A highly pixelated CdZnTe detector based on Topmetal-II$^-$ sensor *

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Abstract: Topmetal-II$^-$ is a low noise CMOS pixel direct charge sensor with a pitch of 83 μm. CdZnTe is an excellent semiconductor material for radiation detection. The combination of CdZnTe and the sensor makes it possible to build a detector with high spatial resolution. In our experiments, an epoxy adhesive is used as the conductive medium to connect the sensor and cadmium zinc telluride (CdZnTe). The diffusion coefficient and charge efficiency of electrons are measured at a low bias voltage of –2 V, and the image of a single alpha particle is clear with a reasonable spatial resolution. A detector with such a structure has the potential to be applied in X-ray imaging systems with further improvements of the sensor.

Keywords: Topmetal, pixel, CdZnTe

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1 Introduction

CdZnTe is an excellent semiconductor material for radiation detection, with high resistivity, large atomic number and high band gap. CdZnTe detectors have been developed for the last twenty years. With their high spatial resolution, they have great potential to be applied in applications such as Compton cameras [1], medical imaging systems and neutrinoless double beta decay experiments [2].

The CdZnTe and the readout module are commonly connected by metal electrodes. In general, they can achieve high energy resolution [3, 4]. CdZnTe detectors with different structures of single crystal were developed to improve spatial resolution [5, 6] for applications. Pixelated CdZnTe detectors have also been developed to improve the spatial resolution. A spatial resolution of hundreds of μm has been achieved to detect X-rays [7–9]. For small CdZnTe pixel detectors, the signal induced by a single particle will be shared by multiple pixels, and the charge sharing effect has been studied in detail [10, 11]. Therefore, in this paper, we will not consider those effects.

Topmetal-II$^-$ is a highly pixelated direct charge sensor with a rather low noise and high spatial resolution. It can be applied into a Time Projection Chamber (TPC) as a charge collector to measure single electrons generated by alpha particles [12] at room temperature without any charge multiplier being necessary. This result prompted us to test whether Topmetal-II$^-$ can be coupled with CdZnTe to measure signals radiated by alpha particles at room temperature.

2 Experiment setup

Topmetal-II$^-$ is a low noise CMOS pixel direct charge sensor that contains a 72×72 pixel array of 83 μm pitch size with a sensitive area of about 6 mm×6 mm. The size of CdZnTe is about 5.8 mm×5.8 mm×2 mm, which is slightly smaller than the sensitive area of Topmetal-II$^-$ sensor to protect the bonding wires. When the sensor and the CdZnTe are combined together, the pixel size of the detector is determined by the pixel size of the sensor.

Only one side of the CdZnTe crystal is plated with a metal electrode (gold) fixed on a Printed Circuit Board (PCB) with a conductive adhesive (3M Scotch-Weld™ Epoxy Potting Compound DP270 Clear, 3M Company, USA), shown in Fig. 1. The inner open square is deliberately naked, without an electrode for signal injection. The other side, without no metal electrode at all, is used to connect with Topmetal-II$^-$ using an epoxy adhesive. The CdZnTe-Topmetal-II$^-$ structure is based on a PCB board as shown in the bottom of Fig. 2(a), which is fixed on a mechanical plane that can be moved up and down

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or left and right.

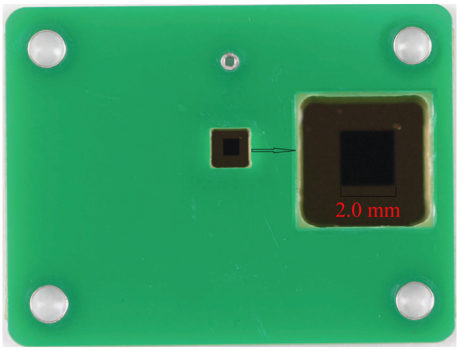

Fig. 1. (color online) The side of a CdZnTe crystal plated with an electrode and coupled to a PCB board. The size of CdZnTe is 5.8 mm×5.8 mm×2 mm. The little square region (black) in the center of the crystal, which is deliberately naked without an electrode, is about 2 mm×2 mm.

