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DETECTION SYSTEM FOR SCANNING ELECTRON MICROSCOPE

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Abstract

The kind of information and the quality of the backscattered electron (BSE) images depend upon numerous features of the detector. Therefore, various types of detectors should be used simultaneously to obtain as much of information as possible. The detection system presented here contains a large area semiconductor detector and a BSE to secondary electrons (SE) converter system. These two different kinds of detectors give different BSE images. After subtracting the signal of a semiconductor detector from that of a converter system, an image with good topography and reduced material contrast can be achieved.

KEY WORDS: Detectors, Backscattered Electrons, Topographic Contrast, Atomic Number Contrast, Signal Mixing, Scanning Electron Microscopy

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Introduction

The interest in backscattered electron imaging has grown together with the expansion of scanning electron microscopy (SEM) applications in different fields. A large amount of information can be gained from the backscattering interactions which is quite often impossible to obtain in the secondary electron mode. The physical background and experimental data of electron backscattering have been described by many authors and reviewed recently by Niedrig (1982, 1984).

Electron detectors suitable for the collection of the BSE for imaging purposes in the SEM have been extensively discussed in the literature and a large number of BSE detector systems have been constructed. Robinson (1980) surveyed these various types of detectors and indicated their usefulness. Moreover, the improvement of the conversion method of BSE (Moll et al., 1978) introduced by Reimer and Volbert (1979) should be added to that survey. The comparison of the noises of various electron detection systems with a scintillator-photomultiplier combination were studied by Baumann and Reimer (1981) and systems with solid state detectors by Oatley (1981). The type of information and the quality of the BSE images depend on numerous properties of the detector. Among them are: take-off angle, acceptance angle and energy filtering. Therefore, different types of detectors should be used simultaneously to obtain as much of information as possible.

However, none of the described detectors produce pure topography. By a mixing of signals from different detectors one can achieve this, but the existing systems do not give satisfactory results in all cases. The method developed by Kimoto and Hashimoto (1966) based on signal subtraction from two semiconductor detectors can frequently introduce artefacts (Volbert, 1982;

Reimer, 1984). The images obtained by the mixing of SE and BSE signals (Volbert, 1982) are influenced by the surface quality of a specimen (dirt, corrosion, contamination) and show strong edge effect.

In this work the authors propose a BSE detection system, consisting of solid state detector and BSE to SE converter, which gives good images of topography by signal subtraction from both detectors.

The BSE solid state detectors are widely presented in the literature. They have been fabricated in many different forms; for example as a single, a paired or an annular construction. Among them there are detectors with a p-n junction or a metal barrier and can be used as well for slow scan rates as for TV imaging (Gedcke et al., 1978; Frost et al., 1981). Although the semiconductor detectors have some disadvantages (low signal to noise ratio, relative high capacity of p-n junction, they work for electrons with energy higher than 10 keV) they have been used frequently because of low cost, possibility for installation with a variation in solid angle and take-off angle and because of the simplicity of the signal mixing from several detectors. At this time solid state detectors are primarily used to obtain compositional images of the surface or to record channelling patterns and contrast. To obtain good material contrast, the detector should cover a large collection angle and should be mounted above the specimen symmetrically around the electron beam.

The BSE to SE converter does not have disadvantages of the solid state detectors but its good sensitivity for electrons with low energy (diffused electrons) can decrease the resolution. In the case of working with one Everhart-Thornley detector only, the converter shows directionality because the major part of the signal originates from the BSE striking the converter plate between the incident beam and the Everhart-Thornley detector. Such system can be treated as a detector mounted at one side (Wells, 1977). It produces both atomic number and the topographic contrasts with a reduced edge effect and a good three-dimensional impression.

Detection system

The detection system for the BSE used in this work and the arrangement of the semiconductor detectors are shown in Fig. 1. The system consists of four large area solid state detectors (each detector has 10mm x 10mm effective area) and a MgO converter of BSE.

