Manufacturing and Packaging of Reliable Bialkali Photocathodes Grown via Sputtering

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POP: 5/21/2018 – 11/20/2020 (6 month no-cost extension)

Motivation

DOE has a need for technologies that can produce robust, reliable and reproducible photocathodes (electron sources) capable of supplying large average currents:

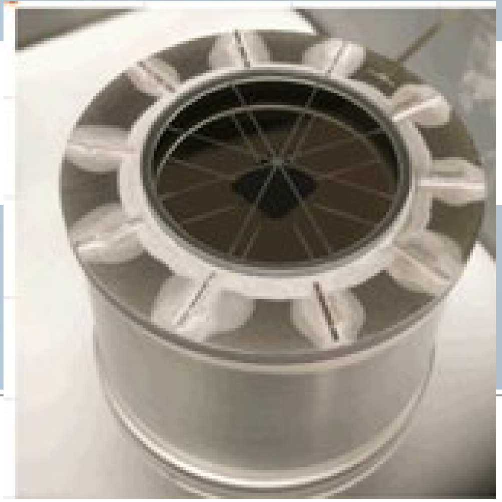
- *Low Energy Electron Cooling for Relativistic Heavy Ion Collider (RHIC) - 50 mA*
- *Jefferson Lab Luminosity Upgrade - 250 mA*

Problem

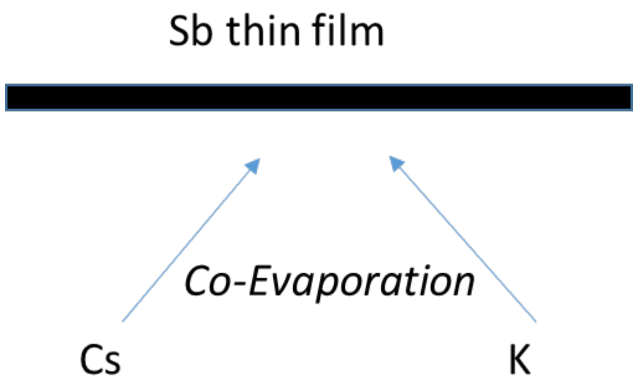
- *K_2CsSb photocathodes can deliver such high currents but they experience rapid burnout*
- *These cathodes may need daily or weekly replacements to sustain performance*
- *Significant challenge in growing these cathodes*

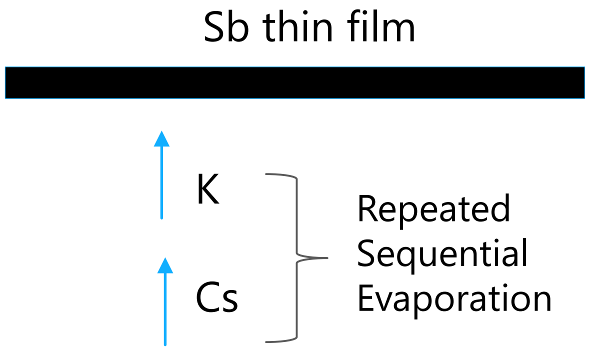
Solution

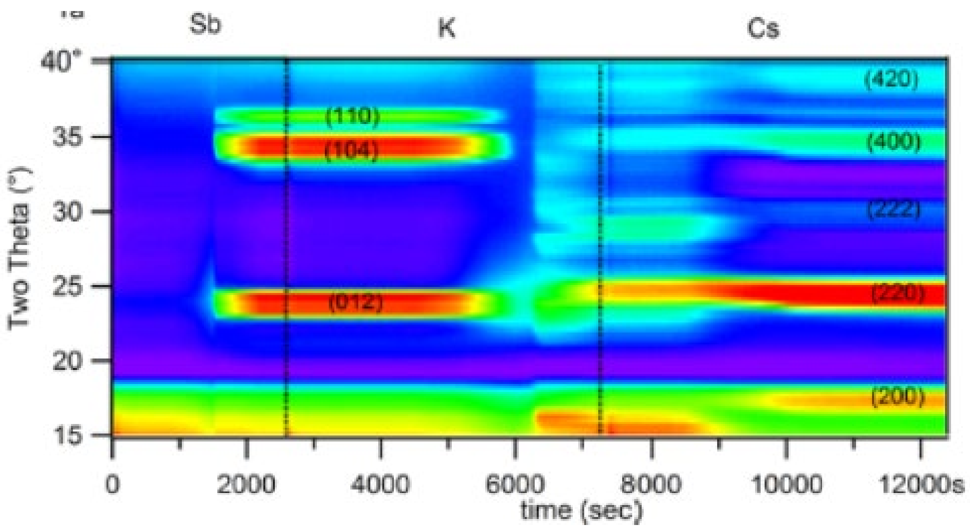
- ✓ *Commercial manufacturing of K_2CsSb photocathodes*
- ✓ *Reliable cathode growth and packaging is necessary*



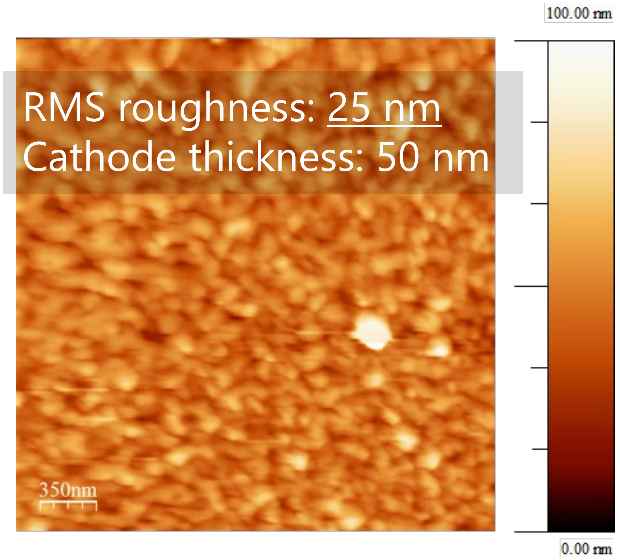
Traditional K_2CsSb Growth - Reliability



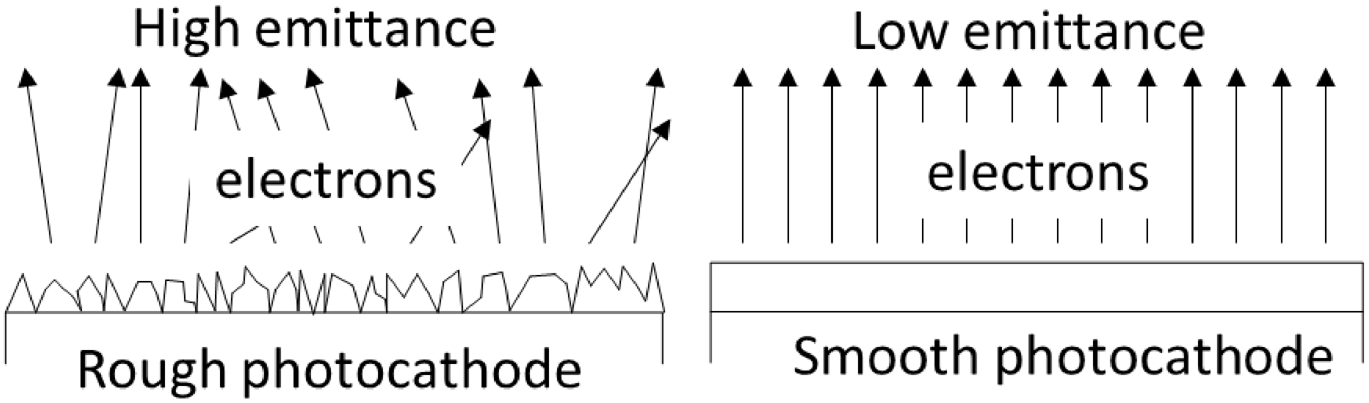




Ruiz-Osés et al., APL materials 2.12 (2014): 121101.

