Manufacturing and Packaging of Reliable Bialkali Photocathodes via Sputtering

- **Dr. Harish Bhandari**, RMD Inc. (Principal Investigator)
- **Dr. John Smedley**, Brookhaven National Laboratory (Collaborator)
- **Dr. Jeffrey DeFazio**, Photonis USA Inc. (Collaborator)
- **Dr. Luca Cultrera**, Cornell University (Collaborator)

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POP: 5/21/2018 – 5/20/2020
RMD Basic and Applied Research and Development

Materials Science
- Scintillators
- Semiconductors
- Imaging Screens

Sensors
- Wide Band Gap Geiger Photodiodes
- APDs SSPMs Photosensors
- Surgical Beta-Probe

Instruments & Systems
- HiRIS – High Resolution Imaging System
- RadEye Detectors
- Hermes G/n w/ isotope ID
- Robotic nuclear power plant concrete analyzer

Inspired by Light
Motivation

- Future upgrade for the Relativistic Heavy Ion Collider (RHIC) at BNL calls for electron cooling, where ultra-cold electron beams will be generated via photocathodes.

- $K_2CsSb$ bialkali photocathode has demonstrated the desired high average current (~50 mA) required for electron cooling operation at RHIC.

- These bialkali cathodes will need to be replaced almost daily, based on their operating conditions.

> Hence, there is a need for commercially-available photocathodes that can be reliably produced and supplied in sufficient quantities.
SBIR Technical Objective

Reliable Growth of Cathodes [BNL]

Commercial Photocathodes (RMD Inc.)

Package Cathodes for Stockpiling [Photonis]

Unseal Cathodes at RHIC [Cornell]
K$_2$CsSb Cathodes – Traditional Growth


RMS surface roughness is 25 nm for 50 nm thick cathode.
Sputtering – A Reliable Cathode Growth Process

Target in a vacuum suitcase

Sputter deposition chamber

Process Specifications

- Cryo and ion pump
- RGA
- Base P $2 \times 10^{-9}$ Torr
- Operating Gas: Ar
- Sputtering Power: 10-15 W
- Operating P: 30 mTorr
- Growth rate > 2 nm/min
- Cathode thickness: 50 nm
- 2 cathodes/hour
Sputtering – A Reliable Cathode Growth Process

Before Sputtering

During Sputtering

Quantum Efficiency

XRR – surface roughness

<table>
<thead>
<tr>
<th></th>
<th>QE_360 nm</th>
<th>QE_530 nm</th>
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<tbody>
<tr>
<td>sample 05 sputter</td>
<td>6.8%</td>
<td>0.5%</td>
</tr>
<tr>
<td>sample 05 Cs</td>
<td>21.4%</td>
<td>2%</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Thickness (Å)</th>
<th>Roughness (Å)</th>
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<tbody>
<tr>
<td>Substrate Si</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>SiO2</td>
<td>7.36</td>
<td>3.94</td>
</tr>
<tr>
<td>1st sputter</td>
<td>532.9</td>
<td>5.75</td>
</tr>
<tr>
<td>After Cs</td>
<td>796.5</td>
<td>5.57</td>
</tr>
</tbody>
</table>

Inspired by Light
Photocathode Packaging

Cornell Puck – #2 cartridge sealed cathode

- Central (round) => Al film passivated region
  - SS puck surface chemically cleaned instead of thermally (different than #1)

- 405 nm LED photoemission map
  - 16.4 % QE @ Al passivated region (24% on #1)
  - ~ 10% on SS (13% on #1)
Unsealing the Cathode

- Sealed cathodes shipped to Cornell
- Unseal the cartridge in vacuum
- Hand off the cathode puck to electron gun
- Generate and analyze the electron beam
Integration – Cathode Growth and Sealing (RMD)

Cathode Prep. Chamber

Cathode Growth Chamber

Preheating and Storage

Cathode Transfer Chamber

Cathode Sealing Chamber

UHV Vacuum: $10^{-10}$ Torr
Bake-able: 200 C
Cathode Growth Chamber

Cathode puck on a heater stage

Puck with a mask (upside down) ready for sputter deposition
Masking the Cathode

Mask

Photocathode
Cathode Sealing Chamber

Light Source for QE monitoring during sealing
Indium Sealing

Band Clamp

Indium Sealing

Band Clamp
Deposition Chamber Under Construction (BNL)

Acknowledgement:
John Walsh (BNL)
Brian Walsh (BNL)
Commercialization Potential

- RHIC – 300 cathodes/year
- SLAC (LCLS-II)
- TRIUMP – 300 cathodes/year
- JLABS EIC
- RI Research Instruments GmbH (New Accelerator in Germany) – 200 cathodes/year
- Cornell - CBETA

*RMD is supplementing the current SBIR R&D effort with internal funding*
Phase II Schedule

- A traditionally-grown cathode to be sealed in the new cathode cartridge design – August’ 19
- The sealed cathode to be unsealed and evaluated at Cornell – September’ 19
- The sputter-grown cathodes to be demonstrated in the new growth chamber - October’19
- The sealing of the sputter grown cathode will be demonstrated – Dec’19
- The unsealing of the sputter-grown cathode will be demonstrated – Jan’20
- The SBIR Phase II ends May’ 20
Questions ?
What is a Photocathode?

Nobel prize for photoelectric effect - 1921

The Spicer “3-Step” Photoemission Model (1958)
1. Optical absorption
2. Electron transport
3. Escape across the surface

“Magic Window” for electron escape

“Band Bending” for low work function

- In 1951 Dr. Alfred Sommer discovered a process for “alkali antimonides” (M₃Sb) preparation that performed better than metal photocathodes
- Hamamatsu uses Sommer’s process in PMT’s (1980’s)
- Process involves reactive evaporation of alkalis’ on Sb