The semiconductor detectors were made of n-type silicon wafers with resistivity 3000 Ωcm^{-1}. The "p" layer was produced by boron implantation. Each detector has the p-n junction at 0.6 µm depth. The width of the depletion layer is about 1.5 µm for an unbiased junction. The front contact on the sensitive surface was made by coating with a Pt layer of 60 nm thickness. The threshold energy of the detector is about 5 keV. The detectors were mounted on 1mm thick copper plated board.

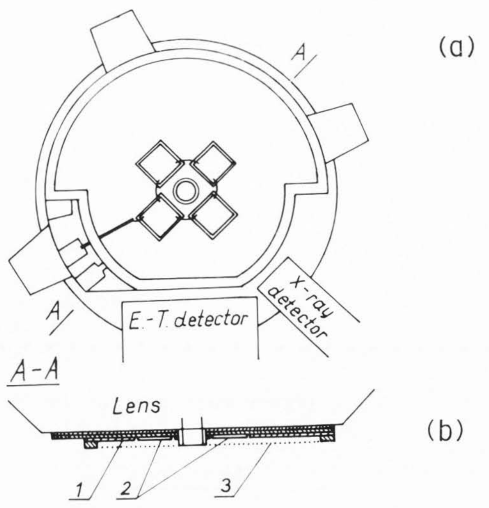

Fig. 1. Arrangement of the detection system: 1-converter plate, 2-solid state detector, 3-metal grid. E-T = Everhart Thornley detector. (a) Top View. (b) section through AA.

The BSE to SE converter was made in a manner similar to that described by Reimer and Volbert (1979). In our case the board (coated with MgO smoke) provides four windows for semiconductor detectors (Fig. 1). The solid state detectors were connected in parallel above the converter plate by means of gold wires. An earthed grid below the converter plate was mounted to suppress or to switch on the converted signal by positive or negative biasing respectively (bias voltage equal to 150V). Together with a biased metal ring above the specimen the system gives opportunity to switch on the SE image or the converted BSE image.

This detection system has been mounted in a Cambridge Stereoscan 180 SEM below the final lens. The microscope was equipped with a standard Everhart-Thornley detector and a thermionic W electron source. An additional amplifier system and mode selector have been used to mix the signals from the described BSE detectors in various ways.

Results and Discussion

To illustrate the possibilities of the detector system, a damaged semiconductor structure and a mineral specimen were investigated. The semiconductor specimen consisted of a polycrystalline silicon wafer with evaporated gold contact. The mineral sample was dolomite with a phase of less Ca (dark), and with inclusion consisting of two phases; one enriched in Fe and Cr (the brightest on micrographs) and the second enriched in Cr, Al and Fe. The mineral surface was coated with a carbon film by vacuum evaporation.

The left column of the micrographs on Fig.2 and Fig.3 presents images obtained by all available detectors separately i.e. the Everhart-Thornley detector, the converter and solid state detectors. In the case of SE images (Fig.2a and Fig.3a) the BSE contribution was decreased by positive biasing of the converter plate. The BSE images obtained in the conversion mode (Fig.2b, Fig.3b) were done with the negatively biased (-50 V) ring placed above the specimen. As was expected good material contrast (Fig.2c and Fig.3c) can be achieved with a wide angle detector placed above the specimen. In present case it was the solid state detector.

The right column of micrographs on Fig.2 and Fig.3 presents the images obtained by signal mixing from different detectors. If the BSE signal from a semiconductor detector is subtracted from the SE signal or from the BSE converter signal the topography images can be obtained. By comparison of the images on Fig.2b with those on Fig.2d and on Fig.3b with Fig.3d one can see that the mixing of BSE signals gives better results than mixing of SE and BSE signals. The latter makes the micrographs very sensitive to the surface quality like corrosion, contamination, dirt (Fig.2b) and with strong edge effect (Fig.3b). The former does not have these disadvanteges and moreover the images obtained by this method show a better three-dimensional impression.

Summary

A wide angle BSE detector in a SEM placed above a specimen gives primarily a material contrast, a BSE detector mounted at side gives both material and topographic contrasts. The mixing of these signals gives the possibility to separate topographic contrast. As an example of such system, an arrangement containing the semiconductor detectors and the BSE to SE converter is described. Presented micrographs show usefulness of the method of BSE signals mixing. It should be pointed out that our results concern untilted specimens or those slightly tilted towards the Everhart-Thornley detector and are primarily useful for low and medium magnifications.

