Frontier Detectors for Frontier Physics

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3D simulation and experimental exploration of implementing double-sided 3D trench electrode detector with 8-inch CMOS Process

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1 Introduction

A double-sided 3D trench electrode detector (DS-3DTED) structure is proposed in this work to investigate manufacturing process implementation of 3D detectors for high energy physics, X-ray spectroscopy and X-ray cosmology applications.

The device electrical characteristics are carried out with TCAD tool, including electric potential and electric field distribution, I-V, C-V, full depletion voltage and transient current with X-ray incidence.

In addition, a manufacture method to realize the DS-3DTED device is presented. Furthermore, a 311 μm deep and 10 μm wide trench has been achieved through Bosch process on the IMECAS 8-inch CMOS platform to verify the feasibility of the device structure. The maximum depth to width ratio is close to 105:1 when the trench width is 2 μm, which is a excellent foundation for the future 3D detectors manufacture with large fill factor and small dead zone.

2 Modeling and simulation

The DS-3DTED has been modeled and simulated with the TCAD softwares.

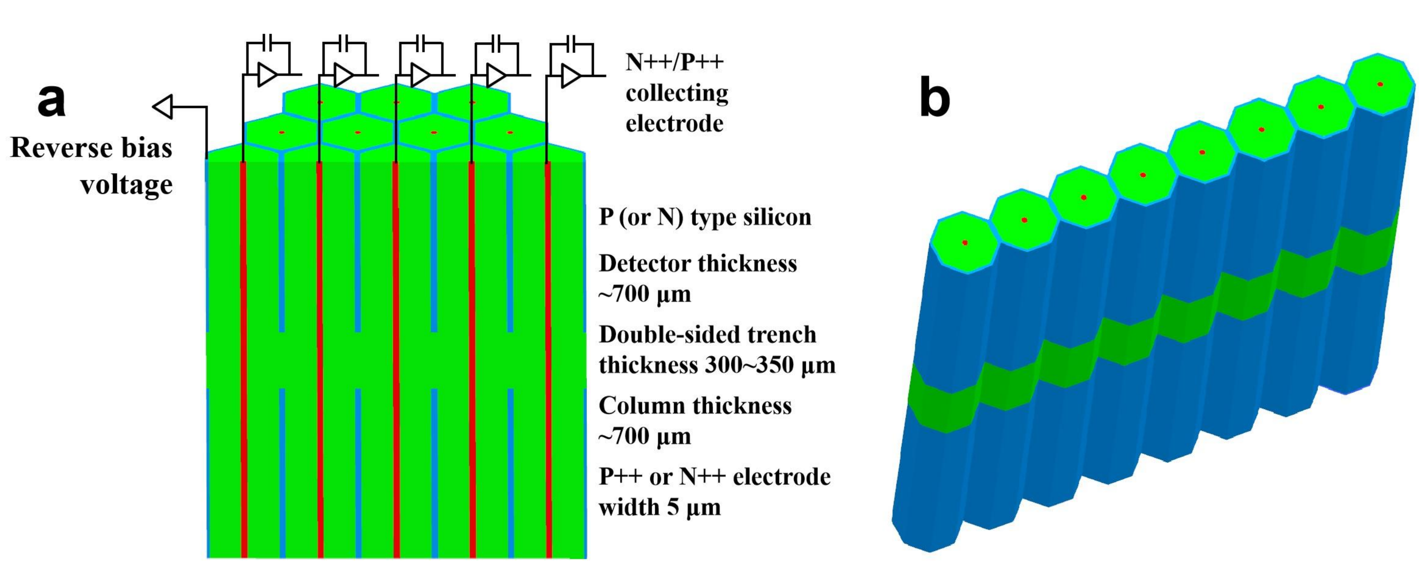

Fig.1 (a) An array of DS-3DTED (hexagonal type); (b) 1D array of DS-3DTED (octagon type).

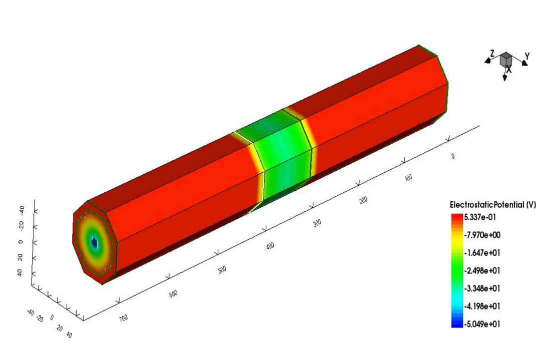

Fig.2 3D electric potential distribution.

