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High-sensitivity compact dosimeter using two silicon X-ray diodes

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Abstract

We have developed a compact dosimeter using two silicon X-ray diodes (Si-XDs). The dosimeter consists of the two Si-XDs, a current to voltage amplifier, a voltage to voltage amplifier, a microcomputer, and a personal computer (PC). The Si-XD is a high-sensitivity photodiode selected for detecting X-rays, and the two Si-XDs are shaded with 50-μm-thick aluminum tape. Subsequently, the two Si-XDs are connected in parallel to increase the sensitivity. On the other hand, a 0.3-mm-thick copper (Cu) filter is attached to one Si-XD to calibrate photon-energy dependence of the dosimeter. In the dose-rate measurement using the Cu filter, the time-average dose rate increased exponentially with increasing tube voltage.

***Keywords*:** semiconductor dosimeter, silicon X-ray diode, twin diode, I-V amplifier, V-V amplifier, energy-dependence calibration

1. Introduction

The silicon X-ray diode (Si-XD) is a high-sensitivity photodiode selected for detecting X rays. Therefore, this diode has been applied as the detector for the first-generation computed tomography (CT) scanners [1, 2] and the X-ray dosimeter [3]. In addition, the Si-XD can be applied to count X-ray photons, and a photon-counting X-ray CT scanner [4] has also been developed.

Without considering the production of characteristic X-rays, the bremsstrahlung X-ray dose rate is proportional to the second power of the tube voltage at a constant tube current. Using a dosimeter with the Si-XD, the dose rate was not proportional to the second power of the tube voltage. If we assume that the dose rate as a function of tube voltage obtained using an ionization chamber is correct, the energy-dependence calibration of the Si-XD is desired.

It is known that the sensitivity of the Si-XD decreased with increasing photon energy. However, because it is not easy to perform energy-dependence calibration using only one Si-XD, the second Si-XD is necessary to increase the high-energy sensitivity. In addition, the sensitivity of the dosimeter increases with increases in the light-receiving surface.

In our research, major objectives are as follows: to develop a compact semiconductor dosimeter with two Si-XDs, to perform photon-energy calibration, to increase the sensitivity, and to measure the time-average X-ray dose rate. Therefore, we developed a compact dosimeter and confirmed the effect of the copper (Cu) filter for increasing the high-energy sensitivity.

2. Experimental methods

2.1. Compact dosimeter

Figure 1 shows the block diagram of a compact dosimeter with two Si-XDs. The two Si-XD are connected to the amplifier module, and the output voltage is input to an analog to digital converter (ADC) in a microcomputer (NXP, LPC11U35). The DC voltage of 5.0 V for the microcomputer is supplied by a personal computer (PC) through a USB cable, and the 3.3-V DC voltage is powered to the amplifier module from the microcomputer (Fig. 2).

The block diagram of the amplifier module with the two Si-XDs is shown in Fig. 3. The Si-XDs are connected in parallel, and the amplifier module consists of a current to voltage (I-V) and voltage to voltage (V-V) amplifiers. The photocurrents flowing through the two Si-XDs are converted into voltage using the I-V amplifier, and the output voltage is amplified using the V-V amplifier. In the I-V amplifier, the output voltage V is given by:

$$V=100\times10^{6}\times I, \quad (1)$$

where I is the total photocurrent flowing through two Si-XDs. The gain of the V-V amplifier is regulated from 100 to 1000 using a variable resistor.

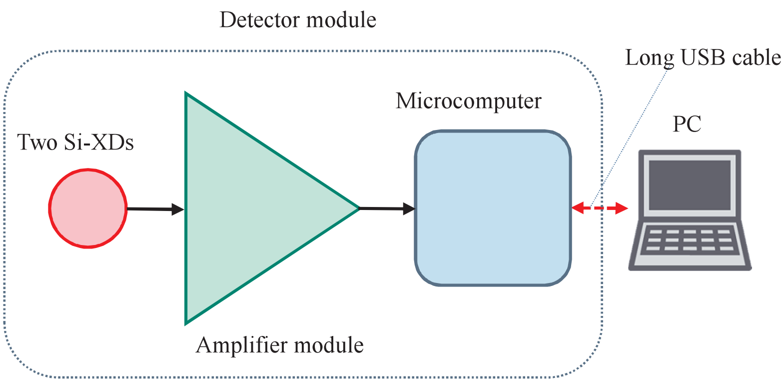

Fig. 1. Block diagram for measuring the X-ray dose rate using two Si-XDs and a PC.

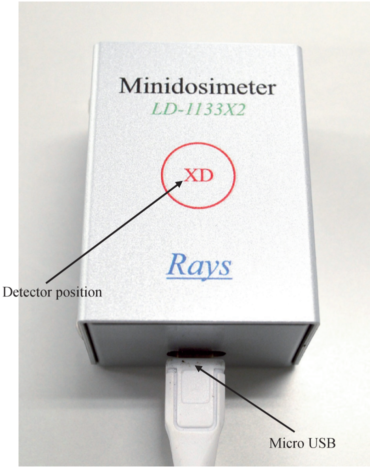

Fig. 2. General view of the semiconductor dosimeter with a micro-USB port.

