PF BL-14A, BL-14B, BL-14C1, AR NW-12A/2011G658

X-ray application of next-generation image sensors using SOI technology

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1 Introduction

The SOIPIX group is developing monolithic pixel sensors using SOI technology. The development project has started as an important subject in KEK Development and Technology Project (KEK-DTP). The sensors were evaluated with monochromatic X-rays at KEK-PF beamlines, PF BL-14A, BL-14B, BL-14C1, and KEK-PF-AR beamlines, NW12A. This document describes a part of the experimental results.

2 Experiment

The experiment was done in 4 beamlines in FY2013. The summary is shown in Table 1. In PF BL-14A, a wide range of X-ray energy is available for various X-ray detector tests and therefore it was used for full depletion voltage, sensor gain, and quantum efficiency (QE) measurement. In PF BL-14B, a large-area and uniform beam in medium X-ray energy (10-17 keV) is available and thus it was used for a demonstration of the phase-contrast imaging and the evaluation of the spatial resolution. In BL-14C1, a large-area and uniform beams in high X-ray energy (25-40 keV) is available and so it was used for tests of the refraction- and absorption-contrast imaging. In AR NW12A, diffraction images for protein crystallography were measured using SOI sensors for the first time.

Table 1: Experiment summary

Beamline	Beam time [year/month]	Beam Energy [keV]	Subjects
14A	2012/6	10	Sensor gain, QE
14B	2013/1	16	Imaging
14C	2012/6	30	Imaging
14A	2013/1	12	Sensor gain, QE
AR NW12	2013/2	12.4	Protein crystallography

3 SOI pixel sensors

SOI image sensors were developed in multi-project wafer (MPW) runs in every year. Various LSI designs were gathered in a common process mask [1]. Therefore, various SOI image sensors have been used in several beam times since 2009 [2-4]. In FY2012, we made two major improvements. A DAQ board, SEABAS1, was upgraded to SEABAS2. The SEABAS2 equips 16-ADC channels and Giga-bit Ethernet SiTCP system [5]. The INTPIX4 has a multiple (13) output and therefore data can be sent in parallel with SEABAS2. The frame rate of INTPIX4 with SEABAS2 for the full pixel of 832 by 512 was about 20 fps during the data acquisition compared with a single readout, about 3-5 fps. Another improvement is the utilization of Float-Zone (FZ-) SOI sensors. FZ-INTPIX5 was successfully fabricated, and the leakage current was two order lower than that of Czochralski- (CZ-) INTPIX5. In 2012, SEABAS1 was used to operate INTPIX5.

4 Results and Discussion

In BL-14A, measurement of the full depletion voltage, the sensor gain, and quantum efficiency in CZ- and FZ-INTPIX5 was done using focused beam in X-ray energy of 10 and 12 keV. After the analysis, it was found that higher X-ray energy is better for the comparison because it reached a plateau at lower back-bias voltages. Therefore we requested another beamtime in May, 2013.

In BL-14B, diffraction enhanced imaging (DEI) experiment was done using FZ-INTPIX5. The pixel size of the INTPIX5 is 12 μm. X-ray energy was set to 16 keV. High-resolution diffraction enhanced images were obtained for the first time as shown in Fig.1.

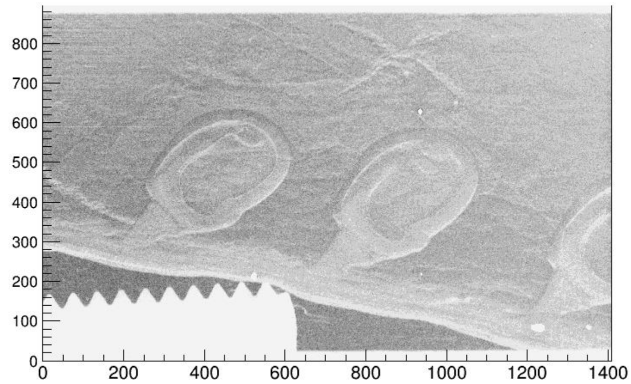

Fig. 1: A diffraction enhanced image of a bean and screw by FZ-INTPIX5.

