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CVD diamond microdosimeters

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Abstract

CVD diamond detectors have been evaluated for use as X-ray dosimeters. The response both at radiological diagnostic and at therapeutic energies of one "detector grade" commercially available parallelepiped CVD sample has been measured and compared with the performances of a "needle shaped" CVD diamond detector grown by the hot-filament CVD technique on a tungsten tip. All the detectors were demonstrated to be very suitable for bio-medical application: they are linear in dose rate, stable and relatively fast, with a signal-to-noise ratio higher than 1000. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Diamond is an ideal material as radiation detector for bio-medical applications [1]. The attractiveness of diamond essentially stems from its radiation hardness, chemical stability against all the body fluids and its absolute nontoxicity. Moreover, diamond is to be considered as a "tissue-equivalent" material since its atomic number ($Z = 6$) is close to the effective atomic number of soft tissue ($Z_{\mathrm{eff}} = 5.92$ for fat and $Z_{\mathrm{eff}} = 7.4$ for muscle) [2]. This fact is particularly important to measure the absorbed dose in biological tissue where the energy deposited by low-energy gamma or X-rays ($< 150\,\mathrm{keV}$) is highly dependent on the atomic number of the material. For this reason the unit of absorbed dose for ionising radiation, the gray (Gy = J/kg), or for dose equivalent, the sievert, is approximately the same for tissue and for diamond.

Improved diamond synthesising techniques have generated new optimism on the possibility of applying diamond in radiation detection, overcoming the difficulties (high cost and poor reproducibility) which limit the widespread application of natural diamond in this field. In particular, the Chemical Vapour Deposition (CVD) technique has proven to be able to produce low-cost "detector-grade" diamond films suitable for application in radiation

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dosimetry [3]. Besides obvious advantages of this technique (low cost, high-impurity control, good reproducibility), it should be emphasised that it is able to synthesise both large-area detectors, as required for medical imaging, and miniaturised detectors. The latter feature is particularly appreciated in radiation oncology units where detectors with excellent spatial resolution and high sensitivity are required for radiotherapic treatments (brachytherapy or stereoactic radiosurgery).

In this paper, we present a study of the performances of two different CVD diamond samples used as radiation dosimeters. The first of them (sample A) is commercially available. The second sample is a needle-shaped detector grown by hot-filament CVD technique on tungsten tip [3,4]. A comparison of the current response of the detectors under X-ray irradiation at low (250 keV) and high (6 MeV) energy is presented.

2. Experimental

The geometrical and electrical characteristics of the CVD diamond samples used in this work are summarised in Table 1. Sample A is a commercial "detector-grade" CVD diamond sample with titanium/gold electrodes deposited on both the surfaces. The diamond was clamped between two gold tips fixed in an insulating (Teflon) block. Fig. 1a shows diagrammatically a cross-sectional view of the detector.

The CVD diamond tip was fabricated by depositing a diamond film (about 10–15 μm thick) by

Table 1
Physical parameters of the CVD diamond detectors

Sample	A	Tip
Shape	Parallelepiped	Pin-point
Deposition technique	Arc-Jet Plasma CVD	Hot-filament CVD
Thickness	0.04 cm	≈ 10–15 μm
Electrode surface	0.62 cm^2	Diameter of W substrate = 200 μm
Electrical resistance at 100 V operating bias	1 TΩ	100 TΩ

