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Design, electrical properties and fabrication method study of a novel 3D-Compound-Shell-Electrode silicon detector

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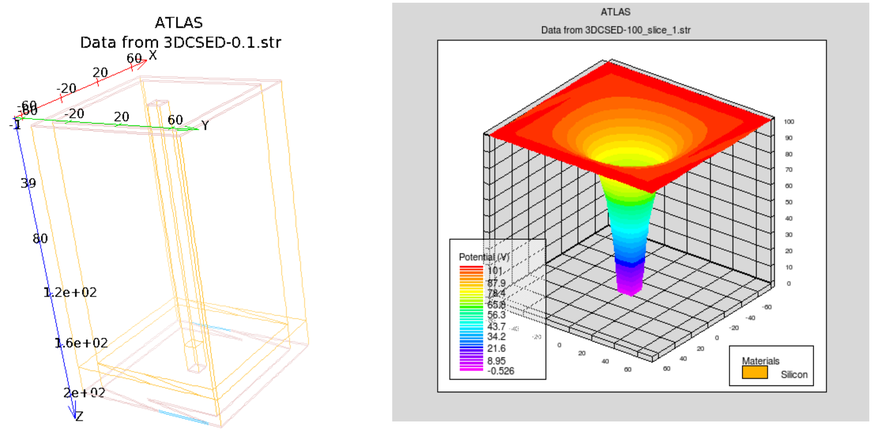
1 Introduction

Recent years, some novel structures have been proposed for the purpose of improving Charge Collection Efficiency (CCE), namely, removing or reducing the proportion of low electric field area. For example, the 3D-open-shell-electrode detector (3DOSED) and the new closed shell-electrode detector。

Based on that, a novel three-dimensional (3D) structure of silicon detector: 3D-Compound-Shell-Electrode detector (3DCSED) is proposed in this work emilating the "dead" area (low electric field area).

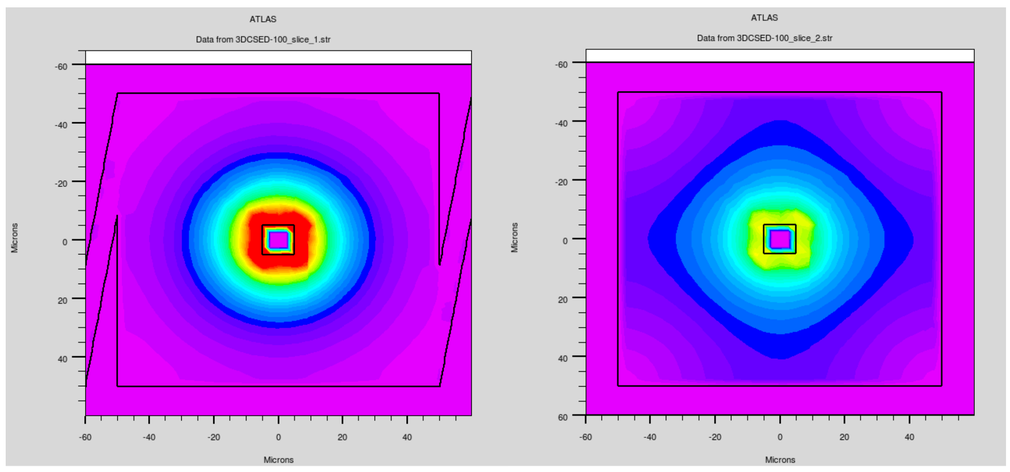
2 Modeling and simulation

The 3D-Compound-Shell-Electrode detector (3DCSED) has been modeled and simulated with the Silvaco TCAD tools.



