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Fundamental study on a disposable condenser dosimeter using a skin-insulated USB-A substrate with a silicon X-ray diode in radiation therapy

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Abstract

To monitor patient-skin doses during the course of radiation therapy, a novel disposable condenser dosimeter without a cable using a skin-insulated USB-A substrate with a silicon X-ray diode (Si-XD) was developed. X-ray-dose measurements were performed at 4 and 10 MV using a medical linear accelerator. The condenser dosimeter consists of a low-priced USB-A mini-substrate and a microcomputer dock. The condenser in the substrate is charged to 3.23 V using the dock before irradiation. The charging voltage is reduced by photocurrents flowing through the Si-XD during the irradiating. After the irradiation, the substrate is inserted into the dock again, and measured the discharging voltages. Thermoluminescence dosimeter (TLD) was used to convert the discharging voltages into doses. Using the condenser dosimeter, the doses were proportional to decreases in the charging voltage. To determine the absolute dose of the condenser dosimeter, one-point calibration using the maximum dose might be desired.

Keywords：condenser dosimeter; disposable USB-A substrate; surface dose; Si X-ray diode; radiation therapy

1. Introduction

Currently, ionization chambers are used widely for measuring absorbed dose in radiation therapy. However, it is not designed to monitor the patient-skin dose during the irradiation course. The skin disorder is often a problem in radiation therapy [1], and it is also known that the absorbed-dose distribution in the patient changes due to the tumor shrinkage and weight loss [2, 3]. Therefore, the measurement of surface doses using a dosimeter is important for monitoring the patient-skin dose, and there is a clinical need for the development of a novel mini dosimeter that can measure the surface dose easily without a cable.

Lately, we have developed a condenser dosimeter without a cable using a surface-mounting mini-substrate with a silicon X-ray diode (Si-XD). We confirmed that the Si-XD dosimeter can measure the doses with small

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standard deviations (SDs) using a low-energy X-ray tube [4, 5], since various X-ray tubes are used clinically to improve the accuracy of dose delivery [6, 7]. In this research [5], we measured the surface dose of photons below 100 keV. Thus, we have to confirm the sensitivity of high-energy X-ray photons for the radiation therapy.

The Si-XD is useful for discharging electric charges in the condenser, and the substrate dimensions can be reduced below 20×20 mm^2 to stick on a patient. In addition, the electric circuit is insulated from the skin of patient by surface mounting, and the substrate may be disposable corresponding to each patient. To measure the dose using the condenser dosimeter with the Si-XD, an optimal dock for charging condenser and for measuring the charging voltage is desired. In this regard, a small high-performance microcomputer was used to construct the dock. Regarding the condenser dosimeter, since high doses can be measured by increasing condenser capacity, we made 0.1- and 1.0-μF-condenser substrates with Si-XDs to determine the optimal condenser capacity used in the radiation therapy. And we performed X-ray-dose measurements at 4 and 10 MV accelerating voltages using a medical linear accelerator (linac) to carry out a fundamental study on this developed disposable condenser dosimeter.

2. Materials and Methods

2.1 Condenser dosimeter

Fig. 1 shows the block diagram including the electric circuit for measuring the dose using a substrate, a microcomputer (mbed LPC11U24, NXP) dock, and a personal computer (PC). When the substrate is inserted into the mbed dock, a condenser in the substrate is charged up to 3.23 V using a pin 10 (P10) in the mbed. The condenser charging voltage is measured using an analog to digital converter (ADC) of pin 20 (P20) [Fig. 1(a)], and the P10 is switched to high impedance after 5.0 s from fully charging. Next, the substrate is removed from the dock and set on the measurement point [Fig. 1(b)]. When the substrate with the charged condenser is exposed to the X-rays, the condenser is discharged by the photocurrents flowing through the Si-XD. After irradiating X rays, the substrate is inserted into the dock again, and the condenser charging voltage is measured using the P20 [Fig. 1(c)]. The dock with a mini-USB port is connected to the PC through a USB cable, and both the condenser charging and the measuring voltages are controlled by the PC.