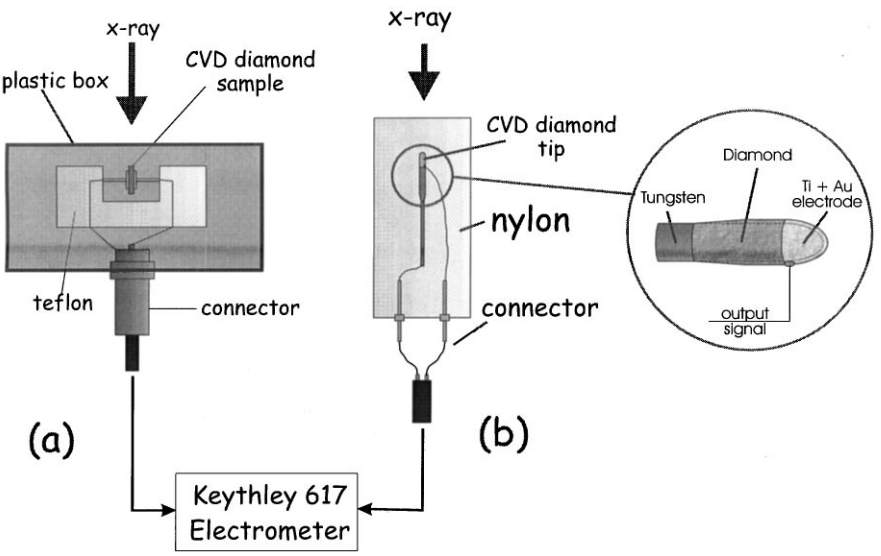

Fig. 1. Scheme of the experimental set-up for the two diamond samples used as X-ray dosimeters.

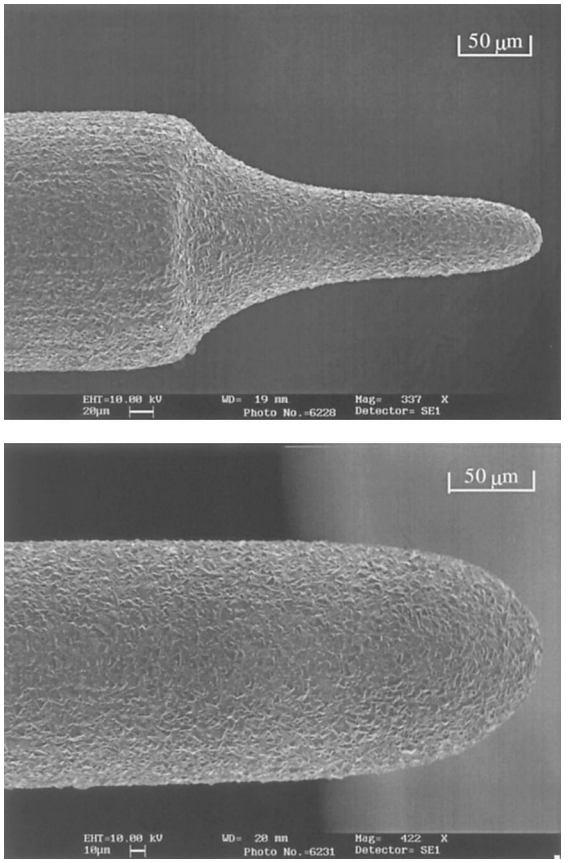

Fig. 2. Scanning electron microscopy photographs of two CVD diamond films grown at the end of three 200 μm tungsten wires etched by the electrochemical method described in Ref. [3] under different etching conditions.

the hot-filament CVD technique on a tungsten tip obtained by electrochemical etching of W wires, 200 μm diameter. Details on the tip formation and deposition conditions can be found in Refs. [3–5]. Fig. 2 shows two different samples of CVD diamond tips deposited on tungsten wires etched in different conditions. A miniaturised diamond solid-state chamber was then fabricated by using the diamond as the sensitive region, the tungsten substrate and a thin titanium/gold evaporated layer as electrodes. The detector was then sealed in a cylindrical polystyrene housing of 20 mm diameter. A scheme of the tip and of the plane parallel diamond detector is shown in Fig. 1b.

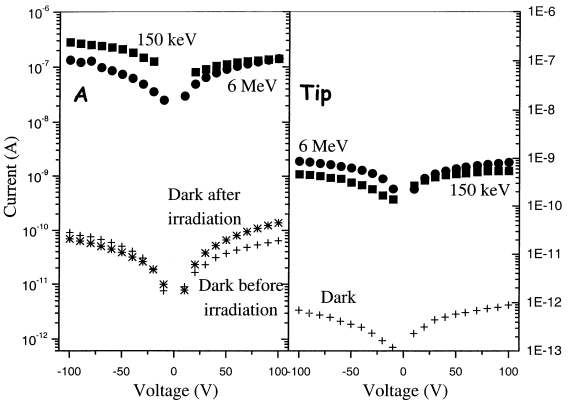

Fig. 3. Sensitivity of the two diamond detectors as a function of applied bias voltage under dark conditions and under X-rays generated by a continuous X-ray source (150 kV_p) and linear accelerator (6 MeV).