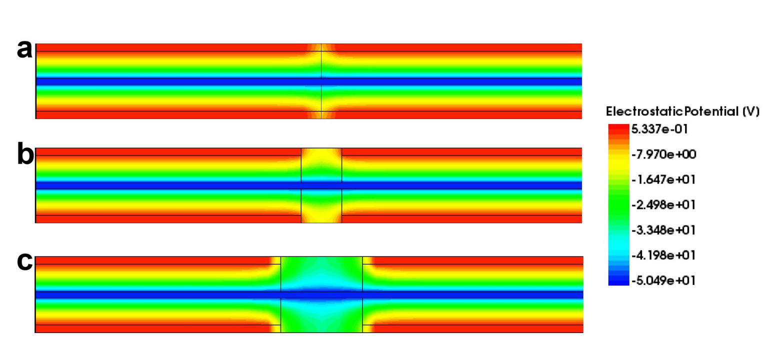

Fig.3 2D electric potential profiles of DS-3DTED.

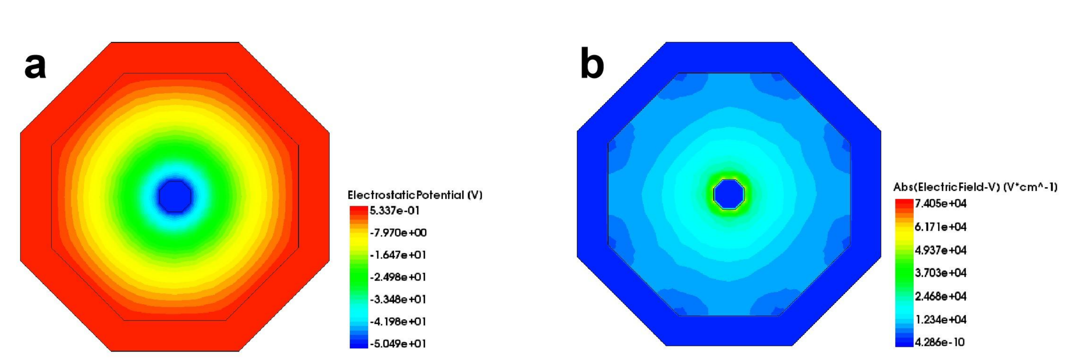

Fig.4 (a) 2D electric potential and (b) electric field profiles of DS-3DTED.

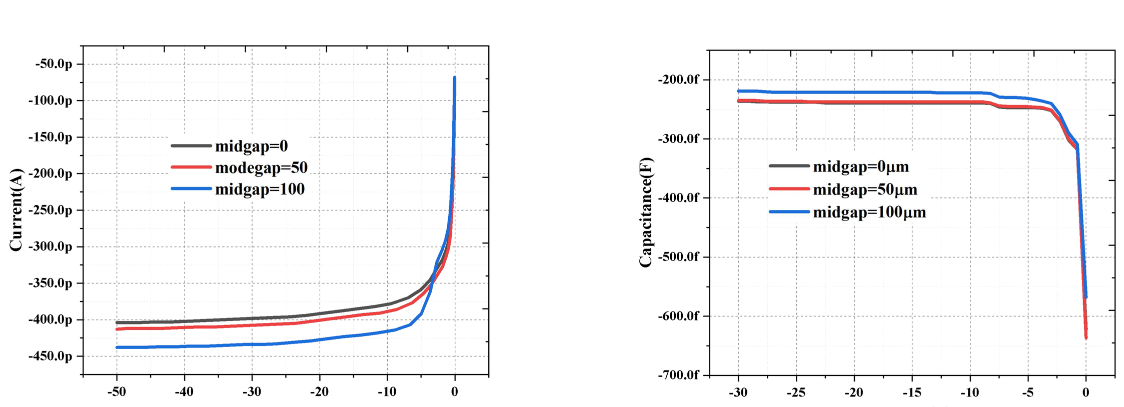

Fig.5 (a) I-V and (b) C-V curves of DS-3DTED.

Fig.2 to Fig.4 show the 3D and 2D electric potential and electric field distribution of DS-3DTED. The bias voltage is applied to the central column electrode, and it is -50 V to make sure the device is fully depleted.

The leakage current is 4×10-10 A, 4×10-10 A and 4.5×10-10 A when the trench thickness is 349.75 μm, 325 μm and 300 μm, respectively. And the capacitance is less than 250 fF.

References

[1]Jackson J N .The ATLAS semiconductor tracker (SCT) [J].Nuclear Instruments & Methods in Physics Research. Section A, Accelerators, Spectrometers, Detectors and Associated Equipment, 2005.

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[4] Johnson I, Bergamaschi A, Billich H,et al. Eiger: a single-photon counting x-ray detector[J]. Journal of Instrumentation, 2014, 9 (05): C05032.

