ANALYSIS AND OPTIMIZATION OF SILICON DETECTOR SUPPORTED BY ELECTRO-PHYSICAL MODELING AND SIMULATION

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1. Introduction

Silicon radiation detectors have been extensively used in a large variety of scientific, medical, and industrial applications for many years. [1, 2] A major breakthrough in silicon detector technology came in the early 1980s from Kemmer, who pioneered the use of the planar fabrication process, derived from microelectronics; [3], exploiting the passivation properties of silicon dioxide and keeping the thermal budget to a minimum, ion-implanted detectors, which allow for fine pitch segmentation of the electrodes and very low leakage currents, became available. Since that time, silicon detector technologies have been continuously advancing and more complex, and reliable detectors could be obtained, featuring outstanding performance in terms of energy, timing or position resolution, long-term stability, and radiation tolerance.

The concept of silicon detector with the trench is presented that potentially allows much thicker devices. The trenches direct the spread of electric field and of current. The study design and simulation results of the structure of the detector will be presented and discussed.

2. Problem description

Investigated Schottky barrier structures based on N-type Si with the donor concentration of $1x10^{13}cm^{-3}$. Circular contact with area A = 0.16 cm^2 was placed on the top of the structure. This contact is located on the surface of structure or etched into structure. Trench is located round the Schottky contact. Our investigation is focused on changing the structure dimensions, like depth of etched Schottky contact, depth of trench and gap between the contacts and trench. An ohmic contact is located on the full area at the bottom of structure (Fig. 1a). In Fig. 1b the simulated structure is shown. There are indicated dimensions of the Schottky contact and trench. Si_3N_4 was used for structure surface passivation. Numerical modeling and simulation were used for study of electro-physical properties of different layout contacts and trenches. Employing the electrical simulation we can determine the breakdown voltage and saturation current of simulated structures. The effects of the changes in the structure geometry can be shown on 2D distribution of electric field, current density and space charge. Electro-physical 2D/3D numerical modeling and simulation is an efficient tool for analysis and optimization of device structure design. Suitable electro-physical model of the device structure was prepared using Synopsys modeling tool Mesh and subsequent electro-physical simulations were performed by Dessis tool [4, 5].

