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SCIENTIFIC NOTE

Energy dependence corrections to MOSFET dosimetric sensitivity

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Abstract

Metal Oxide Semiconductor Field Effect Transistors (MOSFET's) are dosimeters which are now frequently utilized in radiotherapy treatment applications. An improved MOSFET , clinical semiconductor dosimetry system (CSDS) which utilizes improved packaging for the MOSFET device has been studied for energy dependence of sensitivity to x-ray radiation measurement. Energy dependence from 50 kVp to 10 MV x-rays has been studied and found to vary by up to a factor of 3.2 with 75 kVp producing the highest sensitivity response. The detectors average life span in high sensitivity mode is energy related and ranges from approximately 100 Gy for 75 kVp x-rays to approximately 300 Gy at 6 MV x-ray energy. The MOSFET detector has also been studied for sensitivity variations with integrated dose history. It was found to become less sensitive to radiation with age and the magnitude of this effect is dependant on radiation energy with lower energies producing a larger sensitivity reduction with integrated dose. The reduction in sensitivity is however approximated reproducibly by a slightly non linear, second order polynomial function allowing corrections to be made to readings to account for this effect to provide more accurate dose assessments both in phantom and in-vivo.

Key words MOSFET, radiotherapy, energy response, sensitivity, in-vivo dosimetry

Introduction

Phantom and In-vivo dosimetry during radiotherapy applications is an integral part of the radiotherapy treatment process. Traditionally in-vivo dosimetry has been performed with detectors such as Thermo luminescent Dosimeters (TLD's)[1,2] and diodes[3,4]. Newer devices such as radiochromic films[5-7] and Metal Oxide Semiconductor Field Effect Transistors (MOSFET's) are now being used for in-vivo dosimetry procedures.

A MOSFET device has the feature of integrating dose measurements as well as allowing immediate dose readout [8] .Combining this with a very small sensing volume provides many advantages for a MOSFET dosimetry system in radiotherapy. As such, MOSFET detectors are finding applications in radiotherapy radiation dosimetry[9-16]. They have also been used commonly for in-vivo dosimetry[17-19] .

MOSFET detectors operational principles have been examined and described by many authors[20-22]. In summary, a MOSFET's dosimetric ability relies on the measurement of its threshold voltage. By applying a sufficiently large voltage to the MOSFET's silicon gate, a significant number of holes will be attracted to the oxide/silicon surface from the silicon substrate as well as the source and drain regions. When a sufficient concentration of holes has accumulated, a conduction channel is formed, allowing current to flow between the source and drain. The voltage necessary to initiate current flow is known as the threshold voltage. Further information is available in Rosenfeld et al 2001[21].

As MOSFET devices are not water equivalent and have a higher Z we expect the detectors to exhibit a varying sensitivity to dose response with applied energy. The energy dependence of course is expected to be dependant not only on the Silicon oxide layers but the complete detectors construction. That is, the sensitive oxide layers used contribute to the energy dependence as well as the materials used in the construction of the substrate and the detector's housing. As such each type of MOSFET detector can exhibit a different sensitivity response to dose with varying energy. This scenario is similar to other detectors like radiochromic film[23-27] whereby differing construction methods produce different energy responses. This work aims to investigate this effect for a newly redesigned MOSFET commercially available from the University of Wollongong, the CSDS MOSFET dosimetry system. Another aspect of MOSFET dosimetry is the sensitivity dependence to integrated dose history of a MOSFET device. It is known in general that the sensitivity of the device can change with dose history[28-29]. We also plan to investigate this effect using the newly designed CSDS MOSFET devices at superficial, orthovoltage and megavoltage x-ray energies for comparison.

