Development of a Prototype Synthetic Diamond Detector for Radiotherapy Dosimetry

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This thesis detailed an investigation of the suitability of commercially-available single crystal and polycrystalline diamond films made via chemical vapor deposition (CVD) that were not studied previously for use in radiotherapy dosimetry. Novel sandwich-type detectors were designed and constructed to investigate the dosimetric response of diamond films under clinical conditions. Relatively inexpensive diamond films were obtained from three manufacturers: Diamonex, Diamond Materials GmbH and Element Six. Spectrophotometry, Raman spectroscopy and bulk conductivity studies were used to characterize these films and correlate crystalline quality with detector performance. Novel detectors were designed and constructed to investigate detectors under clinical conditions, including Perspex encapsulations and PCBs to minimize fluence perturbations. The dosimetric response of these diamond detectors was examined using a 6 MV beam from a Varian Clinac 600C linear accelerator. Diamond detectors were evaluated by measuring a number of response characteristics.

Polycrystalline CVD diamond films from Diamonex (100, 200, 400-μm thicknesses) were considered unsuitable for dosimetric applications due to their lack of stability, low sensitivity, high leakage currents, high priming dose and dependence on dose rate. High-quality polycrystalline diamond films from Diamond Materials (100, 200, 400-μm thicknesses) displayed characteristics that varied with film thickness. A 100-μm film featured slow response dynamics and high priming doses. Thicker films featured suitable dosimetric characteristics, e.g. negligible leakage currents, low priming doses, fast response dynamics and good sensitivity with small sensitive volumes. Element Six single crystal CVD diamond films (500-μm thicknesses) with small sensitive volumes (0.39 mm^3) exhibited suitable characteristics for dosimetry. These films showed negligible leakage currents (< 1.25 pA), low priming doses

(1–10 Gy), quick response dynamics, high sensitivity (47–230 nC Gy^{-1}) and were weakly dependent on dose rate and directional dependence (±1%).

A relatively inexpensive single crystal CVD diamond film from Element Six that exhibited high sensitivity (230 nC Gy^{-1} at 0.5 V μm^{-1}), amongst other favourable characteristics, was selected for further analyses. An appropriate operating voltage was determined before further clinically relevant measurements could be conducted. This included how changes in an applied electric field affected detector response, and determined whether an optimal operating voltage could be realized within the parameters of conventional instrumentation used in radiation therapy. The results of this study indicated a preference towards using 62.5 V (at ~0.13 V μm^{-1}) out of a range of 30.8–248.0 V for temporal response as required for modulated beams due to its minimal rise time (2 s) and fall time (2 s) yet sufficient sensitivity (37 nC Gy^{-1}) and weak dependence on polarity (±1.5%).

Investigations were then performed on the same diamond detector to evaluate its performance under more clinically relevant conditions. Repeatability experiments revealed a temporary loss in sensitivity due to charge detrapping effects following irradiation, which was modelled to make corrections that improved short-term precision. It was shown that this detector could statistically distinguish between dose values separated by a single Monitor Unit, which corresponded to 0.77 cGy. Dose rate dependence was observed when using low, fixed doses in contrast to using stabilized currents and higher doses. Depth dose measurements using this detector compared well with ion chambers and diode dosimeters. Comparisons of initial measurements with values in the literature indicate encouraging results for fields sizes $< 4 \times 4$ cm^2, but further measurements and comparisons with Monte Carlo calculations are required. Using this detector to make off-axis measurements in the edge-on orientation reduced perturbation of the beam due to its sandwich configuration and thin 150 nm Ag contacts. This diamond detector was found to be suitable for routine dosimetry with conventional radiotherapy instrumentation with a materials cost of $<$ $200.