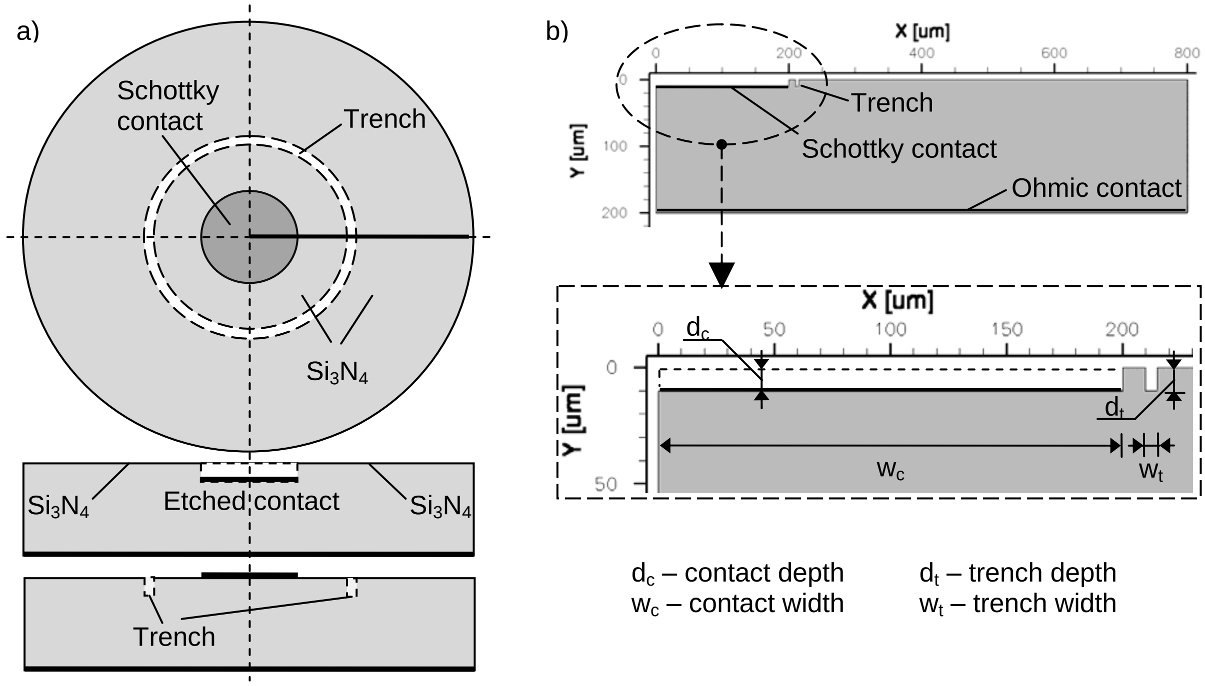

Fig. 1: *a) Structure layout, b) 2D simulation of structure with indication of the Schottky contact with trench or using deep etching.*

3. Experimental results

Analyzed region of investigated structure is indicated in Fig. 1a. Due to symmetry of the structure it is enough to perform the analysis for only a small part of the investigated device. Two-Dimensional (2D) simulation was used for the devices analysis. By default, DESSIS assumes a third-dimension (effective gate width along z-axis) of 1 µm. The area factor is a multiplier for the electrode currents and charges. In Fig. 1b we can see the dimensions of the etched contact and trench. The Schottky contact is etched into the depth of 5 µm, 10 µm and 20 µm, the width is 400 µm. In our simulations were used the trench depths of 5 µm, 10 µm and 20 µm and constant width 5 µm. The gap between the Schottky contact and the trench was 10 µm and 20 µm. In Fig. 2 I-V characteristics of structure with a trench are shown.

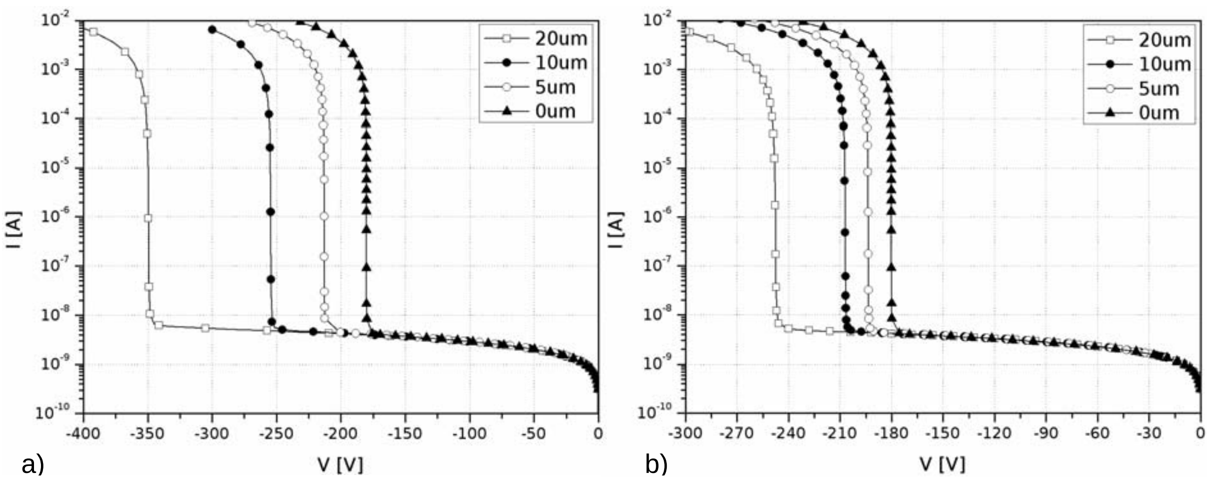

Fig. 2: *I-V characteristics of structures with trench depths of 0µm, 5 µm, 10 µm, 20 µm. Gap between the contact and trench a) 20 µm, b) 10 µm.*

For the structure without trench and etched contact (0 µm) the lowest breakdown voltage was obtained. From Fig. 2 one can clearly see that structure with deeper trench reaches higher breakdown voltage. If the trench is positioned away from the Schottky contact, structure can achieve lower breakdown voltage.

