COMPUTATIONS OF THE LOW VOLTAGE BSE DETECTOR IN SEM

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ABSTRACT

This paper deals with the possibilities of backscattered electrons detection by scintillation detector in low voltage scanning electron microscope (LV SEM). Low energy of signal electrons, especially backscattered electrons, is the reason of lower detectors yield. While the problem of secondary electrons detection was successfully solved by their extraction using a magnetic field and detection in objective lens, efficient detection of backscattered electrons remains unsolved. The initial energy of backscattered electrons of 0.7-3 kV is the energy, on which the light yield of scintillators decreases. Backscattered electrons with this energy will be accelerated to scintillator by electrostatic field and secondary electrons with maximal energy of 50 eV will be filtered by an energy filter or by a magnetic field.

1 INTRODUCTION

Nowadays development of the image formation in scanning electron microscopy is oriented to use of scanning electron microscopy with low accelerating voltage of the primary beam. This type of scanning electron microscopy is often called low voltage scanning electron microscopy. Its main advantage is the possibility of direct observation of insulating and biological specimens without previous metal coating, reduced electron range and increased secondary electron yield. The development of a commercial field emission gun and of the Schottky emission gun in the 1980s has solved the main disadvantages of LVSEM connected with the lower source brightness, greater defocusing due to chromatic aberration and greater sensitivity to stray field and allows the operations with a resolution of 2.5 nm and better, at the a primary beam energy of 1 keV [1, 2].

Secondary electrons (SEs), for topographical contrast observation, and backscattered electrons (BSEs), for material contrast observation, are the main parts of signal in the scanning electron microscope.

While the secondary electrons can be detected either by Everhart-Thornley scintillation detector or by the “in lens” SE detector, the detection of backscattered electrons in LV SEM is an unsolved problem yet. The scintillation-PMT detection system represents the most efficient detector of backscattered electrons in the SEM. The scintillator, the most important part of the scintillation-PMT detection system, can be represented by P47 powder phosphor and yttrium aluminium garnet (YAG) and yttrium aluminium perovskite (YAP) single crystals. Application of the mentioned scintillation materials in LV SEM is restricted by its certain threshold electron energy at which it is capable of generating such an amount of photons that can produce a signal usable from the point of view of the noise level. The scintillators are ranked in the order of threshold energy as follows: YAP single crystal ≈ 1.2 keV, YAG ≈ 1.3 keV, and P47 ≈ 3 keV. The mentioned values are related to the primary beam energy, not to the BSEs energy, which amounts to approx. 70 % of the primary beam energy. For BSEs, the factual energy is thus lower. The solution of the low energy BSEs problem is to accelerate BSEs by an electrostatic field. This acceleration will supply BSEs with a sufficient energy to produce a large amount of photons. Because all signal electrons (SEs and BSEs) are accelerated in this electrostatic field, an efficient energy filter is necessary for SEs and BSEs separation and true BSE image observation. Another possibility of true BSE image observation in LV SEM is implementation of a scintillation detector into a strongly excited magnetic immersion objective lens [3, 4].

2 PROBLEM SOLUTIONS

The electrostatic field for the signal electrons acceleration is created by a high positive bias of 3-5 kV of the conductive layer, which is applied on the scintillator. The energy filter for the SEs separation is represented by a retarding grid with negative bias of around -100 V. This potential is sufficient to deflect the essential part of SEs.

The described low voltage BSE detector and its electrostatic field was simulated by the software package Simion 3D [5] (see fig. 1). The scintillator covered by a conductive layer is placed in a shielding casing, below the scintillator is the retarding grid and the primary beam is shielded by a tube on a ground potential located in the hole in the centre of the scintillator.

