Calibration of a polycrystalline 3D diamond detector for small field dosimetry

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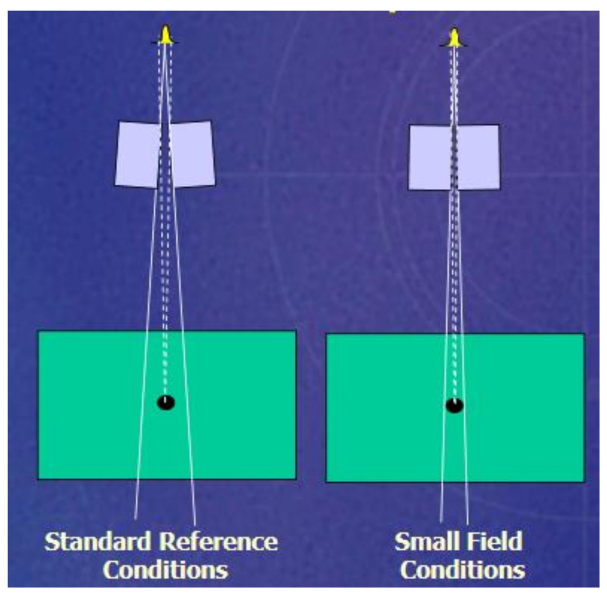
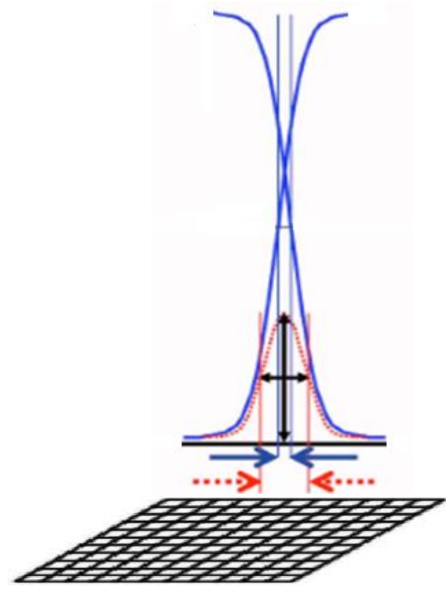
Introduction

In medical radiation dosimetry, the use of small photon fields is almost a prerequisite for high precision localized dose delivery to delineated target volumes. The accurate measurement of standard dosimetric quantities in such situations depends on the size of the detector with respect to the field dimensions.

Thanks to a new technology, polycrystalline diamond devices with 3-dimensional structures are produced by using laser pulses to create graphitic paths in the diamond bulk. By fabricating very narrow and close by columnar electrodes perpendicular to the detector surface, it is possible to create arrays of 3D-cells with very small sensitive volume.

In order to present a solution to the problem of the detector size for small field dosimetry the 3D technology aims to a new highly segmented larger polycrystalline diamond dosimeter to obtain field profiles in a single shot measurement, reducing the uncertainty of the delivered dose.

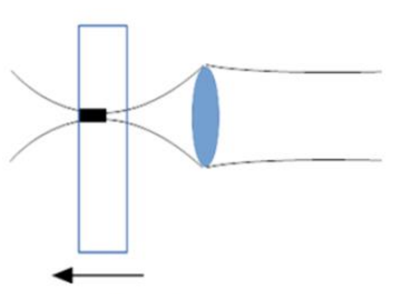


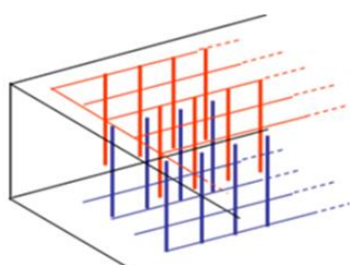


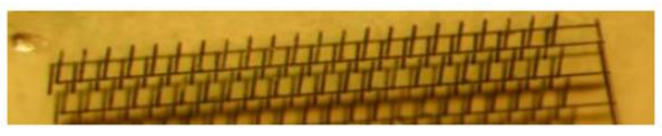
Detector

Device Fabrication

The 3D columnar electrodes are fabricated by a pulsed laser technique. The diamond sample is irradiated by a Ti:Sa fs laser beam whose beam waist moves across the diamond bulk, leaving a graphitic conductive path. The graphitic bulk electrodes are connected by surface graphitization, via a Nd:YAG ns laser beam.