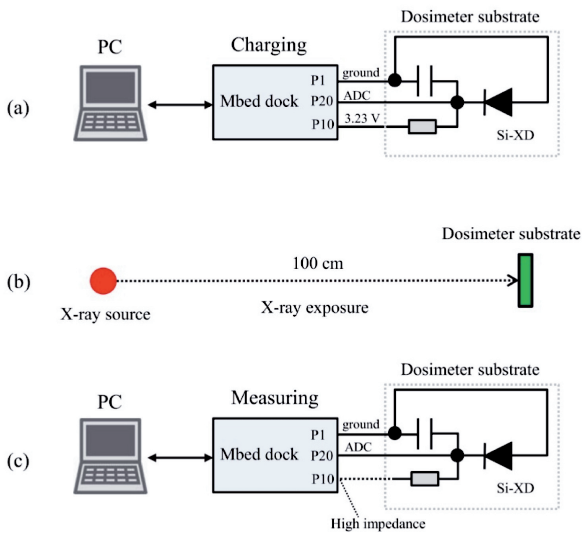

Fig. 1 Methods for measuring the dose using a mini-substrate, an mbed dock, and a PC. The equivalent circuits of the substrate is shown in the same figure. (a) The condenser in the substrate is charged up to 3.23 V by a P10 in the dock, and the condenser charging voltage is measured using an ADC of P20. (b) The substrate is set at an SSD of 100 cm with open fields of 10×10 cm^2 and irradiated by a medical linear accelerator. (c) The substrate is inserted into the dock, and the condenser charging voltage is measured using the P20. Then the dose is calculated using the PC program.

The dosimeter consists of the USB-A substrate with dimensions of 24×14 mm^2, the mbed dock, and the PC [Fig. 2]. The substrate is of a surface-mounting type to insulate skins from the circuit and consists of a 0.1 or 1.0 μF condenser, a Si-XD (S1087-01, Hamamatsu) with photosensitive dimensions of 1.3×1.3 mm^2, and a 10 kΩ resistor. In the Si-XD, X-ray photons are detected directly by a Si diode, and scattered photons including fluorescence from the ceramic are also detected by the Si diode. The Si-XD is shaded using a 25-μm-thick aluminum tape, and the penetrating X-ray photons through the tape are detected using the Si-XD.

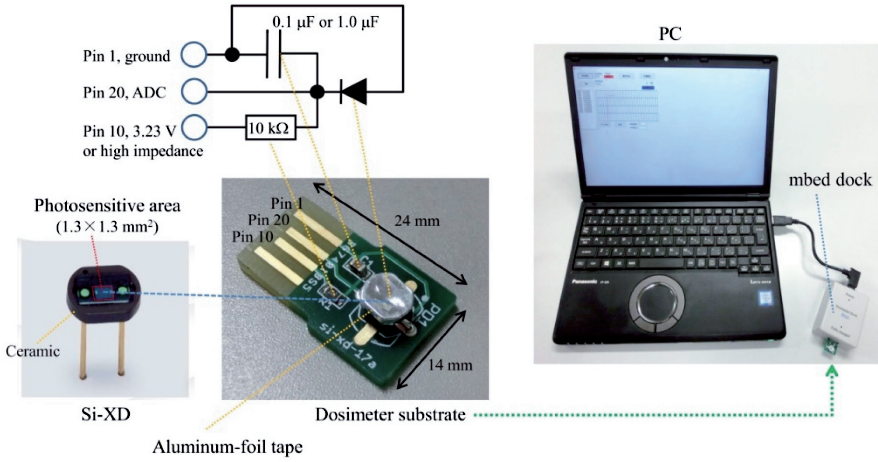

Fig. 2 General view of the condenser dosimeter, the substrate, and its electric circuit.