In BL-14C, X-ray spectrum was measured in X-ray energy of 30 keV using CZ-INTPIX4, and X-ray imaging was demonstrated. The pixel size of the INTPIX4 is 17 μm. Fig.2 shows X-ray spectrum of 30 keV monochromatic X-ray. Energy resolution was about 10 % in rms at room temperature. To analyze in the same data, a high-resolution X-ray image of a fish bone was obtained as shown in Fig. 3. In Fig. 3, we found the sensor had a non-uniform pattern due to improper process at the back side grinding. Therefore the result was reported to the vendor, and then we tried to improve the treatment. To measure X-ray images and X-ray spectra at the same detector is a good feature of integration-type SOI sensors. This was a demonstration of inverse Compton scattering experiment performed at superconducting RF test facility

(STF) under the Quantum Beam Technology Program. The program is a 5-years program supported by Ministry of Education, Culture, Sports, Science and Technology (MEXT) and ended in JFY2012. Eventually, as the result of evaluation experiment in the end of FY 2012, X-ray generation from inverse Compton scattering was confirmed by using CZ-INTPIX4. This is the world first result of the implementation of ICS X-ray sources with superconducting RF technology.

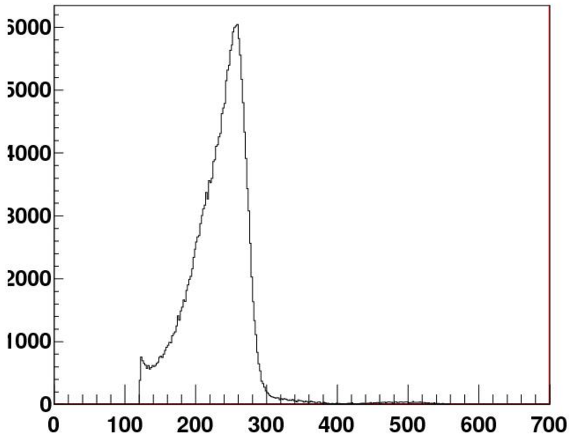

Fig. 2: X-ray spectrum of 30 keV X-ray beam measured by CZ-INTPIX4.

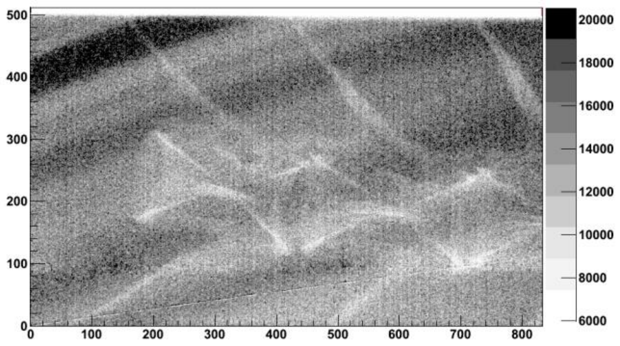

Fig. 3: A high-resolution X-ray image of a fish bone by CZ-INTPIX4.

In AR-NW12A, diffraction images were measured using CZ-INTPIX4 and SEABAS2 DAQ system for the first time. Lithesome crystal was used for taking diffraction data with X-ray energy of 12.4 keV. High-resolution diffraction pattern were obtained. However, the image could not be utilized for the analysis because dead time of a few tens of msec is so large to measure one degree oscillation pattern in a few hundred msec. Therefore, it was realized that a SOI sensor with no dead time must be required to utilize it for protein crystallography.

As for a common issue, the dead time in data readout is large for KEK-PF application experiment. To reduce it, we have a plan to introduce a dual storage capacitor in a pixel to reduce readout dead time and utilize SEABAS2 DAQ board. In KEK-PF and PF-AR experiment, a cooling system is required to handle sensors with low noise operation and to reduce energy resolution. As another issue of the sensor, the radiation hardness is not sufficient. To solve it, we have recently fabricated SOI sensors with double SOI wafers. The fabrication of the 2nd prototype will be completed in 2013 and then we will perform the evaluation test using monochromatic X-rays in KEK-PF.

4. Future plan

In FY2012, p-type and double SOI sensors were also fabricated. Integration-type pixel sensors with dual storage capacitors and counting-type pixel sensors with double SOI will be also fabricated in FY 2013. Those sensors will be tested and demonstrated with monochromatic X-ray in FY2013.

References

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