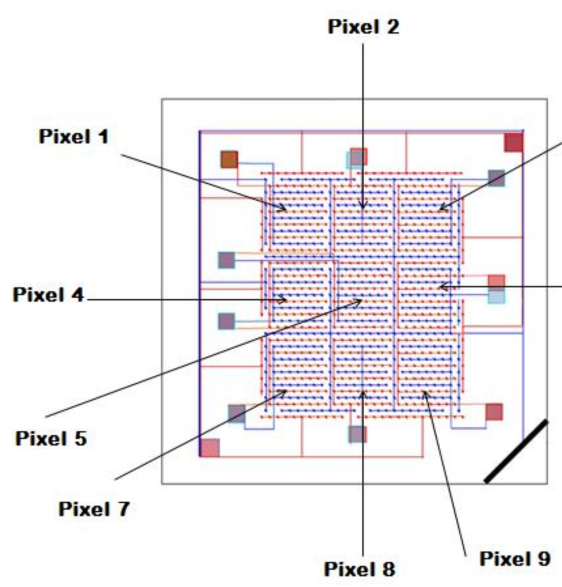


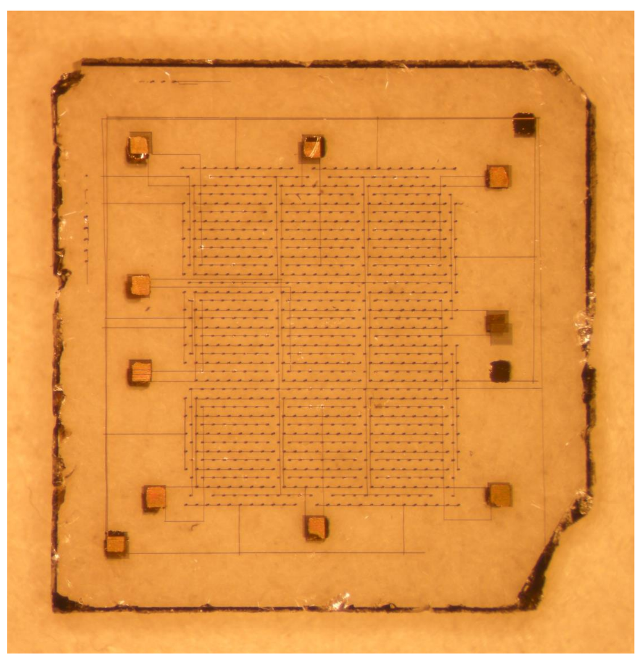




A 3D all carbon detector with an array of 9 3D cells (pixels) have been produced in the framework of the **3DOSE** INFN experiment.

Every 3D-cell of the 9 cell matrix has a sensitive volume of about 750 x 750 x 500 μm^3 made of elementary cells of 114 x 70 x 500 μm^3.

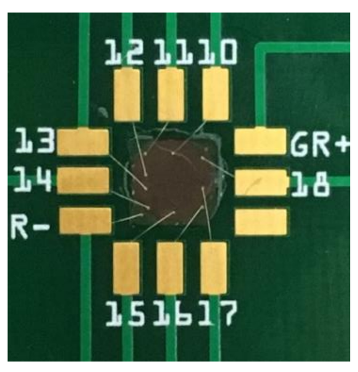


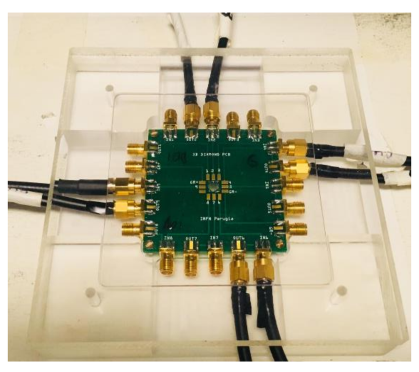


The aim of this work is the study and calibration of the detector 3D cells made for medical small fields dosimetry. This allows any cell's response in current to be converted in dose by scaling with the measured calibration factor.

Measurement Setup

The response of the diamond detector was studied irradiating it with 6 MV photons produced by a medical linear accelerator (Elekta Synergy Sband) with 10 × 10 cm^2 field at the "Santa Maria della Misericordia" Hospital in Perugia.





The detector was encapsulated at a 10 cm depth inside a 14 x 14 x 14 cm^3 PMMA block and placed at 100 cm from the beam source.

For three pixels, the corresponding pads have been fabricated close to the substrate edge and it was impossible to bond them from the back. Hence only 6 from the 9 available pixels have been read out .

