig. 2 shows a new detector system which has a control electrode for secondary electrons and at the same time, it has a conversion electrode which converts backscattered electrons (BSE) generated at high angles into secondary electrons. These secondary electrons carry information on sample compositions. This information has characteristic contrast of backscattered electrons. Backscattered electrons are generally small compared with secondary electrons. When BSE and SE signals are simply combined, available images are of characteristic contrast of SE. We have developed a new detector system which incorporates a set of control electrodes between the specimen and the E × B filter. A negative voltage applied on the control electrodes allows controlled detection of SE which is combined with BSE. The detection of SE is regulated by a negative voltage applied on the control electrodes. The new detector system allows optimum combination of SE and BSE signals for imaging to suit the best interest of operators or their intended applications.

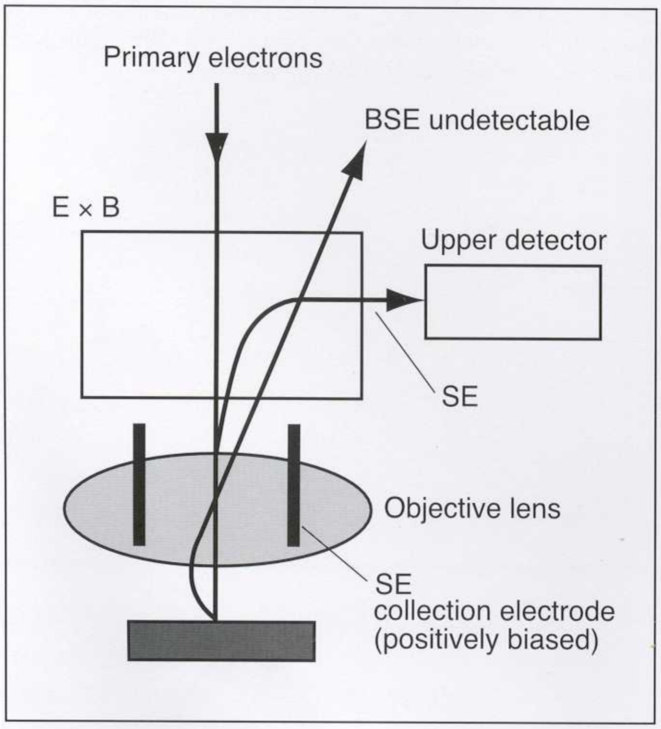


Fig. 1 Conventional secondary electron detector

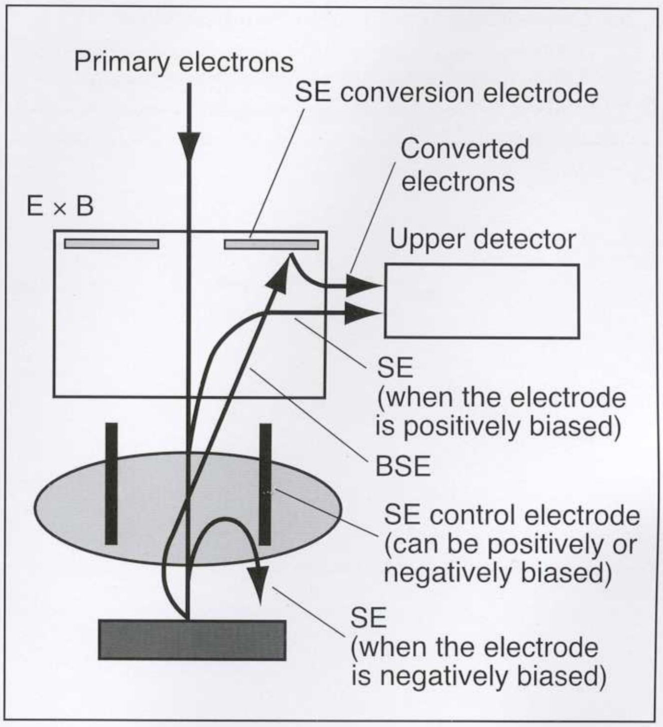
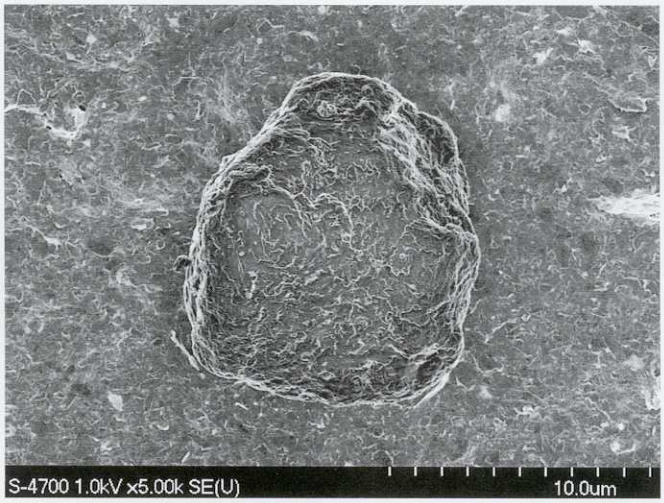


