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COLLECTION OF LOW ENERGY SIGNAL ELECTRONS IN THE ROTATIONALLY SYMMETRIC ELECTROSTATIC FIELD OF A DETECTOR

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ABSTRACT: The rotationally symmetric annular scintillator detector with a scintillation electrode held at a high voltage produces an electrostatic lens which focuses secondary electrons on the axis without their being detected. Only those electrons with a higher energy travelling at a greater distance from the axis are detected. This results in an inhomogeneous signal. Concentric dark and light circles become evident in the image. A retardation grid supplied with a low negative voltage modifies the electrostatic field so that an efficient detection of secondary electrons can be carried out, with the signal being homogeneous over the specimen surface. If the negative voltage supplied to the gird is increased, the secondary electrons are deflected so that they do not arrive at the scintillator and the given system can be used for the detection of low energy backscattered electrons.

ANSAMMLUNG DER NIEDERENERGIE-SIGNALELEKTRONEN IM ROTATIONSSYMMETRISCHEN ELEKTROSTATISCHEN FELD DES DETEKTORS

ZUSAMMENFASSUNG: Der rotationssymmetrische Ring-Szintillator-Detektor mit einer hohen Spannung an der Szintillationselektrode erzeugt eine elektrostatische Linse, die die Sekundärelektronen zur Achse fokussiert, ohne daß sie nachgewiesen werden. Es wird nur der Teil nachgewiesen, der eine höhere Energie hat und sich in einem größeren Abstand von der Achse bewegt. Daraus ergibt sich ein nicht homogenes Signal, das sich durch konzentrische dunkle und helle Kreise in der Abbildung bemerkbar macht. Ein mit einer niedrigen negativen Spannung gespeistes Verzögerungsfilter modifiziert das elektrostatische Feld so, daß die Sekundärelektronen mit einer guten Effizienz nachgewiesen werden und das Signal auf der Probenoberfläche homogen ist. Durch die Erhöhung der negativen Spannung am Gitter werden die Sekundärelektronen so abgelenkt, daß sie den Szintillator nicht erreichen and das beschriebene System zur Detektion der niederenergetischen Rückstreuelektronen angewendet werden kann.

Keywords: secondary electrons, YAG scintillator, electrostatic field, trajectories, computer simulation

Introduction

Under low energy signal electrons we understand electrons that are generated in the specimen after it is hit by the primary electron beam with an energy lower than ~2 keV. Unlike the energy of secondary electrons (SEs) ranging from 1 to 50 eV independently of the energy of primary electrons (PEs), the energy of backscattered electrons (BSEs) depends on the energy of PEs. The energy of most BSEs emitted in the specimen at a high angle is only slightly higher than the energy of PEs. Therefore, BSEs with an energy less than 2 keV are considered as low energy signal electrons.

The most efficient system for the detection of SEs is the Everhart-Thornley (ET) scintillator photomultiplier system (1) positioned at one side of the specimen chamber. The +10 kV voltage supplied to the scintillator produces an electrostatic field in which a certain part of SEs is attracted to the scintillator. The influence of the extraction field on the shape of the beam spot is negligible if the energy of the incident electrons is sufficiently high. However, if the energy of PEs is less than 2 - 3 keV, the extraction field affects the axis of the electron beam, broadens the beam spot and decreases the attainable resolution (2,3). To decrease the influence of the extraction field on the electron beam axis and to increase the collection efficiency for SEs, Volbert and Reimer (4) used two ET detectors positioned opposite to each other. To minimize the influence of the extraction field on the primary beam axis, Zach and Rose (5) suggested and worked out theoretical fundamentals of an electric-magnetic quadrupole detector. This detector was built and tested by Schmid and Brunner (6). To prevent aberrations which broaden the beam spot up to more than 1 nm for an electron beam energy of 500 eV, Zach (7) designed an Electrostatic Detector - Objective - Lens (EDOL) system.