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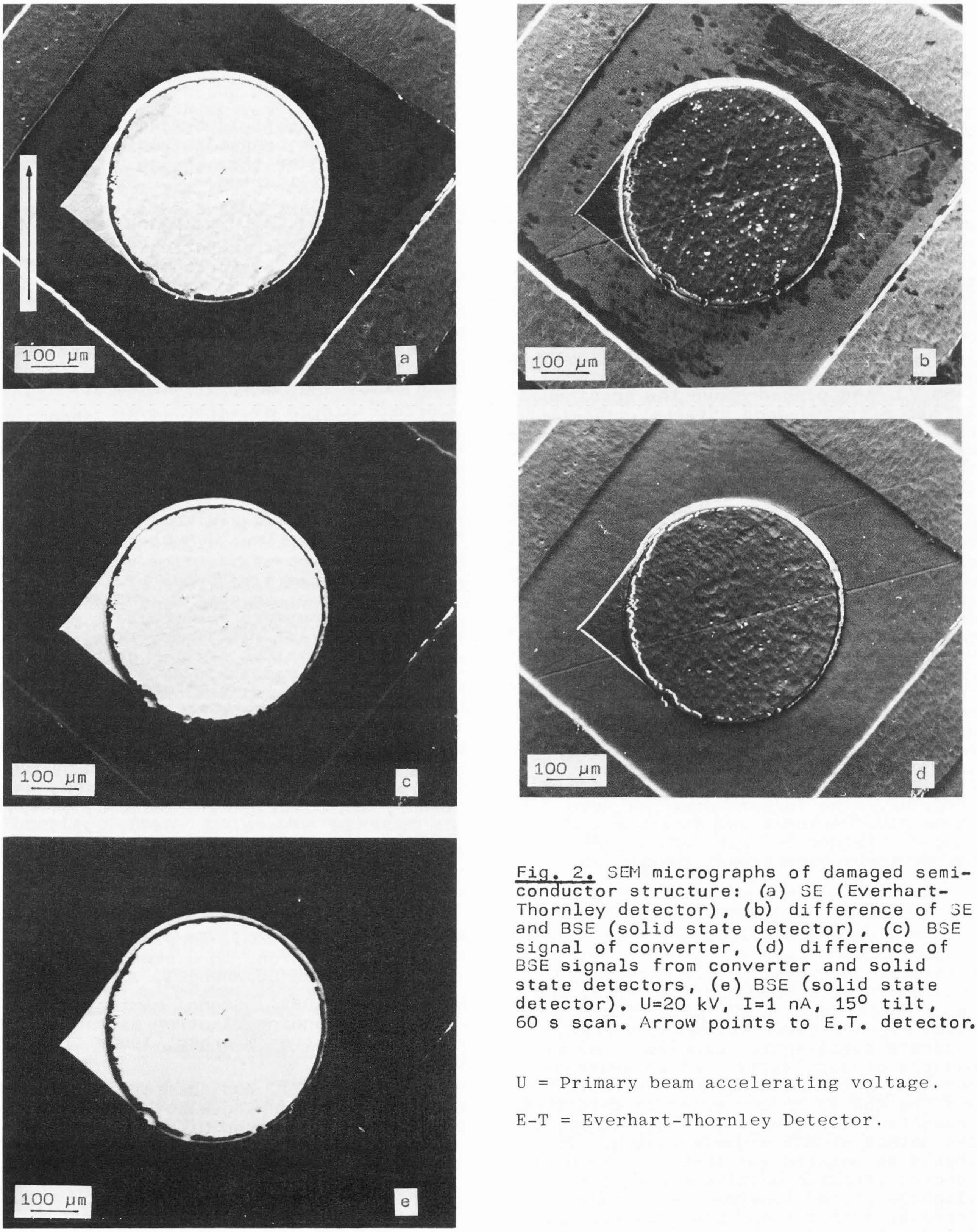

Fig. 2. SEM micrographs of damaged semiconductor structure: (a) SE (Everhart-Thornley detector), (b) difference of SE and BSE (solid state detector), (c) BSE signal of converter, (d) difference of BSE signals from converter and solid state detectors, (e) BSE (solid state detector). U=20 kV, I=1 nA, 15° tilt, 60 s scan. Arrow points to E.T. detector.