Fig. 2 A new detector system

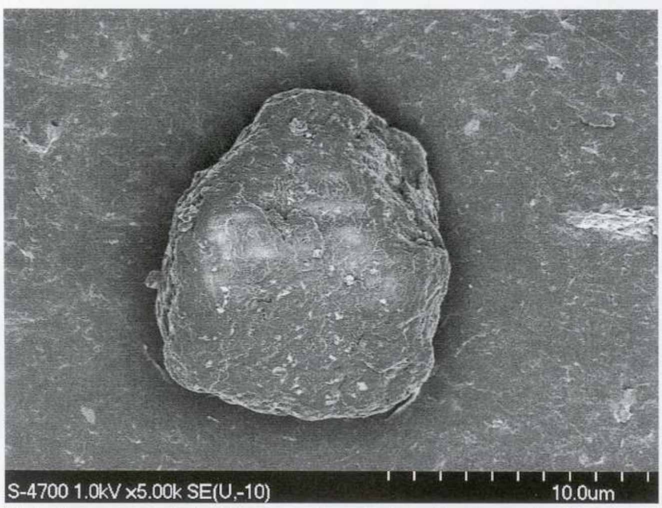
4. INITIAL APPLICATIONS

4.1 Distribution of dispersion materials on toner particles

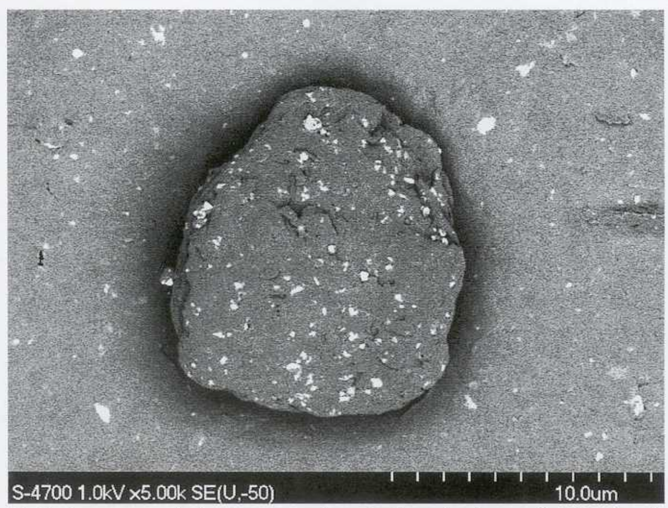
Fig. 3 shows micrographs of toner particles recorded at 1 kV. A) shows a normal secondary electron image and surface topography is clearly observed. B) is a micrograph, recorded using secondary electrons with their energies at 10 eV or lower, in which both topographic and composition information is seen. C) is an image, recorded using secondary electrons by depressing the signal which has energies at 50 eV or lower. It mainly exhibits sample compositions. Dispersion materials such as silica have been seen on toner particles. Backscattered electrons at high angles are sensitive to sample compositions and they are useful for examination of dispersion conditions.