If the specimen is placed within the field of the magnetic lens, the SEs generated at the specimen follow spiral paths along the lines of the magnetic flux and are guided through the upper polepiece of the objective before being attracted to the detector. Detectors positioned in this area are called "in lens" detectors and several arrangements have already been described (8,9). These detectors also disturb the primary beam image formation at low energies below a few keV.

A decrease in the influence of the axial potential of the electrostatic field of the ET detector on the primary beam is usually achieved by shifting the detector to the most remote position from the beam axis (10). However, this decreases the collection efficiency for SEs. Shao (11) suggested a solution to this problem. He introduced an immersion lens and extracted SEs by means of two symmetrically positioned ET detectors.

The rotationally symmetric SE detector placed immediately above the upper polepiece of the objective would appear to be a hopeful solution. Such a rotationally symmetric detector would act as a weak electrostatic lens and would have a negligible influence on the imaging properties of the primary beam.

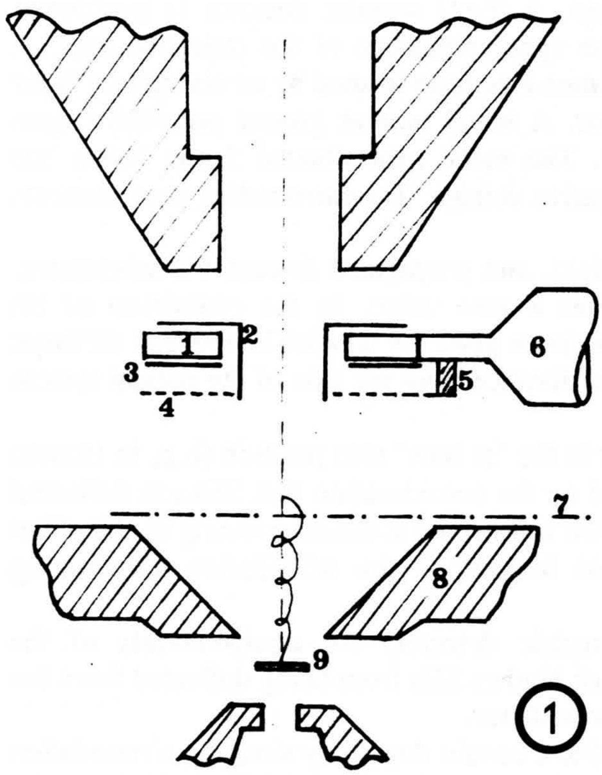
In this article we will analyze a rotationally symmetric extraction system from the point of view of its capability of efficiently extracting SEs and from the point of view of minimizing the influence of its electrostatic field on the primary beam axis.