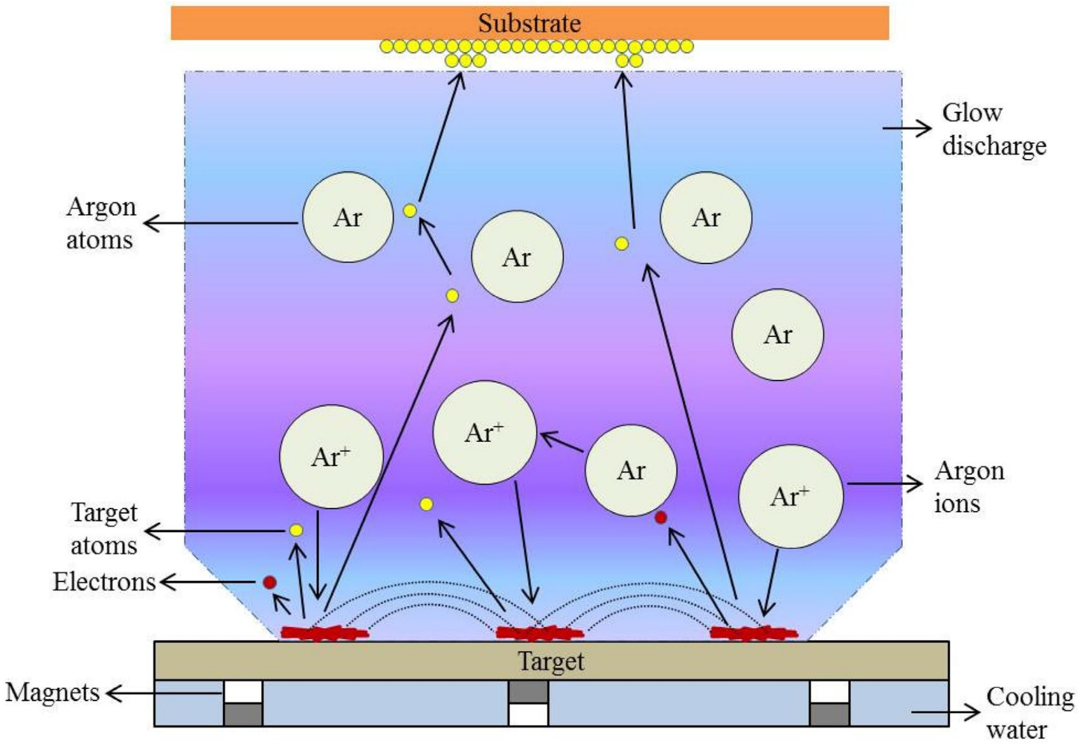


Schubert, S., et al. " APL Materials 1.3 (2013): 032119.



Sputtering – An Alternative Growth Technique

- Sputter film composition matches source (target) material
- Well suited for ternaries (K, Cs, Sb)
- Film uniformity is guaranteed over areas that match the target area
- High deposition rate (up to 100 Å/s)
- High reliability (100s of cathodes from a single target)
- High scalability (automation possible)
- Use of plasma enhances adhesion and lowers surface roughness
- Enables doping of layers
- pn-junction cathodes with abrupt interfaces

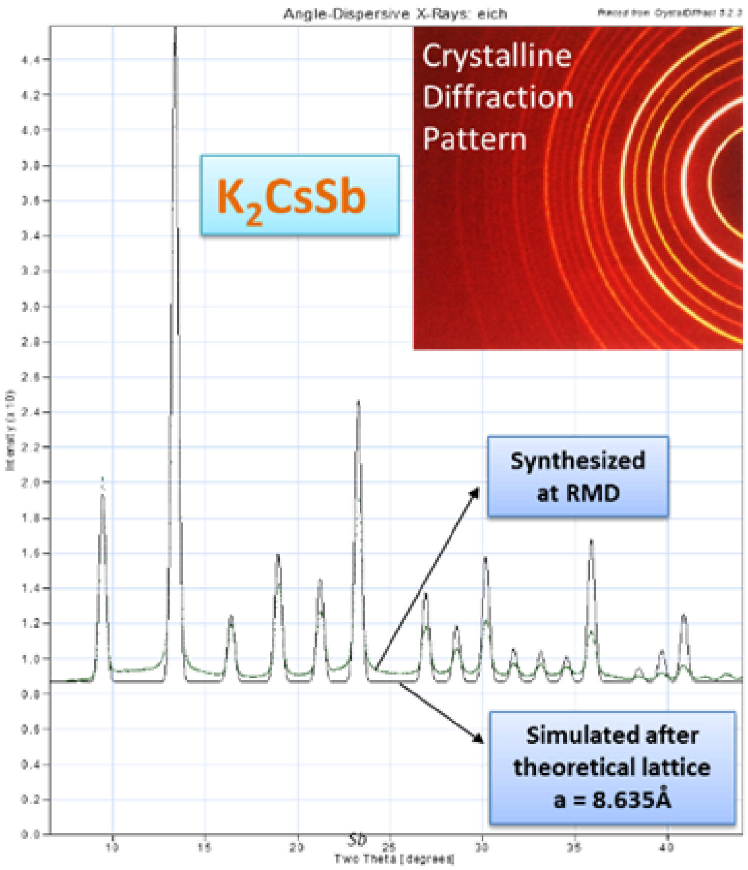


(Image source: Maurya et al. Coatings 4.4 (2014): 756-771.)

Critical component : K_2CsSb Sputter Targets
Minimum Size Desired: 2" diameter

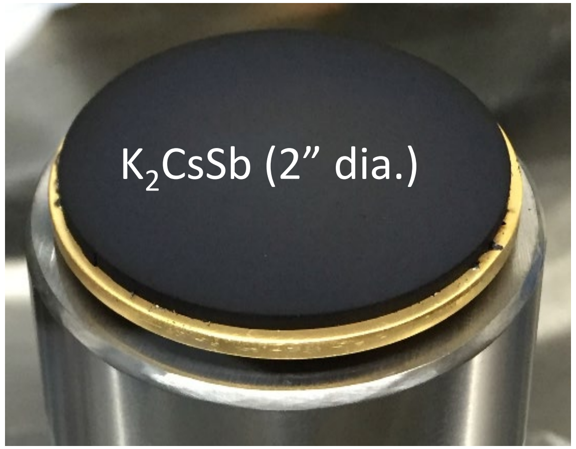
Solid State Synthesis of K_2CsSb (An Innovation)

- A key enabler is the RMD's patented process for synthesizing "bulk" K_2CsSb material



- The cubic phase of the bulk material was confirmed by X-ray diffraction measurements