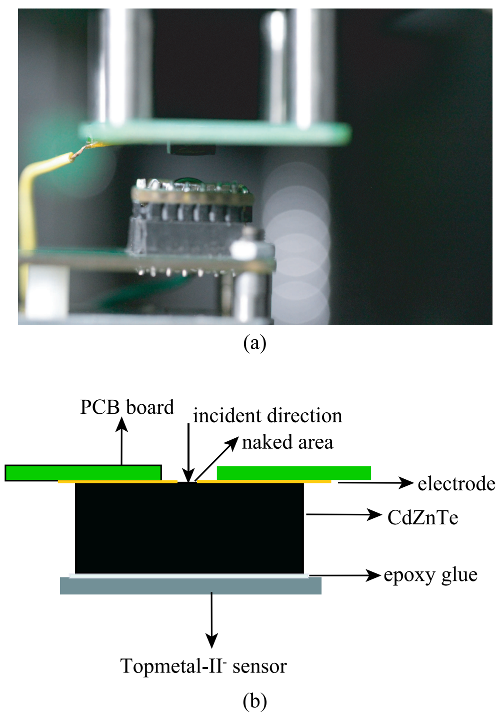

Fig. 2. (color online) Only one side of the crystal is plated with a metal electrode. The other side, which is connected to Topmetal-II$^-$, does not have a metal electrode, so the connection between the crystal and the sensor is certainly not ohmic contact. (a) Photograph of experiment setup. It consists of a Topmetal-II$^-$ sensor, a CdZnTe crystal and a readout system (not shown). (b) Schematic diagram of experiment setup. CdZnTe crystal is coupled to the Topmetal-II$^-$ sensor by an epoxy adhesive.

First, the epoxy adhesive is dropped onto the Topmetal-II$^-$ sensor manually using a syringe, then the sensor is inserted into the slot on the PCB board that is fixed on the mechanical plane. As shown in Fig. 2(a), we can move the crystal slowly down to the sensor, and keep the sensor parallel to the crystal appropriately. Figure 2(b) shows the basic principle structure of the CdZnTe detector. Using an epoxy adhesive as the medium to connect the Topmetal-II$^-$ sensor and CdZnTe crystal is much simpler and more convenient than bump bonding.

3 Results

We mainly test the noise, diffusion, and efficiency of the detector system.

3.1 Noise test

The equivalent noise charge (ENC) of Topmetal-II$^-$ is about 13 e$^-$[13] with no CdZnTe connected, under the condition of $V_{\rm reset}$=800 mV and $V_{\rm ref}$=618 mV[12, 13]. When CdZnTe is connected to Topmetal-II$^-$ via the epoxy adhesive, the electronic noise of the baseline of the same pixels increases about 3 times (from 2.2 mV to 8.3 mV) with a bias voltage -2 V on the CdZnTe, which is a significant increase.

3.2 Diffusion

There is a 2 mm×2 mm area without a plated electrode on the surface of CdZnTe crystal, through which a 650 nm laser signal can be injected. The bias voltage supplied to the CdZnTe is about −2 V. Because the gain of the pre-amplifier of Topmetal-II$^-$ is high, the back bias voltage of the crystal should be low to avoid analog

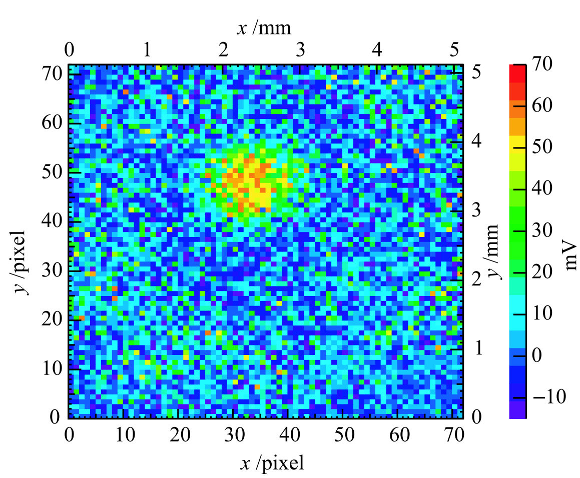

Fig. 3. (color online) A 650 nm laser image by CdZnTe and Topmetal-II$^-$ sensor. The expanded diameter of the induced charge cloud by a 650 nm laser is about 420 μm at a bias of –2 V.

output saturation. We have observed that the expanded diameter of the induced charge cloud by a 650 nm laser is about 420 μm (about 5 pixels) at a bias of −2 V, as shown in Fig. 3. In theory, the electron cloud expands to 318 μm after drifting through the entire thickness of the crystal [11]. The expanded diameter we observed is larger than the theoretical calculation, taking no account of charge diffusion through the epoxy adhesive. The medium of the epoxy adhesive is an important reason for this result.

