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Radiation response and basic dosimetric characterisation of the 'Magic Plate'

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Abstract

Two Dimensional (2D) silicon diode arrays are often implemented in radiation therapy quality assurance (QA) applications due to their advantages such as: real-time operation (compared to the films), large dynamic range and small size (compared to ionization chambers). The Centre for Medical Radiation Physics, University of Wollongong has developed a multifunctional 2D silicon diode array known as the Magic Plate (MP) for real-time applications and is suitable as a transmission detector for photon fluence mapping (MPTM) or for in phantom dose mapping (MPDM). The paper focusses on the characterisation of the MPDM in terms of output factor and square field beam profiling in 6 MV, 10 MV and 18 MV clinical photon fields. We have found excellent agreement with three different ion chambers for all measured parameters with output factors agreeing within 1.2% and field profiles agreeing within 3% and/or 3mm. This work has important implications for the development of the MP when operating in transmission mapping mode.

Keywords

radiation, plate', dosimetric, 'magic, response, characterisation, basic

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Radiation response and basic dosimetric characterisation of the ‘Magic Plate’

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Abstract. Two Dimensional (2D) silicon diode arrays are often implemented in radiation therapy quality assurance (QA) applications due to their advantages such as: real-time operation (compared to the films), large dynamic range and small size (compared to ionization chambers). The Centre for Medical Radiation Physics, University of Wollongong has developed a multifunctional 2D silicon diode array known as the Magic Plate (MP) for real-time applications and is suitable as a transmission detector for photon fluence mapping (MPTM) or for in phantom dose mapping (MPDM). The paper focusses on the characterisation of the MPDM in terms of output factor and square field beam profiling in 6 MV, 10 MV and 18 MV clinical photon fields. We have found excellent agreement with three different ion chambers for all measured parameters with output factors agreeing within 1.2% and field profiles agreeing within 3% and/or 3mm. This work has important implications for the development of the MP when operating in transmission mapping mode.

1. Introduction

Due to the complexity of treatment planning and delivery of IMRT and VMAT, treatment verification is recommended to be done in a phantom at a point using ionization chambers [1], together with 2D dose mapping using relative dose measurements with radiochromic films. Some drawbacks with ionization chambers are due to the necessity of positioning the ionization chamber in a high dose gradient region in IMRT dose distribution during phantom plan creation. Additionally, the corresponding phantom setups on the treatment couch for measuring the delivered dose take a substantial time. Both procedures are time consuming [2]. The steep dose gradients in IMRT fields make single point dose measurements inadequate for verifying the non-uniform dose distributions. Films have an excellent spatial resolution, ability 2D dose mapping, and easy to handle but the disadvantages are the dependence on film scanner readout system, time delay between irradiation and scanning about 24-48 hour. The use of 2D array detectors that don't perturb the radiation field in a phantom is convenient for-real time IMRT and VMAT QA. These dosimeters are required and have advantages in terms of saving time as they do not require careful positioning and repositioning of detection points in a treatment plan (compared with a single ionization chamber). Hence, the time required for data acquisition and analysis is shorter than for films or single ionization chamber. However, these 2D array detectors display the dose distribution only in a single plane. Therefore, the dose measured by them cannot provide information about full 3D dose distribution [3]. This shortcoming prompted development of independent 3D dose verification procedures such as gel dosimeters [4-8], Delta4, ArcCHECK, OCTAVIUS or portal dosimetry [9, 10],



which have the ability to determine the 3D dose distribution in the phantom or the patient. The development of an independent (independent of the radiation delivery system) real-time 2D or 3D dose mapping system is a very important issue and is required for treatment verification. The first stage of development of a dose reconstruction procedure based on sensing the actual fluence during patient treatment would be carried out [11]. The MP was designed to be placed on the treatment head of the linac as a transmission detector during the patient treatment (MPTM) as well as to function as a planar detector for dose distribution measurement in a solid water phantom for the dosimetric verification of IMRT and VMAT treatment deliveries. The MP has been previously described and characterized in dose mode (MPDM) to map a 2D dose distribution in a solid water phantom [12]. However, the main objective of this paper is to demonstrate the potential performance characteristics of the MP system when operated in dose mode (MPDM), i.e. on the patient couch at several linear accelerator potential differences. This paper describes the following characterisation measurements that were carried out such as field size dependence and beam profiles.