Sputter Target

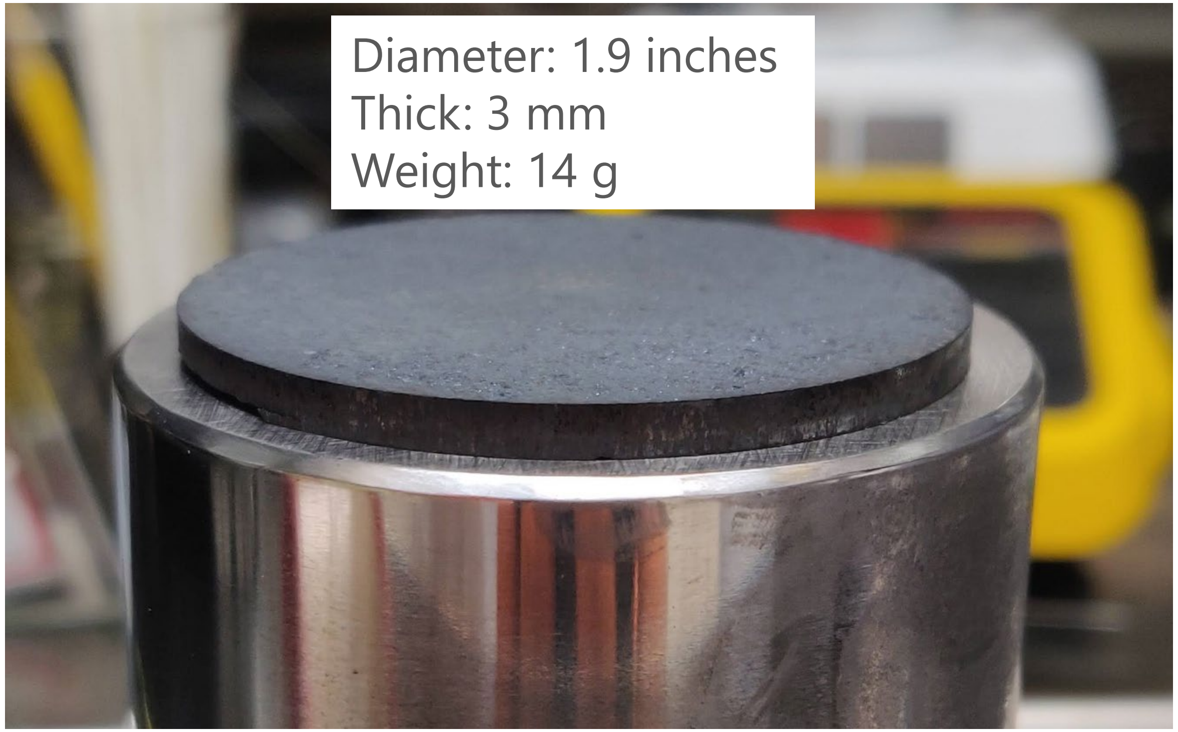


- K_2CsSb sputter targets measuring 2" in diameter are routinely fabricated at RMD