The current/voltage characteristics for all the samples were measured using a Keythley 617 electrometer, both in dark and under a continuous bremsstrahlung source (150 kV) with a Cu filter or a Siemens MD Class MEVATRON 6–15 MeV accelerator for radiotherapy [4].

3. Results

Fig. 3 shows the current/voltage curves for the two samples under high-energy (6 MeV, dose rate 35 mGy/s) and low-energy (bremsstrahlung X-ray beam, tube voltage = 150 kV, dose rate = 60 mGy/s) X-ray irradiation. The signal-to-noise ratio at 100 V bias voltage is of the order of 1000 for both samples. Fig. 3a shows also the difference in the dark current recorded with sample A before and after irradiation as a consequence of the "priming effect" of the radiation which settles the response of the diamond to a stable level [1].

The sensitivity has been calculated by the linear behaviour of the electrical response of the two detectors operating at a bias voltage of 100 V under the bremsstrahlung source irradiation at fixed peak energy of 150 keV and different X-ray tube currents shown in Fig. 4. The slopes of the linear fits are 7 ± 0.7 nC/Gy for the diamond tip and 2.7 ± 0.2 μC/Gy for sample A.

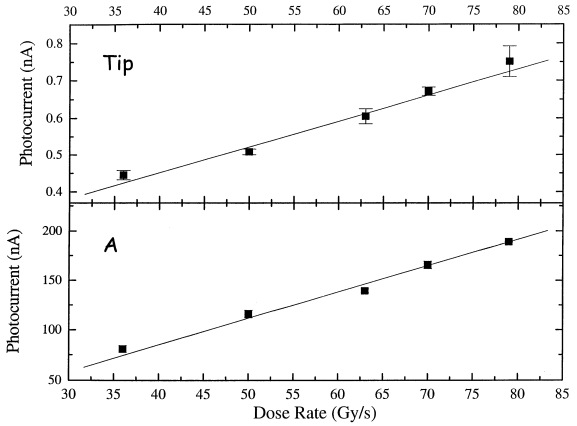

Fig. 4. Photocurrents measured at 100 V bias as a function of dose rate. The X-ray tube voltage is 150 kV.

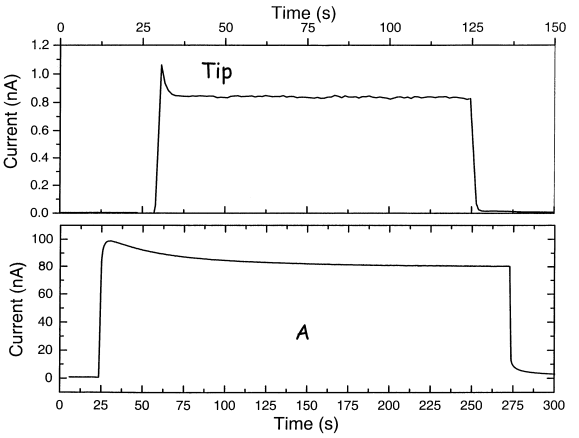

Fig. 6. Photocurrents measured during a 6 MeV beam switch-on–switch-off cycle at 100 V bias as a function of time.

