# Development of silicon and cadmium telluride pixel detectors

Single photon counting pixel detectors were expected to be the next-generation 2D X-ray detectors since the early stages of the third-generation synchrotron radiation facilities. SPring-8 has made X-ray photon counting measurements possible by developing the PILATUS detectors, and a cadmium telluride (CdTe) pixel detector project is ongoing for high energy X-ray applications currently. Both detectors are based on the hybrid pixel detector technology composed of a monolithic semiconductor sensor with pixelated electrodes and a custom-designed application specific integrated circuit (ASIC).

SPring-8 has closely collaborated in the PILATUS project at PSI and contributed to module fabrication and then the development of calibration methods [1-4]. Thus, two detectors of PILATUS-100K and a multi-module system of PILATUS-2M (Fig. 1) have been developed. The specifications of the standard PILATUS-100K sensor are 172 μm × 172 μm in pixel size, 195 × 487 in format, and 320 μm in silicon thickness. On the other hand, one of the PILATUS-100Ks is fabricated with a 450 μm sensor developed by SPring-8. It realizes higher sensitivity and better flatness. The other PILATUS-100K is equipped with a standard sensor, but an original cubic box is used as its housing. This design is useful for mounting the detector on complicated experimental setups.

The former applications with the PILATUS-100K at SPring-8 were an X-ray diffractometer with pulsed magnetic fields at BL19LXU and a time-resolved X-ray diffraction study of directional solidification in steels at BL46XU. These were pioneer studies applied with the PILATUS's good merits as such high frame rate capability and fast readout time in msec order. By using the high counting rate capability of up to $10^6$ X-rays/sec and the 20-bit dynamic range feature, time-resolved X-ray reflectivity studies on a liquid interface were performed at BL37XU. This is 10 times faster than the conventional method with a point detector. Another unique application is the depth-resolved XAFS at BL01B1 and BL37XU, which measures grazing exit fluorescent X-rays from a sample. PILATUS-2M is used for X-ray diffractions and small angle X-ray scatterings at BL19B2 and BL46XU. In particular, an ultra-small angle X-ray scattering is measurable with about 40 m in distance from the sample to the detector at BL19B2.

The high energy X-ray beam is a powerful probe for analyzing deep inside the structure for heavy materials. The PILATUS detector is usable at such high-energy region. In fact, we have applied the PILATUS-100K detector to 70 keV X-ray diffraction experiments at BL22XU with ultra-low gain settings calibrated for high energy applications. However, its detection efficiency decreases to 30% at 20 keV and to lower than 10% above 30 keV. To improve the detection efficiency in the high-energy region, CdTe is regarded as a promising semiconductor material because of its high density and the high atomic number of its components. Therefore, we started a CdTe pixel detector project in 2008 [4-5].

The SP8-01 CdTe detector was designed as a prototype to investigate its performance for high-energy X-ray measurements. The format is 16 × 16 pixels with a pitch of 200 × 200 $\mu m^2$. The other weak point of PILATUS is the single-level comparator eliminating only lower energy X-rays than the threshold level. Therefore, a full-custom ASIC was designed as a readout circuit of SP8-01, which is equipped with a window-type discriminator. The upper discriminator realizes a low-background measurement, because X-ray beams from the monochromator contain higher-order components beside the fundamental X-rays in general.

Figure 2 shows the schematic of the SP8-01 ASIC architecture. The charge sensitive preamplifier together with a shaper converts the input charge generated in the sensor to a bandwidth-limited short pulse, with a height proportional to the energy of the incident X-ray. The content of the pseudorandom 20-bit counter is increased when the pulse falls between the lower- and higher-energy thresholds.

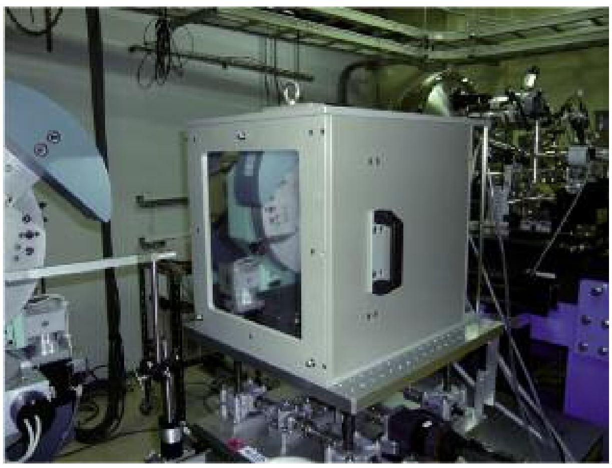

Fig. 1. X-ray diffraction experimental setup of the PILATUS-2M detector at BL46XU.