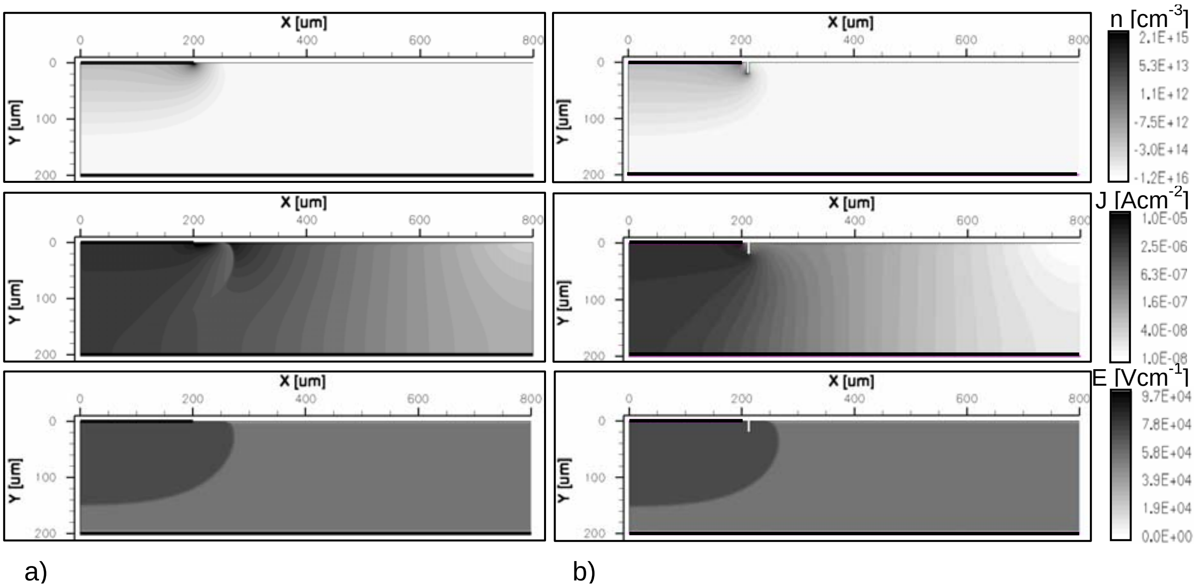

Fig. 3: *2D distribution of electric field, current density and space charge at bias of 180 V, a) structure without etched Schottky contact and trench, b) structure with trench, w_t = 20 µm.*

Fig. 3 shows the 2D simulation results at voltage of 180 V. In Fig.3 a) the original structure without etched contact and trench, in Fig. 3 b) the structure with trench depth of 20 µm is shown. In Fig. 3a is the high current density and intensity of electric field in the region of structure, where the breakdown and destruction is obtained. In Fig.4 2D simulation of structures with the etched Schottky contact at the voltage of 175 V is seen. As one can see, structure with contact etched only 5 µm has no point with high current density In the case of structure with contact etched 10 µm, a point, where the breakdown occurs exist. The etched Schottky contact allows high current density at the edge of the contact.