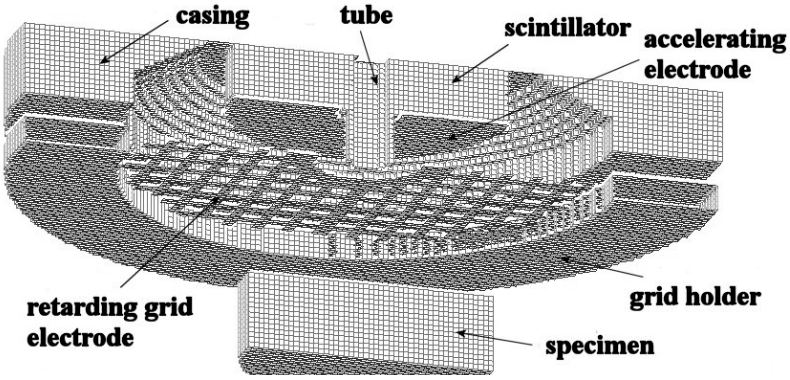

Fig. 1: *Simion model of designed detector.*

Fig. 2 and 3 represent simulations of low energy BSE and SE trajectories in the electrostatic field of the detector. It is evident that the computed trajectories certify the theoretical predictions. When there is a bias of 3 kV on the scintillator and a negative bias of -100 V on the grid, the BSEs, with their energies of 0.5-3 keV, are not affected by the negative bias of the grid and continue on straight trajectories to the scintillator (see fig. 2). SEs with energy of 5 eV are deflected from the detector by an electrostatic field of the grid (fig. 3).

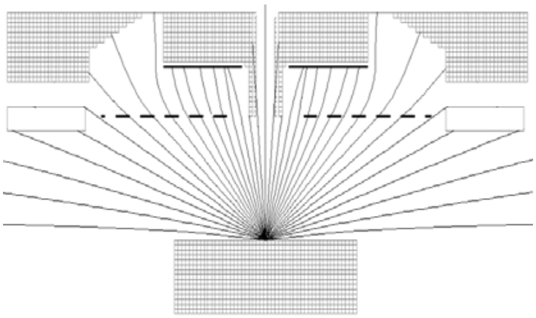

Fig. 2: *Trajectories of 1 keV BSEs. Electrode on the scintillator 3 kV, retarding grid -100 V.*

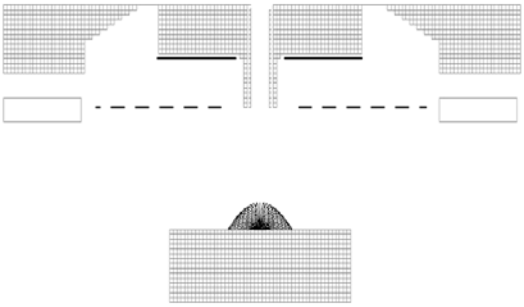

Fig. 3: *Trajectories of 5 eV SEs. Electrode on the sintillator 3 kV, retarding grid -100 V.*

A strongly excited magnetic immersion objective lens is another possibility of SEs separation. The immersion objective lens and the low voltage BSE detector simulated by software package Simion 3D are pictured in fig. 4.

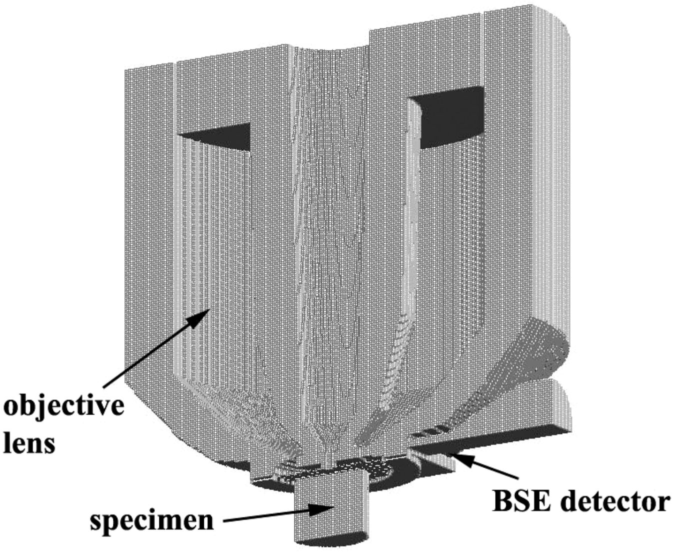

Fig. 4: *The low voltage BSE detector under the pole piece of the immersion objective lens.*