Fig. 3 shows experimental setup for measuring the dose using the substrate and the linac (Clinac iX, Varian Medical Systems). The dose measurements were performed using 4 and 10 MV X-ray beams with open fields of 10×10 cm^2 ranging from 25 to 200 MU. The dose rates of the beams described above are 250 and 300 MU/min. Both the condenser substrates with 0.1 and 1.0 μF condensers are placed simply on a solid water phantom. The overall sizes of the phantom are 30×30×10 cm^3, and the source-to-surface distance (SSD) is 100 cm.

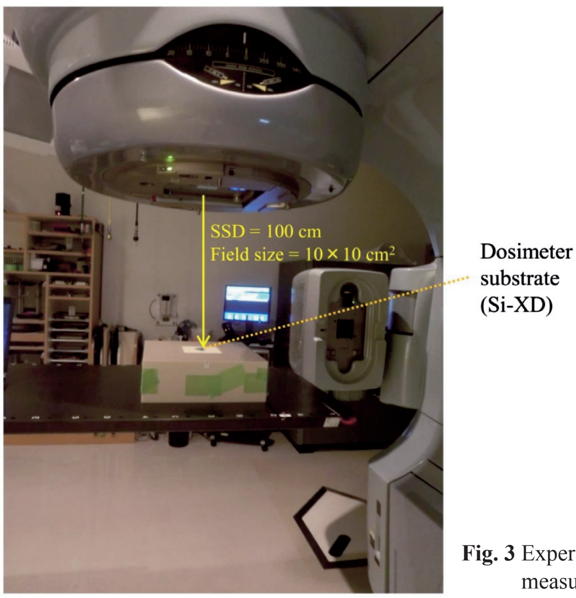

Fig. 3 Experimental setup for measuring doses using the substrate. The dose measurements were performed using 4 and 10 MV X-ray beams.

2.2 Standard dose measurement

The measurement of X-ray dose using an ionization chamber is important to convert discharging voltages into doses. However, the surface dose measurement is quite complicated according to the detector design, and appropriate calibrations are needed for most detectors [8]. In this experiment, we used a thermoluminescence dosimeter (TLD) (LTD Reader 1500, Kyokko) with elements of MSO-S; the diameter and length of the element are 2 and 12 mm, respectively. The absolute doses are calculated as the air-kerma (Gy). Before the X-ray irradiation, the elements are annealed using an oven at a temperature of 300°C and an annealing time of 30 min. The elements were set on the solid water phantom at an SSD of 100 cm same as the measurement condition using the condenser substrate, and we measured the doses using 4- and 10-MV X-ray beams with open fields of 10×10 cm^2 at the MU values of 50 and 100.

3. Results

3.1 Standard dose

Table 1 shows the average doses and SDs measured using the three TLD elements at the indicated conditions. The maximum doses were 0.61 and 0.29 Gy using the 4 and 10 MV X-ray beams, respectively. Using the TLD, we could not measure doses beyond 200 MU owing to over scaling.

Table 1 Average doses and their SDs measured using the TLD reader at the indicated conditions and accelerating voltages of (a) 4 MV and (b) 10 MV.

(a) 4 MV TLD measurement (SSD = 100 cm Field size = 10×10 cm^2)

	TLD lot number			Dose (Gy)	
MU	1	2	3	Average	SD
50	0.31	0.27	0.28	0.29	0.025
100	0.66	0.54	0.65	0.61	0.068

(b) 10 MV TLD measurement (SSD = 100 cm Field size = 10×10 cm^2)

	TLD lot number			Dose (Gy)	
MU	1	2	3	Average	SD
50	0.12	0.16	0.19	0.16	0.031
100	0.25	0.34	0.27	0.29	0.044

Fig. 4 presents the doses measured using the TLD reader at an SSD of 100 cm, and the average doses were proportional to the MU.

