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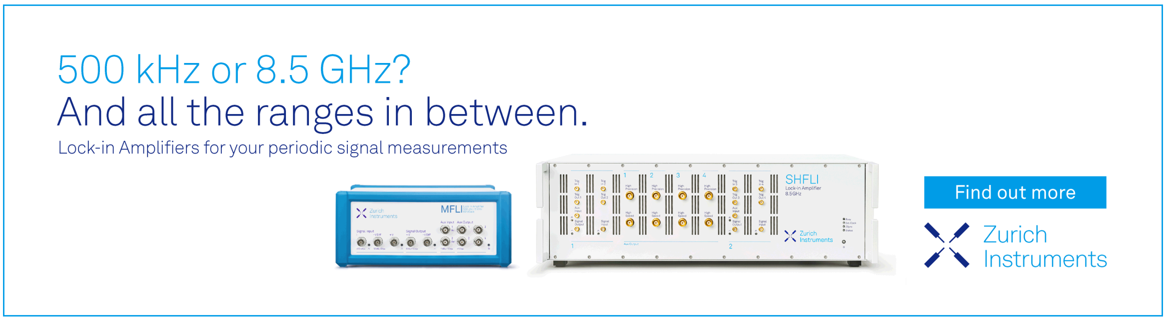

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Test result of the synchrotron radiation experiments using the counting-type SOI pixel for low-energy X-rays

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Abstract. Application of the Silicon-On-Insulator (SOI) technology to a pixelated detector is expected for the imaging experiments using synchrotron X-rays. The SOI pixel detector is advantageous to make a fine pixel with low noise, because there is no mechanical bump bonding. Because the soft X-ray experiments like the surface X-ray scattering (SXS) and diffraction (SXRD) are very important for the surface analysis, we have started to develop a pulse-counting type SOI pixel which is sensitive to low–energy X-rays down to 2 keV. A test-element-group of CPIXPTEG2, was evaluated by using synchrotron X-rays. The CPIXPTEG2 was designed with the double-SOI technology and its total thickness was 75 μm for a smaller dispersion of the charges collected inside the sensor. The non-melting laser annealing was employed in the ground backside to suppress dopant diffusion during activation. We will report on the test results of CPIXPTEG2 using 6 keV X-rays.

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INTRODUCTION

The structural analysis of functional materials for industrial applications is one of the most interested studies in synchrotron radiation science. Their nanostructure around surfaces and atomic structure, including the depth direction, have been investigated in synchrotron X-ray experiments. With a low-emittance synchrotron ring, higher performance is required for an X-ray area detector used in experiments. We have begun developing a new pulse-counting-type area detector based on Silicon-On-Insulator (SOI) technology [1]. SOI technology refers to the use of a silicon wafer with a layered structure of silicon-insulator (buried oxide)-silicon. It is very effective in producing a high-speed and low power consumption circuit. To design a monolithic area detector, two Si layers were prepared: a thick Si substrate for the sensor and a thin Si layer for the circuit. Furthermore, in order to decrease the back gate effect and crosstalk between the sensor and circuit, double SOI technology [2] was used. The double SOI wafer has an additional Si layer (middle SOI) under the buried oxide layer. The middle SOI is effective for decreasing the total ionizing dose effect caused by holes trapped in the buried oxide layer. A cross section of an SOI detector is shown in Figure 1. The double SOI wafer was used in the detector in Figure 1. The experiments for evaluating a test-element-group (TEG) called CPIXPTEG2, designed by the Institute of High Energy Physics, were performed using X-rays at the Photon Factory in KEK (KEK/PF). The main purpose of development of this chip was test of the backside process in order to measure the soft X-ray. The soft X-ray experiments like the surface X-ray scattering (SXS) and diffraction (SXRD) is very important for the surface analysis, so we have started to develop a pulse-counting type SOI pixel which is sensitive to the soft X-rays of its energy E > 2 keV. We carried out both the thinning and the non-melt laser annealing process on the backside. This paper presents the test results of the low energy X-ray measurement.