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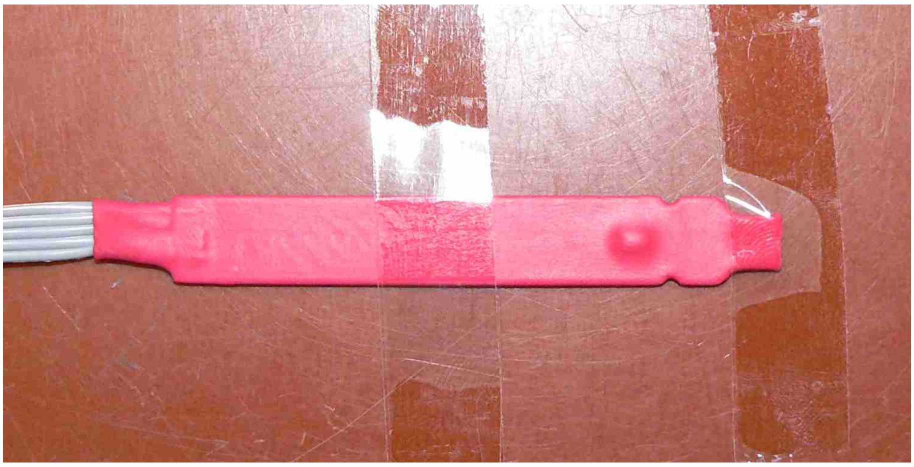

Figure 1. *Picture of the CSDS MOSFET detector. The dimensions of the active detector and packaging materials are 10mm x 60mm x 1mm thick.*

Materials and methods

The MOSFET device tested for energy and sensitivity functionality is the Clinical Semiconductor Dosimetry System (CSDS), a commercially available system manufactured by the Centre for Medical Radiation Physics (CMRP), University of Wollongong (UOW), NSW Australia. It employs the use of dual k type RADFET's on an epoxy bubble surrounding[30]. The system is capable of reading 10 MOSFET's on line with results sent directly to computer via an RS232 connection. Recently these detectors have been modified and repackaged using the more tissue equivalent epoxy surrounding to the active MOSFET chip. This may affect the energy dependence characteristics of the device from the older style devices available from the UOW[31]. The CSDS system and the UOW also have other types of MOSFET devices packaged suitable for other applications, such as the MOSKIN detector[32] which is a surface/ skin dose dedicated device. Figure 1 shows the MOSFET device used and its packaging material. The detectors dimensions (active crystal and packaging) 10 mm wide x 60mm long x 1 mm thick. It is used, whilst connected to a bias voltage packet at + 5 Volts.

Experiments were performed to measure the energy dependant response of the MOSFET device to x-ray in the energy range of 50 kVp to 10 MVp. For dose delivery, the MOSFET's were positioned in a dedicated holder in a solid water phantom of dimensions 30cm x 30cm x 30cm. The phantom was placed on a Gulmay[+] D3300 orthovoltage machine and a Varian 2100C linear accelerator and films were given various absorbed doses from 1 Gy to 5 Gy. Irradiations were performed at the position of Dmax for each beam. This was at the surface for the kilovoltage beams, 1.5 cm for 6 MV and 2.5 cm for 10 MV. The phantom size used provided ample backscatter material for full scatter conditions. The absorbed dose calibrations were performed with a Farmer thimble-type ionization chamber according to the IPEMB protocol for kilovoltage x-rays[33] and IAEA TRS-398 protocol for megavoltage x-rays[34]. The delivered doses were dose to water and no corrections were applied for the influence of solid water or MOSFET device material on absorbed dose. The equivalent photon energy[35] of each beam was calculated from half value layer (HVL) measurements. The beam qualities used were 50kVp, 75kVp, 100kVp, 125kVp, 150kVp, 200kVp, 250kVp, 6MV and 10MV. These energies were found to have equivalent photon energies of 25.2keV, 30keV, 36keV, 54keV, 69keV, 95keV, 123keV, 1400keV, 2200keV respectively. 5 different detectors were analysed at various stages of their radiation life for energy dependence response. Experiments were also performed to evaluate the sensitivity response changes of the MOSFET devices in relation to beam energy and the dose history of the detector. This was performed by exposing the MOSFET to known doses and charting the change in threshold voltage as a function of MOSFET dose history. This was performed on 5 MOSFET's at 3 x-ray energies, 100kVp, 250 kVp and 6MVp.