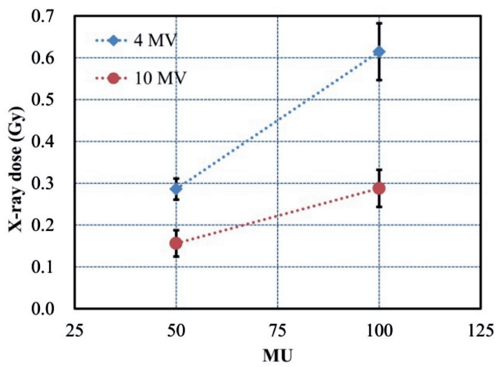

Fig. 4 Absolute doses measured using the TLD reader with elements placed 100 cm from the X-ray source.

3.2 Condenser charging voltage

Table 2 shows the average values of the condenser charging voltages and their SDs at the indicated conditions. The voltage measurements were performed three times, and the maximum SD was 5×10^{-3} V. Therefore, the condenser-discharging voltages corresponding to the doses were quite stable, and the dose measurement could be carried out.

Table 2 Average condenser voltages and their SDs at the indicated conditions. Using a 4 MV X-ray beam with condenser capacities of (a) 1.0 µF and (b) 0.1 µF. Using a 10 MV X-ray beam with capacities of (c) 1.0 µF and (d) 0.1 µF.

(a) 4 MV 1.0µF Si-XD (SSD = 100 cm Field size = 10×10 cm^2)

		Charging voltage Vc (V)	
MU	Measurement times	Average	SD
25	3	3.26	0.003
50	3	3.21	0.003
100	3	3.13	0.004
200	3	2.98	0.002
300	3	2.83	0.002

(b) 4 MV 0.1µF Si-XD (SSD = 100 cm Field size = 10×10 cm^2)

		Charging voltage Vc (V)	
MU	Measurement times	Average	SD
25	3	2.94	0.002
50	3	2.53	0.002
100	3	1.81	0.002
200	3	0.38	0.004
300	3	0.00	0.000

(c) 10 MV 1.0µF Si-XD (SSD = 100 cm Field size = 10×10 cm^2)

		Charging voltage Vc (V)	
MU	Measurement times	Average	SD
25	3	3.25	0.004
50	3	3.24	0.004
100	3	3.20	0.002
200	3	3.12	0.004
300	3	3.03	0.004

(d) 10 MV 0.1µF Si-XD (SSD = 100 cm Field size = 10×10 cm^2)

		Charging voltage Vc (V)	
MU	Measurement times	Average	SD
25	3	3.04	0.002
50	3	2.87	0.005
100	3	2.46	0.002
200	3	1.66	0.002
300	3	0.88	0.002

The condenser charging voltages using 0.1 and 1.0 µF condensers are shown in Fig. 5. Both the condenser charging voltages decreased with increasing MU.