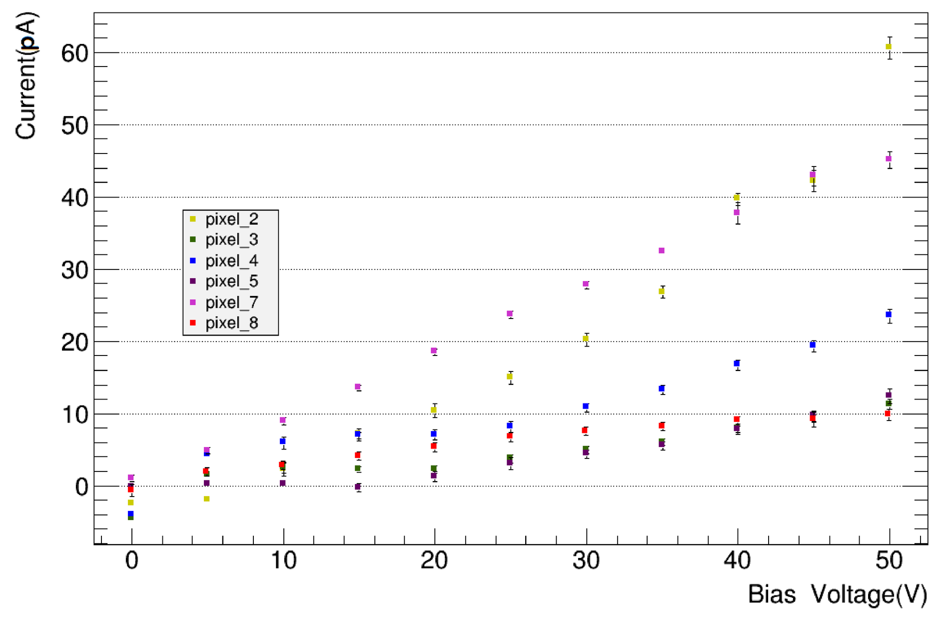
The 3D cells can be readout separately and in parallel . A picoamperometer (Tetramm) with 4 readout channels and an integrated high voltage has been used to readout 4 cells in parallel.

The detector is biased with 10V and the picoaperometer is controlled from the outside of the control room by a custom software.

Results

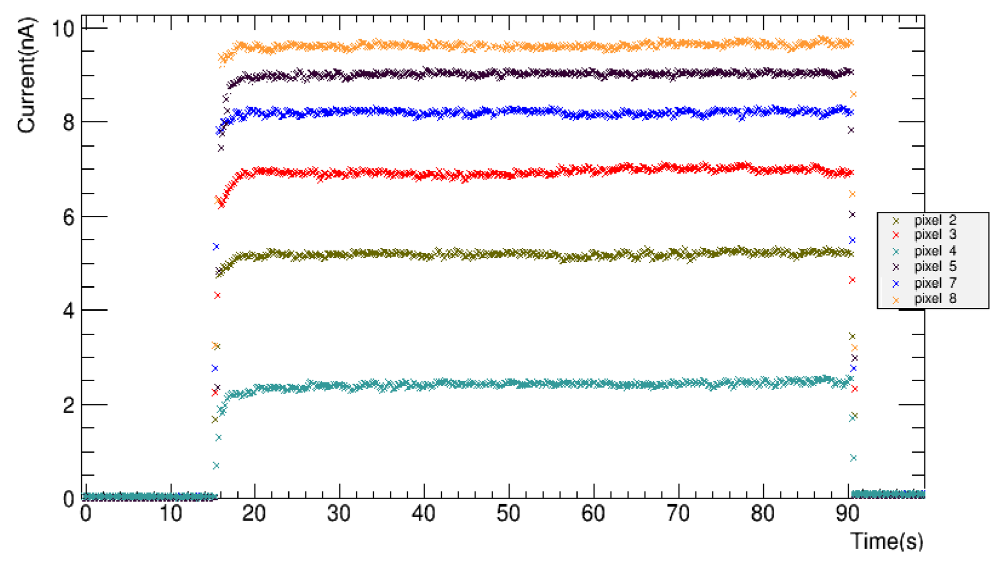
Due to the heterogeneous structure of the polycrystalline diamond substrate, the eventual differences on the resistivity of 3D columns and the contacts of every single pad , it was necessary to study the response of each 3D cell under a large field photon beam (10 x 10 cm^2).

