Status

ALD Secondary Electron Emission Program

Delivered to PSEC Collaboration Meeting
Neal Sullivan
October 15, 2009
Outline

- Status and Summary of Contract
- Progress on MCP ALD equipment
- Progress on MCP Emissive film performance
- Progress on MCP Resistive film performance
- New MCP Application: Special Nuclear Material Detection – Fast Neutron Detector
  - Plastic MCP ALD films development
  - Fast Neutron Detection Simulation development
  - Plastic MCP performance
  - Neutron Detection Experimental Results
    - University of New Hampshire (UNH)
    - Massachusetts Institute of Technology (MIT)
- Summary
Objective: Optimize Arradiance thin film technology process & process equipment to meet performance requirements for LAPR-TOF glass and small sample AAO substrate development.

Work Plan Detail (Glass and AAO substrates):
- MCP manufacturing & performance requirements definition: Inputs from program & Arradiance simulation driven film parameter determination
- Film optimization on 33 mm capillary glass substrates: resistance and emission optimization; process integration and functionality

Work Plan Deliverables:
- Development of ALD emissive & resistive films which meet gain, resistance & uniformity specifications on glass & AAO substrates.
- Process and test of up to 20 capillary glass and 20 AAO functionalized prototype MCPs.
- Proof of Principle Report to the project

Status: Awaiting funding for ALD and Test fixture build to accommodate 33mm samples
Chamber door pulls out for easy load and unload of door-mounted substrate holder.

Easy to reach batch boat design to hold up to twenty-five 1” diameter MCP substrates.

Larger dia substrates (up to 76mm) can be loaded in smaller quantities.

Holder positions substrates such that all substrates see uniform gas flow over entire surface area.
Uniformity for MCPs: High Aspect Ratio & High Surface Area

- Separate gas delivery lines to avoid precursor mixing and contamination.
- Showerhead precursor delivery isolates & distributes uniform gas flow to all MCP substrates.
- Convective, rather than conductive, heating assures uniform temperature across reaction chamber.
- Chamber geometry accommodates MCP structures with uniform heating and gas flow.
- Minimum chamber volume for faster heating, cool-down, pumping times and minimal precursor usage.
- Chamber geometry designed for optimum pressure control.
Commercial GEM-D2 Application I

- Commercial MCP base resistance of $\sim 100M\Omega$ at 1000V.
- Increased SEY of GEM-D2 film
- Short term scrub, extracting 0.02 C at $I_{\text{out}} = 0.3 \mu\text{A}$ (14 hrs), did not degrade gain.
Commercial GEM-D2 Application II: CASCADE First Order Gain (FOG) Analysis

Before and After GEM-D2 Emissive Coating - 60:1 LD 12um Pitch 12 Degree Bias

- 40% increase in first strike SEY
- 30% increase in pore cascade SEY
- 3% increase in apparent LD ratio

FOG Model results fitting measured before and after GEM-D2 data (Solid line is modeled)
## R2D2 Lot to Lot Repeatability

**40:1 LD 10 um Pore Micro Channel Substrate**

### Cascade MCP FOG (V2.6.0)

<table>
<thead>
<tr>
<th>MCP Mechanics</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case2/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Area Ratio</td>
<td>0.6</td>
<td>0.6</td>
<td>1.00</td>
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<tr>
<td>End Spoiling (Dia)</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>Bias Angle (DEG)</td>
<td>5</td>
<td>5</td>
<td>1.00</td>
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<tr>
<td>Pore Dia (um)</td>
<td>10</td>
<td>10</td>
<td>1.00</td>
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<tr>
<td>LD Ratio</td>
<td>41.5</td>
<td>42</td>
<td>1.01</td>
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</table>

### Material Contribution

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case2/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEY (First Strike)</td>
<td>5.5</td>
<td>4.9</td>
<td>0.89</td>
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<tr>
<td>SEY (Pore)</td>
<td>1.381</td>
<td>1.34</td>
<td>0.97</td>
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<tr>
<td>MCP R (MO)</td>
<td>119.1</td>
<td>171.5</td>
<td>1.44</td>
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<tr>
<td>SAT Coef (%)</td>
<td>6.5</td>
<td>5</td>
<td>0.77</td>
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</tbody>
</table>

### Test Conditions

| Input I (pA) | 9.98 | 10.48 | 1.05 |

### Measured Data Legend

<table>
<thead>
<tr>
<th>ID</th>
<th>R(MO) (Ω)</th>
<th>I(pA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R2D2 GCA-030-18</td>
<td>160.7</td>
</tr>
<tr>
<td>2</td>
<td>R2D2 GCA-030-19</td>
<td>144.3</td>
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<tr>
<td>3</td>
<td>R2D2 GCA-030-21</td>
<td>124.9</td>
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<tr>
<td>4</td>
<td>R2D2 GCA-030-22</td>
<td>171.5</td>
</tr>
<tr>
<td>5</td>
<td>R2D2 GCA-030-24</td>
<td>119.1</td>
</tr>
</tbody>
</table>

### Graph

- **Gain** vs **Bias (V)**
- **Graph Legend**:
  - Case 1
  - Case 2
  - R2D2 GCA-030-18: 9.30 (pA)
  - R2D2 GCA-030-19: 12.30 (pA)
  - R2D2 GCA-030-21: 9.54 (pA)
  - R2D2 GCA-030-22: 10.48 (pA)
  - R2D2 GCA-030-24: 9.98 (pA)
SNM detection technology overview

