RDH/IRPT WP8 : Development of large-area monolithic 2D dosimeters made with polycrystalline CVD diamond
Motivation

Modern radiotherapy techniques: **dose-delivery conformal to tumors** to spare healthy tissues

- Intensity Modulated RadioTherapy – IMRT
- Volumetric Modulated Arc Theraphy - VMAT

→ high spatial gradients, strong variations in space and time of dose rate and energy spectrum.

**Requirement:** Tissue equivalent bidimensional dosimeter for pre-treatment verifications

Multi Leaf Collimator (MLC) mounted on the linear accelerator head
VMAT*: Continuous delivery modality

Intensity modulation is obtained thanks to MLC, variable dose rate and variable rotation velocity of gantry

Gantry moving continuously without dead times due to repositioning

VMAT / IMRT comparable in terms of target covering and sparing of healthy tissues;

VMAT reduced treatment time (10-15 times)


M. Bruzzi, IRPT Meeting, Roma 1st February 2016
Diamond Dosimeters

- **it is almost water equivalent**
  - it doesn’t perturb the radiation field → small fields
  - the energy is absorbed as in the water → no correction factors

- **high radiation hardness** → long term stability
- high density → high sensitivity → small dimensions
- non toxic

**Natural diamond**

- **very high production costs, difficult to select stones with proper dosimetric response** ♠️

**Single crystal CVD (Chemically Vapour Deposited) diamond**

- grown on HPHT diamond, not available in large areas ♠️

**OUR CHOICE**: Polycrystalline CVD diamond

- ability to produce large area wafers of 3-5”
- zero/low voltage to reduce polarization effects*

*M. Bruzzi et al., Diamond & Related Materials 20 (2011) 84–92

M. Bruzzi, IRPT Meeting, Roma 1st February 2016
2015 – development of a 2-polycrystalline pixel diamond dosimeter (Florence)

- Material
  - Two polycrystalline diamond films 2.5x2.5cm² active area each, 300µm thick;
  - Premium Detector Grade Element Six, UK

- Contacts
  - Schottky Barriers produced @ University of Florence
  - 12 x 12 matrix, pixel size: 1.8x1.8 mm² → 288 pixels in total

- Read Out Electronics
  - four 64 channels 20 bit current-input analog to digital converter chips able of measuring currents from fAs to mAs; 160µs-1s integration time (50ms)
  - custom printed circuit board;
  - semi-rigid silver-polymer pin-contacts produced by us connecting each pixel of the 144 matrix connecting vias on PCB.

- Measurement
  - Low voltage to get fast and reproducible signals;
  - Device can be moved in x-y directions to cover a wider radiation field area.

M. Bruzzi, IRPT Meeting, Roma 1st February 2016
Experimental Test Set-up

LINAC @ Radioterapia AOUC Firenze

1 pCVD on PCB

2 pCVD in PMMA /front /rear

Connecting pins
Sviluppo firmware e software di un rivelatore bidimensionale per radioterapia
Analysis of the uniformity of the pixels response under a uniform beam

Current and charge response of 288 pixels (active area 5.0x2.5cm² in a 10cmx10cm field ($V_{app} = 2V$)) under a conventional 6MV X beam

- negligible dark current $\rightarrow$ high S/N
- stable response, fast dynamics
- Spread in the sensitivity
  
  $S = \frac{dQ}{dD} \sim 20 \frac{nC}{Gy}$

- Only a few contacts not working properly

M. Bruzzi, IRPT Meeting, Roma 1st February 2016
Calibration under a uniform beam

Charge response of the 288 pixels before and after calibration correction

Before calibration

After calibration
VMAT First experimental Test

- lung cancer treatment
- 2 polycrystalline diamond dosimeters
- Active area: 5.0x2.5cm²

3 measurements: system moved ±0.4cm in the y-direction to cover the entire field

Presented at International Conference on Diamond and Carbon Materials, Bad Homburg, Germany, 8 September 2015
Before calibration – central sector (1)
after calibration – central sector (1)
VMAT map-comparison between experimental and calculated dose maps

VMAT map as measured by the two pCVD diamond

VMAT map as calculated by the TPS

Preliminary Results!

Quantitative data analysis in progress

M. Bruzzi, IRPT Meeting, Roma 1st February 2016
The activity is mainly devoted to demonstrate the procurement capability and quality certification of large size polycrystalline diamond sensors to be used in IMRT.

Delay in procurement of large size diamonds from II-VI USA likely due to LHC priority

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To be delivered in Mar 2016 (8 month delay)
Preliminary test with CR

Charge collection distance
CD ~ 300 um
(Quite good)

CR coincidence between the two 2x2x0.05cm³ II-VI diamond

NEXT: Accurate efficiency mapping with beta source and laser under way
Infrastructure at LNS

Concrete shield already operational at zero degree line for all users

Further instrumentation for users under procurement:
- XZ Device Under Test movement system remotely controlled
- Multi-channel electronics to readout a segmented Secondary Electron System by DC

Under conceptual design:
- Segmented Secondary Electron System (for example Ta foils)
- Custom made in air Faraday Cup
2015 - Papers and Conferences

Conferences:
M. Bruzzi et al., Extraction of VMAT 2D maps of dose with a large-area monolithic bidimensional dosimeter made with polycrystalline CVD diamond
Talk at International Conference on Diamond and Carbon Materials, Bad Homburg, Germany, 8 September 2015

Papers:

- Chiodini, G.; Fiore, G.; Perrino, R.; et al., Diamond detector time resolution for large angle tracks, NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT Volume: 796 Pages: 38-41 Published: OCT 1 2015
WP8 Program 2016

- Tests and data analysis with the 2 diamond system with IMRT/VMAT beams;
- Development of the PCB electronic readout for 3 diamonds (7.5x2.5cm²);
- First tests with the 3 diamond system;
- Comparison of uniformity tests with cce (beta) and radiotherapeutic beam X6MV
- Possible upgrade to a 4-diamond system including one sample from the Lecce Group to cover a 10x2.5cm² area.
Thank you!