A) Normal secondary electron image



B) An image recorded using secondary electrons by depressing the signal which has energies at 10 eV or lower



C) An image recorded using secondary electrons by depressing the signal which has energies at 50 eV or lower

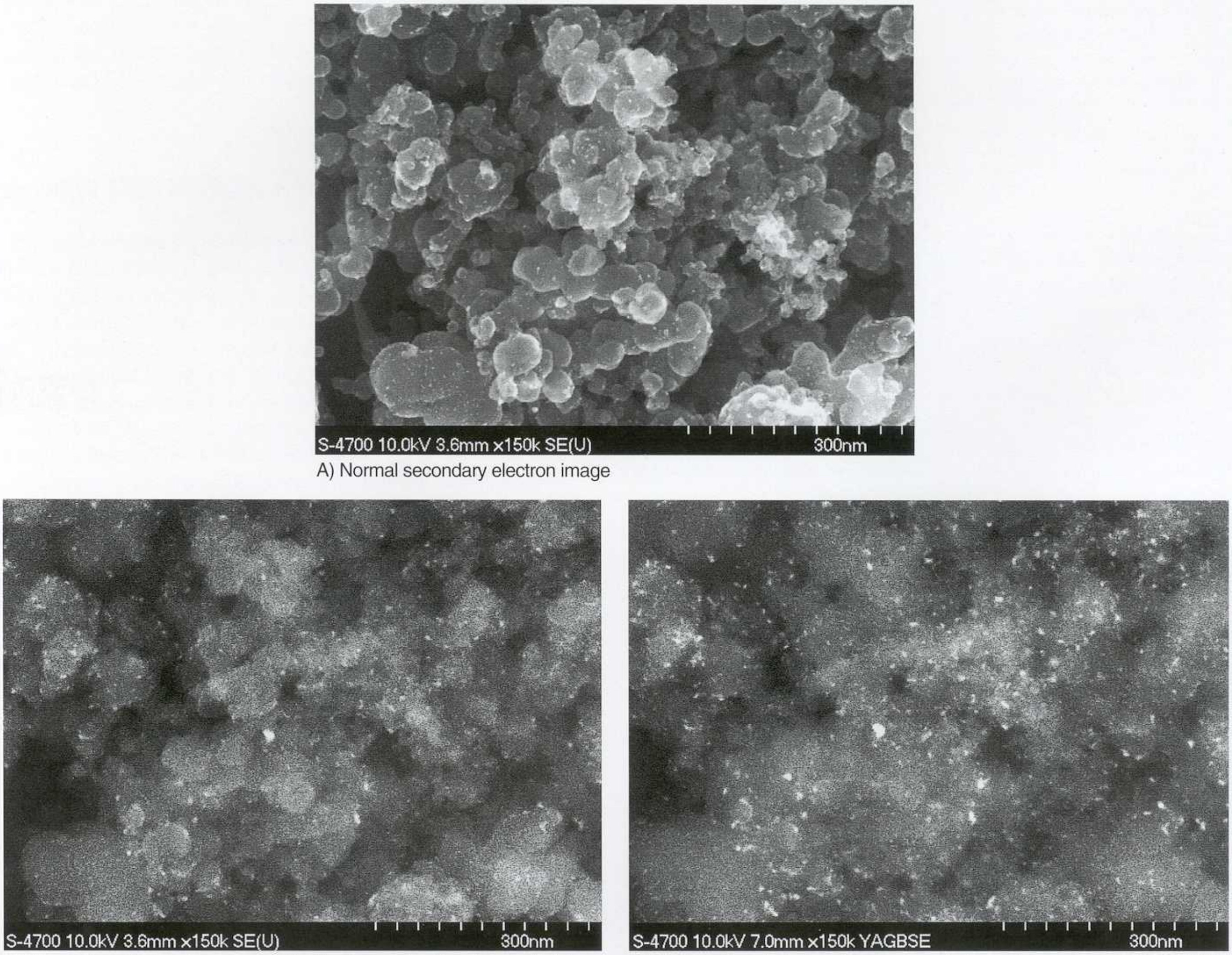
Fig. 3 Observation of toner particles

4.2 Dispersion conditions of metal particles on a catalyst

Fig. 4 shows micrographs of a catalyst with platinum particles of about 5 nm on carbon. Micrograph A) shows a normal secondary electron image using a full range of energies of secondary electrons.

It shows surface details of carbon very clearly. It is difficult, however, to understand dispersion conditions of platinum particles.

Micrograph B) is a secondary electron image using secondary electrons by depressing the signal which has energies of 50 eV or lower. It shows distribution of platinum particles just as good as micrograph C) which was recorded using a separate YAG BSE detector.