U = Primary beam accelerating voltage.

E-T = Everhart-Thornley Detector.

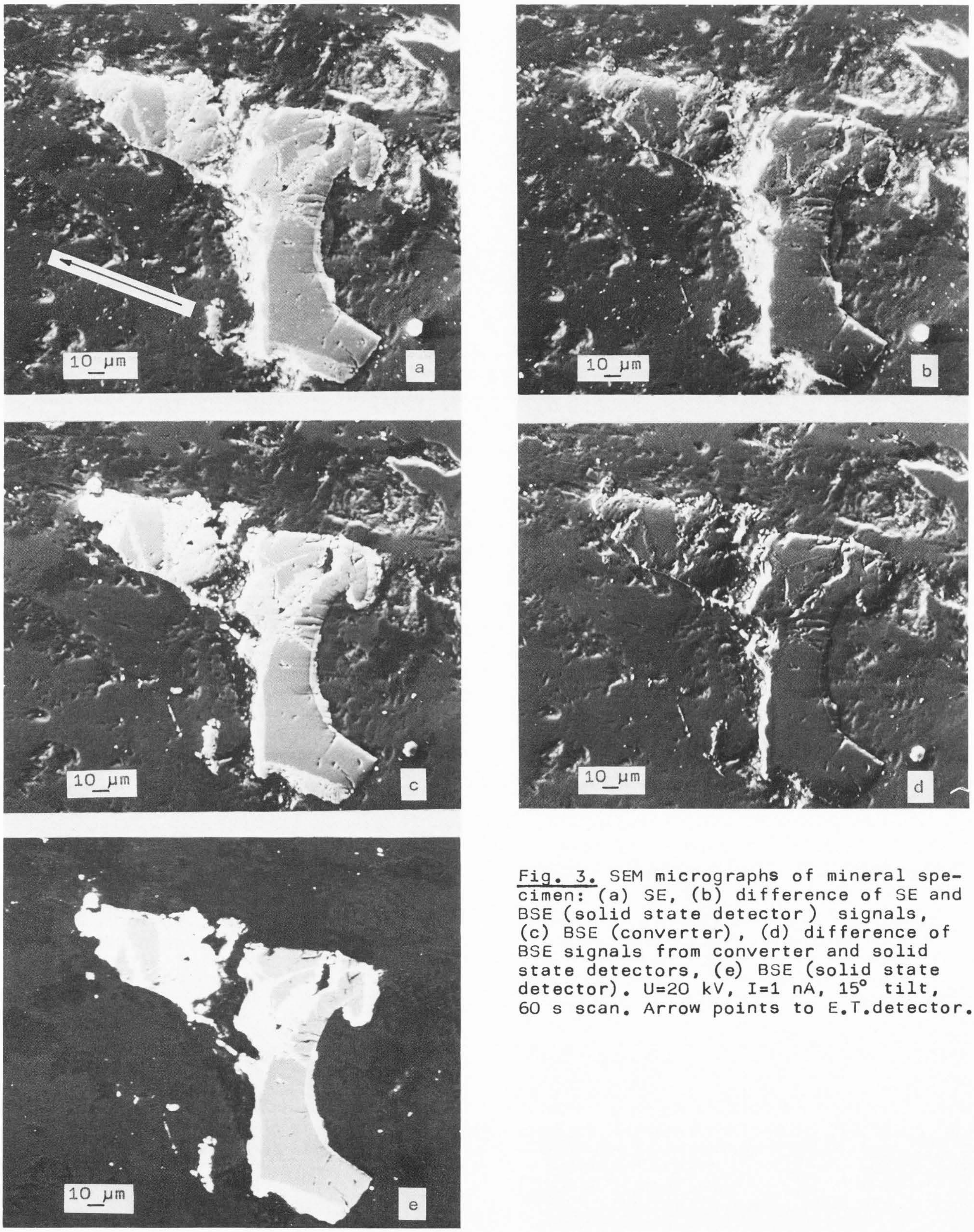

Fig. 3. SEM micrographs of mineral specimen: (a) SE, (b) difference of SE and BSE (solid state detector) signals, (c) BSE (converter), (d) difference of BSE signals from converter and solid state detectors, (e) BSE (solid state detector). $U=20$ kV, $I=1$ nA, 15° tilt, 60 s scan. Arrow points to E.T.detector.

