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Low-dose-rate X-ray detection using a direct-conversion ceramic-substrate silicon diode and a 5.0 m coaxial cable

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Abstract

A direct-conversion silicon X-ray diode (Si-XD) is very useful for detecting low-dose-rate X-rays. The Si-XD is a selected high-sensitivity Si photodiode for detecting X-rays. In this experiment, the Si-XD is connected to an X-ray detecting module through a 5.0 m coaxial cable. The photocurrents flowing through the Si-XD are converted into voltages and amplified using current-voltage (I-V) and voltage-voltage (V-V) amplifiers in the module. At a constant tube current of 0.8 mA, the output voltage increased with increasing tube voltage. The output voltage was proportional to the tube current at a tube voltage of 80 kV.

Keywords: Si X-ray diode, direct conversion, ceramic substrate, X-ray detecting module, CT detector

1. Introduction

To perform molecular imaging using X-rays, we developed several photon-counting energy-dispersive X-ray computed tomography (ED-CT) systems.[1-4] In the ED-CT systems, we usually used cadmium telluride (CdTe) detectors with an energy resolution of 1 % at 122 keV to disperse photon energy. Subsequently, 2-keV-width iodine K-edge CT was performed using s silicon PIN diode,[5] and blood vessels were observed at high contrast.

Recently, we have found a high-sensitivity silicon X-ray diode (Si-XD)[6,7] with a ceramic substrate, and a high-sensitivity CT system has been developed using a direct-conversion Si-XD without scintillators. In addition, gadolinium K-edge imaging has also been carried out utilizing an ED-CT system with the Si-XD by determining threshold photon energy.

Using the Si-XD in conjunction with an X-ray detecting module, although low-dose-rate X-rays can

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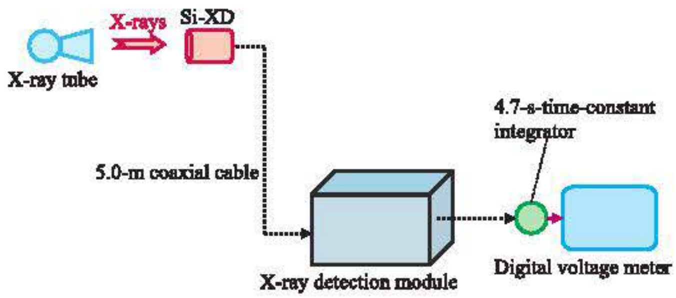

Fig. 1. Block diagram for detecting low-dose-rate X-rays using a Si-XD, a 5.0-m coaxial cable, an X-ray detecting module, and an X-ray generator. The Si-XD is placed 1.0 m from the X-ray source, and the output voltage is measured using a digital voltage meter with an integrator.

Fig. 2. Experimental setup for detecting X-rays.

be detected, we have to use a long coaxial cable between the Si-XD and the module to construct a new module consisting of an analog digital converter (ADC) and amplifiers. Therefore, we have to measure the output voltage when a Si-XD is connected to the module using the long cable. Therefore, we constructed an experimental setup using the long cable and measured X-ray sensitivity of the Si-XD.

2. Experimental methods

2.1. Low-dose-rate X-ray detection

Figure 1 shows a block diagram for detecting low-dose-rate X-rays using a Si-XD (S1087-01, Hamamatsu). Using the Si-XD detector, X-ray photons are detected directly by the light receiving

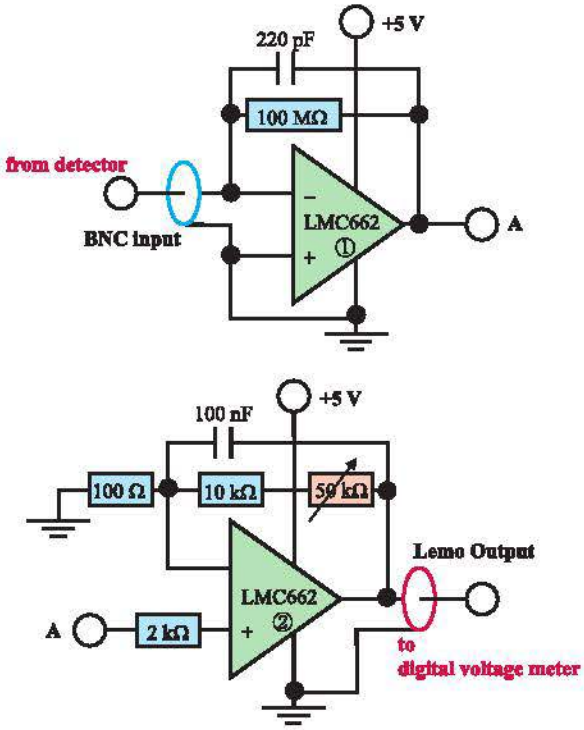

Fig. 3. Circuit diagrams of I-V and V-V amplifiers in the X-ray detecting module.

surface of $1.3 \times 1.3\,\mathrm{mm}^2$, and the detector is shielded using an aluminum (Al) case with a 25-μm-thick Al window and a BNC connector. Subsequently, the detector is connected to an X-ray detecting module through a 5.0-m-length coaxial cable (Fig. 2), and the output is measured using a digital voltage meter and a 4.7-s-time-constant integrator for voltage smoothing.