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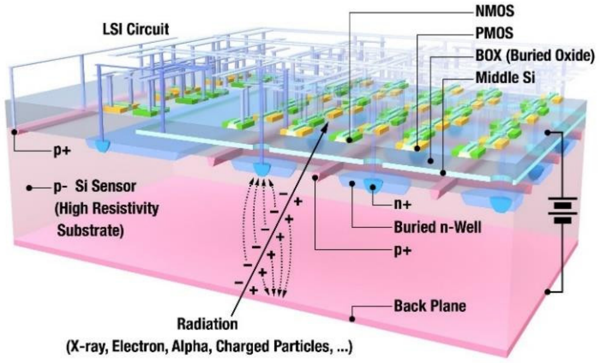


FIGURE 1. Cross section of an SOI detector.

Overview of the CPIXPTEG2

The new counting type pixel TEG, CPIXPTEG2, was designed to satisfy the following specifications.

・p-type sensor.

・64 μm square pixel.

・32×32 pixel array.

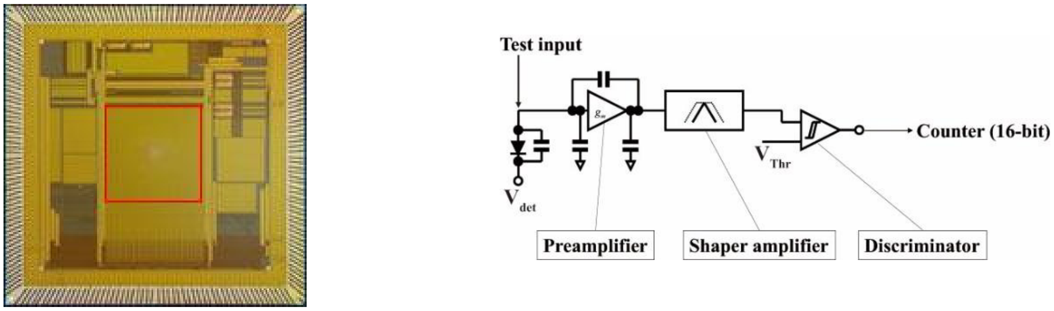
・in-pixel circuit for photon counting consisting of a preamplifier, a shaper amplifier, a discriminator and a 16-bit counter.

・double-SOI wafer.

The total thickness of the chip is 75 μm where sensor layer thickness is about 65 μm. This thickness is enough to detect the 2 keV X-ray. The circuit layer has about 10 μm in thickness and 150 nm thick middle-SOI layer sandwiched by the 145 nm thick insulator layers are located between the sensor and the circuit layer.

A chip layout and a schematic of the in-pixel counting circuit is shown in FIGURE 2. FIGURE 2-(a) shows a chip layout. The pixel array is located in the red line square. FIGURE 2-(b) shows a schematic of the in-pixel counting circuit. The collected charges from the sensor layer is amped and formed by a preamplifier and a shaper amplifier. The signal from a shaper amplifier is discriminated by a 1-threshold discriminator which has 4-bit DAC used for adjusting the threshold level by each pixel. The signals that exceeded the threshold level are counted at the 16-bit counter. The test pulse input is prepared to check the properties of the counting circuit without the sensor.

CPIXPTEG2 was an improved chip of the former chip, CPIXPTEG1. In this improvement, the number of the contact via to the middle-Si was increased then the bias voltage for the middle-Si could be stably applied.



(a)

(b)

FIGURE 2. (a) Chip layout. (b) Schematic of the in-pixel counting circuit.