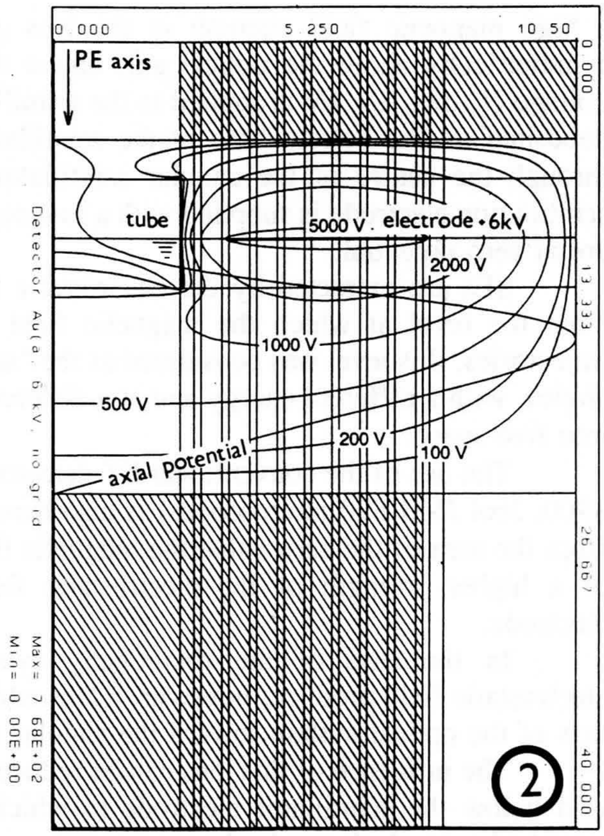
Materials and Methods

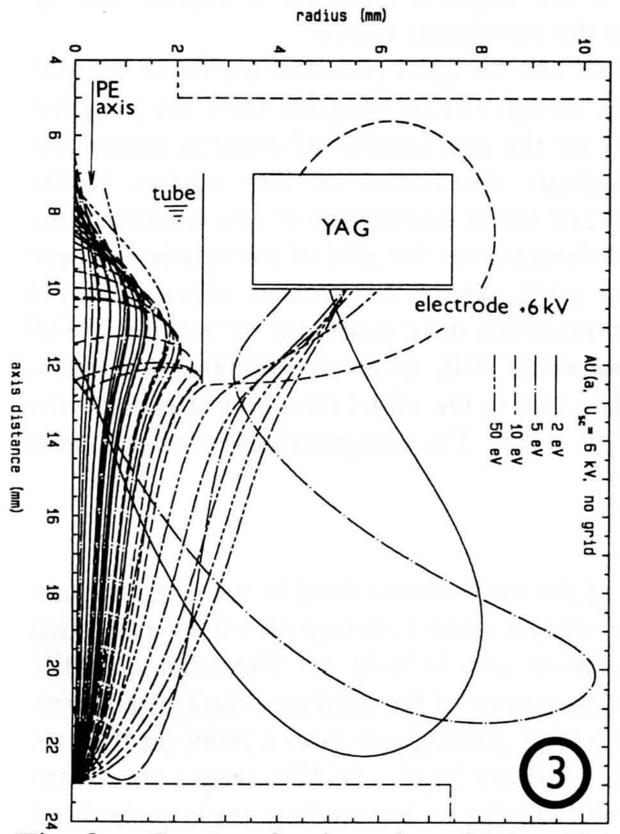
Fig. 1 shows the basic configuration of the "in lens" rotationally symmetric detector of SEs based on the scintillator photomultiplier system with a YAG single crystal scintillator. Primary electrons are focused to a fine probe on a specimen situated in an objective lens with

Fig. 1 Schematic drawing of the "in lens" SE rotationally symmetric scintillation detector (1-YAG scintillator, 2-metal earthed tube, 3-scintillation electrode, 4-retardation grid, 5-grid holder, 6-light guide, 7-level of the zero value magnetic field, 8-objective lens, 9-specimen)

Fig. 2 Course of equipotentials of the electrostatic field without any retardation grid. Axial potential +768 V







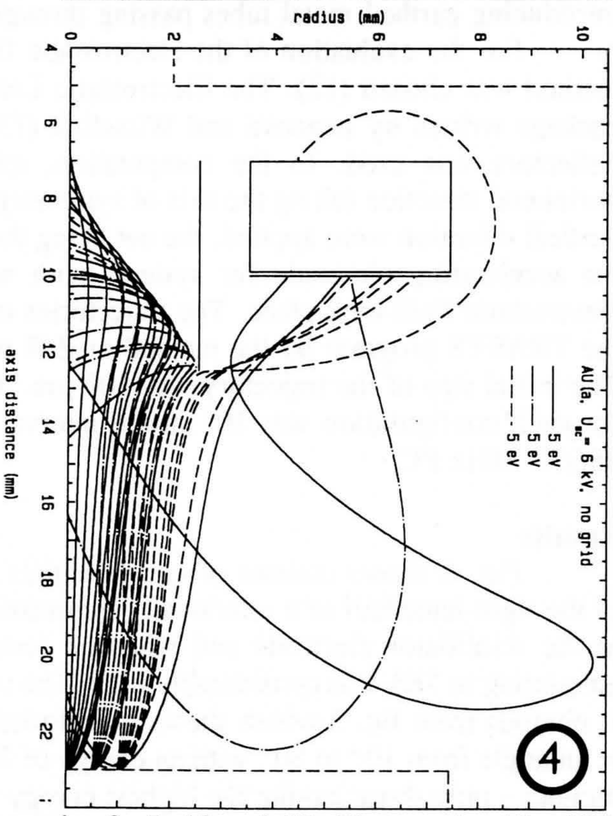


Fig. 3 Course of trajectories of SEs with energies 2; 5; 10 and 50 eV at angles 10 - 80° (in 10° steps). No retardation gird.