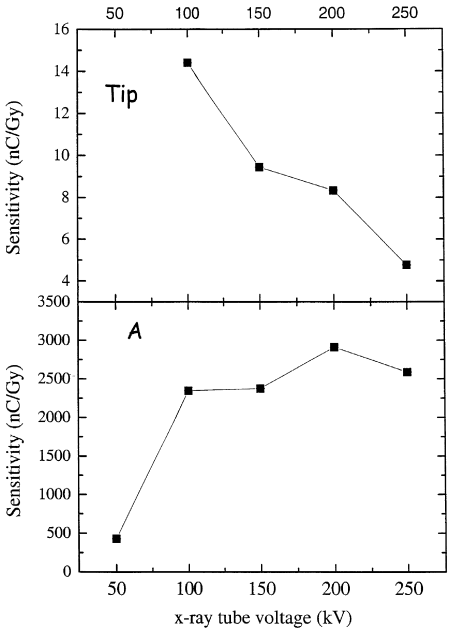

Fig. 5. Sensitivities as functions of X-ray tube peak voltage. The X-ray tube current is 10 mA.

The sensitivities of the two detectors are shown in Fig. 5. The sensitivity of the diamond tip decreases as a function of the peak energy mainly because low-energy electrons produced by low-energy X-rays close to the tungsten substrate are more effective, because of their short range and small thickness of diamond. This result is in agreement with the experimental and simulated response of diamond detectors deposited on molybdenum wires shown in Ref. [5].

Fig. 6 shows the time response of the two diamond detectors exposed to X-rays generated by a linear accelerator for radiotherapy (energy 6 MeV). The initial peak due to the accelerator beam autocalibration is well reproduced in the diamond tip, whereas the response of sample A demonstrates a much slower response which stabilises after 200 s. The fast response of the diamond tip is due to its small capacitance and high electric field due to the small curvature radius of the tip (less than 200 μm) and small thickness (10–15 μm) of diamond.

4. Conclusions

The experimental results shown in this paper show that CVD diamond detectors could be a useful addition to the range of available ionising radiation dosimeters. Table 2 presents a comparison of the performances of the diamond samples presented here and of other dosimeters. The sensitivity of the planar CVD diamond sample A is higher than that of a commercially available natural IIa diamond detector [6,7] whereas the sensitivity-to-volume ratio is approximately the same. This demonstrates, at least in the dose range investigated

Table 2
Performances of different dosimeters evaluated at a X-ray energy of 100 keV

Type	Volume (cm^3)	Sensitivity (nC/Gy)	Sensitivity/volume ((nC/Gy)/cm^3)
Diamond sample A	0.024	2500	10^5
Diamond tip	$< 3 \times 10^{-5}$	14	$> 5 \times 10^5$
Natural IIA diamond[a]	0.0014	175	1.3×10^5
Ionisation chamber[b]	0.144	6.2	43

[a]PTW Riga [7].
[b]Wellhofer Dosimetrie IC 10.

here, that the CVD technique can provide "detector-grade" diamonds with a similar dosimetric quality of natural diamonds but with a much higher reproducibility and lower costs. Moreover, the diamond tip shows a sensitivity close to the sensitivity of a standard ionisation chamber, but owing to its very small volume, a sensitivity-to-volume ratio very close to that of commercially available natural IIa diamond detectors is obtained.

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References

[1] B. Planskoy, Phys. Med. Biol. 25 (3) (1980) 519.
[2] F. Attix, W.C. Roesch, E. Tochilin, Radiation Dosimetry, Vol. 1, 2nd edition, Academic Press, New York, 1968.
[3] E. Vittone, F. Fizzotti, A. Lo Giudice, P. Polesello, C. Manfredotti, Nucl. Instr. and Meth. A 428 (1999) 118.
[4] C. Manfredotti, G. Apostolo, F. Fizzotti, A. Lo Giudice, M. Morando, R. Pignolo, P. Polesello, M. Truccato, E. Vittone, U. Nastasi, Diamond Related Mater. 7 (1998) 523.
[5] C. Manfredotti, F. Fizzotti, M. Galetto, A. Lo Giudice, D. Margherita, C. Ongaro, P. Polesello, E. Vittone, Mater. Res. Soc. Symp. Proc. 423 (1996) 81.
[6] S. Vatnisky, H. Jaervinen, Phys. Med. Biol. 38 (1993) 173.
[7] M. Heydarian, P.W. Hoban, W.A. Beckam, I.M. Borchardt, A.H. Beddoe, Phys. Med. Biol. 38 (1993) 1035.