CdTe pixel detector development at SPring-8

Hidenori Toyokawa, Toko Hirono, Shukui Wu, Morihiro Kawase, Yukito Furukawa, Toru Ohata
Japan Synchrotron Radiation Research Institute, Kouto 1-1-1, Sayo-cho, Sayo-gun, Hyogo 679-5198, Japan
toyokawa@spring8.or.jp

Abstract. This paper describes a CdTe pixel detector development for high energy diffraction experiments at SPring-8. A second prototype detector (SP8-02) was designed with a pixel size of 200 μm × 200 μm and a matrix of 20 × 50. The sensor is bonded to an ASIC with a preamplifier, a shaper, a window-type discriminator and a 20-bits counter in each pixel. The current-voltage characteristics verified that a Pt/CdTe/Al-pixel sensor functioned as an electron-collecting diode pixel detector. This type sensor showed a long-term stability at near room temperature.

1. Introduction
Single X-ray photon counting pixel detectors have become the most powerful detector technology in storage ring synchrotron light sources. In particular, the PILATUS detector has reached a very mature state and represents the largest area detector in this field [1]. However its detection efficiency is limited to less than 10% at higher X-ray energies than 30 keV because of a silicon sensor 320 μm in thickness. In addition the single level comparator eliminates only lower energy background such as fluorescent X-rays. Higher harmonics contaminating an X-ray beam are another source of background, and cannot be removed by the single-level comparator. In order to overcome these problems, a high stopping-power semiconductor material for the sensor and an advanced ASIC for the readout channel are required. CdTe is a promising semiconductor material for high energy X-ray detection, because the high atomic number (Z_{Cd} = 48, Z_{Te} = 52) gives a high quantum efficiency and the large band-gap energy (E_{gap} = 1.44 eV) allows operation at room temperature. Therefore, we have developed CdTe pixel detectors based on the hybrid pixel detector technology.

The first prototype detector (SP8-01) was designed with a pixel size of 200 μm × 200 μm and a matrix of 16 × 16 [2-3]. This detector has an ASIC with a preamplifier, a shaper, a window-type discriminator and a 20-bits counter in each pixel. The detector successfully operated with a photon-counting mode selecting an X-ray energy with the window comparator and a fairly good energy linearity performance was achieved in the X-ray energy region between 15 keV and 120 keV [3].

This study describes the second prototype detector (SP8-02), which was redesigned to 20 × 50 pixels with the same architecture in the pixel circuit. CdTe sensors are generally fabricated with a metal/CdTe/metal structure. We have investigated a Pt/CdTe/Al-pixel configuration by using a high resistivity p-type CdTe wafer 300 μm in thickness. This type sensor operates as an electron-collecting Schottky-diode detector. Electrons have a larger mobility and a longer life than hole in CdTe. The SP8-02 detector realized low leakage currents and a long-term stability at near room temperatures.
2. The Pt/CdTe/Al-pixel sensor

Figure 1 shows a photograph of a Pt/CdTe/Al-pixel sensor 500 μm in thickness. The front side was deposited with a 20 × 50 matrix of aluminum-electrodes 170 μm × 170 μm in size and 200 μm × 200 μm in pitch. A guard-ring electrode was placed along the edge. The surface was covered with a passivation layer having holes 60 μm in diameter on each pixel and the guard-ring. The back side (X-ray irradiation side) was processed with a single platinum-electrode. This electrode configuration of Pt/CdTe/Al-pixel has an advantage that a high Schottky barrier formed on the Al/CdTe interface leads us to operate the CdTe an electron-collecting diode pixel detector [4]. Electrons have a larger mobility (μ_{electron} ~ 1100 cm^2/V·s) and a longer lifetime (τ_{electron} ~ 3 × 10^6 sec) than those of holes (μ_{hole} ~ 100 cm^2/V·s, τ_{hole} ~ 2 × 10^6 sec) in CdTe.