Leakage Current



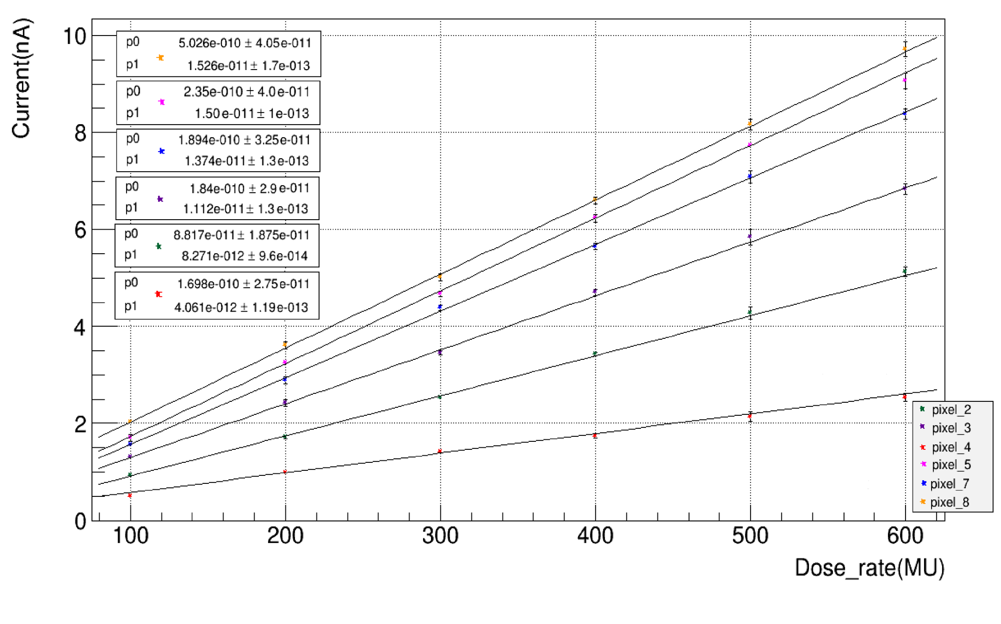
Before irradiating the detector a study of the detector leakage current has been done in order to choose the bias working point. The leakage currents are of the order of tens of picoampers. It was not necessary to apply voltages higher than 50V because the 3D detectors reach the full charge collection efficiency at 30-50V.

Short Time Stability



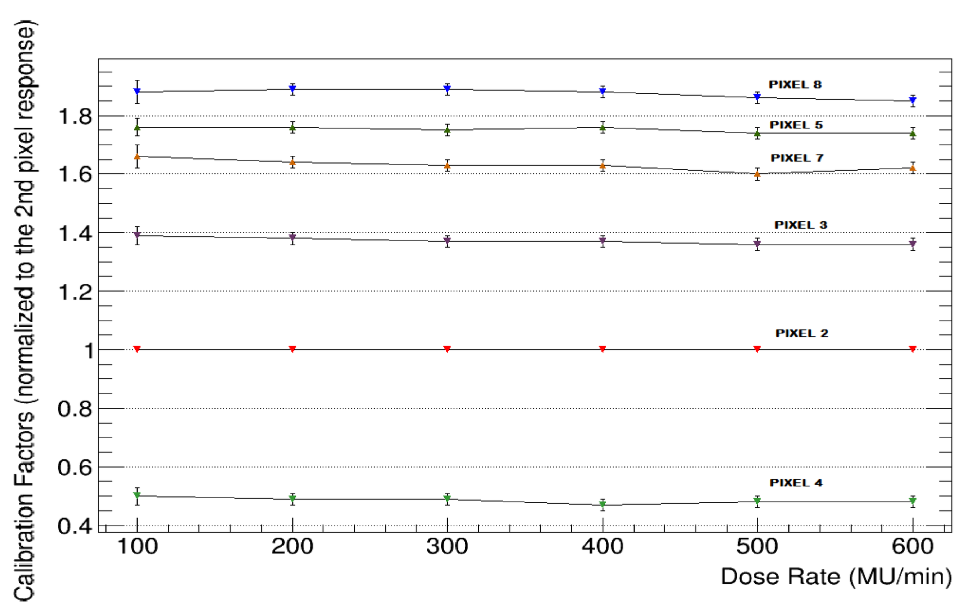
3D diamond cells response while biased with 10V and irradiated with a dose rate of 600MU/min. Each 3D cell has a different sensibility, but the response is stable. The stabilty of the current response was evaluated looking at the standard deviation on the measured mean current value and it is within 2% in the worst case.

Dose Rate Dependence



The photon beam dose rates are limited to six different values that the medical linear accelerator can deliver. Every single 3D cell shows a linear trend with the dose rate. The slope of the linearity curves representing the sensitivity of each 3D cell is different, hence each cell presents a different response to the same external stimulation. The residuals between the predicted values and the measured ones are less than 2.8% (worst case).

Calibration Factors



The calibration factor of every 3D diamond 'pixel' has been calculated normalizing to the 'pixel' number 2. The ratios were assessed for all dose rates and they remain stable within 2.4% ('pixel 7'). An optimization process of several characteristics of the detector, to better understand and if possible reduce the differences of the pixels response, is ongoing.

Conclusions

It was demonstrated that a 3D diamond detector, even if realized in polycrystalline substrate, is a suitable choice to implement dosimetric devices in order to characterize therapeutic photon beams. Each single cell of the array has a different sensitivity to the radiation beam, but the response is linear with the dose rate and stable in time hence different calibration factors can be applied to obtain an overall detector response and reduce the uncertainty of the delivered dose. After optimization, a highly segmented large sensitive area polycrystalline CVD diamond dosimeter will be produced (25 x 25 mm^2).

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