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Low-dose measurement with a MOSFET in high-energy radiotherapy applications

Tsang Cheung[a], Peter K.N. Yu[a], Martin J. Butson[a, b, *]

[a]*Department of Physics and Materials Science, City University of Hong Kong, Kowloon Tong, Hong Kong*
[b]*Department of Medical Physics, Illawarra Cancer Care Centre, P.O. Box 1798, Crown St, Wollongong, NSW 2500, Australia*

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Abstract

The ability of a MOSFET dosimetry system to measure low therapeutic doses has been evaluated for accuracy for high-energy X-ray radiotherapy applications. The MOSFET system in high sensitivity mode produces a dose measurement reproducibility of within 10%, 4% and 2.5% for 2, 5 and 10 cGy dose assessment, respectively. This is compared to 7%, 4% and 2% for an Attix parallel plate ionisation chamber and 20%, 7% and 3.5% for a Wellhofer IC4 small volume ionisation chamber. Results for our dose standard thimble ionisation chamber and low-noise farmer dosimeter were 2%, 0.5% and 0.25%, respectively for these measurements. The quoted accuracy of the MOSFET dosimetry system is partially due to the slight non-linear dose response (reduced response) with age of the detector but mainly due to the intrinsic variations in measured voltage differential per applied dose. Results have shown that the MOSFET dosimetry system provides an adequate measure of dose at low dose levels and is comparable in accuracy to the Attix parallel plate ionisation chambers for relative dose assessment at levels of 2–10 cGy. The use of the MOSFET dosimeter at low doses can extend the life expectancy of the device and may provide useful information for areas where low dose assessment is required.

Keywords: MOSFET; Dosimetry; High-energy X-rays

1. Introduction

Assessment of dose for radiotherapy applications is performed with various type of detectors which are used in specific applications depending on the physical and radiation characteristics (Butson et al., 2003). A Metal Oxide Semiconductor field effect transistor (MOSFET) device has the feature of integrating dose measurements as well as allowing immediate dose readout (Thomson et al., 1984). Combining this with a very small sensing volume provides many advantages for a MOSFET dosimetry system in radiotherapy. As such the MOSFET detectors are finding applications in radiotherapy dosimetry (Butson et al., 1996; Bloemen-van Gurp et al., 2003; Kron et al., 2002; Rosenfeld, 2002; Chuang et al., 2002; Quach et al., 2000). One limiting factor for MOSFET dosimetry is its limited life span where after a large accumulated dose, the linearity of the detector decreases requiring larger doses for the same differential potential change. As such we have investigated a relatively new MOSFET dosimetry system for accuracy at low applied doses (less than 10 cGy) using high-energy X-rays produced by a pulsed radiation linear accelerator which could prolong the life of the MOSFET detectors without severely compromising accuracy of results.

* Corresponding author. Department of Medical Physics, P.O. Box 1798, Wollongong, NSW 2500, Australia. Fax: +61-2-422-659-97

E-mail address: butsonm@iahs.nsw.gov.au (M.J. Butson).

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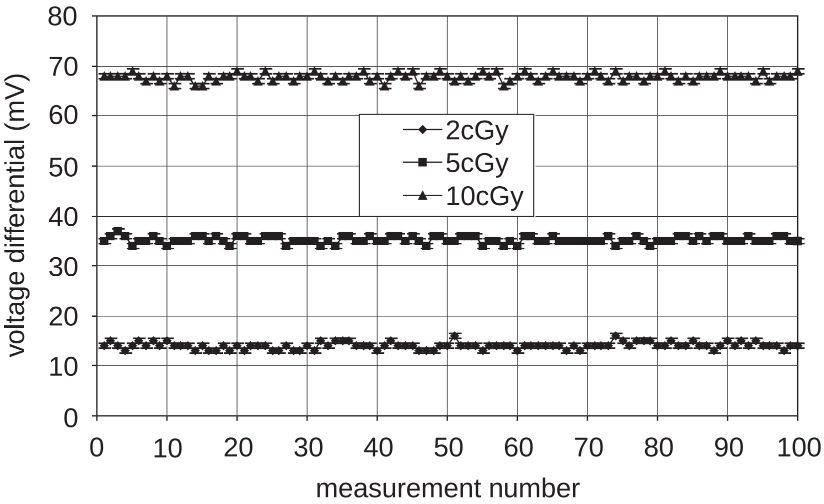

Fig. 1. Accuracy and short term reproducibility of a CSDS MOSFET dosimetry system at low applied doses.