- Hydrogen-rich PMMA microchannel structure
- Graded Temperature ALD deposition
  - Active films deposition at 140°C
- Neutron-proton recoil reaction within plastic at better than 1% efficiency
- Proton initiated secondary electron cascade
- Output pulse $10^3 - 10^6$ electrons
- Standard readout electronics
- Technology is scalable to large format
Summer 2009 Experimental Data Collected

Prof. Jim Ryan UNH - Space Science Center
- 06/04/2009
- PMMA, 2mm, > 40k 50um Pores, 20um wall
- Isotope sources: Cf-252 (n, γ), Am-241/Be (n, γ), Cs-137 (γ), Co-60 (γ), Am-241 (γ)
- Results
  \[ γ \text{ QE } = 8.85E-04 \]
  \[ n \text{ QE } = 3.28E-03 \]

Dr. Dick Lanza MIT - Nuclear Science & Eng.
- 08/19/2009
- PMMA, 5mm, > 40k 50um Pores, 20um wall,
- Thermo Scientific 300 series D-T source (14MeV - pulsed)
- Results
  \[ n\text{QE} \sim 1.2\% \]
  \[ \text{Source limited } t<1.5 \text{ us} \]
  \[ \text{dark count } \sim 0.3 \text{ c/cm}^2/\text{s} \]
SNM Neutron detection simulation overview

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

\( P_1 \) – n-p recoil within the MCP substrate

\( P_2 \) – proton escape into MCP pore

\( P_3 \) – electron avalanche is formed (MCP ~1)

\[ P_1 = 1 - \exp \left( -N_H \sigma_n L_{\text{eff}} \right) \]

\[ L_{\text{eff}} = L_{\text{eff}}(x_0, y_0, \theta, \varphi) \]

\[ N_x = 2 \frac{\rho_{\text{MCP}} m_x \mu_x}{M_x} \sum_i m_i \mu_i \]

\[ S_i(x_0, y_0) < R(E_p(\theta)) \]

\[ S_i(x_0, y_0) = \frac{\sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2}}{\sin(\theta)}; \theta \neq 0, \pi \]

\[ x_1 - x_0 = \left[ \min \left| - \left( g(\varphi) \cdot \xi - O_{i,x} \right) \pm \sqrt{D} \cos^2(\varphi) - x_1 \right| \right]^{\frac{1}{2}} \]

\[ \xi = y_0 - tg(\varphi) x_0 - O_{i,y} \]

\[ y_1 = tg(\varphi) x_1 + \left( y_0 - tg(\varphi) x_0 \right) \]

\[ D = \left( g(\varphi) \cdot \xi - O_{i,x} \right)^2 - \left( O_{i,x} + \xi^2 - \frac{d^2}{4} \right)^2 \frac{1}{\cos^2(\varphi)} \]

\[ \cos(\theta) = \frac{E_p}{\sqrt{E_n}} \]

\[ E_p \in [0, E_n] \]
Neutron detection simulation: proton recoil - P1

PMMA \( (C_5^\text{O}_2^\text{H}_8)_n \)

monomers / cm\(^3\) \( 7.16 \times 10^{21} \)
H atoms / cm\(^3\) \( 5.73 \times 10^{22} \)
C atoms / cm\(^3\) \( 3.58 \times 10^{22} \)
O atoms / cm\(^3\) \( 1.43 \times 10^{22} \)

Cross section of neutron interaction

\[ P = [1 - \exp(-N_i \sigma_i L)](1-A) \]

Interaction with H only

50 \( \mu \text{m} \) circular pores, 20 \( \mu \text{m} \) walls, 1.19 g/cm\(^3\)
Neutron detection simulation results – P1 and P2

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

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

**P1**

**P2**

![Graph of P1 probability vs. Wall thickness for 50 µm pores and En = 2 MeV](image)

![Graph of P2 probability vs. Wall thickness for 50 µm pores](image)

**P1 x P2 probability**

![Graph of P1 x P2 probability vs. Wall thickness for 50 µm pores and En = 2 MeV](image)
Neutron detection simulation: P3 Probability and Event Timing Simulation

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

Note:
P3 – Probability for Amplification Stage is 1.0
Timing for Amplification Stage is < 200 ps

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
**UNH Experimental Summary**

- **Gamma E (eV)**
  - 4.00E+04  |  9.26E-05
  - 6.61E+05  |  2.06E-03
  - 1.20E+06  |  5.22E-03

- **2mm PMMA MCP, 500V bias**

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Pulse source: timing performance MIT measurements with a pulsed source

Predicted QE ~0.8%

Conclusions:

1. QE to 14 MeV neutrons is ~1.2%

2. n and γ counts are comparable at this 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)
Hardware Experimental setup

- 5 mm PMMA MCP, ~50 um pores, 20 um walls, 5° bias angle
- installed above a chevron stack of 50:1 L/D MCPs
- Phosphor screen readout
- Canberra preamp and postamplifier
Summary

- Contract signed – Await funding release
- 2nd Generation ALD Process Equipment ready for PSEC MCP substrates
- Simulation support for SE yield determination from MCP measurements is complete.
- High performance MCP active film results demonstrate success
  - High secondary electron yield results in high gain MCPs
  - Targeted and Repeatable MCP device resistance
- Novel MCP application demonstrated: Fast neutron detector, implemented in high H plastic substrate, with low noise and high efficiency demonstrated
  - ~1% Neutron detection efficiency target
  - < 0.1% Gamma detection efficiency
  - < 0.3 C/s-cm² Noise