A) Normal secondary electron image

B) Secondary electron image recorded by depressing the signal which has energies at 50 eV or lower

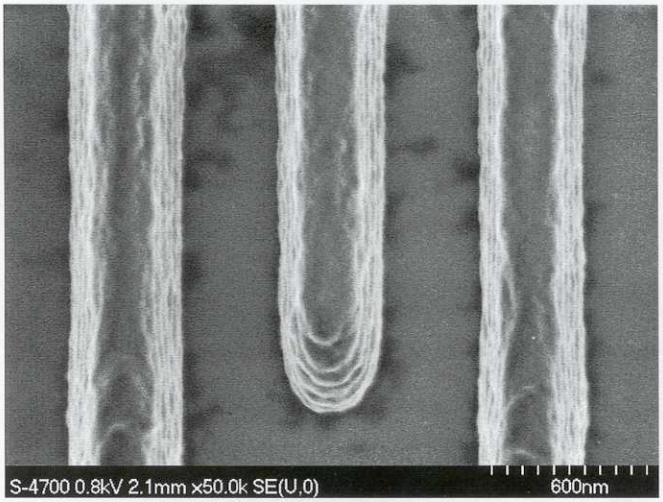
C) Backscattered electron image recorded by using a separate YAG BSE detector

Fig. 4 Observation of a catalyst

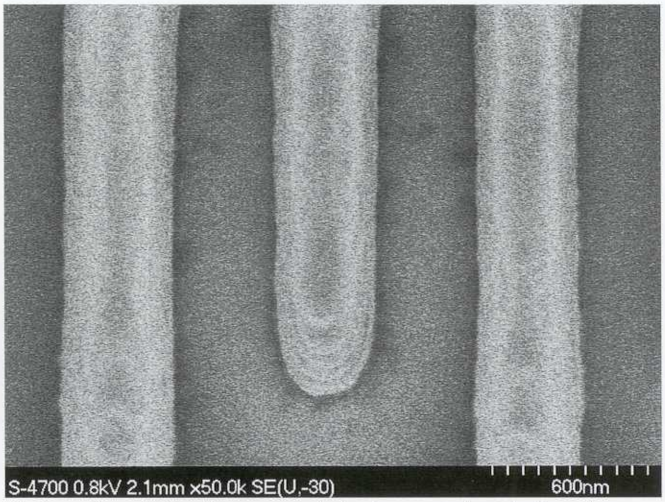
4.3 Observation of resist scum and measurement of pattern width

Fig. 5 shows a line and space pattern on silicon substrate. Micrograph A) is a normal secondary electron image which has information carried by low energy electrons. It shows resist scum on substrate clearly and provides useful information for process evaluation. Micrograph B), on the contrary, is much less sensitive to edge contrast or resist scum. This image was recorded using secondary electrons by depressing the signal which has energies at 30 eV or lower.

It is a good image for precise measurement of pattern width.



A) Normal secondary electron image

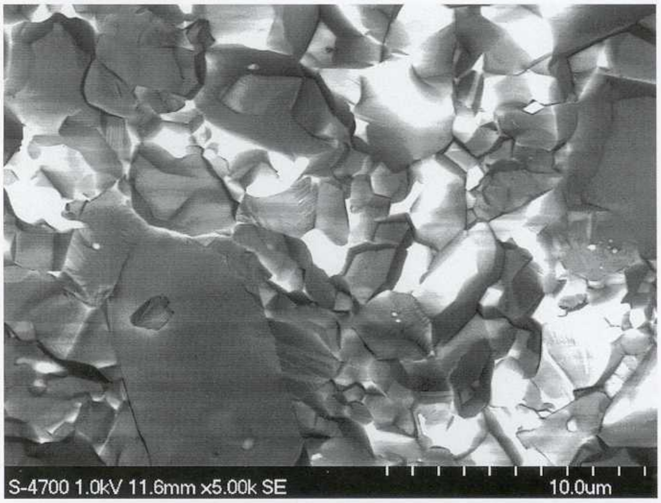


B) Secondary electron image recorded using secondary electrons by depressing the signal which has energies at 30 eV or lower