A magnetic field created by the immersion objective lens affects the SEs so that approximately 70 % of SEs with an energy of 5 eV are focused on helical trajectories into the objective lens (see fig. 5) and there they can be detected by the “in lens” SE detector. The SEs with the emission angle larger then 70 ° impact on the grounded specimen. The electrostatic field of the scintillator doesn’t influence the SEs, because the field works especially between the scintillator and the retarding grid. The SEs thanks to the magnetic field doesn’t reach this area. No SEs can reach the scintillator with potential of 5 kV when the low voltage BSE detector is placed under the pole piece of the immersion objective lens. No negative bias of the retarding grid is necessary.

BSEs are also influenced by this strong magnetic field, but owing to their higher energy, they are not focused into the objective lens. They are spinning around the primary beam trajectory and they can be detected by a low voltage BSE detector. When the working distance is 8 mm, half of BSEs are detected by the low voltage BSE detector and the second half impacts on the shielding tube or goes through the hole in the scintillator.

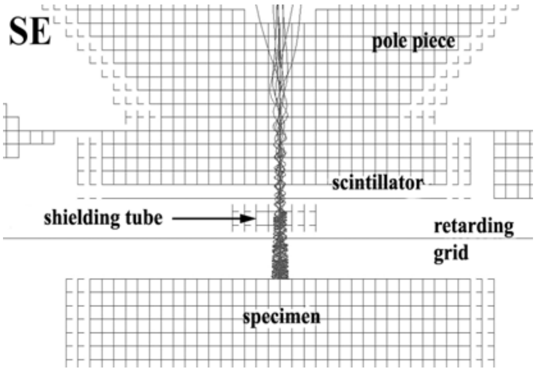

Fig. 5: *The SEs (5 eV) focused into the objective lens. Bias of the electrode on the scintillator is 5 kV. Retarding grid is grounded.*

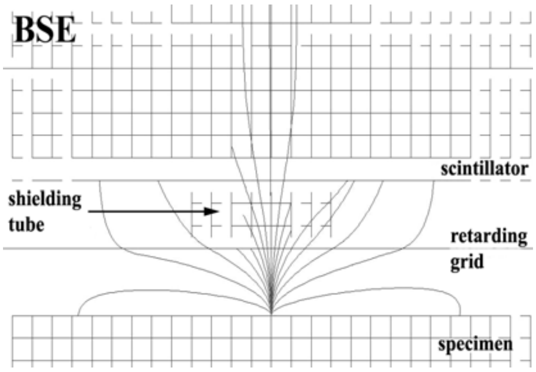

Fig. 6: *The BSEs (1 keV). Part of BSEs impacts on the scintillator and part impacts on the shielding tube or goes through the hole in the scintillator. Bias of the electrode on the scintillator is 5 kV. Retarding grid is grounded.*

3 CONCLUSION

The study of BSE and SE trajectories demonstrated, that above mentioned detector can be used for the BSE detection in LV SEMs. It is necessary to apply a negative bias on the retarding grid in LV SEMs, which are not equipped by the immersion objective lens. In LV SEMs with an immersion objective lens no bias on the retarding grid is needed.

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REFERENCES

[1] Nakagawa, S.: Development of JSM-6320F Scanning Microscope, Jeol News Magazine 31, 1994, p. 36-38

[2] Kazumori, H.: Development of JSM-7400F, Jeol News Magazine 37, 2002, p. 44-47

[3] Steigerwald, M. G. D.: Ultra Low Voltage BSE Imaging. Microscopy Today 11, 2003, p. 26-28

[4] JSM-7400F – Field Emission Scanning Electron Microscope. Jeol product datasheet

[5] Dahl, D. A.: Simion 3D version 6.0, In Proceedings of 43rd ASMS Conf. on Mass Spectroscopy and Allied Topics, Atlanta, 1995, p. 717