3 Transient current and CCE for X-ray incidence

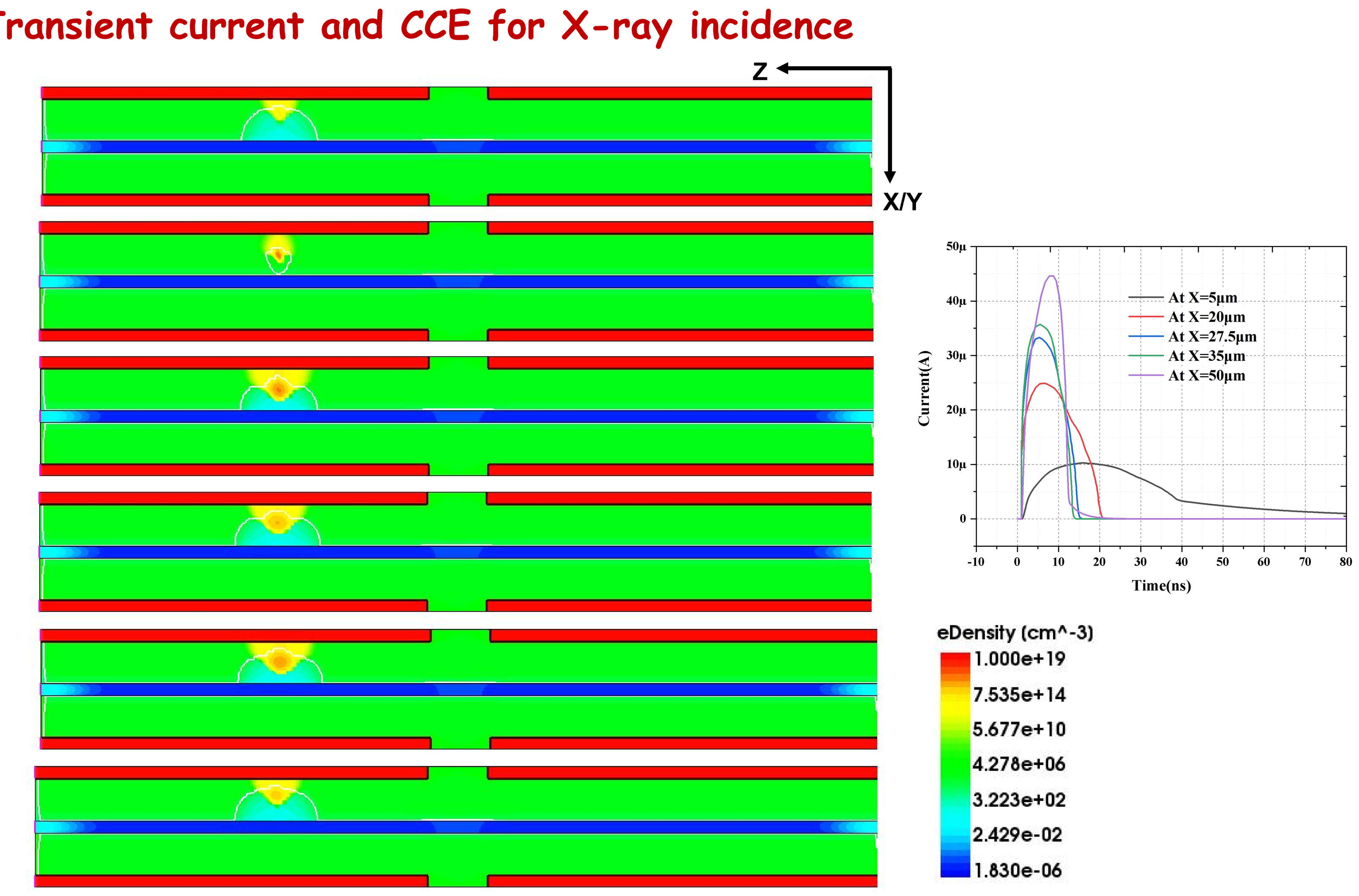

Fig.6 Charge collection process of X-ray incidence and I-t curves of DS-3DTED.

When X-rays are incident, electron-hole pairs are generated, where the holes are collected by the column electrode to form signals, and the electrons are collected by the trench electrode. Consequently, the response speed will be faster when the incident position is close to the column electrode. However, regardless of where the incident position is, the response time is less than 40 ns.