2. Methodology

The MP is a 2D epitaxial silicon diode array with 121 diodes covering an area of $10 \times 10 \text{ cm}^2$ based on thin $50 \text{ }\mu\text{m}$ epi-diode technologies mounted on a 0.6 mm thick Kapton substrate using a proprietary drop-in technology. The MP is designed to be operated in dose mode (MPDM) to map the 2D dose at any depth on the solid water phantom. Measurements were performed in the passive mode (zero volts applied at the electrodes) to minimize the variation of the leakage current and the consequent variation of the baseline of the signal which requires time consuming and frequent recalibration procedures. The radiation source used in these investigations was a Varian medical linac (Model 2100EX) for 6 MV and 10 MV; however a medical linac (Model 2100EX) was used for 18 MV investigations. Prior to any measurements by the MP sensor array a flat field correction (equalization procedure) was prepared by placing the array at a depth of 10 cm in a $30 \times 30 \times 20 \text{ cm}^3$ solid water phantom and exposing it to a $20 \times 20 \text{ cm}^2$ square field size for 20 seconds delivered at 600 MU/Min . A 6 MV, 10 MV and 18 MV linac beams were used in these measurements. It should be noted that in all cases, irradiation field sizes quoted are referred to the field size defined at the source surface distance (SSD) of 100 cm . Each diode is readout individually by a multichannel charge to frequency converter preamplifier called TERA06. The MP fast readout system and associate software corrects and stores all raw and corrected data separately. The potential performance of the 2D array in dose mode (MPDM) when measuring the linac radiation output as a function of the field size was investigated. The output factor measurements were carried out by delivering 100 MUs for squared field sizes ranging from $5 \times 5 \text{ cm}^2$ to $40 \times 40 \text{ cm}^2$. The MPDM was positioned in the standard set-up (depth of d_{max} at 100 cm SSD). Dose outputs were compared with ion chamber measurements taken at the same conditions using Wellhofer compact ionization chamber (Model CC13), Markus ion chamber (Model N23343), Farmer ionization chamber (Model 2571) and the PTW semiflex thimble ion chamber (Model 31010). The ion chamber detectors were connected to a Unidos universal dosimeter (Model 1300698- T10023) and (Model 11439- T10001) for 18 MV medical linac. The beam dose profiles were also measured at different depths (i.e. here at depth of d_{max}) in the solid water phantom by the MPDM were compared with those from the CC13 ionization chamber and the PTW semiflex thimble ion chamber, at the same depth for field sizes ranging from $5 \times 5 \text{ cm}^2$ to $40 \times 40 \text{ cm}^2$ at an SSD of 100 cm using different beam energies that mentioned above. For each profile the MLCs were opened to match the linac jaws. The beam profiles were constructed by stepping the respective detectors laterally across the beam using the patient couch in centimetre steps for MP and millimetre steps for the ionization chambers through each field.

3. Results

Output factor measurement results of MPDM for 6 MV photons are shown in Figure 1(a). The output factor measured using the Farmer ion chamber and CC13 chamber were also included for comparison. The field size dependence of the 2D array central axis (CAX) diode values measured at SDD of 101.5 cm agreed well with both the Farmer chamber and CC13 ion chamber. Discrepancies are within 0.56%

and 1.19 % respectively for all measured field sizes. Figure 1(b) shows the field size dependence of the MPDM CAX diode values at SDD 100 cm. The output factor measured using the Markus ionization chamber and CC13 chamber were also involved for comparison. MPDM measurements have been performed at depth of d_{max} (21 mm in case of 10 MV beam) agreed very well with the Markus chamber and CC13 measurement within - 0.60 % and 0.32 % respectively. Field size dependent measurement results of MPDM for 18 MV beam at 100 cm SSD are shown in Figure 1(c). The output factor measured using the PTW thimble ionization chamber was also included for comparison. The output factors of the 2D array CAX diode values measured at SDD of 103 cm (d_{max}) fit very well with the thimble ion chamber within 0.57 % for all field sizes. Figure 2 (a-c) shows dose beam profiles measured of the MPDM (dots) at depth of d_{max} in absolute terms (independently converted to Gy) compared with dose beam profiles of ionization chambers (lines) measured at the same depth for 6 MV, 10 MV and 18 MV linac beams and SSD of 100 cm. Measurements were made with radiation fields from 5x5 cm² to 40x40 cm² and fields defined by the linac jaws and the MLCs. The 2D array data fit very well the ion chamber profiles with a maximum percentage difference of 3% for all field sizes and for all beam energies tested, both in and out of the irradiation field. Furthermore, the MPDM detector measurements are accurate also in the penumbra region. This case is interesting because it shows some limitations of the 2D array sampling capabilities. The well-known dose volume effect due to the superior spatial resolution of the MP detector elements easily accounts for the small differences observed between the data sets in the penumbra region of the beam profiles. It can be noted that for all field sizes there is limited sampling of the profile where the dose gradient is large (in the edge of the beam). This is because of the field edges actually falls between two adjacent detectors. This is due to the detector design having a 1 cm spacing of the MPDM. Nonetheless the agreement between the two datasets is very good with the 2D array data accurately matching the ion chamber profiles. Above results prove that MPDM is validated against the ion chambers and no perturbation of the field caused by MPDM in a solid water phantom. This demonstrates that the robustness of the 2D array when operated in dose mode.