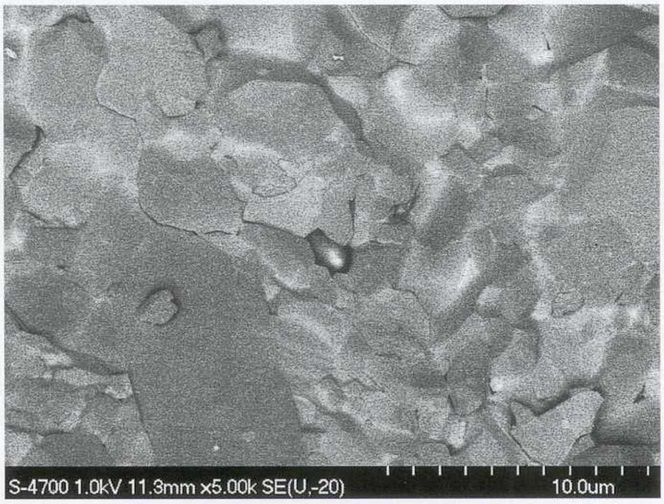
Fig. 5 Observation of a line and space pattern

4.4 Minimized sample charging for observation of ceramics

Low energy secondary electrons, with which normal secondary electron images are formed, allow good surface information but they are very sensitive to sample charging, particularly with insulating samples which are sensitive to surface potentials. Fig. 6 shows observation of uncoated fractured alumina. Micrograph A) is a normal secondary electron image which includes low energy secondary electrons. It shows sample charging artifact. Micrograph B) is an image recorded using secondary electrons by depressing the signal which has energies at 20 eV or lower. It shows crystal grains very clearly without sample charging artifact.



A) Normal secondary electron image

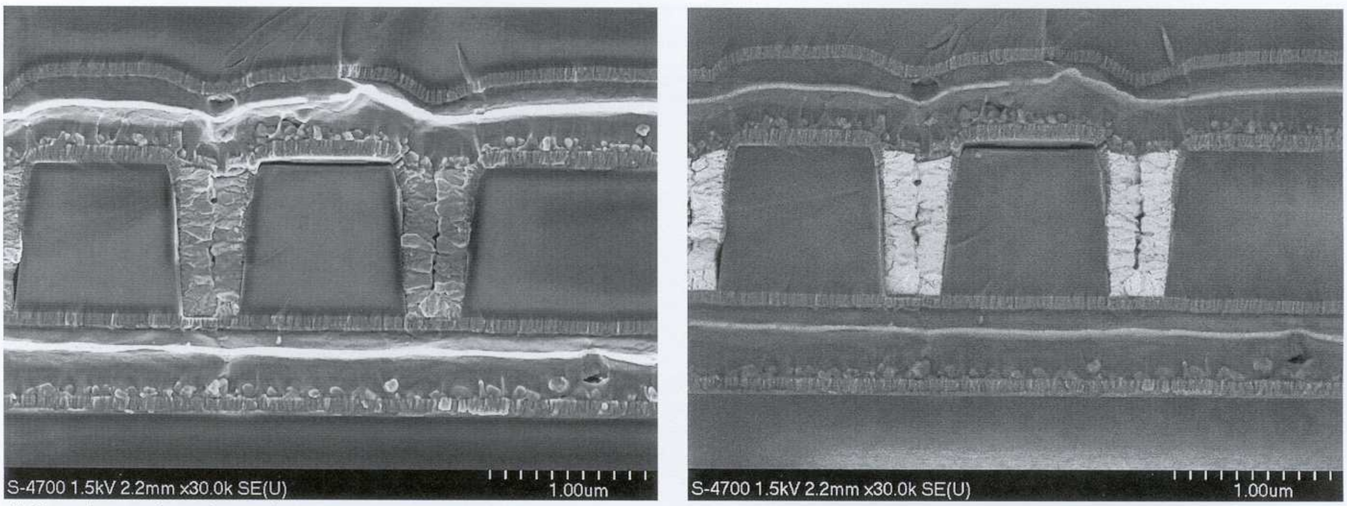


B) Recorded using secondary electrons by depressing the signal which has energies at 20 eV or lower

Fig. 6 Observation of ceramics

4.5 Cross-sectional observation of a semiconductor device

Fig. 7 shows a sectional structure of a portion of wiring in LSI recorded without coating. Micrograph A) is a normal secondary electron image. It shows crystal structures of tungsten plugs 3 dimensionally but strong edge contrast (edges of particles are shining too much) prohibits observation of layer structures. Micrograph B) was recorded using secondary electrons by depressing the signal which has energies at 30 eV or lower. It is much less sensitive to edge contrast and shows layer structures much more clearly reflecting the compositional information.