2. Materials and methods

The "clinical semiconductor dosimetry system" (CSDS) MOSFET dosimetry system evaluated for low dose assessment is a commercially available system manufactured by the Centre for Medical Radiation Physics (CMRP), University of Wollongong, NSW, Australia. It employs an integrating MOSFET with two p-MOSFET devices on the same chip, which are sourced from REM oxford UK (Holmes-Siedle, 2001). The system is capable of reading 10 MOSFETS on line with results sent directly to computer via a RS232 connection. A dual bias MOSFET probe can be used which employs k-type and r-type MOSFETS with gate bias voltage of +12 and +5 V, respectively. The control software and internal microprocessor corrects for any drift of the MOSFET threshold voltage due to slow border states induced by radiation and thermal effects (Savic et al., 1995; Rosenfeld et al., 2001). Results for low dose assessment were made with the high sensitivity sections of the probe (i.e. 12 V bias MOSFET). Measurements were made to analyse the devices accuracy for low applied doses. This was performed in a solid water phantom moulded to fit the device at $D_{\max}$ using a 6 MV X-ray beam in standard conditions. Doses of 2, 5 and 10 cGy were delivered to the device for 100 consecutive measurements. Measurements were also performed to produce a dose calibration curve for assessment of up to 10 cGy in 1 cGy increments. Similar easurements were performed for various types of ionisation chambers for comparison of accuracy. This was performed with a Farmer 2570/1 dose meter (in all cases) along with a 0.6 cc thimble chamber, an Attix Parallel plate chamber and a Wellhofer IC4 small volume chamber.

Table 1
Accuracy (%) of MOSFET dosimetry system and standard ionisation chambers (with 95% confidence limit at quoted dose level cGy)

Dosimeter	2	5	10
UOW MOSFET system	9.8	3.8	2.3
Thimble ionisation chamber	1.6	0.5	0.3
Attix ionisation chamber	8.0	3.5	1.5
IC4 ionisation chamber	20	7.2	3.6

3. Results

Fig. 1 shows the reproducibility of the UOW MOSFET dosimetry system for irradiated dose levels of 2, 5 and 10 cGy at 6 MV X-ray energy. Hundred consecutive irradiations were performed under the same irradiation conditions to highlight any variations in voltage differential which occur for low dose assessment. Table 1 shows the average differential voltage measured for each dose level, 2 standard deviations of the mean and the percentage mean error in measurement at this dose level. Also quoted are results for the same dosed levels for a standard calibration thimble ionisation and dose meter system, an Attix Parallel plate ionisation chamber and a small volume, IC4 ionisation chamber. Results show that the level of accuracy that can be achieved with 95% confidence is approximately 10%, 4% and 2.5% using the MOSFET device at 2, 5 and 10 cGy, respectively. The standard deviations measured in absolute terms are approximately the same for all dose levels and as such represent a noise level within the dosimetry system irradiated

