PhD Thesis Title: "Evaluation of the Radiation Detection Properties of Synthetic Diamonds for Medical Applications"

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ABSTRACT

Aimed at improving the accuracy of dose determination in radiation medicine, this thesis explores the radiation detection properties of synthetic diamond crystals of various types and investigates the possibility of developing a single probe with synthetic diamond as sensor for the dosimetry of various beam types under large as well as small-field conditions. The study was conducted on two HPHT (high-pressure, high-temperature) and eight CVD (chemical vapor deposited) synthesized diamonds of optical grade (OG) and detector grade (DG) qualities of various dimensions. Various non-destructive techniques were employed to characterize the electrical quality and defect levels present within each of the samples.

Detector performances were evaluated using a prototype probe housing constructed of tissue-equivalent materials. The probe has features, which allow diamond crystals to be exposed in different exposure orientations ('edge-on' and 'flat-on') for impinging radiation without having first to re-orient the diamond sensor within its body. All dosimetric measurements taken with the synthetic diamond probe were from exposures to low-energy mammography X-rays (25-32 kVp), and megavoltage therapy electron (7-14 MeV) and photon (^{60}Co γ-ray, 6 and 15 MV X-ray) beams.

The most important findings emphasized in this thesis include:

(1) The main cause of the response instability of the examined crystals necessitating the often cited daily primimg procedure was isolated and ascribed to the presence of ambient light which has the effect of emptying trapping centres present within the diamond sensors. The percentage changes in response between measurements in light and dark conditions conducted over a period of three successive weeks were 2.8±1.2, 25.2±6.3 and 63.0±0.3% for HPHT, DG and OG CVD diamond detectors, respectively. For measurements under light conditions alone using the tested detectors, the difference in response was > 5%, whereas in dark conditions the difference in response was < 3%. This signifies that once the diamond sensors are properly shielded from ambient light and their response stabilized, daily priming is not necessary;

(2) Given the importance of Fowler's dose rate linearity index Δ of solid-state detectors in radiation dosimtry, Δ was used as a relevant tool to identify a number of pertinent defect types which could influence the performances of the diamond detectors. Thermoluminescence emission was also identified as a suitable parameter that could be utilized to probe the performances of diamond crystals. These findings suggest that diamond crystals could be selected or perhaps tailor-made with various defect levels which when used as sensing elements for dosimetric applications display optimum performance;

(3) Measurements of output factors under small-photon-field conditions demonstrated that an accuracy level within 3% could be achieved if the diamond detector size is ≤ 3/4 of the field size, with the 'edge-on' orientation being an appropriate detector geometry for field sizes below 1x1 cm^2. In addition, the HPHT diamond sensors due to their low defect levels were found to show an overall better performance compared to the CVD crystals. A sensitivity value of 197.3 nC Gy^{-1} mm^{-3} was established with the probe using a HPHT diamond sensor in a radiation field of size 0.4x0.4 cm^2 compared to a value of 136.1 nC Gy^{-1} mm^{-3} obtained with a small-field diode detector;

(4) The dosimetric performances (i.t.o relative dose distributions, directional and dose rate response) of the diamond probe (using selected crystals as sensing elements) on exposure to various teletherapy beams were found to be in close agreement with reference dosimeter data in the order of 1–2% with or without dose rate dependence corrections. Such performance was attributed to the near-tissue equivalence of the synthetic diamond probe and its low and stable background signal.

Overall, the study illustrated that differences in crystal quality due to the presence and influence of defect levels could cause a variation in the performances of various diamond sensors. Once a crystal is selected (based on the influence of defect levels) and coupled to the probe, then the near-tissue equivalent synthetic diamond probe could be used for clinical applications of various beam types in large as well as small radiation fields as demonstrated by the results of various dosimetric characterizations.

References to author publications that relate specifically to the dissertation:

1. **Ade, N**., Nam, T.L., 2015. *The influence of defect levels on the dose rate dependence of synthetic diamond detectors of various types on exposures to high-energy radiotherapy beams*. Radiat. Phys. Chem. **108**, 65.
2. **Ade, N**., Nam, T.L., Derry, T.E., Mhlanga, S.H., 2014. *The dose rate dependence of synthetic diamond detectors in the relative dosimetry of high- energy electron therapy beams*. Radiat. Phys. Chem. **98**, 155.

3. **Ade, N**., Nam, T.L., Mhlanga, S.H., 2013. *An evaluation of some pertinent parameters that influence the dosimetric performance of synthetic diamond detectors*. Radiat. Phys. Chem. **86**, 42.
4. **Ade, N**., Nam, T.L., Assiamah, M., 2012. *A synthetic diamond probe for both low-energy mammography X-rays and high-energy electron therapy beams*. Radiat. Phys. Chem. **81**, 232.
5. **Ade**, **N**., Nam, T.L, Mhlanga, S.H., *Effects of impurities and defects on the performances of synthetic diamond crystals when used as radiation sensors for medical applications*, in Proceedings of the SAIP2012: the 57th Annual Conference of the South Africa Institute of Physics, edited by Johan Janse van Rensburg (2014), pp. 459 - 463. ISBN: 978-1-77592-070-0. Available online at http://events.saip.org.za