Fig. 4 Course of trajectories of SEs with an energy of 5 eV coming out from points at distances 0.0; 0.5 and 1.0 mm from the optical axis at angles 10 - 80° (in 10° steps). No retardation grid.

a high magnetic field strength in the lens gap. A YAG annular detector is positioned symmetrically about the optical axis above the upper polepiece of the objective lens. A voltage U_{sc} of a few kV is applied to the scintillation electrode formed by an aluminium layer deposited on the bottom base of the scintillator. A metal tube at ground potential passes through the centre of the annular scintillator. The metal grid situated 2 mm below the scintillation electrode is supplied with a low negative voltage. The surrounding lens elements are at zero potential.

SEs are extracted by the electrostatic field, and propagated toward the scintillator, from the level at which the magnetic field has a zero value. In the evaluation of SE trajectories, this level was considered as the "specimen plane" at which SEs move at different angles, with a different energy and at a different distance from the axis of the optical system into free space.

The use of the conventional ET detector in the "in lens" side position (e.g. in Hitachi S900, Jeol JSM 890 microscopes) is also based on the consideration that SEs are deflected from the area of the zero value the magnetic field toward the scintillator owing to the effect of a higher strength of the electrostatic field formed by the scintillation accelerating electrode.

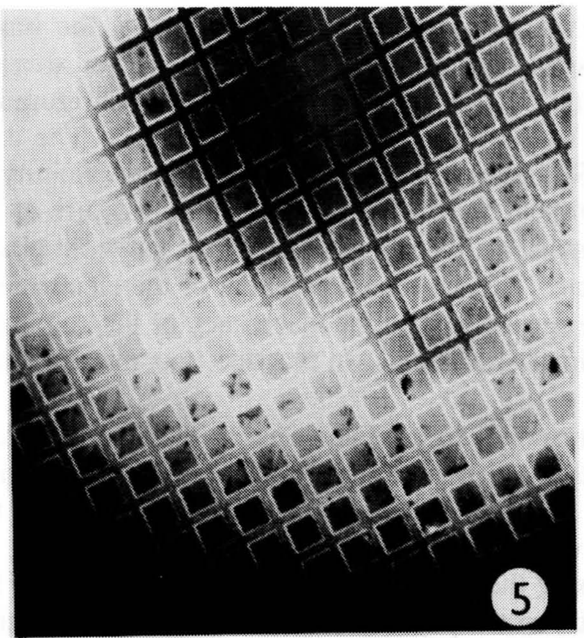
In the case of the rotationally symmetric detector, the equipotentials of the electrostatic field produce, however, a lens which hinders SEs from being deflected from the axis of the optical system toward the annular scintillator.

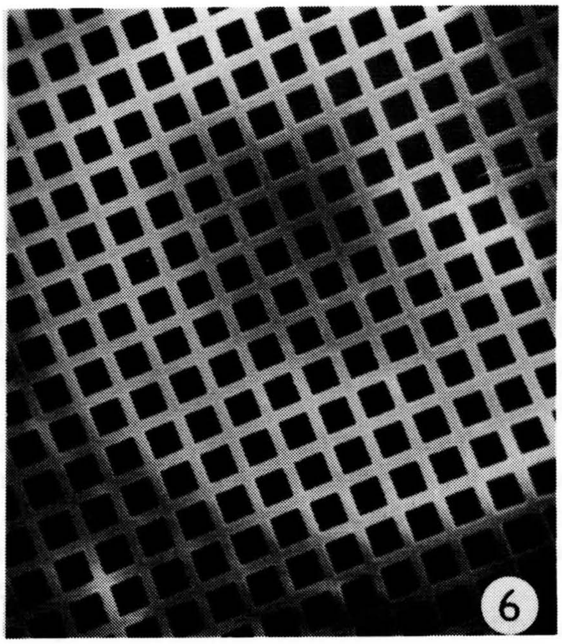
The influence of this lens can be reduced to a certain degree by situating a retardation grid below the scintillator electrode to which a low negative potential is applied and by introducing earthed metal tubes passing through the scintillator centre.

