3D diamond detectors for small field dosimetry in photon beam radiotherapy


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Outline

- Small field dosimetry issues
- 3D diamond detectors
- Standard photon beam dosimetry
- Small photon beam dosimetry
- Optimization of fabrication process, geometry and readout of 3D dosimeters
- Conclusions
Small field dosimetry issues

- Small fields < 3x3 cm²
- Lateral charged particle equilibrium is lost
- Volume averaging due to the detector dimension

Complexity of dose calculation (Alfonso formalism)
3D Diamond detectors for dosimetry

Why 3D Diamond for dosimetry:

- Low bias voltage (few V) with high active volume;
- Reproducibility of the elementary 3D cell
- An 'all-carbon' detector exposed to the beam (tissue equivalence)
- High spatial segmentation, even 0.1 x 0.1 mm²
- High resistance to radiation damage
5x5 cm²
6MV photon beam

Repeatability
within 1%

\( \delta = 0.998 \)
indicates linear dependence

Residuals
between the predicted values and the measured ones are less than 2%.

\[ I = I_{\text{dark}} + KD^\delta \]
Offset due to the uncertainty on the detector position inside the PMMA. For a 2mm shift on the detector position, a maximum relative deviation of 2.7% and a mean relative deviation of 1.7% are obtained.
Small photon beam dosimetry

A mechanical system for linear motion in x, y axes in remote control with 210 nm minimal step used for beam profile measurement.
Reconstruction of small beam profiles (200 steps)

Readout pixel (0.5mm$^3$)

- 16 mm x 16 mm
- 32 mm x 32 mm
- 4 mm x 4 mm
Small photon beam dosimetry—Firenze Hospital

Field size 8 mm x 8 mm

Comparison between:
- diamante 3D
- Diamante PTW 60019 (2.2 mm diameter)
- SFD Diode (0.6 mm diameter)
Comparison between:

- 3D diamond
- PTW 60019 diamond
- Exradin W1 scintillator
- DIAPIX

Underestimation of the absorbed dose for the smaller fields due to the uncertainty on the position of the detector inside the PMMA phantom

- Design of mechanical structures for high precision positioning of the detector inside the PMMA
New 3D detectors with multiple independent cells readout (Diamond & Diamond on Iridium)

Work in progress

Diamond

DOI

Front

Back
New 3D detectors with multiple independent cells readout

4 / 8 cells readout in parallel

TETRAMM Picoamperometer with 4 readout channels and an integrated high voltage source

Control software developed
3D Diamond & Diamond on Iridium detectors
dark current
3D Diamond single cells response

Diamond @ 20V, 4 mA 160 kV X-ray tube

Rise time of about 2-3 sec (dominated by the time that the x-ray tube employs to reach the preset current value)
3D Diamond single cells response

3D Diamond @ 20V

The single cells current increases linearly with the tube current (Seifert) (3% of deviation)

Linearity of response with the x-ray tube current for all 3D cells

Pixel Current(A)

Pixel_1
Pixel_2
Pixel_3
Pixel_4
Pixel_5
Pixel_6
Pixel_7
Pixel_8

X_ray_tube_Current(mA)

\[ p0 = 1.005e-01 \pm 8.38e-03 \]
\[ p1 = 1.319e+01 \pm 8.09e-03 \]
\[ p2 = 2.33e+02 \pm 5.36e-01 \]
\[ p3 = 1.022e+02 \pm 5.17e-01 \]
\[ p0 = 7.07e+02 \pm 7.015e+01 \]
\[ p1 = 1.503e+03 \pm 1.29e+02 \]
\[ p0 = 1.349e+03 \pm 7.23e+01 \]
\[ p1 = 1.402e+03 \pm 9.38e+01 \]
\[ p0 = 1.335e+03 \pm 8.44e+01 \]
\[ p1 = 1.138e+03 \pm 9.67e+01 \]
\[ p0 = 1.85e+03 \pm 4.86e+01 \]
\[ p1 = 1.25e+03 \pm 9.15e+01 \]
\[ p0 = 5.91e+03 \pm 6.34e+01 \]
\[ p1 = 1.45e+03 \pm 2.36e+01 \]
3D Diamond on Iridium single cells response

Very long rise and fall times (does not depend on the time the x-ray tube takes to reach the preset current value)

The single pixel current is not always linear with the tube current (Seifert)

DOI currently not favored in the choice of the substrate.
Comparative tests on hospital beam – work in progress
3D Diamond detector optimization

Work in progress

- Direct bonding on graphite -> all carbon dosimeter

- Focus optimization -> Decrease resistivity and increase column uniformity
Next? New highly segmented polycrystalline diamond dosimeter

256 pixels 3D diamond matrix

256 low noise readout channels
Conclusions

✓ Results demonstrate the feasibility of 3D diamond devices for dosimetry of standard clinical megavoltage photon beams, showing a linear dose response, repeatability and time stability.

✓ Small field beam profile have been measured with a 3D diamond single cell of 0.5 mm x 0.5 mm x 0.5 mm active volume showing good compatibility with other clinical dosimeters.

✓ The development of a new sensor connection technique (direct bonding on graphite) and the optimization of the laser focus are ongoing.

✓ A new highly segmented polycrystalline diamond dosimeter will be produced. Due to the simultaneous measurement of many points, a higher accuracy in measurements of very small size field profiles would be possible and the need of using many not standard correction factors will be greatly reduced.