Results and discussion

Figure 2 shows the measured energy dependence of the new CSDS MOSFET Dosimetry system detectors when exposed to x-rays in the energy range of 50 kVp to 10 MV. No noticeable differences were seen in energy dependence due to the radiation dose history of the MOSFET device for the 5 detectors investigated. The figure shows the photon equivalent energy values for the x-ray beams which is the monoenergetic equivalent x-ray energy which produces the closest match to depth dose characteristics of the beams in question. The highest level of sensitivity is seen with photon energy of 75 kVp and a decrease in sensitivity at lower and higher energies from this point. When normalized to 1 at 6 MV x-ray energy the CSDS MOSFET detectors produce up to a 3.2 times over response at 75 kVp energy. In comparison, results for T&N (Thomson and Nielsen) MOSFET's were 4.3 at 31 keV equivalent and silicon diodes were 6.43 at 49 keV[36]. Thus these devices are comparable if not slightly lower in energy response to

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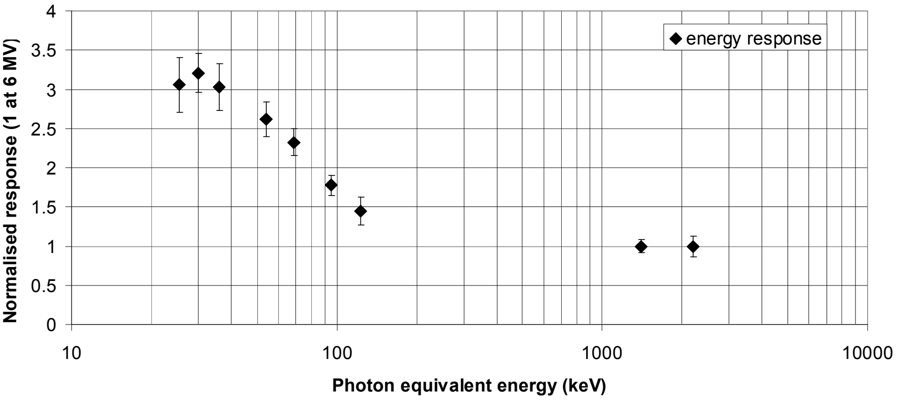

Figure 2. *Energy dependant response of the CSDS MOSFET device to x-ray energy ranging from 50 kVp up to 10 MV. The highest sensitivity was seen at 75 kVp and produced a response approximately 3.2 times that as measured at 6 MV x-ray energy.*

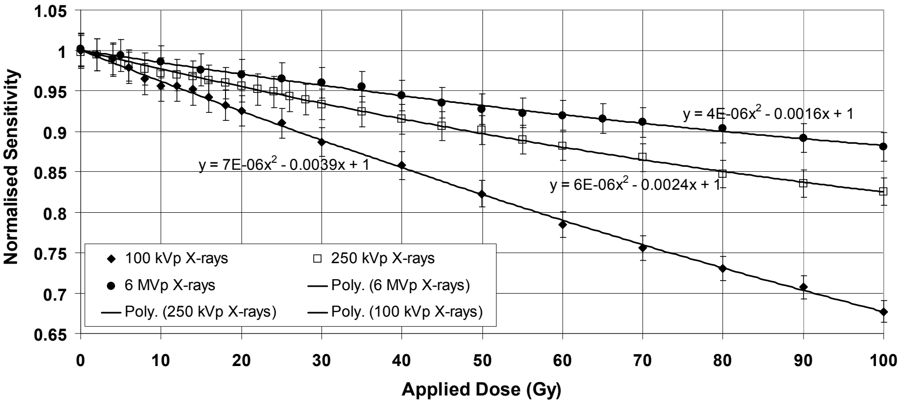

Figure 3. *Sensitivity ratio of the CSDS MOSFET device as a function of integrated dose history of the device at various selected x-ray energies. Of note is the increased reducing in sensitivity at superficial energies compared to megavoltage energy. The decrease is however reproducible and thus correctible.*

standard in-vivo semiconductor dosimeters used in Radiotherapy applications.