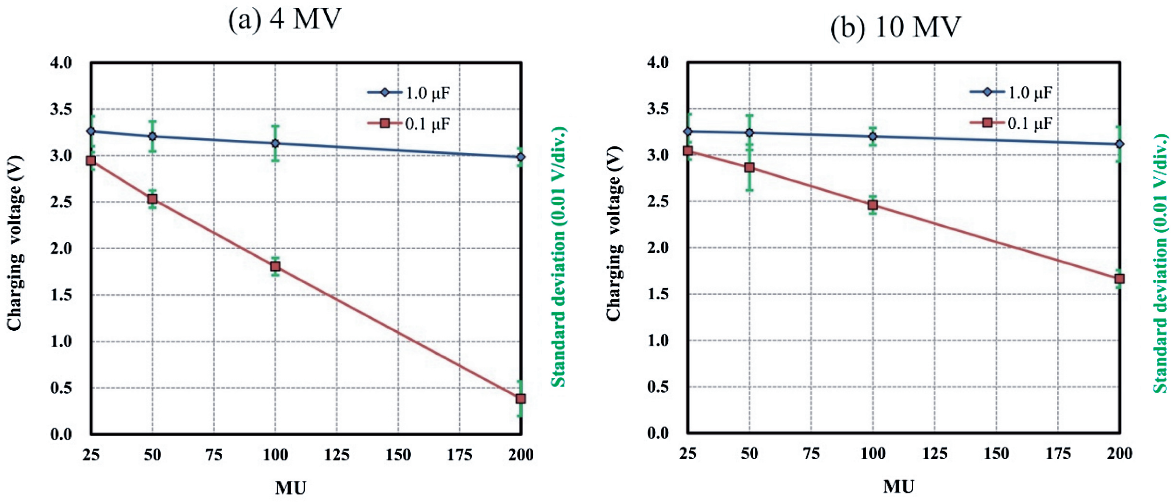

Fig. 5 Condenser charging voltages after irradiating X-rays at the indicated conditions. The charging voltage is reduced by irradiating X-rays. Variations with X-ray beams of (a) 4 MV and (b) 10 MV.

3.3 Surface doses using substrate

Fig. 6 shows the X-ray doses measured by the 0.1-µF-condenser substrate using 4 and 10 MV X-ray beams with changes in the MU. The absolute value of the dose was determined by one-point calibration using maximum values of 0.61 and 0.29 Gy. At a constant accelerating voltage of 4 MV, the dose increased with increasing MU [Fig. 6(a)]. Subsequently, the dose also increased with increases in MU at a constant voltage of 10 MV [Fig. 6(b)]. The doses of 4 MV were approximately twice those of 10 MV due to the difference of build-up region.

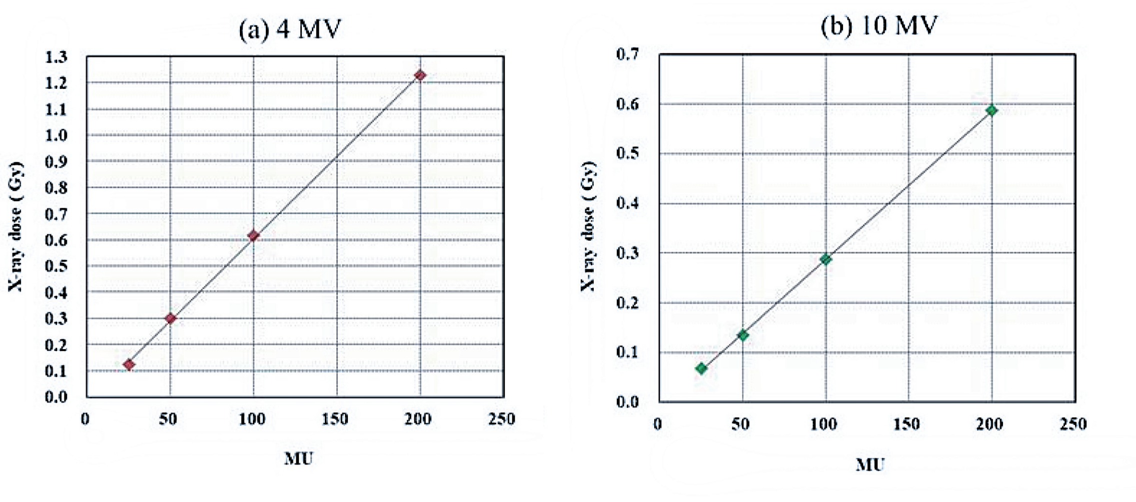

Fig. 6 Measured doses determined by one-point calibration using the maximum values with changes in the MU at accelerating voltages of (a) 4 MV and (b) 10 MV.

The doses determined by two-point calibration using both the maximum and minimum doses for 4 and 10 MV beams are shown in Fig. 7. At a constant accelerating voltage, the dose increased with increasing MU. However, the doses at a 0 MU were not 0 Gy owing to the TLD characteristics.