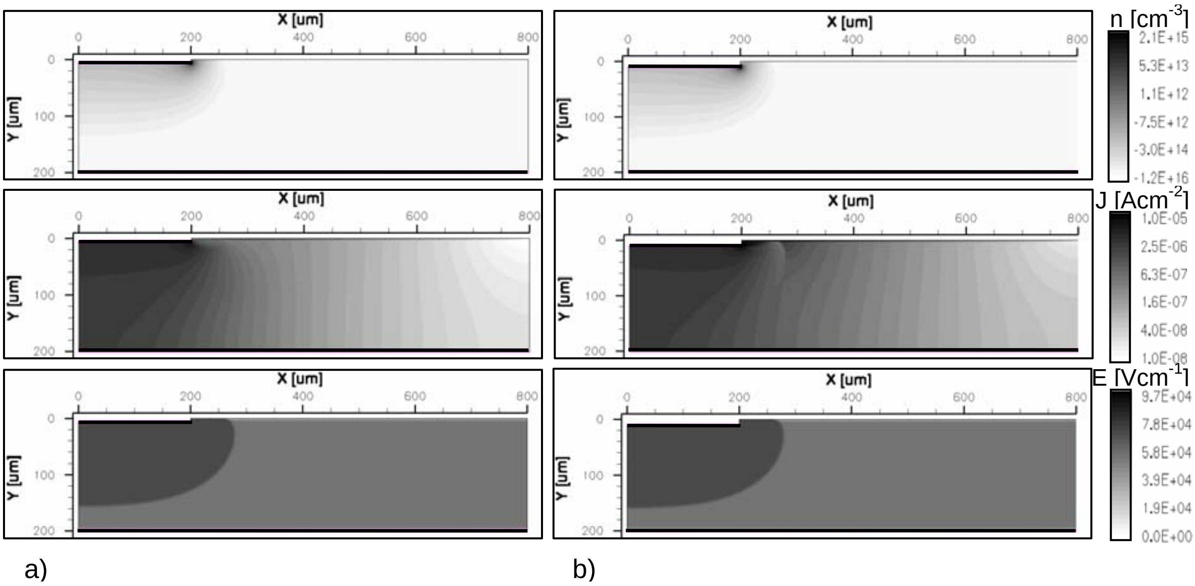

Fig. 4: *2D distribution of electric field, current density and space charge at 175 V, a) structure with the etched Schottky contact w_c = 5 µm, b) structure with etched Schottky contact w_c = 10 µm.*

I-V characteristics of the structure with the etched Schotky contact are shown in Fig. 5. The Schottky contact etching depth is 5 µm, 10 µm, and 20 µm. This figure clearly illustrates, that the depth of contact 5 µm increases the breakdown voltage. The dependence of breakdown voltage versus Schottky contact and trench etching depth is presented in Fig. 5b. It is seen that the trench in the structure improves electric performances.

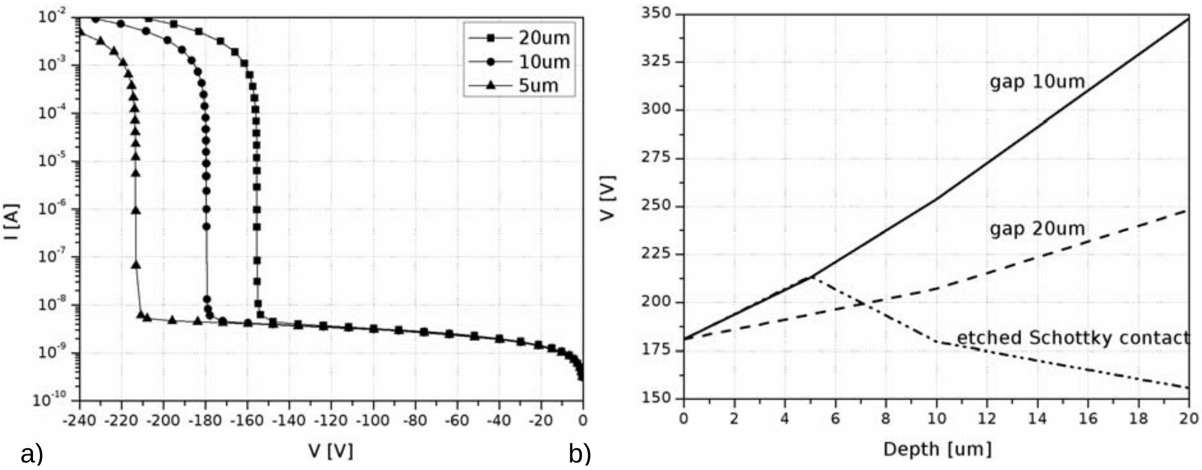

Fig. 5: *a) I-V characteristics of structures with the etched Schottky contact, b) dependence of breakdown voltage on etching depth of trench and the Schottky contact.*

Conclusions

2-D numerical device modeling and simulations were applied to the study of electro-physical behavior and reliability of analyzed radiation detector. The simulation of static breakdown voltage V_{BR} was used for analyzing the properties of structures. The results of analysis clearly show that the trench structure has better properties than original structure. The structure of silicon detector with the trench is presented that potentially allows much thicker devices. The trenches direct the spread of electric field and of current and prevent the creation of points of high electric field. The etched Schottky contact will increase breakdown voltage, but only to a limited value depending on particular topology and geometry used.

Acknowledgement

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References:

[1] G. F. Knoll, Radiation Detection and Measurement, 3rd ed., Wiley, New York, 2000.

[2] G. Lutz, Semiconductor Radiation Detectors-Device Physics, Springer-Verlag, Berlin, 2007.

[3] J. Kemmer, Fabrication of low noise silicon radiation detectors by the planar process, *Nucl. Instrum. Methods*, **169**, 499-502, 1980.

[4] ISE Dessis, Synopsys, user manual, ver. A-2009.06, Synopsys, 2009.

[5] W. Kai, K. Karim, Silicon X-Ray Detector With Integrated Thin-Film Transistor for Biomedical Applications, *IEEE Journals & Magazines*, **147 – 149**, 2010