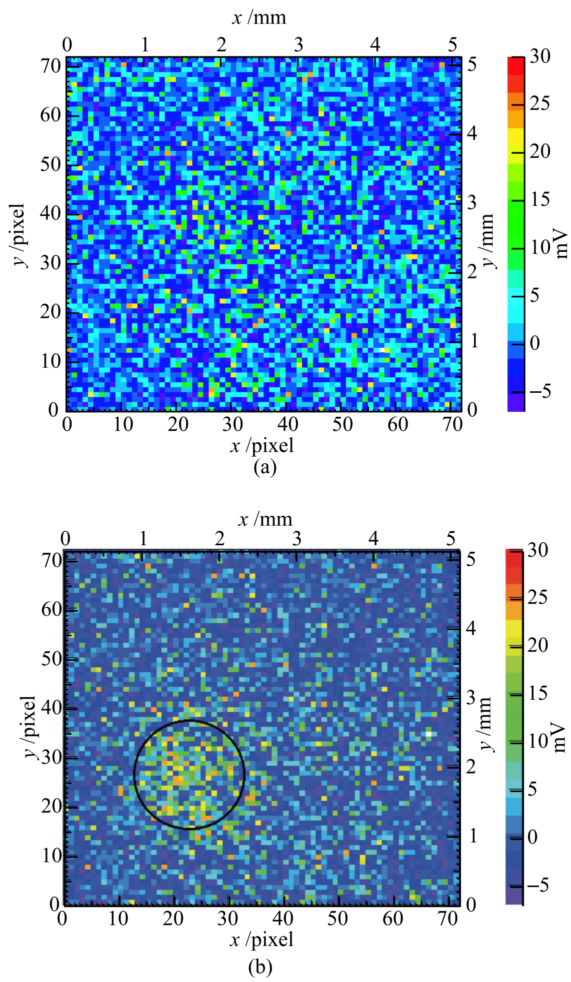

Fig. 4. (color online) (a) Two dimensional image of Topmetal-II$^-$ without particles injected into CdZnTe. (b) Alpha image by CdZnTe and Topmetal-II$^-$ sensor. The alpha source is placed on the top of the CdZnTe crystal. Alpha particles can pass through the air between the CdZnTe and the plane of alpha source and inject into the CdZnTe. The charge cloud generated by the alphas will be collected by the Topmetal-II$^-$ sensor to form a two dimensional image. The expanded diameter of the induced charge cloud from one alpha particle is about 500 μm (about 6 pixels) at a bias of −2 V.

3.3 Efficiency

To calculate the efficiency of the detector, we use a collimated alpha source to inject a signal into the CdZnTe crystal. The number of particles detected by a Geiger counter is about 300 per minute. For comparison, we put an image of the sensor without any signal injected in Fig. 4(a).

The collimated alpha source was placed on the top of the crystal corresponding to the part without an electrode (Fig. 2(b) Naked area). The size of the collimated hole that alpha particles can pass through is about 1.5 mm. The image of a single alpha is clear with a reasonable spatial resolution, as shown in Fig. 4(b), and the counts are comparable to a Geiger counter. We can loop pixels to sum the value of signals generated by alpha particles to get the total charge value. The saturated pixels are not revised and are treated as bad pixels. The alpha energy is about 5.4 MeV. The ionization W-value of CdZnTe is about 4.6 eV. The charge collection efficiency of the CdZnTe detector coupled with Topmetal-II$^-$ is estimated as ∼3.5%, which is rather low.

4 Summary

Topmetal-II$^-$ is a low noise CMOS pixel direct charge sensor that contains a 72×72 pixel array of 83 μm pitch size. CdZnTe is an excellent semiconductor material for radiation detection. We use an epoxy adhesive as the medium to connect the Topmetal-II$^-$ sensor to a CdZnTe crystal to build a detector that has a good spatial resolution with −2 V bias voltage. This method is simpler and more convenient than bump bonding. We tested the performance of such a CdZnTe detector coupled with a Topmetal-II$^-$ sensor. We observed that the expanded diameter of the induced charge cloud by a 650 nm laser is about 420 μm at a back bias of −2 V, and the image of a single alpha is clear with a reasonable spatial resolution for the charge cloud induced by a 650 nm laser. However, at such a low voltage, the charge collection efficiency of CdZnTe detector coupled with Topmetal-II$^-$ is very low (∼3.5%).

5 Outlook

Through this experiment, we have found that it is feasible to use this simple method to get a CdZnTe detector with a reasonable spatial resolution corresponding to the bias voltage. Due to the characteristics of the sensor itself, we cannot supply a higher bias voltage (such as 10 V) on the same crystal, as the diffusion of charge signal on the crystal is very large and the spatial resolution is not very high. In order to get a good enough spatial resolution that matches the size of the pixels, we need to continue improving the bias voltage to minimize diffusion of charge inside the CdZnTe crystal by optimizing the design of the sensor and obtaining CdZnTe crystals with a higher resistance.

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