A) Normal secondary electron image

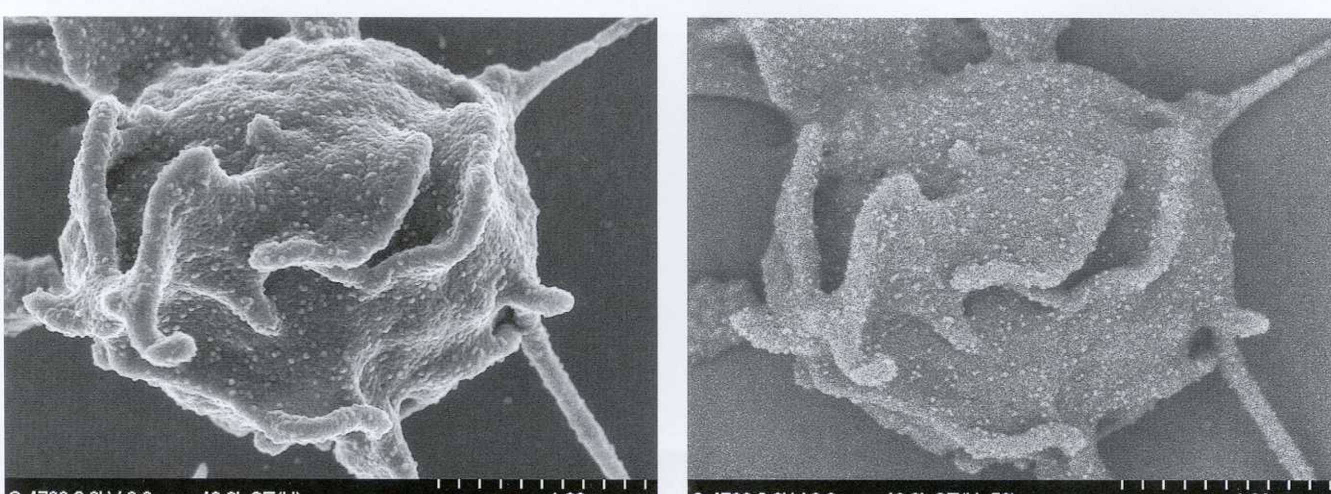
B) Recorded using secondary electrons by depressing the signal which has energies at 30 eV or lower.

Fig. 7 Cross-sectional observation of a semiconductor device

4.6 Applications to immuno-SEM technique

The immuno-SEM technique allows 2 dimensional distribution of specific proteins by labeling of colloidal gold after a reaction of antibody with specific proteins on cell surface. The new detector system is useful in this area. Fig. 8A) is a secondary electron image taken at 2 kV. (The sample is α_{IIb} β_3 integrin on activated blood platelet after reaction with mouse antibody, α_{IIb} β_3 integrin antibody and colloidal gold (about 10 nm) labeling goat anti-mouse (IgG).

This micrograph shows distribution of colloidal gold particles on the sample surface but it also shows fine topographic details and edge effect which prohibits observation of correct distribution of gold particles. On the other hand, micrograph B) allows observation of gold particles much more clearly with dominant compositional information and without edge effect.



A) Normal secondary electron image

B) Recorded using secondary electrons by depressing the signal which has energies at 50 eV or lower

Fig. 8 Applications to immuno-SEM technique

5. CLOSING

We have introduced a new electron detector system and some initial applications. The new electron detector system allows the following advantages:

1) It allows information of secondary electrons and backscattered electrons in Table 1. It allows optimum imaging taking advantage of this information.
2) It allows high resolution backscattered electron imaging at low operating voltages (0.5 ~ 5 kV) which has been difficult with conventional SEMs.
3) Change of information is simple without the need of changing detectors, or electron optical conditions.

The new electron detector system is convenient for routine operations so that it will be useful for various applications in the future.

References:

1) R. Tamochi, et al; Proc. 50th Japan Electron Microscopy, P157 (1994)
2) T. Suzuki, et al; Hitachi Technical Data SEM Sheet No. 64