4 CMOS compatible fabrication method and key process development of 3D trench electrode

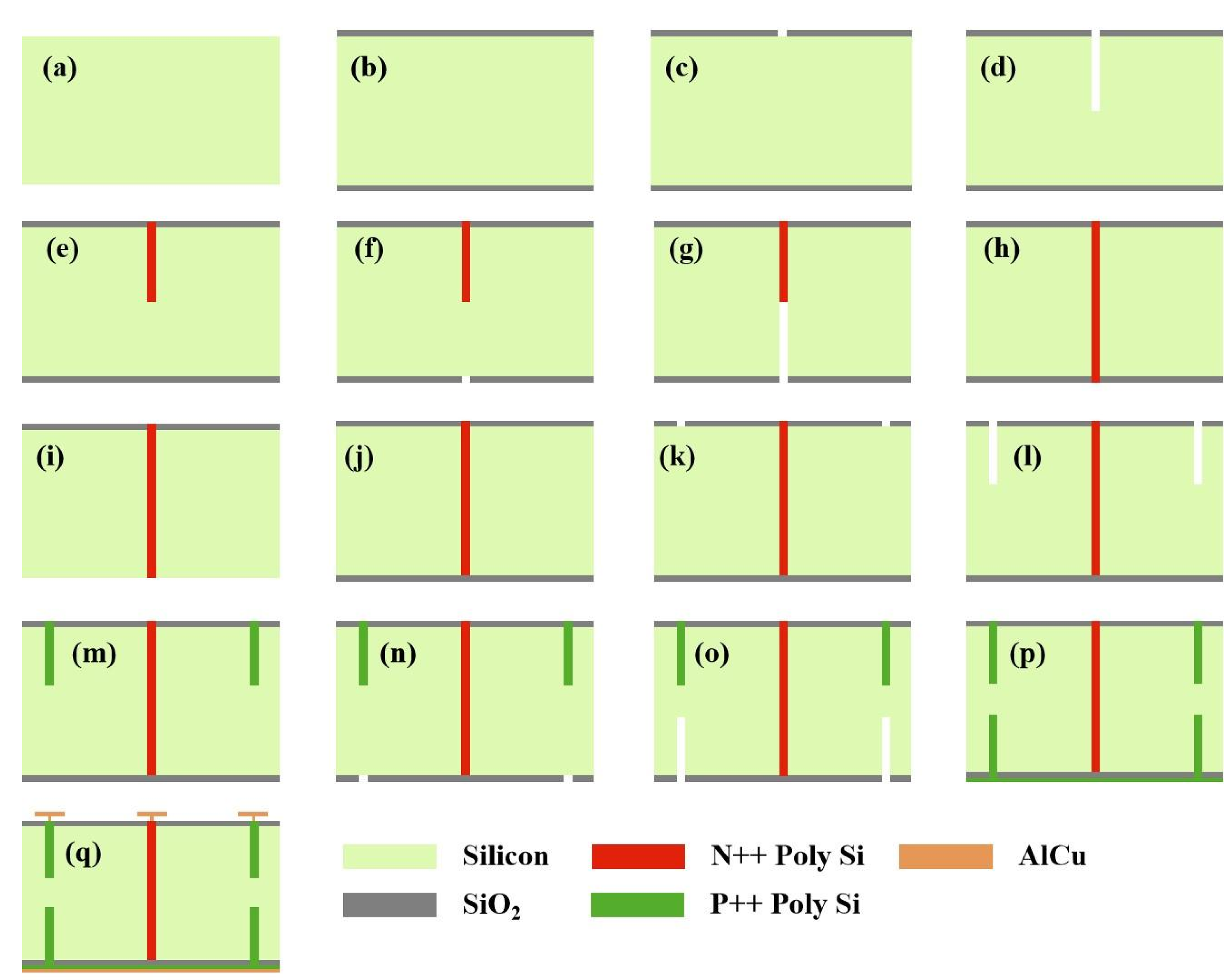

Fig.8 The possible processing of DS-3DTED.

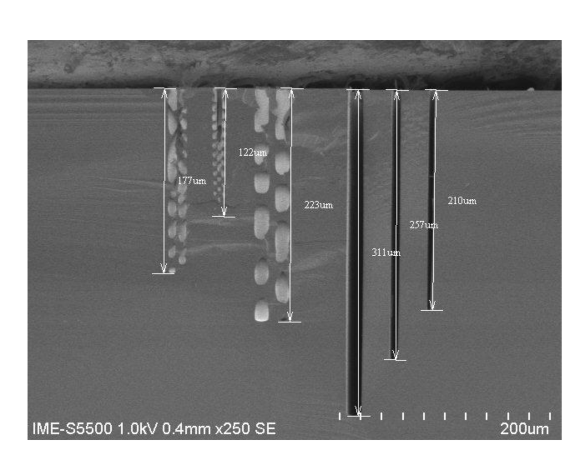

Fig.9 SEM of Bosch process.

The DS-3DTED fabrication process is relatively complicated and presented in Fig.8.

The etching of the 3D trench and column electrodes has been performed using Bosch technology.

5 Conclusion

A double-sided 3D trench electrode detector (DS-3DTED) structure is proposed and simulated. The electric field distribution in the effective region is very symmetrical, and the proportion of the dead region of the device is small.

Dark current on the order of 10^{-10} A, capacitance is less than 250 fF.

The response time is less than 40 ns.

Utlizing Bosch technology, the thickness of the 3D trench electrode can reach 311 microns, and the depth-to-width ratio can reach 105:1.