![Figure 1: SP8-02 CdTe pixel sensor](image1)

Figures 2 shows a photograph of the second prototype CdTe detector assembly (left) and an X-ray image with a 241-Am X-ray source (left), where the intensities were collected using flat field illumination from the same source. The pixel electrodes of CdTe sensor were bump-bonded to the SP8-02 readout ASIC by the gold-stud bonding technique [5]. The ASIC has 55 control pads, which were wire-bonded to the electrical pins on a ceramic package. Negative bias voltage was applied with wires connected to the X-ray irradiation side electrode. We achieved an excellent bonding yield with no dead pixels as shown in figure 2 (right).

![Figure 2: SP8-02 detector assembly and an X-ray image collected a flat field.](image2)

3. Current-voltage characteristics

We measured the current-voltage (I-V) characteristics of the SP8-02 Pt/CdTe/Al-pixel sensor. The detector was placed in a thermostatic chamber. The detector bias was applied on the platinum-electrode. The aluminum-electrodes and the guard-ring were set to the ground level through the ASIC. We observed reverse bias characteristics with negative voltages and forward bias characteristics with positive voltages as shown in figure 3. Namely, the Pt/CdTe/Al-pixel sensor functions as an electron-collecting diode pixel detector. The leakage currents were 10.5 nA, 1.6 nA, and 0.3 nA with the bias voltage of -300 V at room temperature, 5 degrees C, and -10 degrees C, respectively. The currents...
were low enough to be operated the detector even at room temperature. In addition, the performance was significantly improved at 5 degrees C.

Figure 3: Current-voltage characteristics of SP8-02 Pt/CdTe/Al-pixel sensor at room temperature (closed circle), 5 degrees C (triangle), and -10 degrees C (open circle).

4. Long-term stability study

Long-term stability of the SP8-02 Pt/CdTe/Al-pixel sensor was investigated with a 241-Am X-ray source. The total counts from all the pixels were measured by performing threshold scan of the low edge of the discriminator. The upper-level threshold was set to the voltage of -1000 mV. Each exposure time was 10 seconds. The first scan was started immediately after applying the bias voltage of -300 V to the sensor, and then repetitive scans were performed until 12 hours later at 15 minute intervals.

Figure 4 (a) shows the result at room temperature. The solid line, the dashed line, and dotted lines are corresponding to the first scan, the last scan, and in-between scans, respectively. The lower voltage side (left side) corresponds to the high energy side and the edge around -250 mV is caused by 60 keV X-rays from 241-Am. The rapid increase between -50 and -100 mV is due to noise contributions. We observed a decrease in the counting rate with the passage of time. This degradation is considered to be a drop in charge-collection efficiency because of the typical polarization effect in CdTe Schottky sensors. However, the counting rate was still more than 50 % even after 12 hours. This degradation is slow enough to be used in most synchrotron radiation experiments.

The detector was placed in the thermostatic chamber and we investigated the temperature dependence of its long-term stability. Figure 4 (b) shows the result at 5 degrees C. The long-term stability was successfully achieved at the near room temperature and the counting-rate drop was less than 12% at the threshold voltage of -200 mV during 12 hours. One of different conditions was the leakage currents as shown in fig. 3. This condition leads us to a more simple cooling procedure in designing the final detector system.
5. Summary and outlook

We have developed the second prototype CdTe pixel detector of SP8-02. The current-voltage characteristics verified that the Pt/CdTe/Al-pixel sensor functioned as an electron-collecting diode pixel detector. The long-term stability was successfully achieved at 5 degrees C. We continue to study the possibility of operating the detector at much higher temperature between 5 degrees C and room temperature. We are considering a water cooling system to optimize the temperature for the final detector system.

Now we are designing a large area detector with the SP8-02 ASICs having a 3-side buttable form. The sensor is going to be 8.5 mm × 40.8 mm in size and have 40 × 200 pixels. 8 ASICs can be bump-bonded to one sensor without dead-detection area. This will be a single module unit and we are going to build multi-module detectors covering about 4 cm × 8 cm in area with 4 × 2 modules.

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