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# Strengthened electric field technique implemented on CZT detectors

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ABSTRACT

This paper presents the development of a simple electrode structure which only requires a simple readout and is suitable for a large cube CZT crystal, such as a $10 \times 10 \times 10\ mm^3$ crystal. A technique named the strengthened electric field (SEF) is investigated in detail and implemented to improve the performance of the detector. Signal processing was also studied to demonstrate its feasibility to further improve the detector's performance. A SEF line anode (SEFLA) prototype and an SEF point anode (SEFPA) prototype were designed, fabricated and tested. Experimental results demonstrated the effectiveness of the SEF technique. The SEFLA detector achieved an energy resolution of 1.6% (FWHM)@662 keV with 4.0 keV noise (FWHM) and SEFPA 1.8% with 5.0 keV noise. Cathode signal is used to do both the rejection and the correction in the SEFLA prototype. At the cost of detection efficiency, the low energy tail is reduced, while the energy resolution and the *P*/*C* ratio are further improved. Possible improvements of the detectors are discussed.



## 1. Introduction

CZT is a very attractive material for radiation detectors due to its high atomic number, high density, high energy resolution and room temperature operation. However, the holes mobility-lifetime product is very low in CZT crystals, making the CZT detectors very different from HPGe detectors in terms of spectroscopic performance.

In recent years, a single polarity charge sensing (SPCS) technique implemented on CZT detectors has been shown to develop at a rapid pace [1]. Many structures based on SPCS technique have been proposed to overcome severe hole trapping, such as the virtual Frisch Grid [2], Drift Strip [3], CAPture™ Plus [4], Pixel Array [5], and Coplanar [6]. However, the Frisch Grid and Drift Strip are best suited for bar crystals, while CAPture™ Plus works well for hemi-cube crystals. Pixel Array needs complicated readout and the structure of Coplanar is a little complicated. Our goal was to develop a structure which is suitable for a large cube crystal with a simple readout.

In this paper, the details of the SEF technique are reported. A SEFLA (SEF line anode) detector [7] and a SEFPA (SEF point anode) detector were designed, fabricated and tested. By taking advantage of the SPCS and SEF techniques, the performance of the detectors improved. Cathode signal processing was investigated theoretically in the SEFLA/SEFPA detector and proved effective in further performance improvement by measurements using the SEFLA prototype.

## 2. SEF technique

Inspired by the coaxial HPGe detector, the line anode structure shown in Fig. 1 (left) was studied by Zhang et al. [8]. Although the SPCS technique was implemented, the performance of the line anode detector was still poor. The photo peak of the gamma ray had both low and high energy tails. The cause of the low energy tail can be attributed to a very weak electric field near the bottom cathode. The electrons are very slow when drifting toward the anode and can be severely trapped. Therefore, the charge collection efficiency in this region is very poor. On the opposite, the electric field near the top of the side cathode results very strong, and the electrons are not affected by trapping. The events from this region contribute to the high energy tail (details are shown in Fig. 5).

In order to make the electric field more uniform in the detector, the side cathodes are segmented into several strips with applied increasing biases. The line anode is biased at 0, while the opposite cathode is at $V_{bias}$ (negative) and $V_{strip}$ of side strips is increasing (details are shown in Table 1). This method is named strengthened electric field (SEF) technique because that the electric field in most

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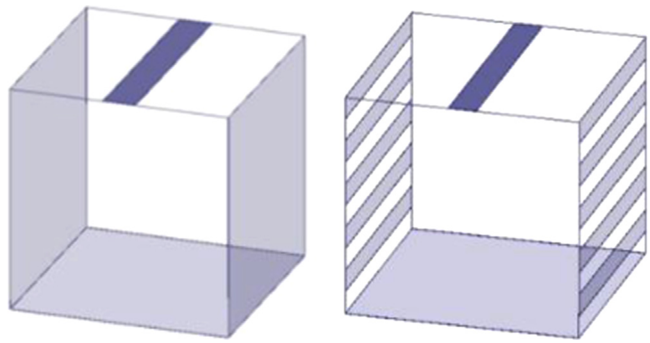

**Fig. 1.** The structure of detectors: line anode (left), SEFLA (right). *Notes*: For the simulation and prototype in this paper, the crystals are $10 \times 10 \times 10\ \text{mm}^3$ and the width of the line anodes are both 1 mm. The width and the gap of side strips are both 1 mm.

**Table 1**
Applied voltages. The unit is the volt.

| Case | Cathode | Strip 1 | Strip 2 | Strip 3 | Strip 4 | Strip 5 | Anode |
|---|---|---|---|---|---|---|---|
| SEFLA | −1400 | −1300 | −1130 | −980 | −830 | −730 | 0 |
| Line anode | −1000 | −1000 | −1000 | −1000 | −1000 | −1000 | 0 |
| SEFPA | −1400 | −1200 | −1000 | −850 | −600 | −500 | 0 |
| Point anode | −1000 | −1000 | −1000 | −1000 | −1000 | −1000 | 0 |

*Note*: In the SEF case, higher bias between anode and cathode is applied due to the reduced leakage current as discussed in Section 3.1.

volume is strengthened. The improved structures of the SEFLA and SEFPA are shown in Figs. 1 and 2 (right), respectively.

