Prototype X-ray Detectors Based on CVD Diamond

Stuart Lansley[1,2,*], Gregory Betzel[1], Florentina Baluti[1,3], Lou Reinisch[4], and Juergen Meyer[1]

[1] University of Canterbury, Christchurch, NZ
[2] The MacDiarmid Institute for Advanced Materials & Nanotechnology, NZ
[3] Christchurch Hospital, Christchurch, NZ
[4] Jacksonville State University, AL, USA
* stuart.lansley@canterbury.ac.nz

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

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.

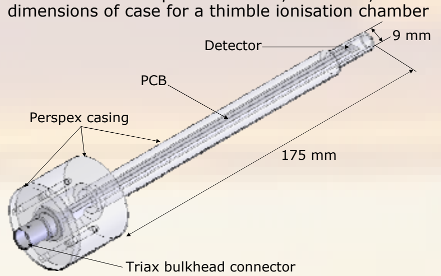
Experimental Details

Material

Description	Size (mm)	Thickness (μm)	Appearance	Doping (ppm)
Diamond Materials GmbH				
Optical quality CVD, polished & laser cut	5 × 5	100	Transparent	N/A
	5 × 5	200	Transparent	N/A
	5 × 5	400	Transparent	N/A
Diamonex Division of Morgan Advanced Ceramics				
Freestanding polycrystalline CVD as-grown	5 × 5	100	Black, rough	N/A
	5 × 5	200	Black, rough	N/A
Element Six Ltd				
Single crystal CVD, polished 1 side, other lapped	3 × 3	500	Transparent	[N]<1 [B]<0.05
Single crystal CVD, polished 2 sides	3 × 3	500	Transparent	[N]<1 [B]<0.05

Device Fabrication

- Sandwich-type device structure
- Ag contact (~200 nm thick) on each face; 2 mm Ø on 5×5 mm tiles, 1 mm Ø on 3×3 mm tiles
- Housed within Perspex enclosures, as shown; dimensions of case for a thimble ionisation chamber



Experiments

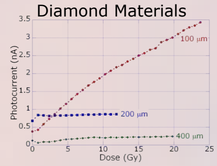
- Varian 600C treatment linear accelerator; Oncology Service, Christchurch Hospital, New Zealand
- 6 MV photons
- Device positioned at isocentre
- 1 m source–device distance
- 10 cm deep in block of solid water
- 10×10 cm² field size used
- Triaxial cabling out of room
- Farmer 2570/1 dosimeter; used 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

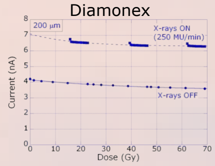
Results

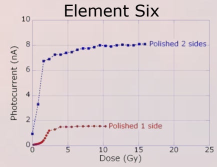
Material Comparison

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.



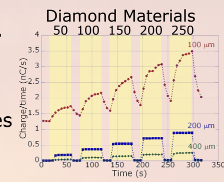


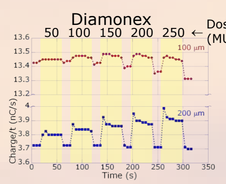


Transient Response

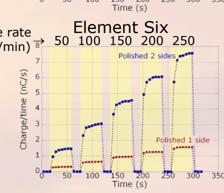
Detector response to 50, 100, 150, 200, and 250 monitor units per minute (as indicated); charge was measured over 4-second intervals. All devices had been primed.

Yellow highlight indicates when the beam was on.



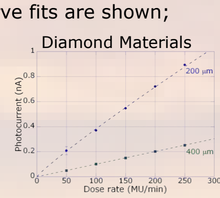


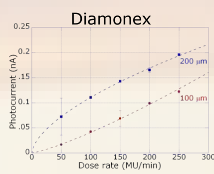
Dose rate (MU/min)

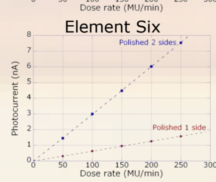


Sensitivity

Photocurrent as a function of dose rate. Power-law ($I_{ph} \propto D^{\Delta}$) curve fits are shown; as described by Fowler in Radiation Dosimetry Vol.III, Academic, New York (1966). Δ values and approx. linear sensitivities are listed in the table below.





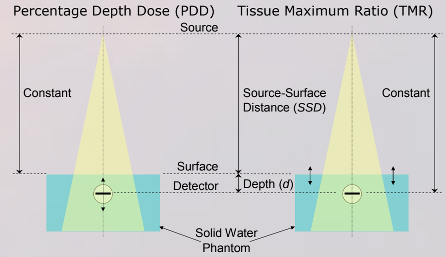


Summary

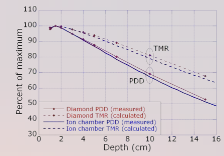
Description	Thickness (μm)	Power law Δ	Approx. linear sensitivity (nC/Gy)	(nC/Gy.mm³)
Diamond Materials GmbH				
Optical quality CVD, polished & laser cut	100	N/A	N/A	N/A
	200	0.94	26.1	41.5
	400	1.00	7.65	6.09
Diamonex Division of Morgan Advanced Ceramics				
Freestanding polycrystalline CVD as-grown	100	1.16	4.08	13.0
	200	0.61	4.61	7.34
	400	N/A	N/A	N/A
As above but matte	400	N/A	N/A	N/A
Element Six Ltd				
Single crystal CVD, polished 1 side, other lapped	500	1.00	47.7	121
Single crystal CVD, polished 2 sides	500	1.01	230	586
Single crystal HPHT Type Ib, polished 1 side, other lapped	500	N/A	N/A	N/A

Beam Profiling (E6, polished 2 sides)

Depth-Dose Profiling



Can convert PDD to TMR: $TMR = \left(\frac{PDD}{100}\right) \cdot \left(\frac{SSD + d}{SSD + d_{max}}\right)^2$

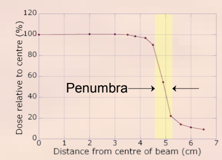


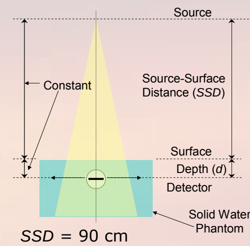
The diamond detector appears to slightly over-measure doses at depths beyond D_{max} (1.5 cm at 6 MV), relative to an ion chamber.

Off-Axis Profiling

SSD & *d* kept constant.

Detector moved across and beyond the beam.





SSD = 90 cm
d = 10 cm
Field size = 10 cm × 10 cm
Penumbra ≈ 0.7 cm

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 586 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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