2.2. X-ray detecting module

In the module, the photocurrents flowing through the Si-PIN are converted into voltages and amplified using current-voltage (I-V) and voltage-voltage (V-V) amplifiers, and the output from a small connector (ERA.00.250.CTL, Lemo) is measured using a digital voltage meter. To construct low-noise high-sensitivity amplifiers, a low-ripple smoothing circuit for an alternating current (AC) adopter is necessary.

The main circuit diagrams of the X-ray detecting module are shown in Fig. 3. The photocurrents are converted into voltages using the inverse I-V amplifier with a 2-fA-bias 2-channel operational amplifier (LMC662, National Semiconductor). The V-V amplifier utilizes the second channel of LMC662 with a non-inverse amplifying circuit. The gain of the V-V amplifier increases with increasing resistance in a 50 kΩ variable resistor.

(a)

(b)

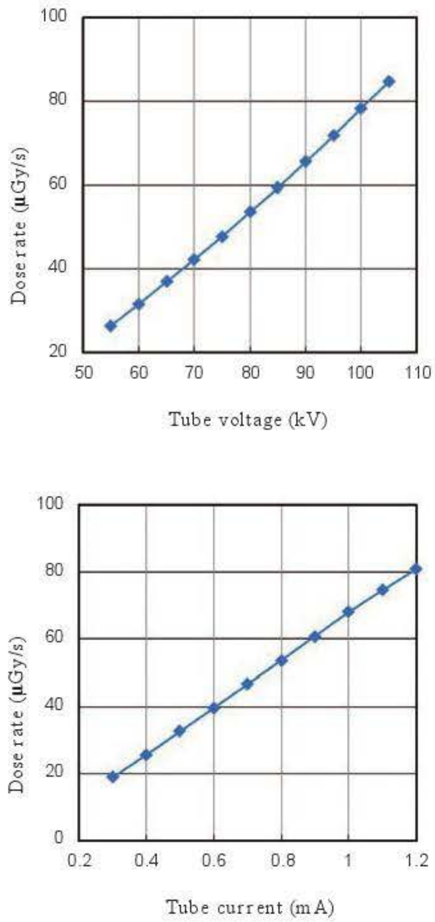

Fig. 4. X-ray dose rate measured using an ionization chamber placed 1.0 m from the X-ray source. (a) Tube voltage dependence at a tube current of 0.8 mA, and (b) tube current dependence at a tube voltage of 80 kV.

3. Results

3.1. X-ray dose rate

The measurement of X-ray dose rate is very important because the relative sensitivities of the detectors are roughly proportional to the dose rate. The X-ray dose rate from the X-ray generator was measured using an ionization chamber (RAMTEC 1000 plus, Toyo Medic) without filtration (Fig. 4). The chamber was placed 1.0 m from the X-ray source. At a constant tube current of 0.8 mA, the X-ray dose rate increased with increasing tube voltage [Fig. 4(a)]. On the other hand, the dose rate was proportional to the tube current at a constant tube voltage of 80 kV [Fig. 4(b)]. At a tube voltage of 80 kV and a current of 0.8 mA, the X-ray dose rate was 53.7 μGy/s.

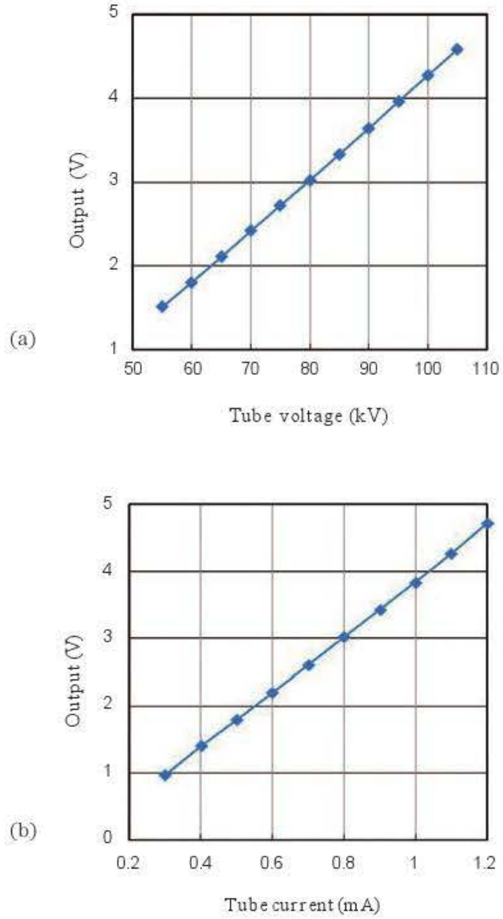

Fig. 5. Output voltages from the module. (a) Variations with the tube voltage at a tube current of 0.8 mA, and (b) variations with the tube current at a tube voltage of 80 kV.

3.2. Module output

Figure 5 shows the output voltages from the Si-XD detector measured using the X-ray detecting module. At a tube current of 0.8 mA, the output increased with increasing tube voltage [Fig. 5(a)]. As shown in Fig. 5(b), the output voltage was in proportion to the tube current at a tube voltage of 80 kV.

4. Discussion and conclusions

We constructed a low-dose-rate low-noise X-ray detecting module for semiconductor diodes, and this module with an ADC and a tablet personal computer will be applied soon to a compact X-ray dosimeter. In particular, the Si-XD was connected to the X-ray detecting module using a 5.0-m-length coaxial cable, since we had to measure output voltages using the cable.

In the former experiment, the Si-XD was connected directly to the module. In the near future, the X-ray detecting module consisting of an ADC and the two amplifiers would be developed to measure X-ray dose to avoid radiation exposure for observers.

Acknowledgments

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