(a) (b)

Fig.1 (a) Simulated schematic of a 3D-Compound-Shell-Electrode detector (3DCSED) unit cell; (b) Simulated 3D potential distribution

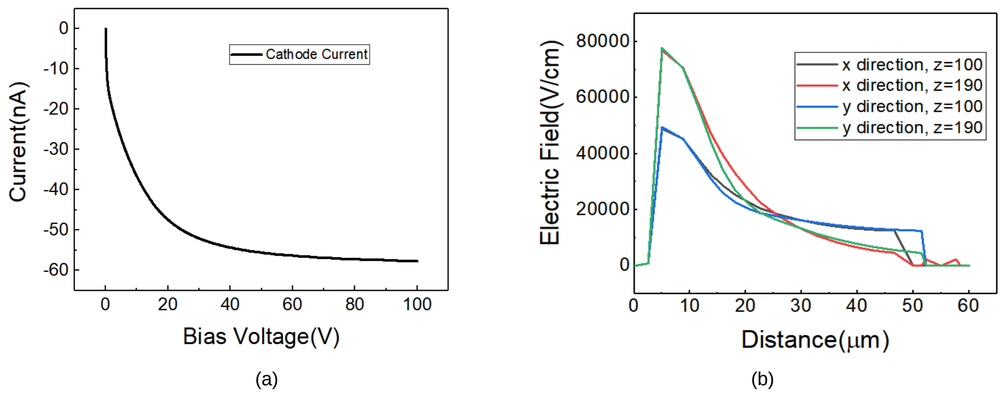


(a) (b)

Fig.2 Electric field distribution, and the largest value is 7×10^4 V/cm; (a) z = 190 μm; (b) z = 100 μm

The electric potential and electric field distributions are uniform, and in effective area electric field distribution with closed trench electrode is more uniform and has better symmetric performance than that with the open trench electrode.

The leakage current is below 60 nA. Under bias voltage of 100 V, the electric field value is below 3×10^5 V/cm, which means the detector does not reach breakdown.



(a) (b)

Fig.3 (a) I-V characteristic; (b) Electric field distribution

References

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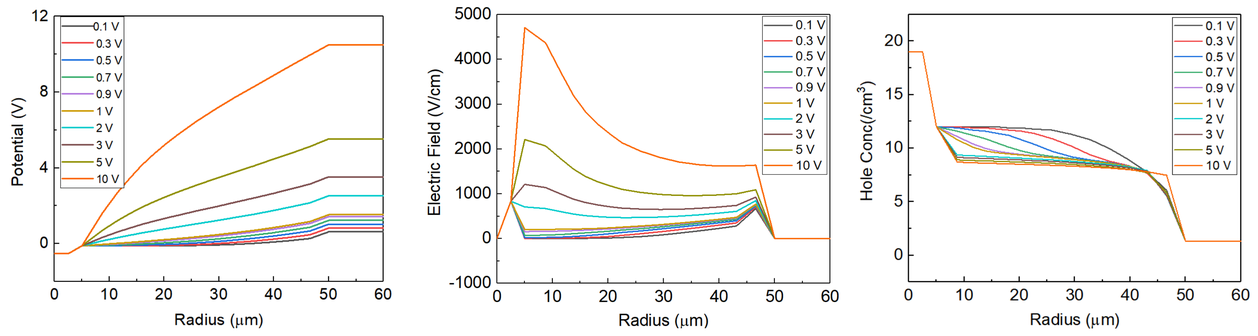
[2] Manwen Liu et al., "Electrical properties study under radiation of the 3D-open-shell-electrode detector", AIP Advances 8, 055211 (2018).
[3] Chen, J. et al, "3D simulations of device performance for 3D-Trench electrode detector", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 796, 34–37, 2015.



(a) (b) (c)

Fig.4 (a) The electric potential distributions with radius; (b) The electric field distributions with radius; (c) The hole concentration distributions with radius

The full depletion voltage is about 1 V without radiation. Usually, the full depletion voltage is proportional to the radiation level. When the radiation fluence is 1×10^{16} n_{eq}/cm^2, the full depletion voltage is about 100 V.

3 Possible fabrication method study

In a 3DCSED, an open trench electrode will be etched about 10% of the detector thickness from the bottom side of the detector to meet the close trench electrode etched about 90% of the detector thickness from the top side.

This ensures not only the unit structure be stable in the fabrication process, but also the detection efficiency can be guaranteed through the optimization of the electrode structure comparing to conventional 3D-Trench-Electrode detector.

In this method, the deep etching is processed by Deep Reacting Ion Etching (DRIE) or laser with respective processing procedures.