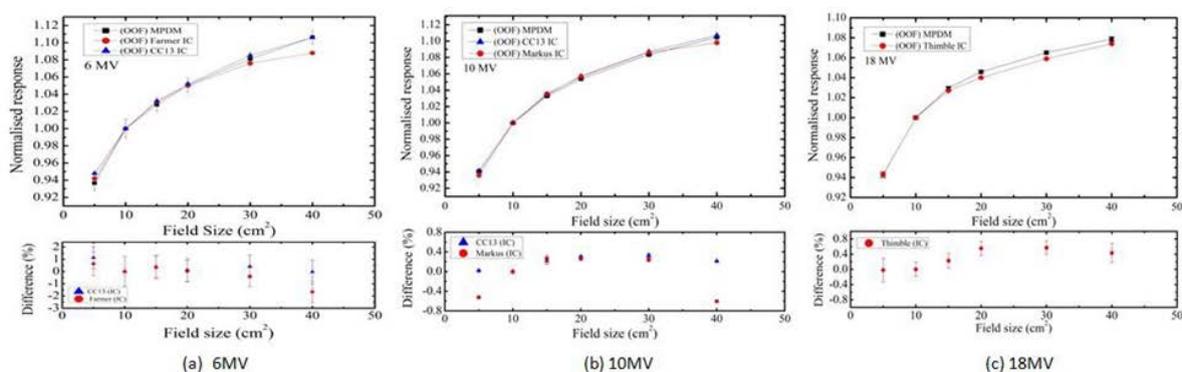


Figure 1. (a-c): Output factor comparison between 2D MPDM and ion chambers. The local percentage difference is also shown. Data were acquired at d_{max} in standard set-up using solid water phantom. 6MV, 10 MV and 18 MV beam were used for this study.

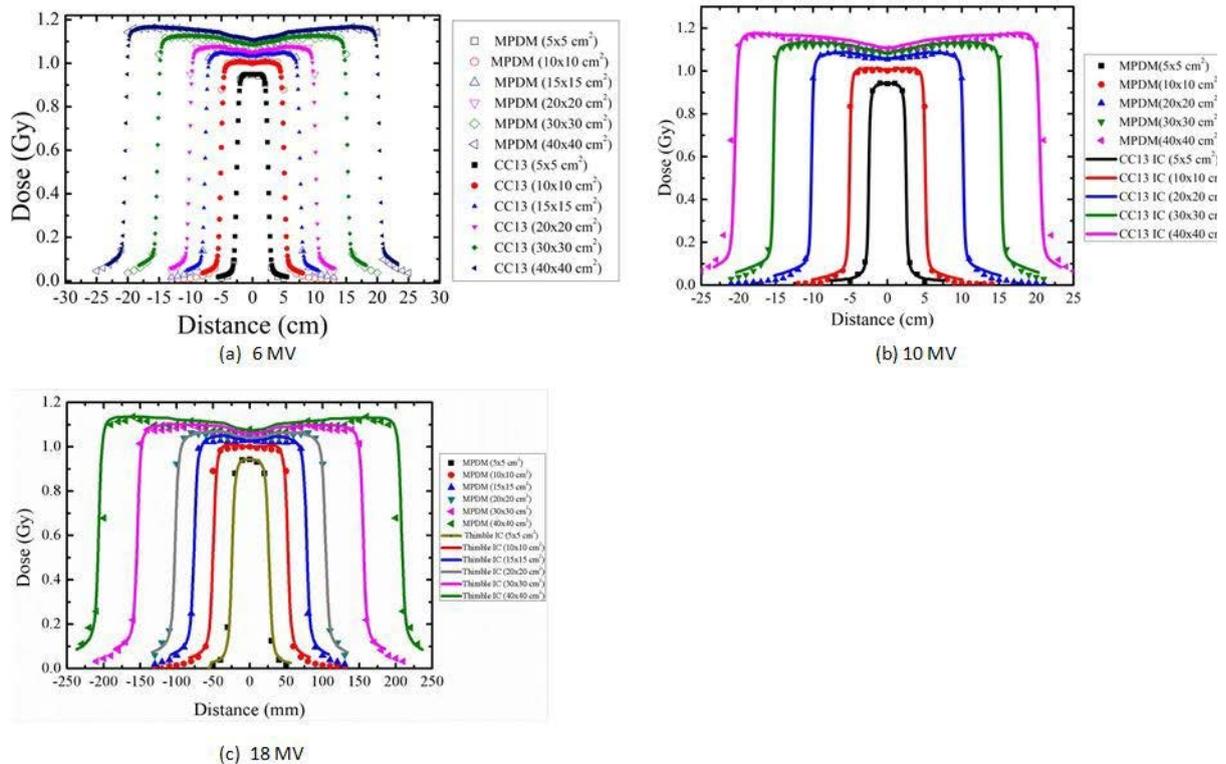


Figure 2. (a-c): Comparison between measured doses using ion chambers (CC13 and PTW Thimble chambers) and measured doses using Magic Plate in solid water phantom (MPDM) at d_{max} . 6 MV, 10 MV and 18 MV were used for this study.

4. Conclusion

The radiation response of the MPDM was characterized. The 2D array of epitaxial silicon based detectors with drop-in packaging showed properties suitable to be used as a simplified multipurpose and non-perturbing 2D radiation detector for radiation therapy dosimetric verification. On the basis of the broad range of tests performed in this thesis, we conclude that the 2D array is a dosimetrically accurate and sensitive tool and that it can be a useful device for QA and verification of clinical radiotherapy beams of various radiation quality.

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