One aspect of MOSFET dosimetry is an inherent decrease in sensitivity with applied dose that is seen for any given dosimeter. This is known to be caused by alterations in the effective electric field applied to the MOSFET during irradiations which causes an accumulation of holes at the Si-SiO2 interface[28]. Depending on the performance characteristics of the MOSFET device, eg, dual versus singular bias voltage) this effect can be larger or smaller for an individual type of device[29]. Figure 3 shows the decreasing sensitivity of the CSDS MOSFET (UOW – Centre for Medical Radiation Physics) dosimeters as a function of applied dose for 3 energies, 100, kVp, 250 kVp and 6MVp. When the response is normalized to 1 at the start of the MOSFET's life a slightly non linear but reproducible low second order polynomial decrease in sensitivity is seen. Lavallee[28] stated that they noticed a change in the decrease rate for the first and second half of the lifetime of the MOSFET device, however our results using 5 detectors did not show the same characteristics and the decrease remained reproducible over the life of the MOSFET device. Of interest is that the ratios of the approximation gradients at the energies tested is related to the ratio of energy dependence of the MOSFET device. That is, the decrease in sensitivity seen is directly dependant on the change in threshold voltage on the device at any given energy. This effect allows the user to define the sensitivity correction function at one given energy and apply the results at any other applied energy within the energy range tested thereafter. So, in effect, calibration for dose history at one energy along with energy dependant sensitivity values will provide enough information to calculate the dose history response corrections at all energies.

Figure 4 shows the dose response of a MOSFET device for raw results and corrected response at 100 kVp, 250 kVp and 6 MV x-ray energy. Corrected, means that the reduction in sensitivity of the device due to dose history is calculated and taken into account. As seen, an approximately linear response is seen over this applied dose range. From the figure, it can be seen that larger corrections apply for the lower energy beams like 100 kVp. These results show that sensitivity corrections need to be applied

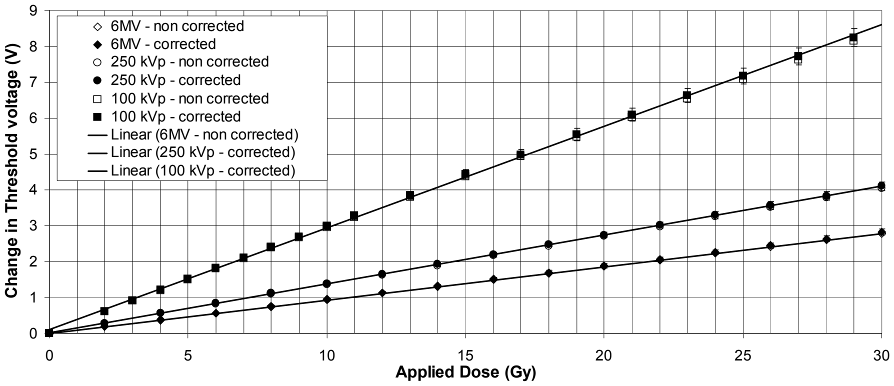

Figure 4. *Dose response of the MOSFET devices to various x-ray energies. The raw data and corrected data are shown for comparison.*

to MOSFET's during dosimetry to provide more accurate assessment of dose. Our results showed that an approximate 0.13 % per Gray reduction in sensitivity is seen at 6MV (life time average) whereas an approximate reduction of 0.33 % per gray is see for 100 kVp x-rays (life time average). As such, lower kilovoltage x-ray beams need larger corrections to sensitivity per unit dose and are more susceptible to errors and uncertainties if corrections are not applied.

We would recommend that sensitivity corrections are calculated for each new MOSFET device used in the clinic and that periodic checks are made to results to verify that the correction equations used are still valid during the MOSFET's dosimetric life time.

Conclusion

The newly redesigned CSDS MOSFET devices produce an energy dependence of up to 3.2 times over the energy range of 50 kVp to 10 MVp. This is slightly lower than other semiconductor MOSFET and diode devices quoted in the literature. The MOSFET device also exhibits a reduction in sensitivity with respect to integrated dose history however the effect was measured to be reproducibly and fitted by a second order polynomial over the lifetime of the MOSFET device. Using the appropriate model, the dose response can be corrected for this effect to provide a higher level of accuracy for dose assessment using the CSDS[5] MOSFET dosimeter.

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