K_2CsSb Target Fabrication

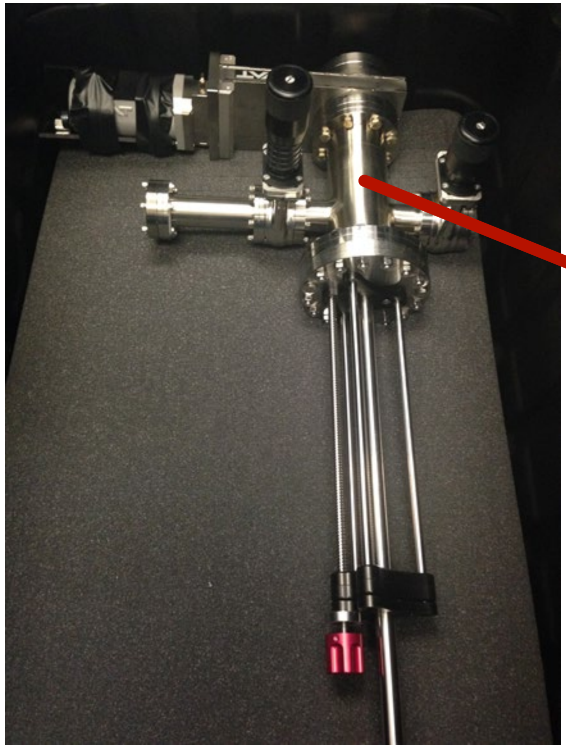
Thin

Thick

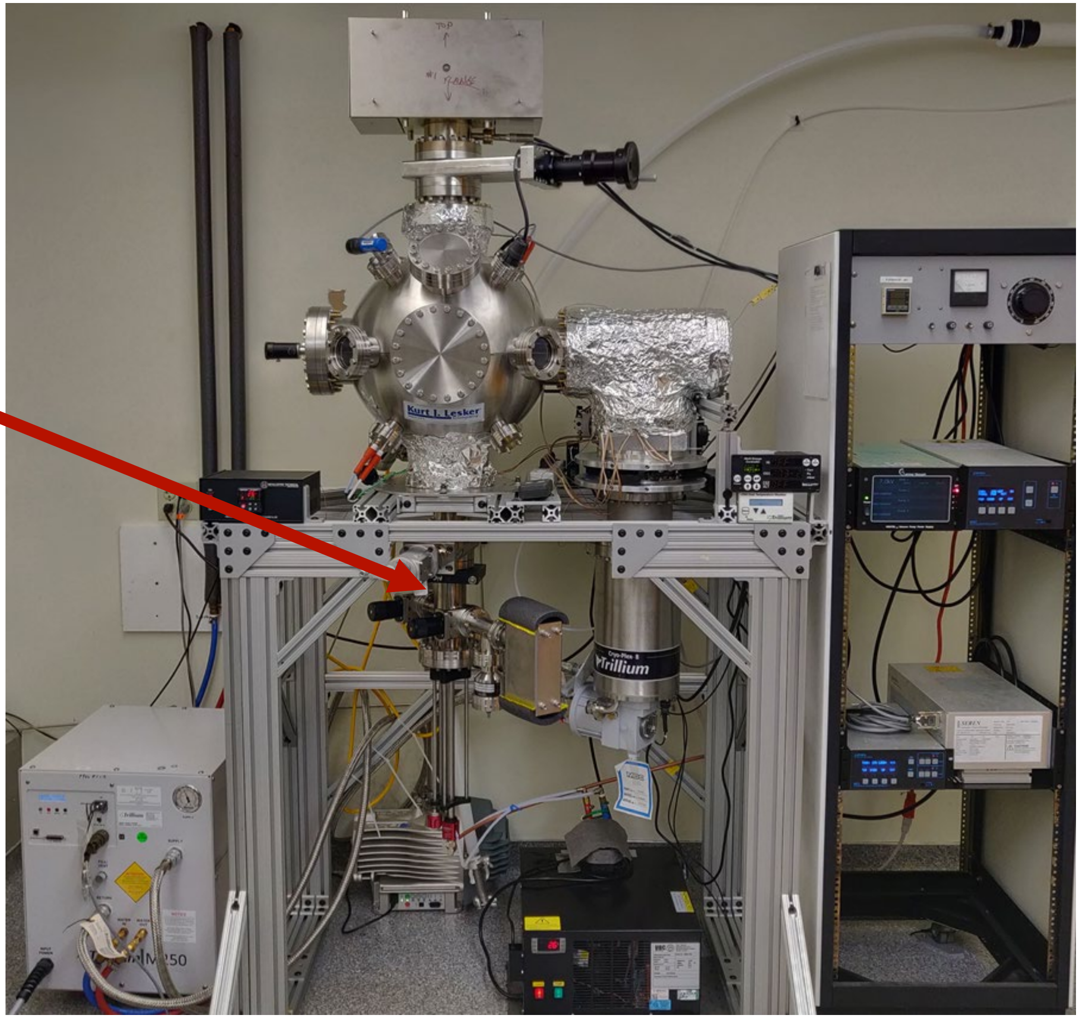


- To improve target robustness: Strain>10,000 psi, Post-press anneal at 100 C

Sputtering – A Reliable Cathode Growth Process



Target in a vacuum suitcase

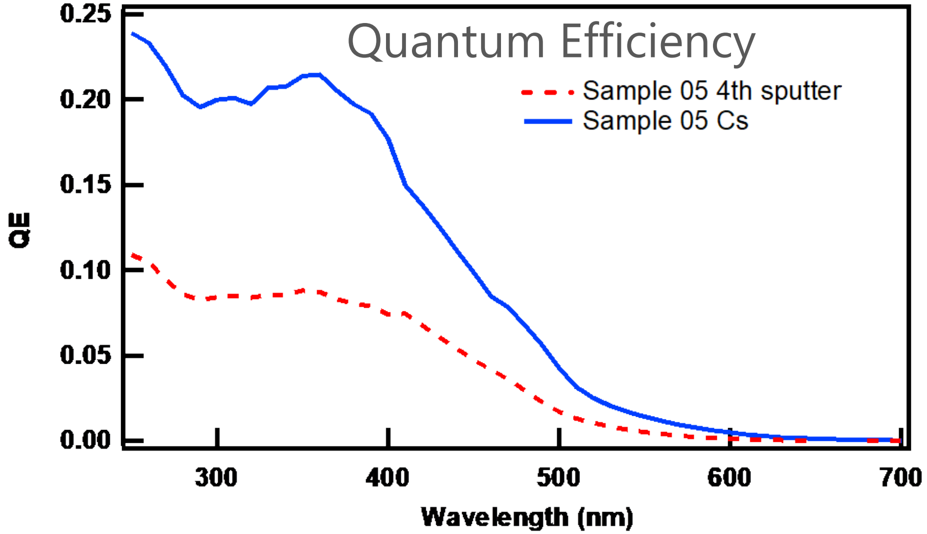


Sputter deposition chamber

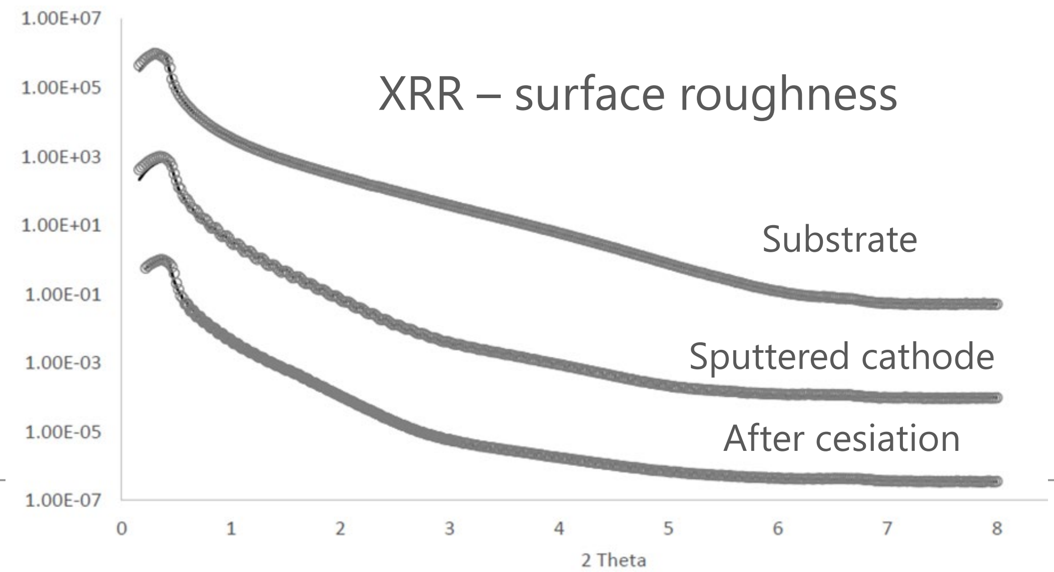
Process Specifications

- Cryo and ion pump
- RGA
- Base P $2x10^{-9}$ 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



	QE_360 nm	QE_530 nm
sample 05 sputter	6.8%	0.5%
sample 05 Cs	21.4%	2%

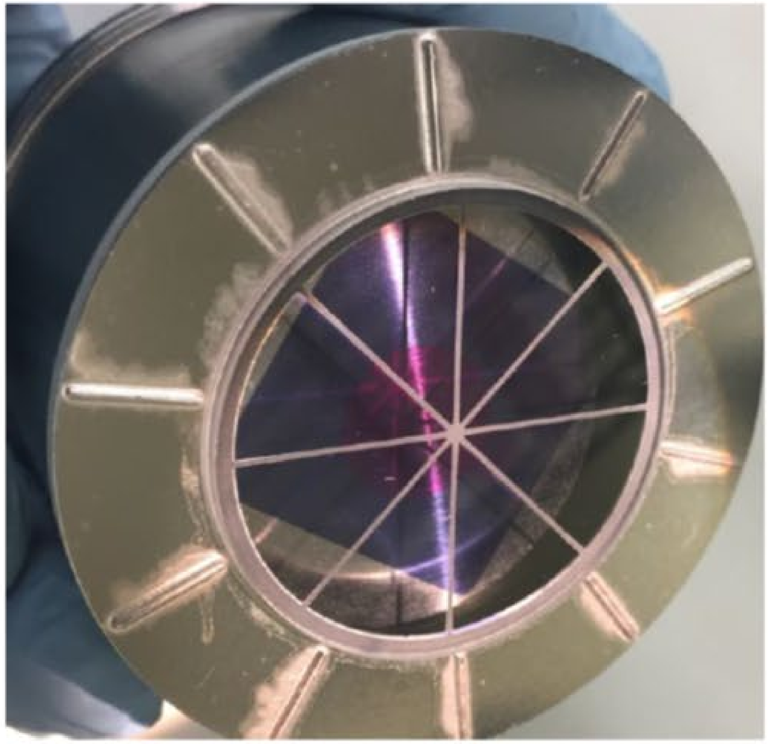


	Thickness (Å)	Roughness (Å)
Substrate Si		3.75
SiO2	7.36	3.94
1st sputter	532.9	5.75
After Cs	796.5	5.57

