Characterisation of a novel diamond-based microdosimeter for radiation protection of astronauts

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Outline

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• Evolution of microdosimetry at CMRP
• Diamond microdosimetry
• Experimental measurements
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• 2\textsuperscript{nd} study- characterisation of detector response to GCR
• Summary
Introduction

• One of the major issues for manned space exploration is the health hazard posed by the exposure of Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE) to crew members.

• Nowadays there is the need of **accurate detectors**, capable of measuring **dose equivalent in a mixed radiation field**, typical of a space environment.

• Microdosimetry is an approach that allows accurate measurement of dose equivalent in any mixed radiation field, on a cellular level (1-5μm), [H, Rossi & M, Zaider].

• Microdosimeters may be adopted as a monitoring system for radiation protection purposes.
Microdosimetry

The linear energy transfer is equal to the energy $dE$ which a charged particle loses at a distance $dx$ [H, Rossi & M, Zaider].

\[ LET = \frac{dE}{dx} \]

Units: keV/um

High LET hits to the nucleus increase probability of multiple DNA breaks

Radiotherapy traversal of a cell in BNCT

Nucleus of cell

~10 µm

[A. B Rosenfeld]
**SOI microdosimetry**

**Optical Microscope Image**

**2 MeV Alpha Microbeam IBIC**

**SOI Device:**

[A. B Rosenfeld, A. Wroe, A. L Ziebel, S Guatelli, P Bradley, I. Cornelius]

Can be successfully used for regional microdosimetry in a space environment

Requires tissue equivalent correction (Si)

**Next step:** substitute silicon with diamond, as material of the SV

**Schematic concept**
Diamond based microdosimetry
Why diamond?

- Radiation hardness.
- High resistivity (>10¹³ Ωcm)
- Large band gap (5.5eV)
- Low dark current (1 pA/cm² at room temperature)
- Good temperature stability.
- High carrier mobilities allow for fast signal collection.
- Low dielectric constant -> low capacitive load with the negligible dark current means a low noise.

[G.T.Betzel]
The Design

Our Microdosimeter utilises diamond as the sensitive volume (SV) material of choice. These SV’s are surrounded by boron doped diamond.

The contacts used are:
- Aluminium (top)
- Gold (back)

Advantage
High electric field can be applied due to SV size
Charges can be collected in a short range before they are trapped in defect centres.
Experimental measurements: IBIC Study (ANSTO)

- Well defined sensitive volumes (SV)
- Higher charge collection occurring towards the edge of the aluminium pad
A closer look at the aluminium pad

Upon inspection there does appear to be some non-uniformity in the aluminium pad.
Goal of the Geant4 simulation study

• To analyse the Charge Collection Efficiency (CCE) in terms of detector design
  ➢ Study of the effect of device geometries (Al contact widths) on the detector response

• To characterise the response of the novel diamond based microdosimeter developed at CMRP
  ➢ In a mixed radiation field of interest for radiation protection in space
Geant4 simulation experimental set-up

- Simulation of the energy deposition per event deriving from proton, alpha and heavy ion particle fields, with an energy range typical of GCR and SPE, in the diamond SV.
Some relevant dimensions

- Depth: 1.36 μm
- Total depth of substrate: 300 μm

Dimensions:
- 480 μm (height)
- 600 μm (length)
- 150 μm (width)
- 90 μm
Model of the radiation field

- This simulation utilises General Particle Source (GPS) to model the radiation field.
- The radiation field in this initial work has been limited to a pencil beam incident orthogonally upon a SV within the device.
- Particles and energies were chosen depending upon the requirements of the study.
General Particle Source - GPS

- GPS allows ease for switching between monoenergetic particles and a spectrum as typified by GCR.
- GPS has been chosen as it allows greater versatility than Geant4 particle gun. This will become increasingly important in future work.
Physics List

• Physics List:
  • Low Energy Package to describe electromagnetic interactions down to 250eV
    • Range cut = 1 micrometer
  • QGSP_BIC_HP physics list for hadronic interactions
  • Hadronic interactions modelled for hadrons and ions
  • QGS- Quark Gluon String model
  • BIC- Binary Ion Cascade model
  • HPneutron (High Precision) used to describe in detail all neutron interactions with energy < 20 MeV

QGSP_BIC_HP:
Used in radiation shielding, protection and medical applications

GEANT4 v. 9.4
1st study: effect of Al contacts on energy deposition

- **Particle:** Beryllium nuclei
- **Energy:** 5.48 MeV
- **Aluminium contact thickness:** 0, 0.5, 1 and 1.5 um
- **Number of events:** 10^4 events were executed
- **Output:** Energy deposition histogram
  Stored as ROOT file

Geant4 simulation
Experimental set-up
Results of 1st study: Stripped beryllium ions (5.48MeV)

- Effect of different Al thickness on the energy deposition spectra deriving from energetic beryllium in the diamond SV

![Energy deposition graph for 0umAl](image1)

![Energy deposition graph for 0.5umAl](image2)
Results of 1st study: Stripped beryllium ions (5.48MeV)

- Effect of different Ti thickness on the energy deposition spectra deriving from energetic beryllium in the diamond SV
## Range of beryllium (5.50MeV) - SRIM

<table>
<thead>
<tr>
<th>Material</th>
<th>dE/dx (keV/um)</th>
<th>Range (um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>733.84</td>
<td>7.71</td>
</tr>
<tr>
<td>Diamond</td>
<td>1401.39</td>
<td>4.07</td>
</tr>
</tbody>
</table>
2nd study: Characterisation of response to GCR

Study of the response of the device to Galactic Cosmic protons

Each simulation consisted of $10^6$ events.

GCR proton and alpha particle fluence from creme96 [7] [8]
Monoenergetic protons

Energy deposition

1 GeV

Energy deposition

50 MeV

Energy deposition

1 MeV
GCR protons

Depicts the energy deposition spectra from GCR protons that span the energy range of 1MeV/nucleon to 10GeV/nucleon.

~ 25 keV
Monoenergetic alpha (1\mu mAl)

1GeV/nucleon

50MeV/nucleon

1MeV/nucleon

10^5 events
Depicts the energy deposition spectra from GCR alpha that span the energy range of 1MeV/nucleon to 10GeV/nucleon.
Summary:

1st study: Device optimisation
- The Al contacts (0 – 1.5 um) have been shown to affect the energy deposition spectra. This explains the difference in charge collection as seen in experimental work.

2nd Study- Response of diamond microdosimeter to GCR
- Characterisation of detector response with GCR proton & alpha. Study should be extended to include HZE, i.e. (C, O, Si, Fe)
- Model GCR as an isotropic field
- Model detector as well as space shuttle.
References:

[2] A. B Rosenfeld, SOI microdosimetry presentation
That's all Folks!