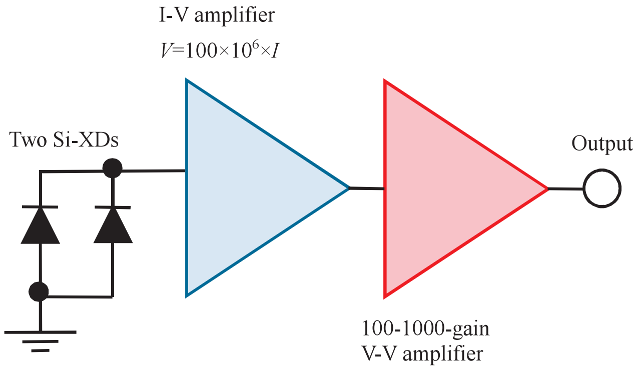

Fig. 3. Block diagram including the electric circuit of the amplifier module with the two Si-XDs.

2.2. Measurement of X-ray dose rate

The standard dose rate was measured using a dosimeter (Toyo Medic, RAMTEC 1000 plus) with an ionization chamber (Scanditronix, DC300). The chamber was placed 1.0 m from the X-ray source at a constant tube current of 30 µA without filtration.

Using the compact dosimeter, the output voltage from the amplifier module is roughly proportional to the X-ray dose rate. To perform the output-voltage to dose-rate conversion, we utilized one-point calibration using both the maximum dose rate and the maximum output voltage at a tube voltage of 109 kV and a current of 30 µA.

Figure 4 shows a main screen of the program for measuring the X-ray dose rate and the integral dose. The dose rate measurement was performed without saturation of the output voltage. First, the output voltage without X-ray exposing was canceled using a Reset icon. After inputting a coefficient for the voltage to dose-rate conversion, the measurement can be carried out using a Start icon. In the dose rate measurement utilizing energy-dependence calibration, a 0.3-mm-thick Cu filter is attached to one Si-XD.

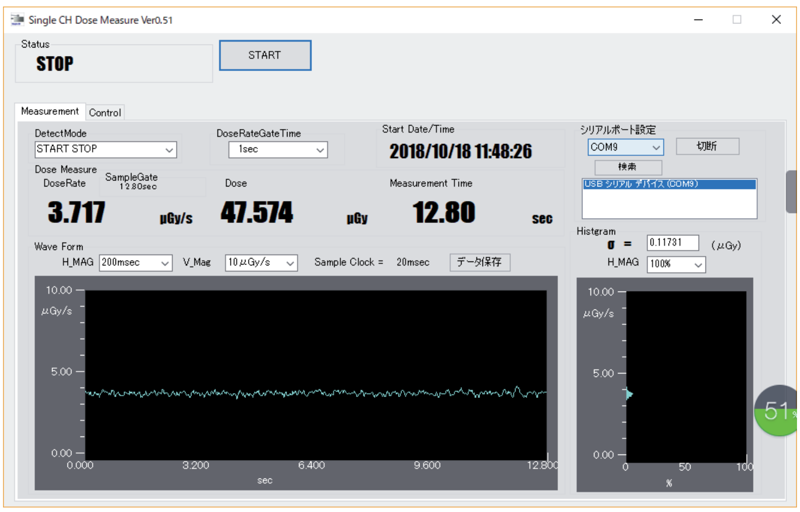

Fig. 4. Main screen of a computer program for measuring X-ray dose rate using the semiconductor dosimeter.

3. Results

Figure 5 shows the X-ray dose rate measured using the ionization chamber with changes in the tube voltage at a tube current of 30 μA. The dose rate roughly increased with increasing tube voltage. The dose rate was not proportional to the second power of the tube voltage. The maximum dose rate was 4.25 μGy/s, and the fluctuations of the rate were observed.

The X-ray dose rate measured using two Si-XDs without filtration is shown in Fig. 6. The dose rate increased with increasing tube voltage and was not in proportion to the second power of the tube voltage. The dose rate was measured as the average value for 10 s, and the dose-rate fluctuations were not observed at all.

Figure 7 shows the dose rate measured using the 0.3-mm-thick Cu filter. The dose rate increased exponentially with increases in the tube voltage, and no fluctuations were observed.

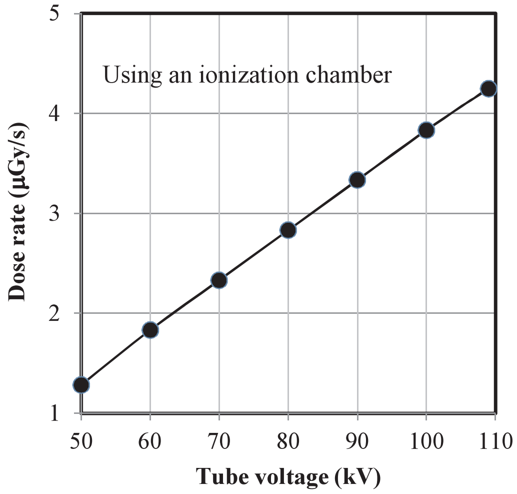

Fig. 5. Standard X-ray dose rate measured using the ionization chamber at 1.0 m from the X-ray source and a tube current of 30 μA.