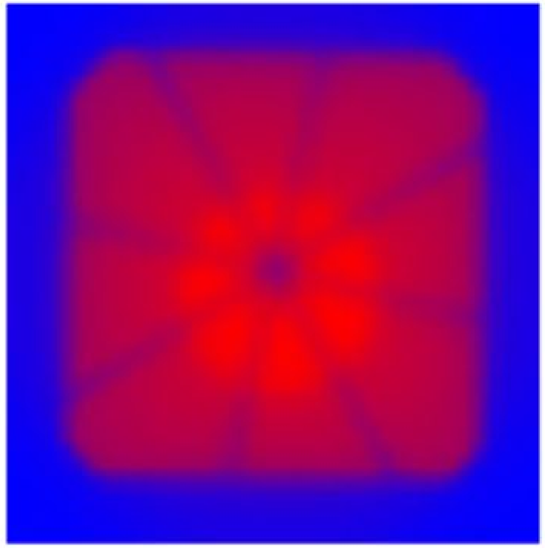
Photocathode Packaging

Cornell Puck – #2 cartridge sealed cathode

- Detail

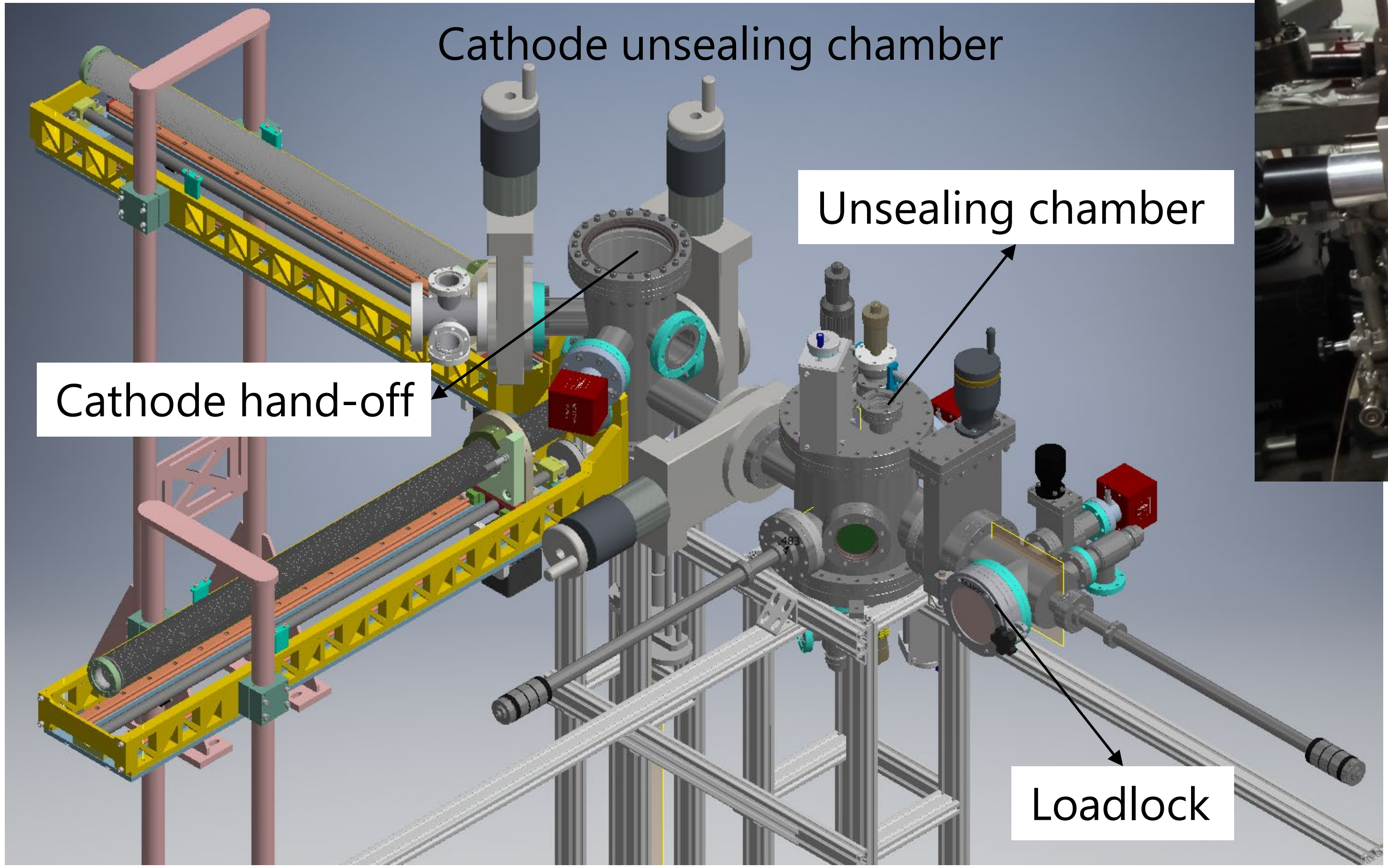


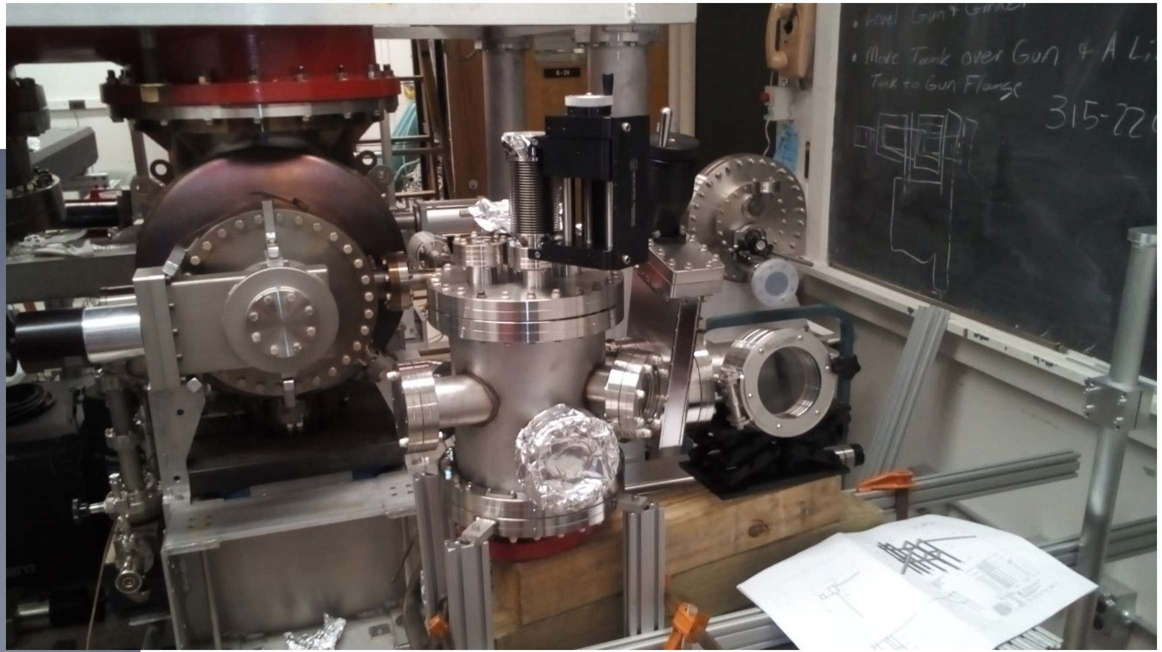
- Central (round) => Al film passivated region
  - SS puck surface chemically cleaned instead of thermally (different than #1)



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

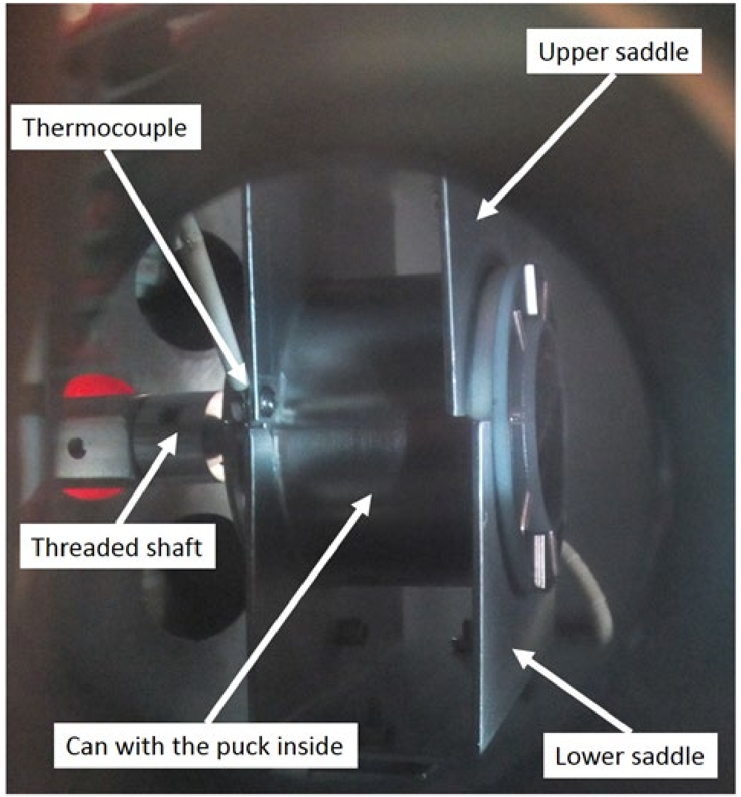
Unsealing the Cathode (Cornell)

