Novel Plastic Microchannel-Based Direct Fast Neutron Detection

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Outline

- Microchannel plate (MCP) background
- Arradiance functional thin film technology
  - Atomic Layer Deposition (ALD)
- Substrate independent MCP technology
  - Secondary electron emissive films
  - Conductive films
- Fast neutron MCP detector
  - Concept
  - Functionality
  - Simulation
- Fast neutron MCP detector experimental
- Fast neutron MCP detector results
- Summary and Future Work
MicroChannel Plate (MCP) Technology

- Mature (1960s) MFG, Expensive, Bulk materials determine performance, High Z content, limited size (<10cm), difficult process control
- Event counting: >10^7 gain, <0.01 c/cm^2-s noise, high efficiency, <10µm spatial resolution, <50ps rms temporal resolution

![Diagram of MCP production process](image)

Elemental composition of MCP glass:

<table>
<thead>
<tr>
<th>Z</th>
<th>Element</th>
<th>Weight percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>Pb</td>
<td>47.8</td>
</tr>
<tr>
<td>8</td>
<td>O</td>
<td>25.8</td>
</tr>
<tr>
<td>14</td>
<td>Si</td>
<td>18.2</td>
</tr>
<tr>
<td>19</td>
<td>K</td>
<td>4.2</td>
</tr>
<tr>
<td>37</td>
<td>Rb</td>
<td>1.8</td>
</tr>
<tr>
<td>56</td>
<td>Ba</td>
<td>1.3</td>
</tr>
<tr>
<td>33</td>
<td>As</td>
<td>0.4</td>
</tr>
<tr>
<td>55</td>
<td>Cs</td>
<td>0.2</td>
</tr>
<tr>
<td>11</td>
<td>Na</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Density ~ 4.0 g/cm^3.

Wiza, Nuclear Inst. & Meth., Vol 162, 1979, 587

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ALD MCP Technology

- MCP performance tied to glass composition

ALD:
- Device optimization is decoupled from substrate.
- Semiconductor processes & process control.
- Materials engineering at the nanoscale
- Functional films composed of abundant, non-toxic materials.

Advantages:
- High conformality (>500:1)
- Scalable to large areas
- Digital thickness control
- Pure films
- Control over film composition
- Low deposition temperatures (50-300°C)

- Thin film growth that relies on self-limiting surface reactions
- Gas A reacts with a surface
  - excess precursor & reaction by-product removed.
- Gas B is introduced to the evacuated chamber – reacts with surface bound A
  - excess precursor & reaction by-product removed.
- Repetition of A – B pulse sequence to build film layer-by-layer
ALD Functional Films: Substrate Independent MCP

- SE yields >5 possible vs MCP < 3
- Conductivity range > 7 orders of magnitude
- Ohmic conduction, Stable in applied E field, TCR < 1%

10 µm pore, Soda Lime glass substrate, 40:1 L/D, R~280 MW
5-10x gain increase vs. commercial MCPs
Fast Neutron Detection Technology

- Hydrogen-rich PMMA MCP
- Graded Temperature ALD
  - Active films deposition at 140°C
- Proton initiated electron cascade
- Output pulse $10^3 - 10^6$ electrons
- Standard readout electronics

Timing histogram of events detected under 120Hz-modulated UV illumination.

$\leq 1\mu$s per UV power supply specs

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Fast Neutron Detection Simulation: P1 and P2 Probabilities

\[ P_{\text{detection}} = P_1 \times P_2 \times P_3 \]

- \( P_1 \) – n-p recoil within the MCP substrate
- \( P_2 \) – proton escape into MCP pore
- \( P_3 \) – electron avalanche is formed (MCP ~1)

\[ P_{1*P2*P3} \]

Pores are 50 \( \mu \text{m} \)

- En = 2 MeV neutron, 50 \( \mu \text{m} \) pores
- En = 10 MeV neutron, 50 \( \mu \text{m} \) pores

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Fast Neutron Detection Simulation: P3 Probability and Event Timing

Operating at 1200V Bias (Average Gain 47)
P3 - Probability 0.9 for 100:1 LD 50 um Pores

For 99.9% of events, we should expect a pulse timing uncertainty in coincidence mode of operation of ±1.5 ns
For 90% of events, we should expect a pulse timing uncertainty in coincidence mode of operation of < ± 1.0 ns

Note:
P3 – Probability for Amplification Stage is 1.0
Timing for Amplification Stage is < 200 ps
Detector Hardware Experimental Setup

- 2 & 5 mm PMMA MCP, ~50 µm pores, 20 µm walls, 5° bias angle
- installed above a chevron stack of 50:1 L/D MCPs
- Phosphor screen readout
- Canberra preamp and postamplifier
Isotope Sources: Experimental Setup