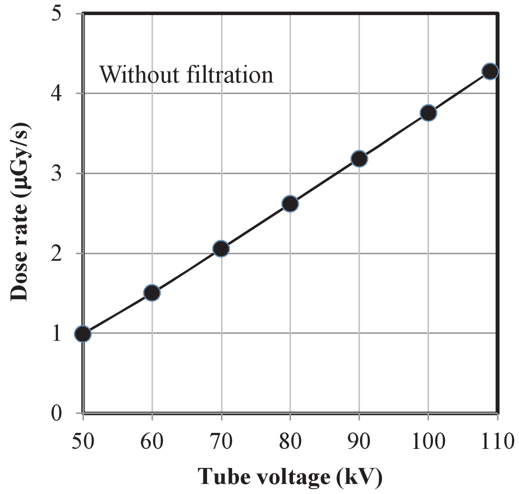

Fig. 6. X-ray dose rate measured using the semiconductor dosimeter with two Si-XDs without filtration at a distance of 1.0 m and a tube current of 30 μA.

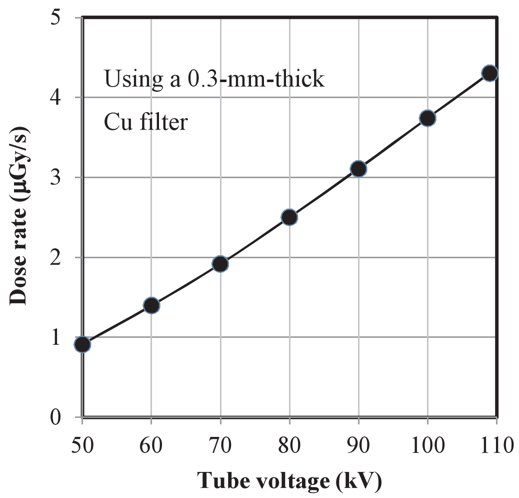

Fig. 7. X-ray dose rate measured using the semiconductor dosimeter and the Cu filter at a distance of 1.0 m and a tube current of 30 μA.

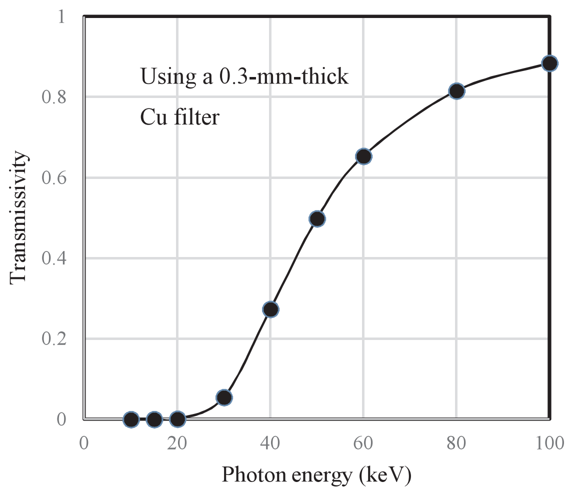

Fig. 8. Transmissivities of the X-ray photons using the 0.3-mm-thick Cu filter.

4. Discussion

In standard, the X-ray dose rate is measured using the ionization chamber, and novel chambers have been developed corresponding to the objectives [5, 6]. However, it is not easy to improve the time response and to reduce the price of the dosimeter. In these regards, using the Si-XDs, the time response is quite short, and the price can easily be reduced.

Figure 8 shows the transmissivity of the X-ray photons as a function of the photon energy using the Cu filter. The transmissivity substantially increases beyond 30 keV and has a value of 0.88 at an energy of 100 keV. Thus, the energy-dependence calibration for high-energy photons beyond 50 keV is accomplished.

At a tube current below 30 μA, the dose rate at 1.0 m from the X-ray source fluctuates. Therefore, the measurement of the time-average dose rate is very useful in the low-dose-rate measurement. Using this dosimeter, the integral dose and the standard deviation can also be measured simultaneously.

In the standard dose-rate measurement, although we used the ionization chamber, it was difficult to measure the rate owing to the fluctuation. Therefore, the ionization chamber with a function for averaging the dose rate should be used in the low-dose-rate measurement.

5. Conclusions

We developed a semiconductor dosimeter using two Si-XDs and performed photon-energy-dependence calibration using a 0.3-mm-thick Cu filter. Utilizing the two-diode method, the sensitivity increased, and several energy calibrations can be carried out by changing the filter element and thickness.

Acknowledgments

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