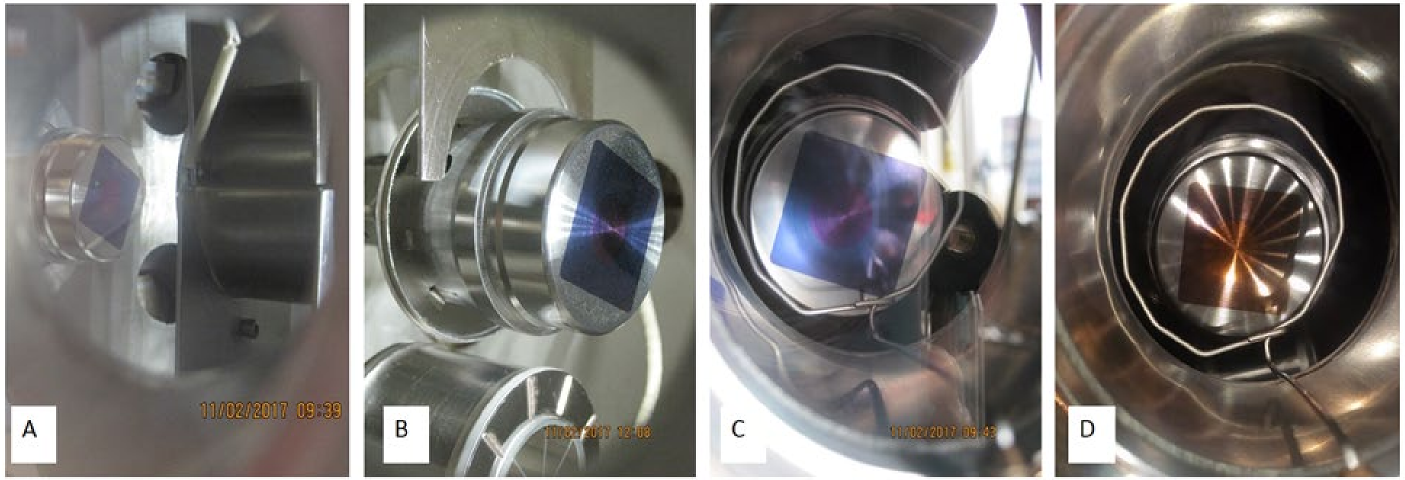


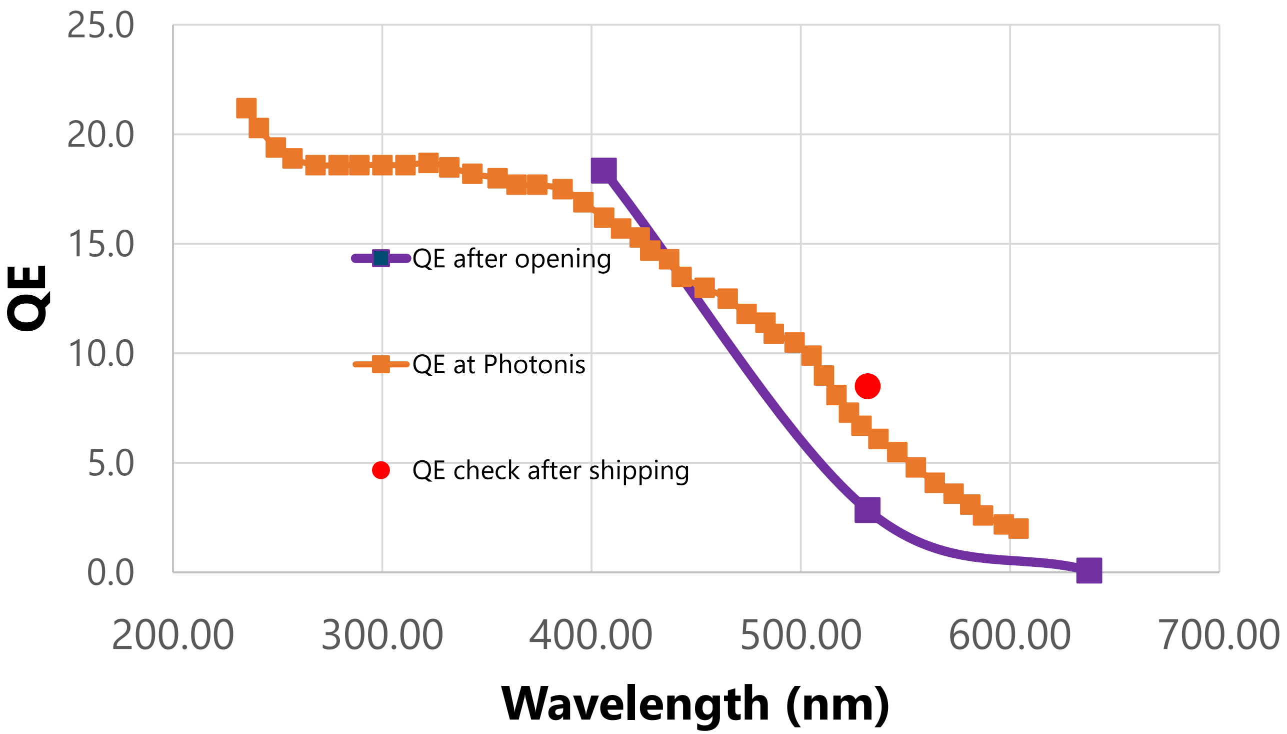


- Sealed cathodes shipped to Cornell
- Unseal the cartridge in vacuum
- Hand off the cathode puck to electron gun
- Generate and analyze the electron beam