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Test result of the counting circuit in the test bench

The evaluation of the properties of the in-pixel counting circuit was done by use of a function generator in the test bench before the synchrotron radiation X-ray test. It was done by inputting the step pulse whose pulse height was corresponding to the 6 keV X-ray through the input capacitance. The output signals from both the preamplifier and the shaper amplifier was measured. By this test, we found out a problem that the total gain of the analog circuit was 5 times lower than a designed value. The pulse height of the shaper amplifier output signal was so low that the discriminator could not respond and was comparable to the noise level. We tried to increase the gain by adjusting the bias current which was used to operate the core amp and the feedback amp in both the preamplifier and the shaper amplifier. We succeeded to make the pulse height 10 times higher. Although the pulse height became much higher than the noise level, but unfortunately, it was not enough to respond the discriminator yet. Therefore, we change the experimental plan of the synchrotron radiation test without using the in-pixel 16-bit counter. The analogue signal from a preamplifier was outputted from a pixel. It was inputted to external counting circuit and a photon-counting experiment was done.

Result of the synchrotron radiation X-ray experiment

Synchrotron radiation test was conducted using 6 keV X-ray in KEK/PF BL-14A. The experimental setup was shown in FIGURE 3. The X-ray microbeam, less than 10 µm in diameter, was formed with a pin-hole made by gold which has a hole of 5 µm in diameter. Temporal change in incident beam intensity was monitored by the ionization chambers. We could use a laser module instead of the pin-hole. It was very useful for alignment of the pixel array on the beam line. The absolute beam intensity was measured by a NaI scintillator which was aligned instead of CPIXPTEG2.

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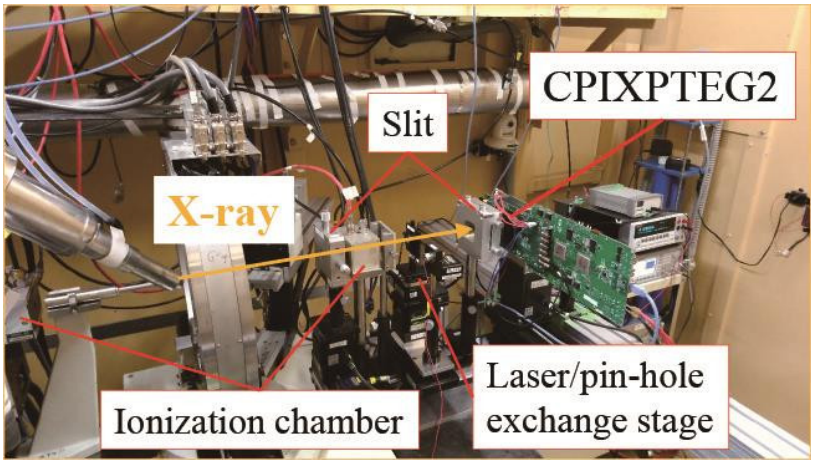
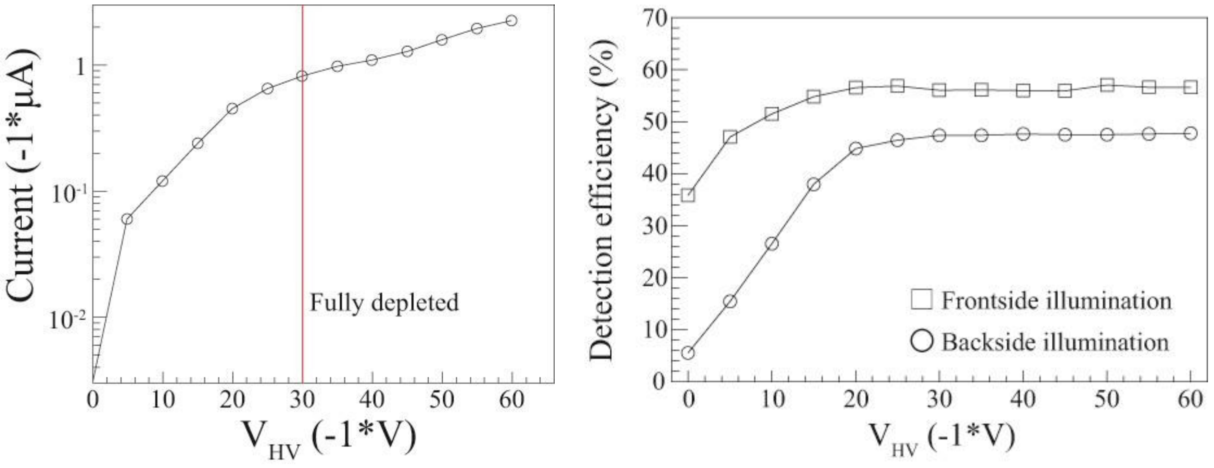