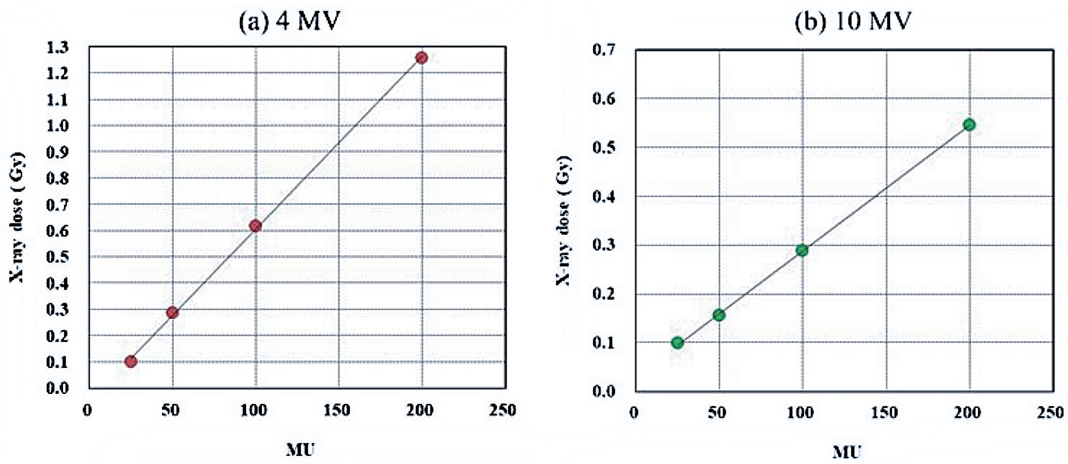

Fig. 7 Measured doses determined by two-point calibration using the maximum and minimum values with changes in the MU at accelerating voltages of (a) 4 MV and (b) 10 MV.

4. Discussion

The charging-voltage decreases using the 1.0 μF condenser were much smaller than those using the 0.1 μF, and the 0.1 μF-condenser substrate was used for the dose calibration and measurement. Utilizing one-point calibration, the minimum dose of 0 Gy at 0 MU was used, and the doses were proportional to the MU values. Utilizing two-point calibration, the minimum dose was not 0 Gy, and the one-point calibration might be useful for determining the doses using the condenser dosimeter. In addition, it is necessary to determine the calibration factor using one-point calibration, since 0 Gy should be used at 0 MU.

Using the ionization chamber, it is not easy to measure the surface dose owing to large dimensions. Therefore, we used the TLD dosimeter instead of the chamber, and the energy dependence of the TLD element is almost constant at the high-energy region.

In the absolute dose measurements, it was difficult to measure the doses beyond 200 MU using our TLD reader. Furthermore, the SDs measured by TLD were larger than those using the condenser dosimeter with Si-XDs. Therefore, the condenser dosimeter might be useful for measuring doses with high accuracies when the absolute doses are determined correctly.

Using the silicon X-ray diode, it is easy to measure the low-energy photons. In addition, high-energy photons using a medical linear accelerator could also be measured, since the high-energy photons are scattered by the ceramic substrate behind the silicon diode, and scattered low-energy photons from the substrate are absorbed by the silicon.

Since the height of Si-XD in the substrate is 5 mm, it is impossible to measure the patient-skin dose directly using this substrate. However, the measured surface doses should be proportional to the patient-skin doses. It suggests that this condenser dosimeter is useful for monitoring the skin-dose variations during the radiation therapy.

The sensitivity of the condenser dosimeter increases with decreases in the condenser capacity and to increase in the photoelectric area of the Si-XD. In addition, a Darlington transistor for the Si-XD will be useful to amplify the photocurrent and to improve the detector sensitivity.

Using a USB-A connector, we could easily measure the charging voltage after irradiating X-rays immediately; the mbed is connected to the PC using a mini-USB connector. Therefore, we have realized a low-priced dosimeter system in conjunction with a PC.

5. Conclusions

We developed a condenser-discharge dosimeter with a USB-A mini-substrate and a low-cost mbed dock for charging and measuring the voltage. The Si-XD substrate is of a surface-mounting type, and the patient's skin is insulated from the circuit. The doses were proportional to decreases in the charging voltage, and it was possible to measure the doses beyond 1.0 Gy using 4 and 10 MV X-ray beams from the linac. To measure the dose variations using the TLD reader, the one-point calibration using the maximum dose should be used.

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Declarations of interest: none

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