Discussion with Reviewers

V.N.E. Robinson: Some experimental work by Wells and a theoretical study by George and Robinson have shown that you get more topography variation by detecting the low takeoff angle BSE and more atomic number variations when you detect high takeoff angle BSE. Subtraction of a high takeoff angle BSE signal from a low takeoff angle BSE signal would be expected to yield an image showing better topography contrast, irrespective of the type of detector employed.
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George EP and Robinson VNE. (1977) The influence of electron scattering on the detection of fine topographic detail in the SEM, Scanning Electron Microsc.1977; I: 63-70.
Authors: We agree with your suggestion, however, working with high and low take off angle detectors requires high tilt angle of a specimen,which is quite often inconvenient. It should be pointed out that the presented system consists of two high take-off angle detectors. The detectors were chosen because of the simplicity of their assembling in any type of SEM. The way of mixing proposed may be applied also to other detectors. It would be interesting to use the wide angle scintillator(Robinson detector) instead of semiconductor diode because of better detection properties of scintillators.

H. Niedrig: Which are the minimum energies of BSE to be detected with your detectors (solid state and converter) well above the noise pulses?
Authors: The smallest primary electron energy, we have used for the solid state detector was 10 keV and for the converter 5 keV (although it could be smaller). The whole system has shown good detection parameters for the energy higher than 15 keV.

S. Moll: Can you discuss, predict or present micrographs comparing low kV (3-8) and high kV (20-30) performance using the various modes of operation of this detector system? It should be noted that the conversion detector should have good performance at low kV.
Authors: To obtain the images with good topography one should work with low kV but with detectors used in our system we were able to work only with high kV.

V.N.E. Robinson: Did you make your own solid state detectors or did you purchase them? If you made them, how did you control the boron implantation?
Authors: The detectors were fabricated in Institute of Electron Technology, Technical University of Wrocław. The dose of boron was controlled by integration of the beam current, measured on the specimen during implantation.

V.N.E. Robinson: What was the bandwidth of your solid state detectors?
Authors: It was about 50 kHz.

S. Moll: When using the subtraction modes, please describe the method used to adjust or normalize the signals from each detector such that the subtraction did not represent an arbitrary amplitude or "signal modulation depth" for each signal.
Authors: The normalization of the signal was performed in line scan mode of SEM. Before subtraction the gains of the detector amplifiers were adjusted, to obtain equal levels of Z contributions to the signals. After subtraction a definite calibration of gains was made. It should be added, that it is impossible to eliminate the material contrast but it should be minimized.

V.N.E. Robinson: Have you used this system in any other combination to suppress topography contrast?
Authors: No, we have not used it for this purpose. However, it seems to be possible to improve the material contrast by subtraction of the topographic contrast signal obtained by our method from the BSE/SE converter signal. It can be accomplished by applying an additional mixing stage.

H. Niedrig: What energy half-width does your solid state detector show for illumination with monoenergetic electrons?
Authors: At present we are not able to perform such experiment.

B. Volbert: In your summary you state that this technique is limited to low magnifications. Are these limitations due to the specific experimental set-up or are these principal limitations?
Authors: These limitations are caused by a large lateral spread of backscattered electrons. So, they are basic limitations.

B. Volbert: Since the BSE/SE converter is a highly sensitive detector for low energy BSE I would expect a difference in information depth, comparing it with a semiconductor detector with a threshold energy of about 5keV. Subtraction of the signals therefore should result in pure depth information. Are there any experiments done or planned in comparing the information depth of the different BSE-detection systems?
Authors: The presented results are preliminary. The experiments are continued with others BSE detection systems to compare their information depths.