SCINTILLATION SECONDARY ELECTRON DETECTOR FOR VP-SEM

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Abstract: The article deals with the scintillation secondary electron detector for a variable pressure scanning electron microscope, its electrode system optimization and measurement of the pressure in the detector for different types of pressure limiting apertures.

Keywords: Scintillation SE detector, secondary electrons (SE), variable pressure scanning electron microscope (VP-SEM), voltage contrast.

1. INTRODUCTION

Variable pressure scanning electron microscope (VP-SEM) operates with the pressure of gasses in the specimen chamber from vacuum to thousands of Pascals which allows studying of insulating materials without charging artifacts as well as effects on phase interfaces, wet samples including biological ones without special preparation. For detection of the signal electrons in VP-SEM scintillation and ionization detectors are commonly used. At the ionization detector secondary and backscattered electrons are amplified in the process of impact ionization in the electric field with a voltage of several hundred volts created between a grounded specimen and the detector electrode system in a gas environment of the specimen chamber.

Scintillation detectors (SD) are used for detection of secondary electrons (SE) in scanning electron microscope (SEM) which operates at vacuum. Secondary electrons excited from the sample surface have mostly energy from 1 eV to 5 eV, maximally 50 eV. To evoke scintillations in the scintillator material electrons energy at least 3 keV, optimally 10 keV is required. For this purpose a thin conductive layer is prepared on the scintillator surface, voltage of about 10 kV is connected to this layer. In the created electric field secondary electrons receive needed energy. In the VP-SEM the higher pressure in the specimen chamber doesn't allow to connect a high voltage to the scintillator because of problems with electric discharges in gas.

2. SCINTILLATION SECONDARY ELECTRON DETECTOR FOR VP-SEM

In our experimental scintillation SE detector for VP-SEM (Fig.1), there is the scintillator of the detector placed in a separately evacuated chamber evacuated by the turbomolecular pump. The scintillator chamber is separated from the specimen chamber by two pressure limiting apertures A1 and A2. The space between the apertures is evacuated by the rotary pump. This system of differential pumping enables to maintain the pressure of 5 Pa at the most in the scintillator chamber at the pressure of water vapors up to 1000 Pa in the specimen chamber.

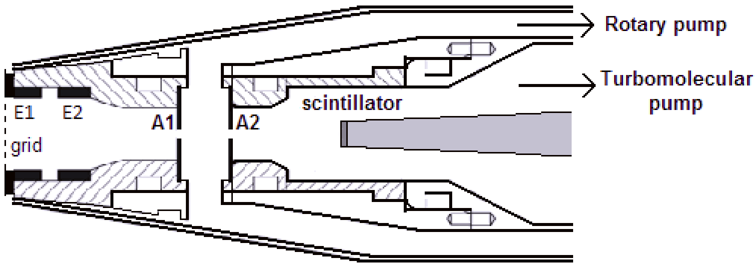

Figure 1: Scintillation secondary electron detector for VP-SEM.

3. OPTIMIZATION OF SECONDARY ELECTRONS COLLECTION

To enhance collection of secondary electrons with the scintillation SE detector for VP-SEM, especially at lower pressures in the specimen chamber, the grid is used at the entry of the detector. The grid is interconnected with the electrode E1 and the voltage on this electrode doesn't exceed 400 V. Distribution of the electric field of the detector was simulated with Simion software. The output of the simulation for the detector with the grid is shown on the Fig. 2.

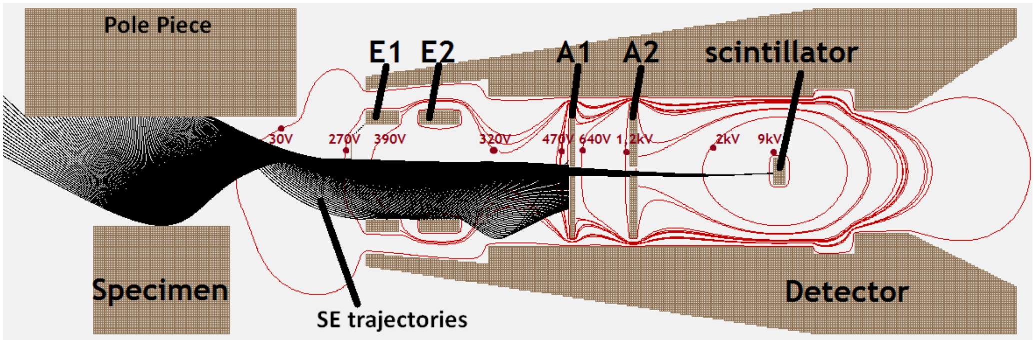

Figure 2: Simion simulation of electrostatic field of detector with a grid and SE trajectories.

Simulations for the detector with the grid proved an increase of the electric field potential in front of the detector. Higher potential of the electric field leads to a better focus of secondary electrons into the detector. Simulations of the SE trajectories show that the grid in front of the detector can increase the number of detected secondary electrons of about 50 %.