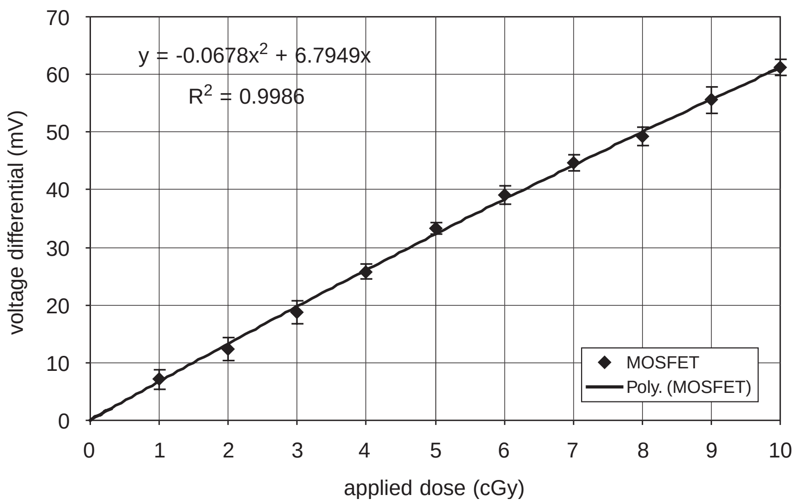

Fig. 2. CSDS MOSFET dose response curve for 6 MV X-rays up to 10 cGy applied dose.

in standard clinical conditions. This is influenced by factors such as the thermal variance of the system as well as electrical and radio frequency interference from surrounding linear accelerator components and associated equipment. This level of accuracies are comparable to the Attix ionisation chamber and superior to the IC4 small volume chamber. The thimble chamber results represents our highest achievable reproducibility within our department under standard irradiation conditions assuming correct absolute calibration of monitor unit to dose conversion parameters on the linear accelerator.

Fig. 2 shows a dose response curve for the CSDS MOSFET dosimetry system at low dose assessment of 6 MV X-rays. Results are given for doses up to 10 cGy applied dose irradiated in standard conditions. A slightly non-linear relationship (2nd order polynomial) was found for dose response over this low dose range, however, a linear line of best fit could also be used and lies within the error limits of measurements. By using small applied doses during irradiation evaluations, the life span of a MOSFET device can be prolonged. Also the MOSFET device could be used for relatively small dose assessment. This may be important for areas such as peripheral dose assessment or IMRT field segment dose assessment whereby a small dose segment is delivered and verified. The non-linearity response of the MOSFET with accumulated dose effect can be seen by a comparison of results given in Figs. 1 and 2. Results for 10 cGy applied dose in Fig. 1 is approximately 68 mV potential differential where as in Fig. 2, 10 cGy is approximately 62 mV potential differential. Results quoted in Fig. 1 were performed in the early life of the MOSFET detectors whereas results quoted in Fig. 2 were performed at a later stage of the MOSFETs life. It is estimated that an approximate accumulated dose of 30 Gy had been applied to the MOSFET detector in between the quoted experimental results. The approximate 10% decrease in dose response in absolute terms over this dose range is not a problem when small applied doses are used for analysis but highlights the fact that calibration standards should be performed at the same time as experimental results to provide the highest level of dose assessment accuracy. Due to its high spatial resolution and ease of readout, a MOSFET dosimeter can be a highly useful device in radiation dosimeter especially in areas of steep dose gradients. Although, the MOSFET dosimeter is not as accurate by any means compared to a farmer-type thimble ionisation chamber. Its accuracy is however comparable to the Attix parallel plate ionisation chambers at these low dose levels and superior to the IC4/Farmer dose meter combination. As such the CSDS MOSFET dosimetry system provides an adequate measure of dose at low dose levels for high-energy photon beam irradiations used for therapy applications. This may be beneficial to prolong the life of the MOSFET detectors when matching the required level of accuracy to applied doses.

4. Conclusions

The CSDS MOSFET dosimetry system provides an adequate dose assessment at low dose levels with an accuracy of less than 10%, 5% and 2.5% within 95% confidence for 2, 5 and 10 cGy applied doses, respectively. This is comparable to the Attix ionisation chambers used at these dose levels. As such the CSDS MOSFET dosimetry system provides an adequate measure of dose at low dose levels for high-energy photon beam irradiations used for therapy applications and may be beneficial to prolong the life of the MOSFET detectors when matching the required level of accuracy to applied doses.

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