FIGURE 3. Photograph of the experimental setup. The X-ray microbeam, less than 10 µm in diameter, was formed with a pin-hole and irradiated to the pixel array.

The trends of the dark current and the detection efficiency against the sensor bias V_{HV} was measured. The results are shown in FIGURE 4. The measured dark current is shown in FIGURE 4-(a). It was very stable, almost -1 µA, around -30 V which corresponds to the sensor bias of fully depleted. The trends of the detection efficiency against V_{HV} is shown in FIGURE 4-(b). The data sets were measured by both frontside illumination (open square) and backside illumination (open circle). The sufficient counts was measured by V_{HV} = 0 V because this sensor was naturally depleted by about 10 μm without V_{HV}. Using these data sets, the thickness of the dead layer was evaluated. For frontside illumination setup, X-rays transmitted through the 10 μm-thick circuit layer was detected. The detection efficiency measured above the fully depleted voltage of -30 V was about 56% so that we obtained the thickness of the depletion layer using following formula.

$$D_{eff} = \mathrm{T}(t_{circuit}) \times \mathrm{A}(t_{dep}), \tag{1}$$

where, D_{eff}, T, A, $t_{circuit}$ and t_{dep} means detection efficiency, transmission rate, absorption rate, thickness of the circuit layer (=10 μm) and thickness of the depletion layer, respectively. The obtained t_{dep} value was about 47 μm. This result means that there is 18 μm of the dead layer on the sensor surface. For backside illumination setup, the detection efficiency calculated using above values of thickness of the depletion layer and dead layer was consistent with the experimental result. The possibility of the answer for this problem of too thick dead layer was that the electric field around the sensor surface was maybe weak. If this case was occurred, the signal carriers recombined before they were collected by the charge collection electrode, or leaked to adjacent pixels. Therefore, even if the sensor is fully depleted, it seems that there is an apparent dead layer.



(a) (b)

FIGURE 4. (a) Dark current versus sensor bias V_{HV}. This sensor is fully depleted with the bias voltage of -30 V. Above that bias, the dark current is about -1 μA in stable. (b) Detection efficiency versus V_{HV}. Open squares shows the trends of the detection efficiency against the V_{HV} obtained by frontside illumination setup and open circles shows those obtained by backside illumination setup. This sensor is naturally depleted by about 10 μm and the data sets obtained by V_{HV} = 0 V is consistent with calculated value.

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Summary

The study of a counting type SOI pixel for the soft X-ray was started in KEK/PF. The backside process aiming the soft X-ray counting was performed. In the evaluation of the in-pixel counting circuit by using the test pulse input, we found out the problem of shortage of the total gain of the analogue amps. We succeeded to increase the gain by adjustment of the amps so that we carried out the synchrotron radiation experiment by use of X-ray of 6 keV. Evaluation of the thickness of the dead layer was done and it obtained 18 μm. Though the non-melt laser annealing was done, this value was too thick. The possibility of this reason is that the electric field around the sensor surface was maybe weak so that the signal carriers were lost by recombination or leaked to adjacent pixels. Now we are analyzing and discussing to solve this problem.

As a future plan, it is necessary to modify the counting circuit of CPIXPTEG2, and we continue the evaluation experiment towards the development of the soft X-ray detector.

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REFERENCES

1. Y. Arai, et al, Nucl. Instr. Meth. A636 (2011) 531.
2. T. Miyoshi, et al, Nucl. Instr. Meth. A732 (2013) 530.

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