Evaluation of the counting efficiency of a pcCVD diamond detector irradiated by 62 MeV/u carbon beams

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CVD Synthetic Diamonds

Synthetic diamond offers, over more conventional materials, a combination of unique properties which make it an attractive alternative for a wide range of applications in the field of X-, γ-rays and charged particle detection.

**scCVD diamond samples**
- Can be purchased with different thicknesses and area up to 1 cm²
- Exhibit high purity and low dislocation concentration which leads to high mobilities and longer lifetimes of the charge carriers
- Show CCE \( \frac{Q_c}{Q_g} = 1 \)

**pcCVD diamond samples**
- Are available in larger sizes (it allows to develop detectors having larger active areas)
- Have a larger amount of intrinsic defects (shorter lifetimes of the charge carriers)
- Show CCE \( \frac{Q_c}{Q_g} = 0.1 - 0.6^* \)

*Particle intensity monitors based on pcCVD diamond samples may suffer from a reduction in their counting efficiency. Indeed, the partial CCE may generate signals having amplitudes below the threshold value of the discriminator.*
The Goal

Key parameter under study is the counting efficiency ratio between a pcCVD and scCVD diamond detectors as a function of the beam intensity measured by a SEETRAM.

This study will allow to understand the dependence of the counting efficiency ratio respect to the following parameters:

- Beam Intensity
- Absorbed ions

Additional tasks:

- SEETRAM calibration with the SC-DD
## Diamond Detectors

<table>
<thead>
<tr>
<th>Sample</th>
<th>Type</th>
<th>Dimensions (mm$^2$)</th>
<th>Electrodes (nm), Type</th>
<th>Active Area (mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2340622-5</td>
<td>pcCVD</td>
<td>20 x 20 x 0.3</td>
<td>100, Au</td>
<td>18.5 x 18</td>
</tr>
<tr>
<td>2340622-6</td>
<td></td>
<td></td>
<td>50/100, Cr/Au</td>
<td></td>
</tr>
<tr>
<td>2340622-10</td>
<td></td>
<td></td>
<td>100, Al</td>
<td></td>
</tr>
<tr>
<td>534-8A</td>
<td>scCVD</td>
<td>4.2 x 4.2 x 0.16</td>
<td>100, Au</td>
<td>3.2 x 3.2</td>
</tr>
<tr>
<td>534-8B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>534-9A</td>
<td></td>
<td>4.2 x 4.2 x 0.2</td>
<td>50/100, Cr/Au</td>
<td></td>
</tr>
<tr>
<td>534-9B</td>
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</tbody>
</table>

### X-rays test settings

<table>
<thead>
<tr>
<th>Distance (mm)</th>
<th>Tube Voltage (kV)</th>
<th>Tube Current (µA)</th>
<th>Ø Collimator (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>40</td>
<td>90</td>
<td>2 (Flux cone &lt; 5°)</td>
</tr>
</tbody>
</table>

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15th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD19)
X-rays Tests (i)

- Electric field applied 1 V/μm on all devices
- Sensors show different dynamic response, leakage current and signal-to-noise ratio according to the electrodes type
Experimental Setup @LNS Facility

- Vacuum chamber integrated and aligned in the Zero Degree beam line
- No counting losses due to the detectors geometry [LISE++]
- Direct comparison of the detectors performance (no correction factors introduced)

- Beam: fully stripped $^{12}\text{C} @ 62 \text{ MeV/u}$
- Intensity: variable [slits opening, attenuation factors (1, 10, 100, 1000)]
SC-DD Counting Efficiency Assessment

- Data collected at the beginning of the experiment
- Linear relationship up to 1.25 MHz [Slope coefficient: 0.9998 ± 0.0004]
- SC-DD shows 100% counting efficiency
The calibration factor was found as linear parameter of a second order polynomial fit 
\[ K = (6295 \pm 320) \times 10^{14} \text{ ions/A}, \text{ uncertainty } \sim 5\% \]

\[ N_{\text{ions}} = I_{\text{SEM}} \cdot K \]
Counting Efficiency Ratio

Absorbed ions: 
(4.5, 7.9, 15)·10^9 ions/mm^2

PC-DD Counting Efficiency [< 700 kHz*]: (94.8 ± 2.5)%
Counting Efficiency Ratio

\[ R = \frac{N_{PC-DD}}{N_{SC-DD}} \]

Increase with the absorbed ions

Probably due to an increase of the radiation damage in the scCVD diamond material causing the device to have, with on-going irradiation, a smaller counting efficiency

Decrease with the rate

Linked to the different signal length of the PC-DD as compared to that of the SC-DD (from waveform analysis 14 and 3 ns respectively)

PC-DD has higher probability of being affected by pile-up
Long term measurements recorded with electric field applied of 1 V/μm

No remarkable effects on the signal after $^{12}$C irradiation
Conclusions

- SC-DD proved to be a very good alternative to the standard absolute reference intensity monitor based on scintillators.

- SC-DD can be used to calibrate the SEM within ~5% uncertainty.

- PC-DD counting efficiency $\left(94.8 \pm 2.5\right)\%$ for absorbed ions up to $7.9 \cdot 10^9$ ions/mm$^2$ and beam rate below 700 kHz.

The counting efficiency achieved together with the demonstrated radiation hardness open new perspectives for the use of PC-DDs as particle intensity monitor.

Integration and technical design of PC-DDs within the particle detector combination (PDC) along the beam line in the Super-FRS@FAIR is under discussion.

Detailed information regarding this research work are included in the PhD thesis of S. Schlemme (2019) which can be found here: [https://tuprints.ulb.tu-darmstadt.de/8843/](https://tuprints.ulb.tu-darmstadt.de/8843/)