On the basis of simulations the observation of a standard specimen of tin spheres on carbon substrate was realized with horizontal field of view 3 µm at the pressure of water vapors of 20 Pa (Fig. 3). Previous observations of the same sample at the pressure of water vapors around 20 Pa with the detector without grid were impossible due to a low signal level. This experiment proved the increase of the number of detected SE by the detector with grid at low pressure of water vapors in the specimen chamber.

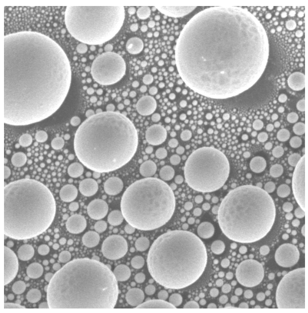

Figure 3: Tin spheres on carbon. Pressure of water vapors 20 Pa. Field of view: 3 µm.

4. OPTIMIZATION OF THE DETECTOR APERTURE SYSTEM

Simulations of trajectories of secondary electrons with Simion software showed that increasing of holes diameters in the apertures A1 and A2 or usage of a special hexagonal mesh with 300 – 1000 of small hexagonal openings as an aperture A2 of the detector brings more of secondary electrons to the scintillator. According to these results simulations of a gas flow in the detector were realized with Cosmos FlowWorks software (Fig. 4).

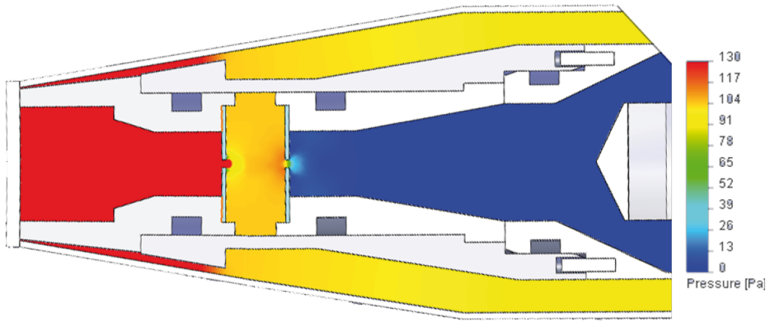

Figure 4: Cosmos FlowWorks simulation of pressure in the scintillation SE detector.

The output data from Cosmos FlowWorks software for different diameters of holes in the apertures A1 and A2 showed that the increase of the diameter of only one hole in apertures will cause only minimal pressure increase in the scintillator chamber (Tab.1).

	Pressure in the scintillator chamber [Pa] for holes diameters in the apertures A1 and A2 [mm]			
Pressure in specimen chamber [Pa]	A1 = 0.6 mm A2 = 0.6 mm	A1 = 0.6 mm A2 = 0.8 mm	A1 = 0.8 mm A2 = 0.6 mm	A1 = 0.8 mm A2 = 0.8 mm
200 Pa	1.24 Pa	2 Pa	1.4 Pa	2.3 Pa
400 Pa	2 Pa	3.6 Pa	2.6 Pa	4 Pa
800 Pa	2.6 Pa	4.9 Pa	2.9 Pa	5.4 Pa
1000 Pa	3.4 Pa	5.6 Pa	4 Pa	6.5 Pa

Table 1: Pressure in scintillator chamber in dependence on pressure in specimen chamber for different diameters of holes in apertures A1 and A2. Values obtained from Cosmos FlowWorks simulations.

Based on simulations, experiments were realized at which the pressure in the scintillator chamber was measured in dependence on the pressure of water vapors in the specimen chamber for different sets of apertures A1, A2. Results of these experiments for different diameters of holes in apertures A1, A2 are presented in Tab. 2. Experiments with usage of a hexagonal mesh with different number of hexagonal openings in a position of the aperture A2 are presented in Tab. 3.

Results of experiments showed that possible sets of apertures are A1 = 0.6 mm with A2 = 1 mm maximally, A1 = 0.8 mm with A2 = 0.6 mm maximally or A1 = 0.6 mm and A2 the hexagonal mesh with 1000 hexagonal openings. Other aperture combinations will bring problems with electric discharges in a gas at the scintillator.

Subsequent experiments were oriented to observation of the image of a power transistor by a method of voltage contrast with the scintillation SE detector. The method of voltage contrast is typical for detection of secondary electrons and proves detection possibility of the detector. Voltage contrast was observed on the emitter – base junction of a power transistor with a voltage in reversed direction of 10 V.

Results of the observation of the voltage contrast on the power transistor proved that the usage of the hole diameter of 0.8 mm at position of the aperture A1 of the detector is impossible because of an increased noise in the specimen image at pressures over 200 Pa in the specimen chamber.