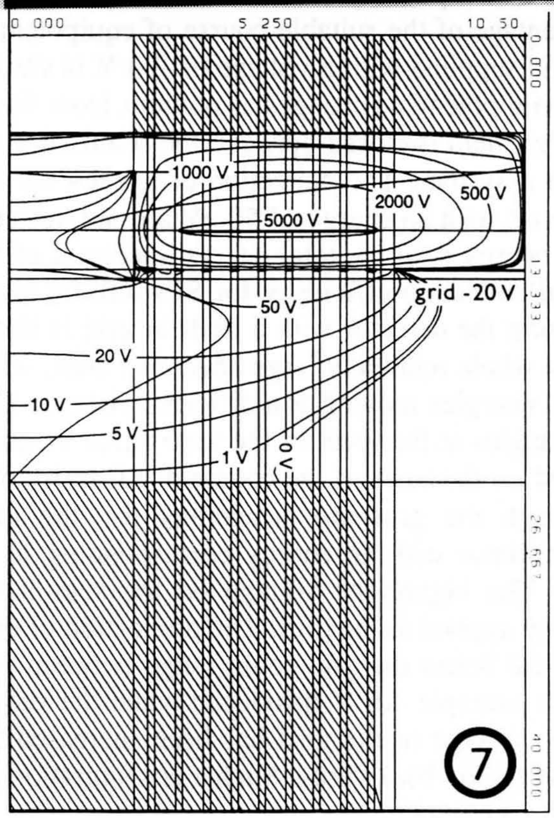
For the evaluation of the electrostatic field and the axial potential the finite element method was chosen (12). The Electrostatic Lens Design (ELD) program from the program package written by Lencová and Wisselink (13) for the computation of electron lenses and deflectors was used. In the computation, quadratic distribution of fine meshes in the horizontal direction (along the axis of symmetry) and linear distribution of fine meshes in the vertical direction were applied, the net being the densest near the grid of the system (or near the accelerating electrode for systems with no grid), where the greatest changes in the electrostatic field took place. The trajectories of electrons were evaluated by making use of the TRASYS program by the method of Z-R potentials (14), with interpolation on a mesh. The initial step of the trajectory was 100 μm. The step in the initial direction of trajectories for each configuration was 10° in the interval 0° - 90°. The computations were run on a 486/33 MHz PC.

Results

Fig. 2 shows courses of equipotentials of the electrostatic field in the cross-section of the right-hand half of a rotationally symmetric system when a voltage of +6 kV is applied to the scintillator electrode and when no retardation grid is built in. The axial potential amounting to 768 V is considerably high. The consequence of the produced electrostatic lens is obvious from fig. 3 which shows trajectories of SEs coming out from a point on the axis at an angle from 10° to 80° with an energy of 2, 5, 10 and 50 eV. Of SEs, only a very small number - only those having the highest energy and moving at the smallest angle at the level of the zero value magnetic field - are incident upon the scintillator. The majority of SEs are focused on the axis of the optical system and pass through the metal tube without being detected. Fig. 4 shows the collection of secondary electrons with an energy of 5 eV that move at a different distance from the axis of the optical system. Only those SEs are detected that move at a greater distance from the axis and at a small angle at the level of the zero of