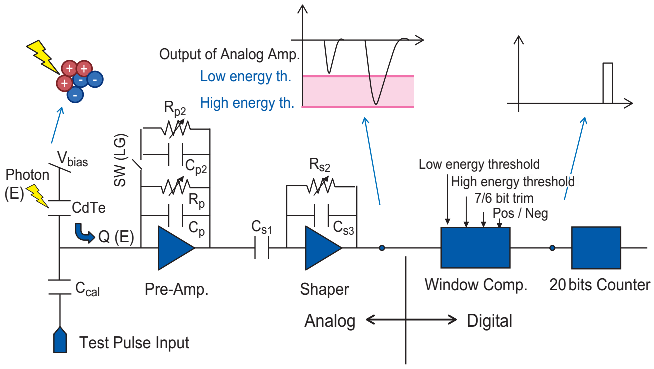


Fig. 2. Schematic of the SP8-01 ASIC architecture for CdTe pixel detector.

The preamplifier is equipped with a gain adjust switch. An additional feedback capacitor and resistor can be switched on in the low-gain mode. The designed energy ranges for the low- and high-gain modes are 15 – 40 keV and 30 – 100 keV, respectively. The parameters of the circuit were optimized to meet the requirements of dead time (less than 100 nsec) and energy linearity in the regions of interest by performing a circuit simulation with T-SPICE from Tanner Research Inc.

Figure 3 shows the SP8-01 prototype detector mounted on a ceramic package. The ASIC chips were processed with a TSMC 0.25 μm CMOS technology, and CdTe sensors were bump-bonded to the ASIC chips by a gold-stud bonding technique. The sensor thickness is 500 μm, which has an absorption efficiency of almost 100% up to 50 keV and 45% even at 100 keV.

To demonstrate the function of the window comparator, we simultaneously moved the higher- and lower-energy thresholds to maintain the difference between them. X-ray beams were attenuated with metal plates and irradiated onto the detector directly. The integral linearity for the high-gain mode was 98% in the region of 15 – 40 keV and that for the low-gain mode was 90% in the region of 30 – 100 keV.

In the next step, we proceed to the SP8-02 detector. The SP8-02 ASIC was designed as a 3-sided buttable layout with 20 × 50 pixels. The one cell architecture follows that for SP8-01. We plan to fabricate double chips and 2 × 4 chip detectors without an inter-chip gap on the sensor. The 2 × 4 chip detector will be designed as a module to build a larger-area detector.

We developed three types of CdTe sensor for SP8-01. Type 1 was designed for the electron collection operation composed of a Schottky contact with aluminum electrodes on the pixel side and a platinum electrode on the common electrode side. Type 2 is a hole collection sensor with a Schottky contact of an indium common electrode and platinum pixelated electrodes. Type 3 has ohmic contact structures on both sides with platinum electrodes. However, we could only test the type 1 sensor of SP8-01 because of bonding failures by the vendor. Therefore, we will investigate the detailed performances of these types with the SP8-02 detector.

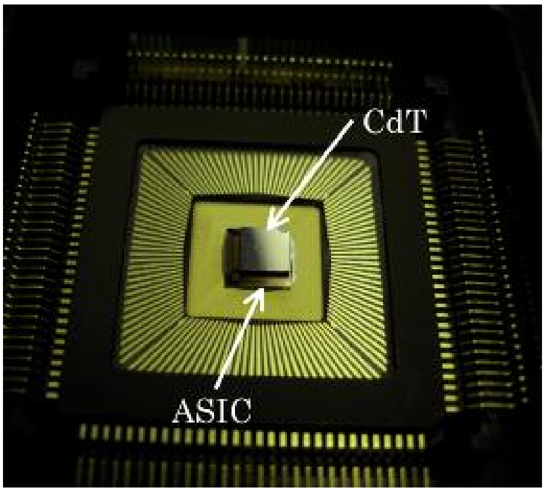


Fig. 3. SP8-01 prototype detector with CdTe sensor (200 μm × 200 μm in pixel size, 3.2 mm × 3.2 mm in detection area, and 500 μm in thickness) and ASIC (16 × 16 pixels) mounted on a ceramic package.

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**References**

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