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Am-241</th>
<th>Cs-137</th>
<th>C-60</th>
<th>Cf-252</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma (keV)</td>
<td>1.9 mQ</td>
<td>760 µQ</td>
<td>43.7 µQ</td>
<td></td>
</tr>
<tr>
<td>Flux MCP/s</td>
<td>36% @ 60, 38% @ 12-22</td>
<td>661</td>
<td>1.17; 1.33</td>
<td></td>
</tr>
<tr>
<td>Flux MCP/s</td>
<td>1.76x10^5</td>
<td>7.03x10^4</td>
<td>8.08x10^3</td>
<td>~10^7</td>
</tr>
</tbody>
</table>

- Isotopes ~15cm from liquid scintillator detector spectra collected over 110s (real time).
- Mesytec MPD-4. is used to record PMT data

Reduction of flux by filters

- Pb: Gamma 0.251328, Neutron 0.778787
- Wax: Gamma 0.697481, Neutron 0.384746

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Gamma Isotope Sources MCP Results Summary

PMMA, 2mm, > 100k 50 µm Pores, 20µm wall

\[\begin{array}{|c|c|}
\hline
\text{Gamma E (eV)} & \text{QE} \\
\hline
4.00E+04 & 9.26E-05 \\
6.61E+05 & 2.06E-03 \\
1.20E+06 & 5.22E-03 \\
\hline
\end{array}\]
Cf-252 MCP Experimental Results Summary

Counts in 96 seconds detected by PMMA MCP only (chevron subtracted)

<table>
<thead>
<tr>
<th>Filter</th>
<th>Count rate (cps/detector)</th>
<th>$\gamma$ QE</th>
<th>$n$ QE</th>
</tr>
</thead>
<tbody>
<tr>
<td>no</td>
<td>125</td>
<td>0.000885</td>
<td>3.28E-03</td>
</tr>
<tr>
<td>1” Pb</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5” wax</td>
<td>83</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$n$ QE well matched to simulation
D-T Source (Thermo 320) Experimental Setup

Filters: Lead (2”), polyethylene (1”, 2”), borated plastic (1”)

Lead shielding around the detector

MCPs
5 mm PMMA MCP, ~50 µm pores, 20 µm walls, 5° bias angle installed above a chevron stack of 50:1 L/D MCPs

Polyethylene shielding around the source

Source

~30 cm

Technical Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron Yield</td>
<td>1.0E+08 n/s</td>
</tr>
<tr>
<td>Neutron Energy</td>
<td>14 MeV</td>
</tr>
<tr>
<td>Typical Lifetime</td>
<td>1,200 hours @ 1x10⁸ n/s</td>
</tr>
<tr>
<td>Pulse Rate</td>
<td>250 Hz to 20 kHz, continuous</td>
</tr>
<tr>
<td>Duty Factor</td>
<td>5% to 100%</td>
</tr>
<tr>
<td>Minimum Pulse Width</td>
<td>5 µsec</td>
</tr>
<tr>
<td>Pulse Rise Time</td>
<td>Less than 1.5 µsec</td>
</tr>
<tr>
<td>Pulse Fall Time</td>
<td>Less than 1.5 µsec</td>
</tr>
<tr>
<td>Maximum Accelerator Voltage</td>
<td>95 kV</td>
</tr>
<tr>
<td>Beam Current</td>
<td>60 uamps</td>
</tr>
</tbody>
</table>
D-T Source Experimental Results Summary

Conclusions:

1. QE to 14 MeV neutrons is ~1.2%
2. Believe n and γ counts are comparable at source settings
3. Timing better than 1.5 μs (measurement limited by the source)
4. MCP dark count very low (~0.3 c/cm²/s)

Predicted QE ~0.8%
Conclusions and Future Work

- Functional films – Improved performance, substrate independence
  - Emissive Layer - Optimized SE yield and tailored conductivity
  - Conductive layer - “Ohmic” conduction, Low TCR
- First Plastic MCP results demonstrated
- Fast neutron detector demonstration
  - > 1% Neutron detection simulation target
    - 2mm MCP QE=0.003
    - 5mm MCP QE=0.012
  - < 0.1% Gamma detection “simulation” target
    - Energy dependence QE=9.26x10^{-5} – 5.22x10^{-3}

Future Work

- Optimization for Neutron QE > 10%
- Gamma Sensitivity
- Energy Sensitivity < 500 keV
- Demonstrate timing < 1.5ns
Acknowledgements

- Prof. James Ryan

- Dr. Richard Lanza