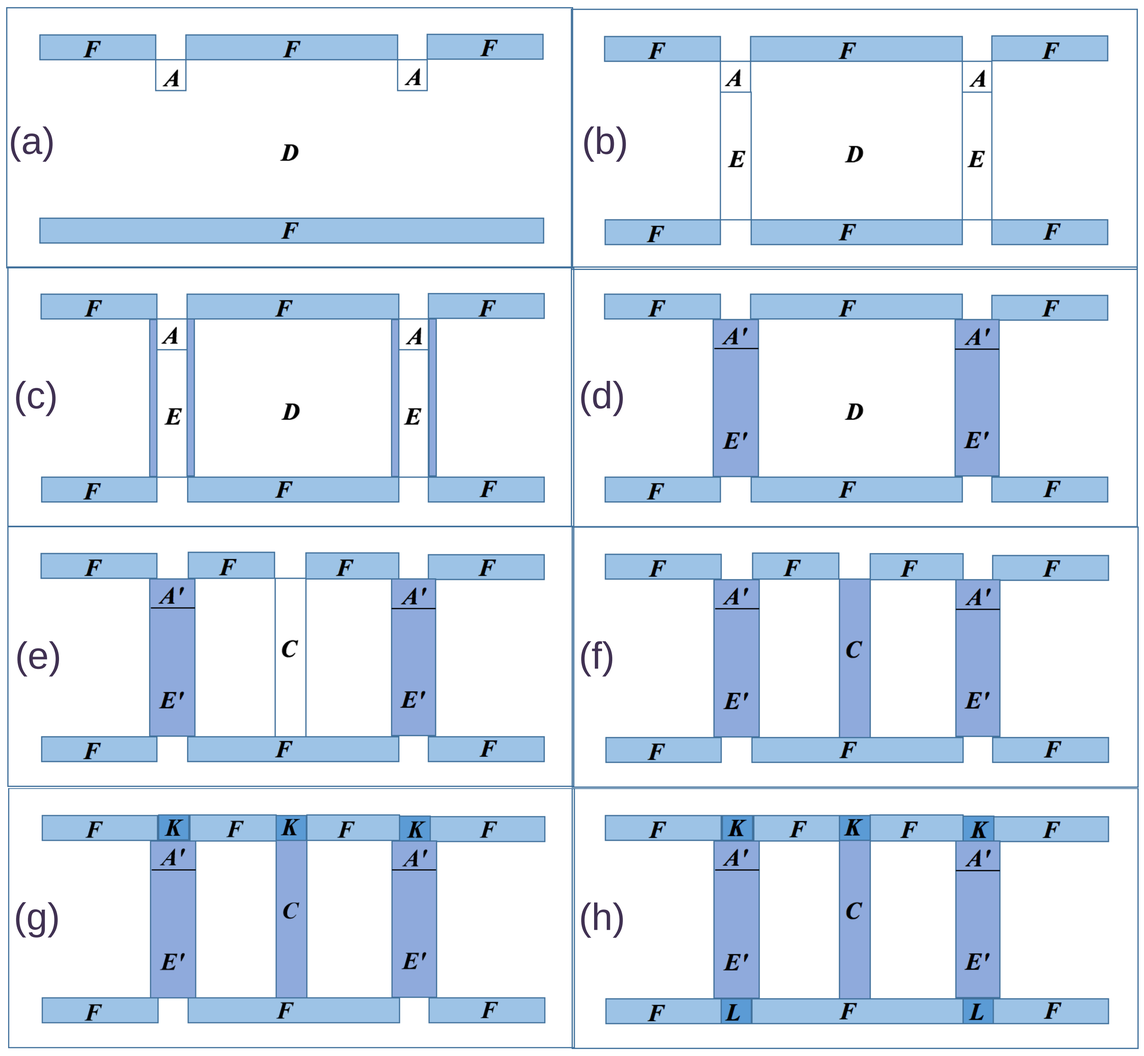


Fig.5 The possible processing of 3DCSED fabrication

4 Conclusion

The potential and electric field distributions are uniform and with no saddle point.

The electric field value when z = 190 μm is larger than that when z = 100 μm in z direction.

The leakage current is 60 nA. The full depletion voltage is about 1 V.

We propose a method to fabricate the 3DCSED. In this method, the deep etching is processed by Deep Reacting Ion Etching (DRIE) or laser with respective processing procedures.