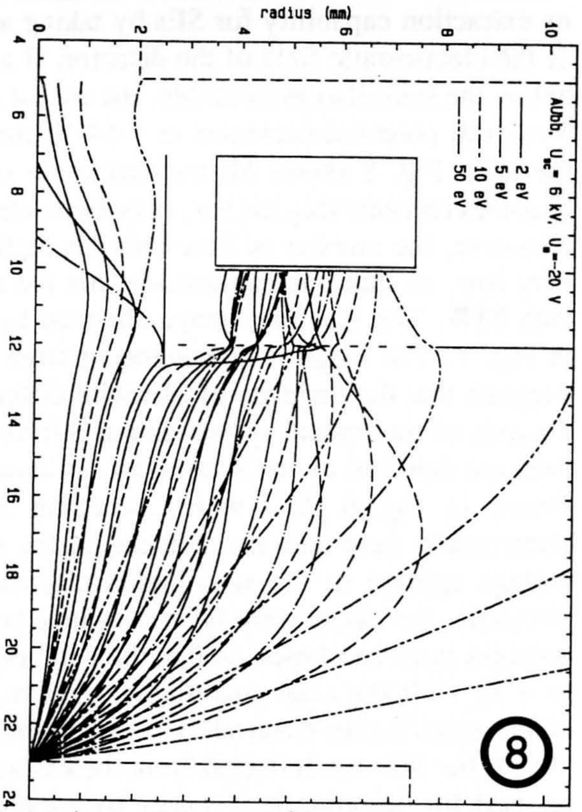


Fig. 5 Inhomogeneity of the SE signal recorded using a detector without any retardation grid according to the configuration of the electrostatic field and SE trajectories shown in Figs. 2, 3 and 4. Beam energy 2 kV, magnification 250×.

Fig. 6 Inhomogeneity of the SE signal recorded using a detector without any retardation grid when the voltage supplied to the scintillation electrode is decreased to 3 kV.

Fig. 7 Course of equipotentials of the electrostatic field with a retardation grid supplied with a voltage of -20 V. Axial potential +54 V.

Fig. 8 Course of trajectories of SEs with energies 2; 5; 10 and 50 eV coming out from one point on the optical axis at angles 10 - 80° (in 10° steps). Detector with a retardation grid supplied with a voltage of -20 V.

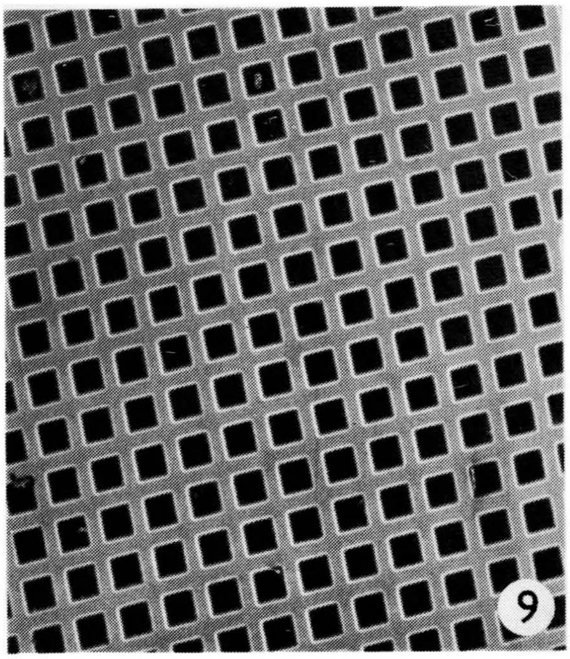
value magnetic field. On the basis of the evaluations one could conclude that the image would suffer from an inhomogeneity of the signal detected above all from a larger area the specimen. The experiment illustrated in Fig. 5, for which a geometrical configuration corresponding to that shown in Figs. 2 and 4 was used, proves the assumption. The dark centre of the image represents the signal of SEs following spiral paths in a close vicinity of the axis of the magnetic lens and escaping, without being detected, through the centre of the metal tube of the detector. The light circle represents the signal of SEs detected from places more remote from the axis of the magnetic lens. The high axial potential of the electrostatic field of this detector deforms the image in the dependence on the inaccuracy of the alignment of the axis of the detector system with the primary beam axis. In practice, this misalignment is very probable.

