CVD Diamond X-ray Detectors for Radiotherapy Dosimetry

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Introduction
Dosimetry plays an important role in radiation environments such as hospital x-ray imaging and treatment facilities. It is used during system calibration to assess beam characteristics for later use in treatment planning, but can also be used during patient exposure to confirm the exposure dose. Diamond has been proposed as a material for the construction of radiation detectors for many years, for reasons including its near-tissue equivalence and radiation hardness. Diamond-based detectors for radiotherapy applications are commercially-available, but the scarcity of suitable high-quality natural diamonds results in low quantities of unique detectors that need to be individually calibrated and hence are very expensive. Recent developments in the synthesis of diamond should enable the development of cheaper diamond-based x-ray detectors with more reproducible characteristics. Here we present the characteristics of detectors fabricated on various synthetic diamond films.

Experimental Details

<table>
<thead>
<tr>
<th>Material Details</th>
<th>Description</th>
<th>Size</th>
<th>Thickness</th>
<th>Appearance</th>
<th>Doping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond Materials GmbH</td>
<td>Optical quality CVD, polished &amp; laser cut</td>
<td>5 x 5 100</td>
<td>Transparent</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 x 5 200</td>
<td>Transparent</td>
<td>N/A</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>5 x 3 400</td>
<td>Transparent</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diamonex Division of Morgan Advanced Ceramics</td>
<td>Freestanding polycrystalline CVD as-grown</td>
<td>5 x 5 100</td>
<td>Black, rough</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 x 3 200</td>
<td>Black, rough, N/A</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Element Six Ltd</td>
<td>Single crystal CVD, polished 1 side, other lapped</td>
<td>5 x 3 500</td>
<td>Transparent</td>
<td>N/A</td>
<td></td>
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<tr>
<td></td>
<td>Single crystal CVD, polished 2 sides</td>
<td>5 x 3 500</td>
<td>Transparent</td>
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<td></td>
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Device Fabrication
- Sandwich-type device structure
  - Ag contact (~200 nm thick) on each face; 2 mm Ø on 5 x 5 mm tiles, 1 mm Ø on 3 x 3 mm tiles
  - Housed within Perspex enclosures, as shown; dimensions of case for thimble ionisation chamber

Experiments
- Varian 600C treatment linear accelerator; Oncology Service, Christchurch Hospital, NZ
- 6 MV photons
- Device positioned at isocentre
- 1 m source–device distance
- 10 cm deep in block of solid water
- 10 x 10 cm field size used
- Triaxial cabling out of room
- Farmer 2570/1 dosimeter; used to apply bias (~250 V) & measure charge
- Dose rates of 50, 100, 150, 200, & 250 monitor units (MU) per minute; 1 MU = 0.778 cGy for above conditions

Results

Material Comparison
- Priming: Detector response measured as a function of cumulative dose during priming of the devices; dose-rate of 250 monitor units per minute used (~1.95 Gy/min). Diamonex material exhibits a dark current that decreases with exposure to x-rays.

Sensitivity
- Photocurrent as a function of dose rate. Power-law (Iph ∝ D) curve fits are shown; as described by Fowler in Radiation Dosimetry Vol.III, Academic, New York (1966).
- A values and approx. linear sensitivities are listed in the table below.

Conclusions
- X-ray detectors have been fabricated from a range of commercially-available chemical vapour deposition (CVD) diamond. They have been packaged and tested in a clinical environment, using clinical apparatus and following clinical procedures: 6 MV linear accelerator, solid water phantom, dosimeter. Some devices exhibited highly desirable characteristics, such as negligible dark currents (sub-pA), low priming doses (few Gy) and high specific sensitivities (up to 585 nC Gy⁻¹ mm⁻³), demonstrating the potential of these devices as simple-to-use, small size, tissue-equivalent, sensitive x-ray dosimeters.
- The performance of such devices in clinical applications, such as beam profiling (both depth and off-axis) is currently in progress.

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