Outline

• Neutron signatures in sCVD diamond
• Signal analysis in real-time
• Applications
Diamond Detectors

Synthetic chemical vapor deposition diamond:

• Solid-state detector.
• Little impurities (N < 5 ppb, B < 3 ppb).
• Thermal robust.
• Radiation hard.

Uniquely suited for diagnostics in rough environments like fission and fusion reactors.
Detecting neutrons with diamond detectors
Thermal neutrons

External converter needed: $^6\text{Li}$, $^{10}\text{B}$, $^{235}\text{U}$, ...
Fast neutrons

Diamond sensor serves as neutron converter.
Background considerations

- Neutron interactions in surrounding materials \((n,\gamma), (n,p), (n,a), \ldots\)
- In-beam \(\gamma\) from the neutron source.
- ...
Current signals in sCVD diamond
Equivalent circuit diagram

Schockley-Ramo Theorem

\[ I = q \cdot \frac{v_{\text{drift}}}{d} \]
Signal shapes in sCVD

Homogeneous ionization (MIP, γ):

\[ E = \frac{u}{d} \]

\[ R \]

\[ u \]

\[ v_b \]

\[ v_h \]

\[ A [V] \]

\[ t [\text{ns}] \]
Signal shapes in sCVD

Point-like ionization:

\[ E = \frac{u}{d} \]

\[ R \]

\[ A \text{ [V]} \]

\[ 0 \quad 0.05 \quad 0.1 \quad 0.15 \quad 0.2 \quad 0.25 \quad 0.3 \]

\[ -4 \quad -2 \quad 0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \quad 14 \]

\[ t \text{ [ns]} \]
Signal shapes in sCVD

Point-like ionization:

\[ E = \frac{u}{d} \]

\[ R \]

\[ u \]

\[ v_e \]

\[ v_n \]

\[ A [V] \]

\[ t [ns] \]
Signal shapes in sCVD

Point-like ionization:

\[ E = \frac{u}{d} \]
Signal shapes in sCVD

Point-like ionization:

\[ E = \frac{u}{d} \]

\[ R \]

\[ v_e \]

\[ v_h \]
Signal shapes in sCVD

Point-like ionization:

\[ E = \frac{u}{d} \]

**New definition:**

**Ballistic Centre**

\[ t_{d,h} = t_{d,e} \]
Simulation: point-like ionization
Experiment: point-like ionization

The graph shows the voltage $A$ over time $t$ in nanoseconds for different drift mechanisms. The voltage peaks at different times, indicating the distinct arrival times of $h^+$ and $e^-$ drifts, with $h^+$ having a faster arrival time compared to $e^-$. The ballistic center is also marked with an arrow, showing the theoretical arrival time without drift effects.
Requirements

1. sCVD diamond sensor.
2. RF-shielded detector design.
3. Low detector capacitance (RC time constant).
4. 2 GHz Broadband Amplifier.
5. Real-time data acquisition and analysis.

With these ingredients, background reactions to neutron measurements can be rejected.
Signal analysis
## Selection criteria

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area A</td>
<td>Deposited energy in the detector</td>
</tr>
<tr>
<td>Base width $w_b$</td>
<td>Drift time</td>
</tr>
<tr>
<td>FWHM</td>
<td>Signal shape and drift time (if no high-energy neutrons)</td>
</tr>
<tr>
<td>Form factor F</td>
<td>Signal shape</td>
</tr>
</tbody>
</table>
Form-factor
Distinguishing by shape

- **Form-factor**

\[ F = \frac{\text{calculated area}}{\text{measured area}} = \frac{h \cdot w_b}{A} \]

Rectangles: \( F = 1 \)

Triangles: \( F = 2 \)
Distinguishing by drift time

Measurement with 14 MeV neutrons

Counts

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Distinguishing by drift time

- Measurement with 14 MeV neutrons
- Selection criteria $F < 1.4$

Counts

$10^4$

$10^3$

$10^2$

0 2 4 6 8 10 12 14 16

$w_b$ [ns]

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Three application examples:

1. Thermal neutrons
2. Fast neutrons
3. Mixed field (reactor core)
Three application examples:

1. Thermal neutrons
2. Fast neutrons
3. Mixed field (reactor core)
ATI, Vienna, Austria

- Measurement at a thermal neutron beam line at the TRIGA Mark-II reaction.

- $^6$Li converter for thermal neutron conversion.

- High $\gamma$-background.

\[
\begin{align*}
\text{n} & \rightarrow \gamma \\
6\text{Li} & \rightarrow \alpha \\
\text{sCVD} &
\end{align*}
\]
Recorded spectrum without PSA

Selecting the relevant signals


96% γ-Background Rejection Efficiency
Three application examples:

1. Thermal neutrons
2. Fast neutrons
3. Mixed field (reactor core)
EC-JRC, Geel, Belgium

- Measurement at the Van de Graaff accelerator of EC-JRC in mono-energetic neutron beam.
- sCVD sensor used as converter.
- Proton recoil background.
Measurement of 14.3 MeV neutrons

Selecting the relevant signals

Selecting the relevant signals


99.95% Background Rejection Efficiency
21.7% Efficiency
Three application examples:

1. Thermal neutrons
2. Fast neutrons
3. Mixed field (reactor core)
• sCVD Diamond + $^6\text{Li}$ neutron converter.
• In the core of the thermal reactor CROCUS.

• n-γ discrimination?
• Can the fast neutrons be identified?
Total Spectrum

Photons

$^6\text{Li}(n,\alpha)^3\text{H}$

Fast Neutrons

Fast Neutrons


PRELIMINARY
On-going research at EPFL Lausanne

Christina Weiss
Conclusions
Conclusion

• Current signals in diamond detectors reflect information on the initial charge-distribution profile in the diamond sensor.

• This allows to identify signals from different origins (MIP or cp entering the sensor, versus nuclear reactions inside the sensor).

• Via pulse-shape analysis the background in neutron measurements can be reduced significantly.

• This allows to extract the neutron interactions, even from measurements with significant background.
Thank you for your attention!

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