Unsealing the Cathode in Ultra-High Vacuum

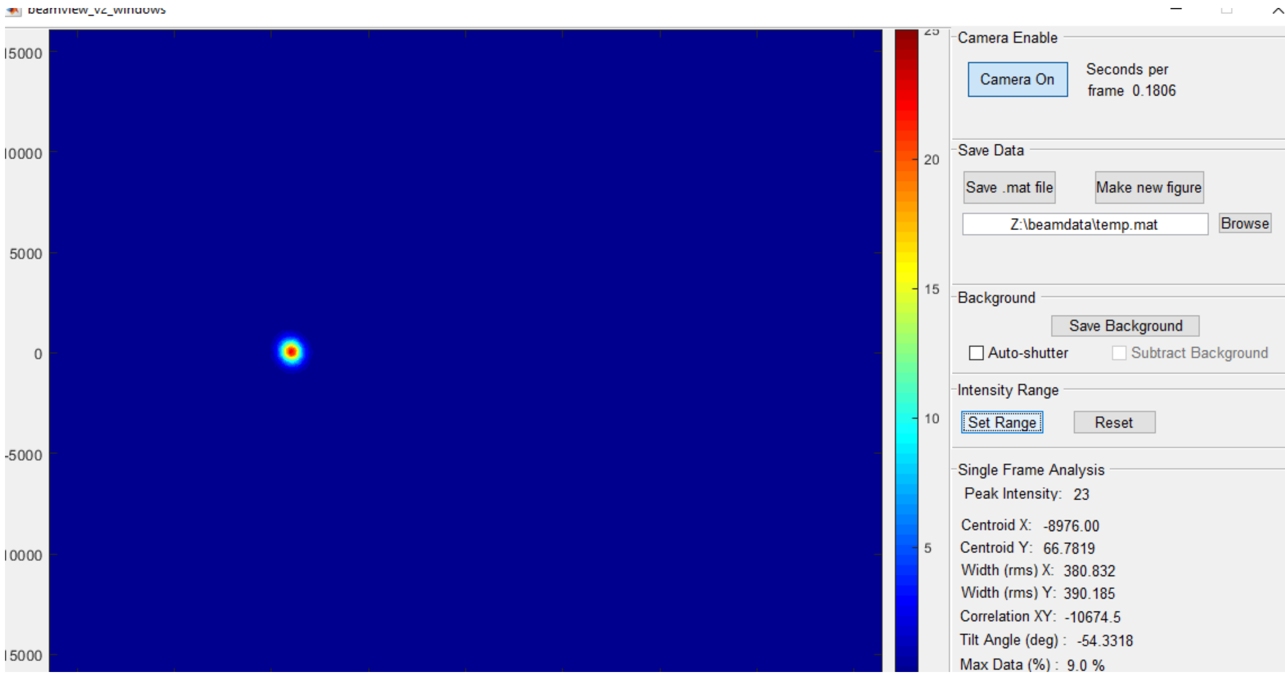




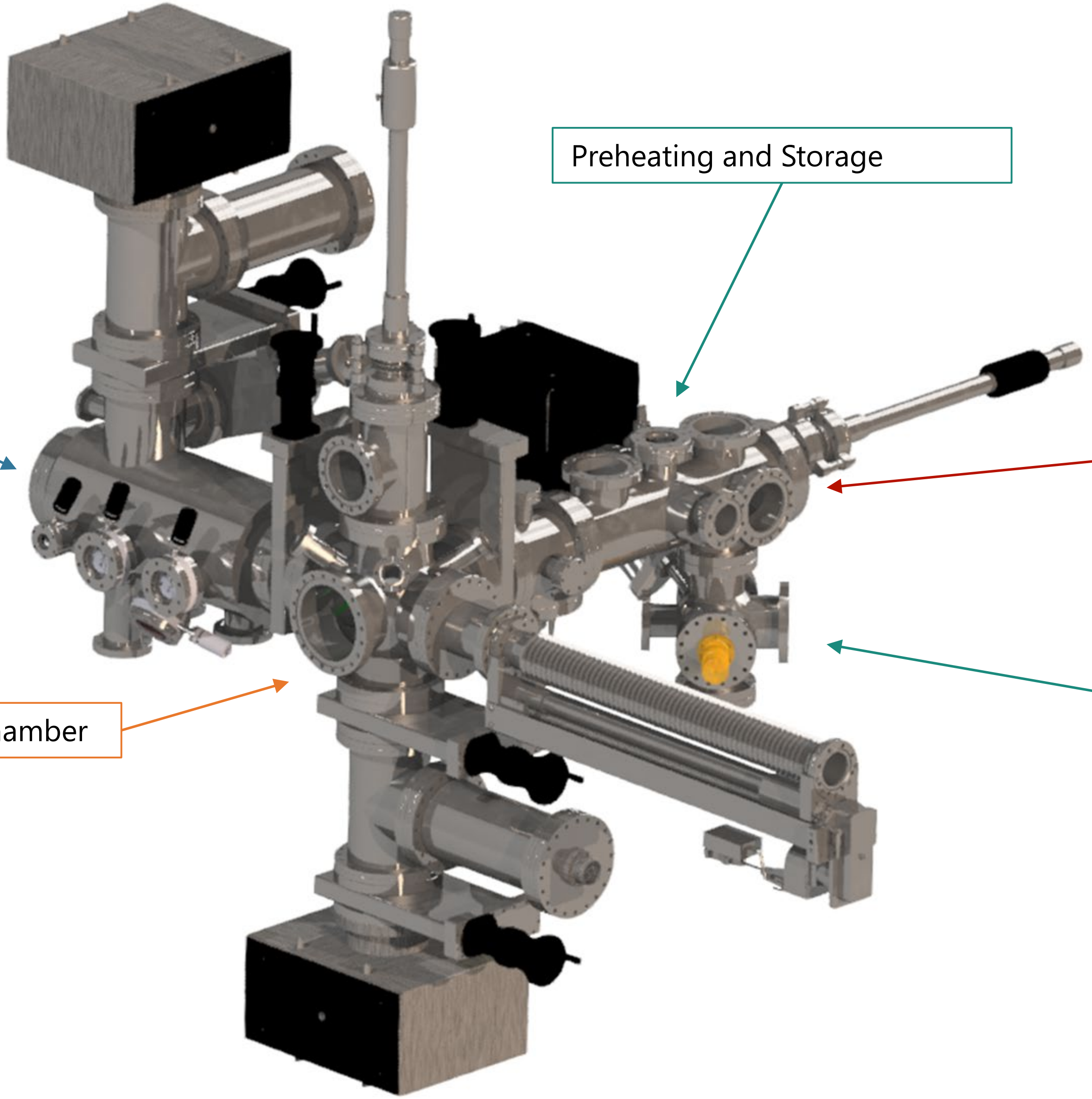


First Beam Generated from a Packaged Photocathode

- A packaged cathode was successfully unsealed at CHESS and held in vacuum for several weeks
- The cathode puck was successfully handed-off to the gun electrode
- Photoelectrons were produced (200 kV gun voltage) using 405 nm laser diode
- CHESS group plans to use this cathode to perform beam alignment of the magnetic elements
- Another sealed cathode is on hand and will be introduced once the beamline will be fully commissioned

