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Measurement of quantum efficiency of back-illuminated imaging device with pixel size 1.4 × 1.4 μm^2

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Using a commercially available PC board and the camera module attached, a soft X-ray imaging device was fabricated of which the pixel size is 1.4 × 1.4 μm^2 and about 1/10 of the conventional one. The quantum efficiency of the imaging device was increased as the increase of photon energy from 250 eV to 1000 eV depending on the surface materials.

1 Introduction

Over the past 10 years, typical pixel size of commercially available soft X-ray image sensors has been limited to 13 × 13 μm^2 because of the process rule of the manufacturer [1, 2]. On the other hand, back-illuminated (BI) type CMOS sensors in visible (VI) wavelength region have been supplied to the market and mounted on popular cameras. The VI BI-CMOS sensors are called the same "back-illuminated type sensor" as in SX wavelength region, but a color filter is deposited on the surface photodiode layer of the VI BI-CMOS sensor for color separation [3, 4]. When a VI BI-CMOS sensor is irradiated by the SX light, the SX light is absorbed by this color filter because of the strong interaction of the SX light with the color filter. If the color filter layer can be removed from the VI BI-CMOS sensor before the irradiation, the VI BI-CMOS sensor will have a sensitivity in the SX wavelength region.

Raspberry Pi is an educational single board computer which is equipped with a quad-core ARM chip, and Unix derived OS, Raspbian, works on it [5]. Pi Camera V1.3 is a camera module of Raspberry Pi, which is equipped with a visible BI-CMOS sensor (OV5647, OmniVision) that has an image area of 2592×1944 pixels with a pixel size of 1.4 × 1.4 μm^2 [6]. This camera module can be separated from the computer board, and images can be obtained by a standard program which works on Raspbian. The pixel size of the image sensor OV5647 is small enough comparing with the ones of the conventional SX imaging devices, moreover, the cost of the image sensor with peripheral equipment are very low. In this study, operation of Pi Camera V1.3 is checked in SX wavelength region after removing the color filter from the surface of the image sensor [7, 8].

2 Experimental Details

The color filter layer of the image sensor was removed at first. Color filters of image sensors are often made by mixing optical dyes in resist materials [3]. Peeling off resist layers on the surface of semiconductors is a standard technique in semiconductor processes. In the present case, the color filter is made of acrylic resin and was peeled off by a solution of a resist stripper. Then the sensor was rinsed with isopropyl alcohol, with water solution of an optical neutral detergent, and with distilled water. The OV5647 chip before and after removal of the color filter is shown in Figure 1 (a) and (b), respectively.

Fabricated image unit is shown in Figure 2. The front side of the OV5647 chip was covered with a protection case, and then a Peltier device (TES1-3102LT125, Laser Create Corp., Japan) was bonded to the backside of the chip via a Cu plate which is 2 mm thick. A Pt resistance temperature sensor (M222-100-A, Heraeus) was attached to the Cu plate, and its temperature was measured to control the Peltier device. The Cu block was adhered to the hot side of the Peltier device, and the temperature of the hot side decreases by the air through a vacuum flange adhered tightly to the Cu block. The temperature was cooled down to 5 °C or less under the ready mode of the Peltier device and was increased to 10 °C under the operation mode.

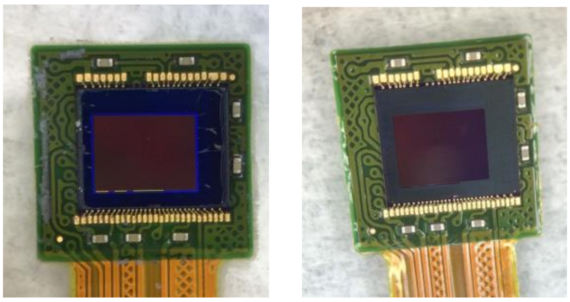

Figure 1. OV5647 chip before, (a), and after, (b), removal of the color filter.

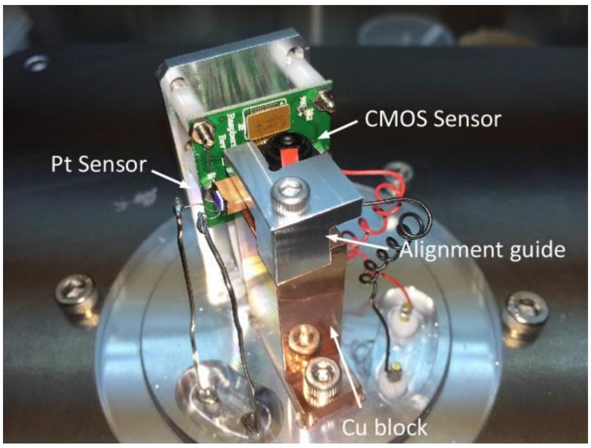

Figure 2. Fabricated image sensor unit.

The measurement was made using the beamline, BL-11D, at Photon Factory, KEK, Japan [9]. The photon energy region of the beamline is divided by two diffraction gratings, G1 (2400 grooves/mm, R=55.2 m, 250 – 1300 eV) and G3 (2400 grooves/mm, R=22.9 m, 60 – 280 eV). A photodiode (SXUV100, Optodiode Corp.) was also installed in front of the CMOS sensor to measure the absolute photon intensity.

3 Results and Discussions

Figure 3 shows the quantum efficiency curve of the CMOS sensor. The value of the quantum efficiency was increased as the increase of the photon energy. Some dip structures can be observed at 150 eV, 300 eV, and 450 eV. These structures are originated from the Si, C, and N atoms of the sensor surface, which correspond to the results of XPS measurements. The result of the quantum efficiency suggest that the sensor will be useful in SX measurements.

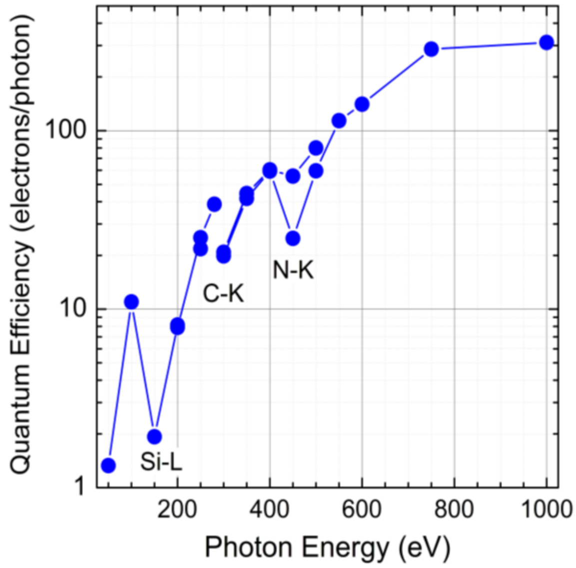

Figure 3. Quantum efficiency of OV5647 after removal of the colour filter deposited on the sensor surface.

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