	Pressure in the scintillator chamber [Pa] for different holes diameter in apertures A1, A2 [mm]				
Pressure in specimen chamber [Pa]	A1 = 0.6 mm A2 = 0.6 mm	A1 = 0.6 mm A2 = 0.9 mm	A1 = 0.6 mm A2 = 1.0 mm	A1 = 0.8 mm A2 = 0.6 mm	A1 = 0.8 mm A2 = 0.8 mm
50 Pa	0.9 Pa	0.7 Pa	0.8 Pa	0.8 Pa	1.1 Pa
100 Pa	0.9 Pa	0.9 Pa	1 Pa	0.9 Pa	1.5 Pa
200 Pa	1 Pa	1.3 Pa	1.4 Pa	1.1 Pa	2.2 Pa
300 Pa	1.2 Pa	1.6 Pa	1.8 Pa	1.4 Pa	3.1 Pa
400 Pa	1.5 Pa	2 Pa	2.3 Pa	1.8 Pa	4 Pa
500 Pa	1.7 Pa	2.3 Pa	2.7 Pa	2.1 Pa	5 Pa
600 Pa	2 Pa	2.6 Pa	3.1 Pa	2.6 Pa	6 Pa
700 Pa	2.3 Pa	3 Pa	3.6 Pa	3.2 Pa	
800 Pa	2.6 Pa	3.4 Pa	4 Pa	3.7 Pa	
900 Pa	2.9 Pa	3.8 Pa	4.5 Pa	4.3 Pa	
1000 Pa	3.3 Pa	4.4 Pa	5 Pa	4.9 Pa	

Table 2: Measured pressure in the scintillator chamber in dependence on pressure in specimen chamber for different diameters of holes in apertures A1 and A2.

	Pressure in scintillator chamber [Pa] for hexagonal mesh in position of aperture A2		
Pressure in specimen chamber [Pa]	A1 = 0,6 mm A2 = 300 holes	A1 = 0,6 mm A2 = 400holes	A1 = 0,6 mm A2 = 1000holes
50 Pa	1 Pa	1 Pa	0,9 Pa
100 Pa	1,4 Pa	1,4 Pa	1,4 Pa
200 Pa	2,1 Pa	1,9 Pa	1,5 Pa
300 Pa	2,8 Pa	2,5 Pa	1,8 Pa
400 Pa	3,4 Pa	3 Pa	2,2 Pa
500 Pa	4 Pa	3,5 Pa	2,6 Pa
600 Pa	4,7 Pa	4 Pa	2,9 Pa
700 Pa	5,3 Pa	4,5 Pa	3,3 Pa
800 Pa	6,1 Pa	5 Pa	3,7 Pa
900 Pa	7 Pa	5,7 Pa	4,1 Pa

Table 3: Measured pressure in the scintillator chamber in dependence on pressure in specimen chamber for hexagonal mesh with diameter of 3 mm with different number of openings in the position of the aperture A2.

Usage of the hexagonal mesh with 1000 openings at position of the aperture A2 brings good results up to pressure 500 Pa in the specimen chamber. Above this pressure the detector was unstable.

Best results were obtained with the hole diameter of the aperture A1 of 0.6 mm combined with the hole diameters of the aperture A2 of 0.6 mm, 0.8 mm, 0.9 mm and 1 mm.

Usage of the hole diameter of 0.6 mm at the position of the aperture A2 brings the possibility to observe quality voltage contrast up to the pressure of 400 Pa in the specimen chamber, increasing of the hole diameter to 1 mm allows to obtain a quality voltage contrast on the power transistor at a pressure over 600 Pa in the specimen chamber. The hole diameter of 1 mm at the position of the aperture A2 extends also the possibility of the observation of the voltage contrast at low pressures under 10 Pa.

The voltage contrast on the power transistor for the detector with the grid and with the hole diameters A1 = 0.6 mm, A2 = 1 mm at pressures of water vapors 20 Pa, 100 Pa and 500 Pa is seen on Fig 5.

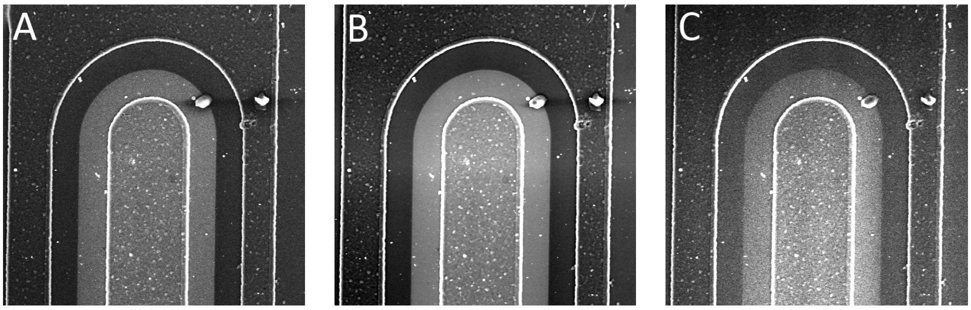

Figure 5: Voltage contrast on PN junction of power NPN transistor for pressure of water vapors: A - 20 Pa, B - 100 Pa, C - 500 Pa.

5. CONCLUSION

The article is oriented on optimization of the scintillation SE detector by usage of a grid on the entry of the detector and of different types of apertures A1 and A2. The voltage contrast method was used for verification of the possibility of the secondary electrons detection by the detector.

Next work will be oriented on improvement of the secondary electrons detection at pressures under 10 Pa in the specimen chamber and on usage of a new type of the scintillation material in the detector.

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