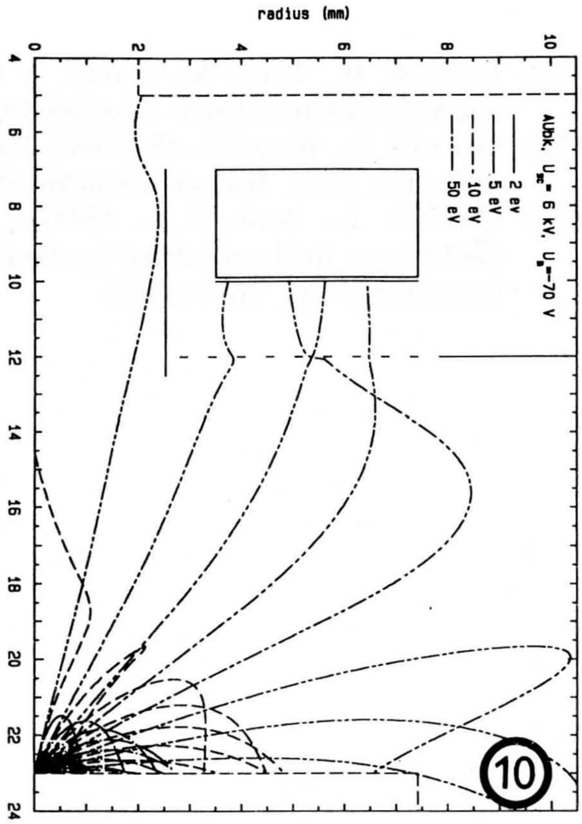
The image inhomogeneity which corresponds to a certain degree of separation SEs which are attracted to the scintillator, depends on the course and magnitude of equipotentials of the electrostatic field of the detector. Fig. 6 shows an increase in homogeneity when the voltage applied to the scintillation electrode was decreased from 6 kV to 3 kV.

The problem can be solved by decreasing the influence of the electrostatic lens of the detector and the influence of the axial potential on the primary beam axis, and by increasing its extraction capability for SEs by taking advantage of the suitable course of equipotentials of the electrostatic field of the detector. If a grid supplied with a voltage of -20 V is situated below the scintillation electrode, the course of equipotentials changes as obvious from fig. 7. The axial potential decreases to +54 V, the high field is closed between the scintillator and the grid. Fig. 8 shows SE trajectories in such a system. The collection efficiency for SEs becomes considerably higher, only some electrons with an energy of 50 eV are not detected. However, the number of SEs with this higher energy is in the total energy spectrum of SEs very low, so that one can assume that the total collection efficiency for SEs will be higher than 85%. The resulting image obtained by using the detector with a built-in grid is shown in Fig. 9. The signal is homogeneous from the whole relatively large specimen area, which suggests that the majority of SEs with different energies moving at a different distance from the axis of the optical system and at different angles at the level of the zero value magnetic field are detected by the scintillator, as assumed on the basis of the course of SE trajectories shown in Fig. 8. SEs which penetrate through the grid are accelerated by the inner electrostatic field and are incident on the scintillator with an energy corresponding to the voltage applied to the scintillation electrode. The higher the voltage on the scintillation electrode, the higher must be the negative voltage applied to the grid. The proportion of these voltages must be chosen so that the axial potential below the grid could range between +10 to +50 V. If the axial potential is negative, for example -10 V (produced when the voltage of the scintillation electrode is +6 kV and the voltage of the grid has been increased to -70 V), the SEs are deflected from the extraction region backwards. Such a configuration can be used for detecting low energy backscattered electrons.

Fig. 9 Homogeneity of the SE signal recorded using a detector equipped with a retardation grid according to the configuration of the electrostatic field and SE trajectories shown in Figs. 7 and 8.

Fig. 10 Course of trajectories of SEs with energies 2; 5; 10 and eV coming out from one point on the optical axis at angles 10 - 80° (in 10° steps). Detector with a retardation grid supplied with a voltage of -70 V.





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