The potential distribution of the original structure without side strip shown in Fig. 3 (right) is given by Ansoft Maxwell [9] under a certain bias $V_{\text{bias}}$ (negative). When the SEFLA structure (Fig. 3 (left)) is under the same bias $V_{\text{bias}}$, the bias $V_{\text{strip}}$ of any specific side strip in the SEFLA structure should not be higher than the potential at the corresponding position of the strip center in original structure. Otherwise, it will cause severe charge sharing and will produce a large insensitive region near the side strips. Bias on each strip can be fine adjusted to optimize the electric field distribution and make sure that the detector has the best response.

## 3. Simulation

A simulation model of the charge collection processes in CZT detectors is built. Fig. 4 shows the simulation tools and process. The weighting potential and the electric field are calculated by Ansoft Maxwell [9]. Geant4 [10] is used to simulate the initial energy deposition information. Induced Current Calculator (ICC), which is a self-developed C++ package, is used to calculate the output signal of the detector. The details of this simulation can be accessed at [7].

### 3.1. Spectrum improvement

Simulation is done to compare the line anode detector (Fig. 1 (left)) and the SEFLA detector (Fig. 1 (right)) under the same bias of 1000 V. The results of the simulations for planes perpendicular to the line anode direction are shown in Fig. 5.

By the SEF technique, due to the strengthened electric field near the bottom side, the electrons generated here take a shorter time to drift to the anode and have less trapping, which leads to the increase of charge collection efficiency. For the region near the top side, the weakened electric field causes electrons to take a longer time to drift and to be trapped more, and the charge collection efficiency decreases. Therefore, the whole detector has a more uniform response.

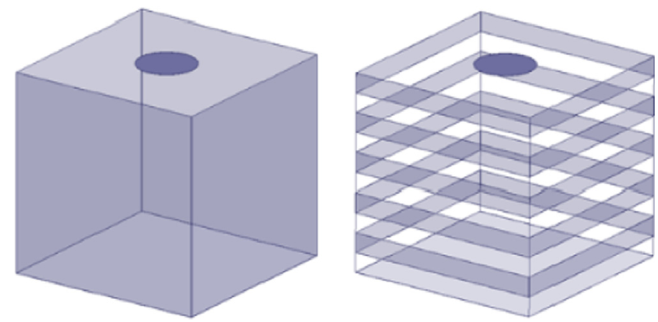

**Fig. 2.** The structure of detectors: point anode (left), SEFPA (right). *Notes*: For point anode detector, the upper surface was manufactured as a point anode and the other five surfaces were manufactured as a cathode. For the simulation and prototype in this paper, the crystals are $10 \times 10 \times 10\ \text{mm}^3$ and the diameters of the point anodes are both 3 mm. The width and the gap of side strips are both 1 mm.

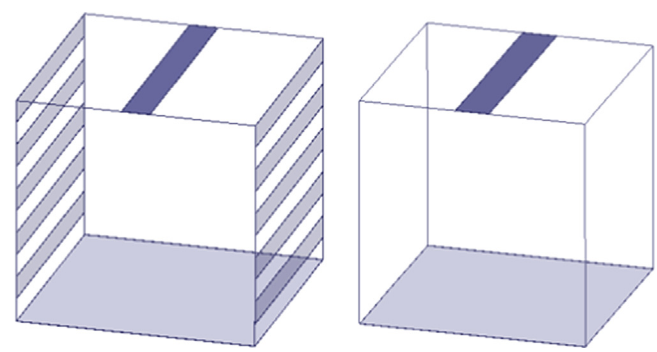

**Fig. 3.** The structure of each detectors: original SEFLA structure (left) and original structure without side strips (right). *Note*: The widths of line anodes are the same as Fig. 1.

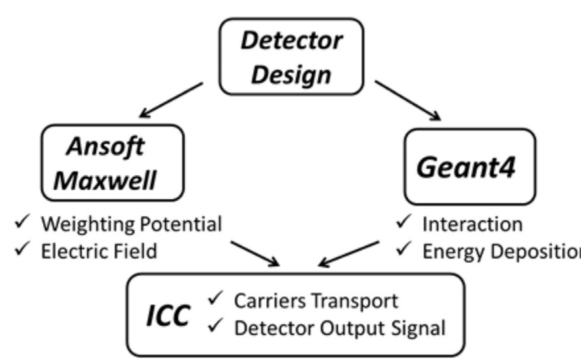


**Fig. 4.** Simulation tools and process.

Meanwhile, the leakage current is reduced due to a weakened electric field near the anode. This means that, at the same electronic noise level of the line anode detector, the SEFLA detector can be operated with a higher bias to further strengthen the electric field, providing a further improvement of the detector response.

Comparison of simulated spectra of the line anode detector and the SEFLA detector are plotted in Fig. 6. One can see that the SEFLA detector has a higher energy resolution, a better photo to Compton ratio, and the high energy tail is removed [7,8].

However, the SEF technique will induce some disadvantages. There are charge sharing and insensitive regions near the side strips, which will reduce the detection efficiency and the photo peak efficiency slightly. Compared with the line anode detector, this specific SEFLA detector as described above lost about 2% total detection efficiency.