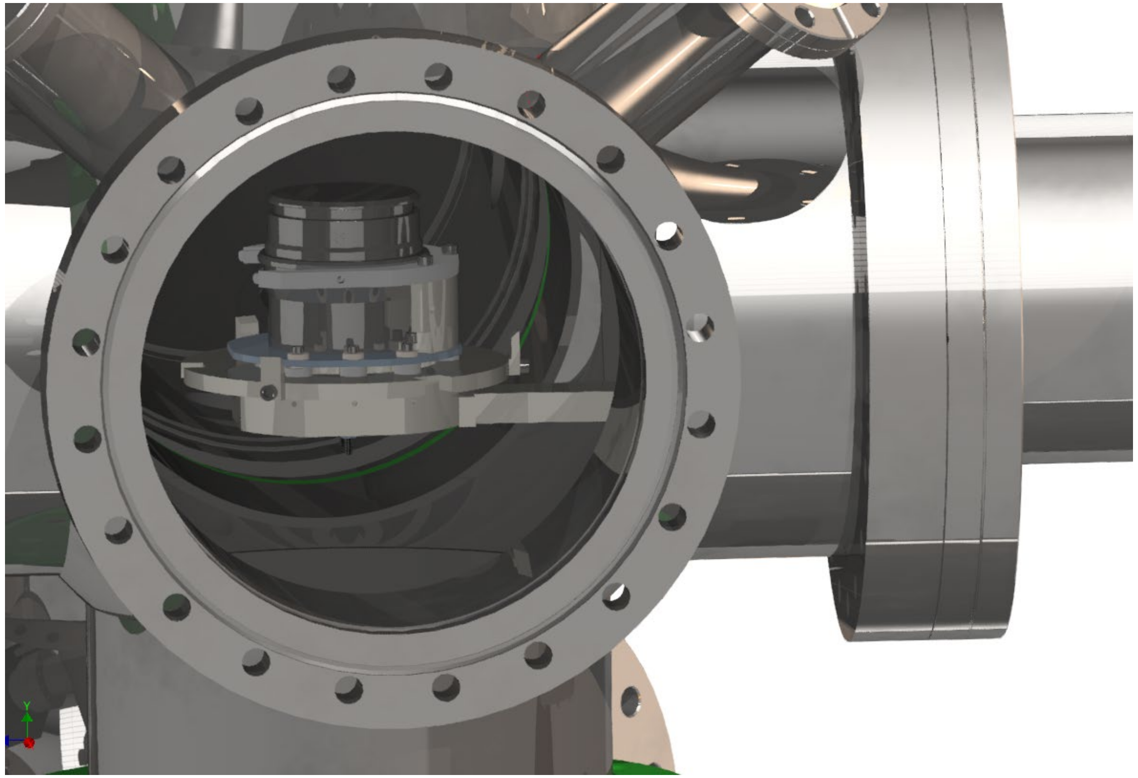


Integration – Cathode Growth and Sealing (RMD)

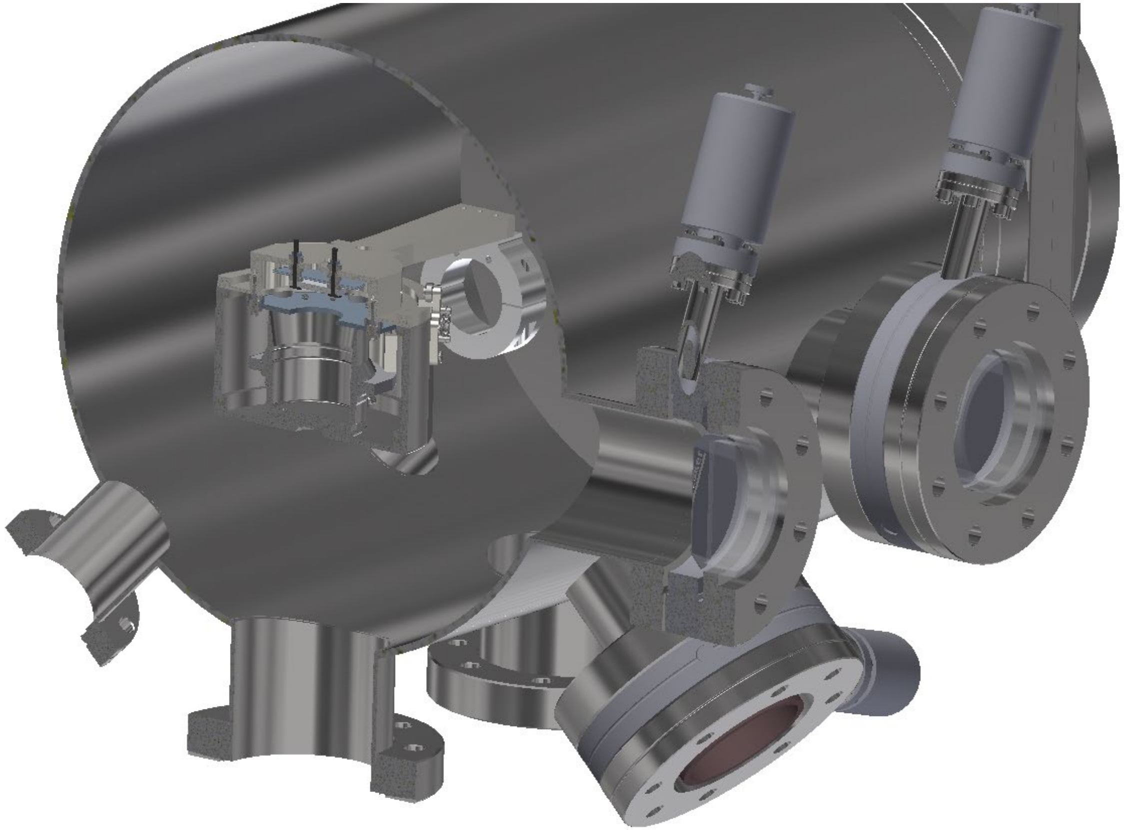


UHV Vacuum: 10^{-10} Torr
Bake-able : 200 C

Cathode Growth Chamber

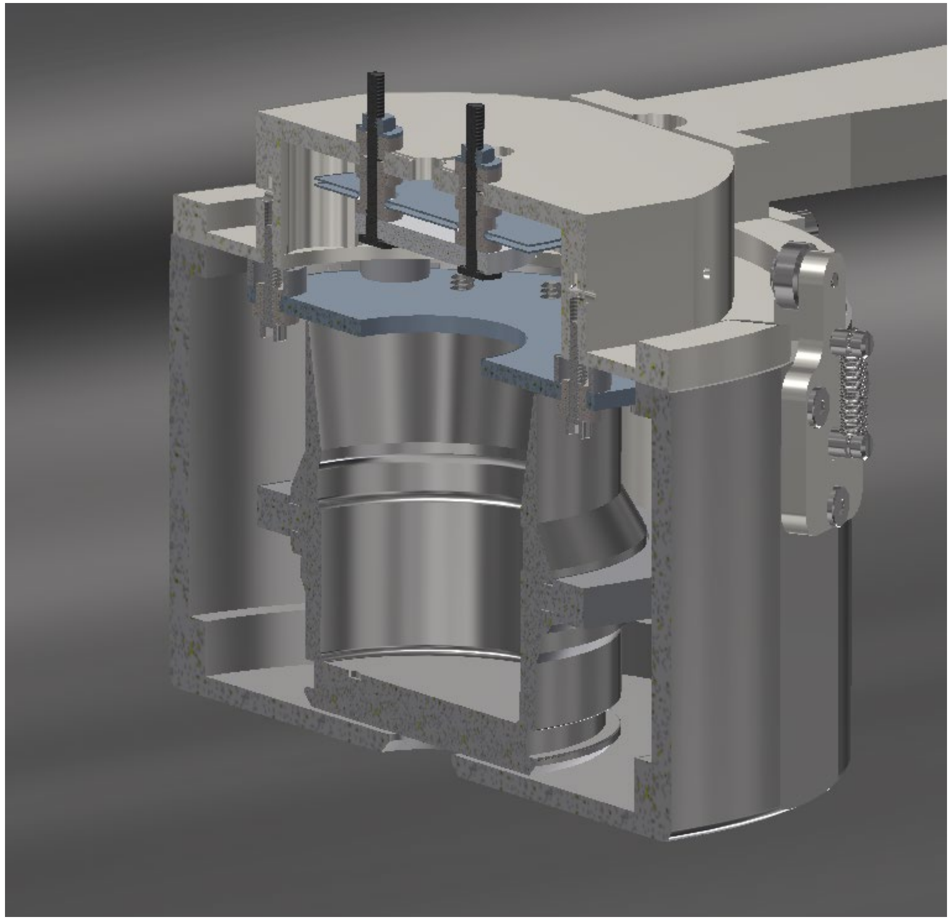


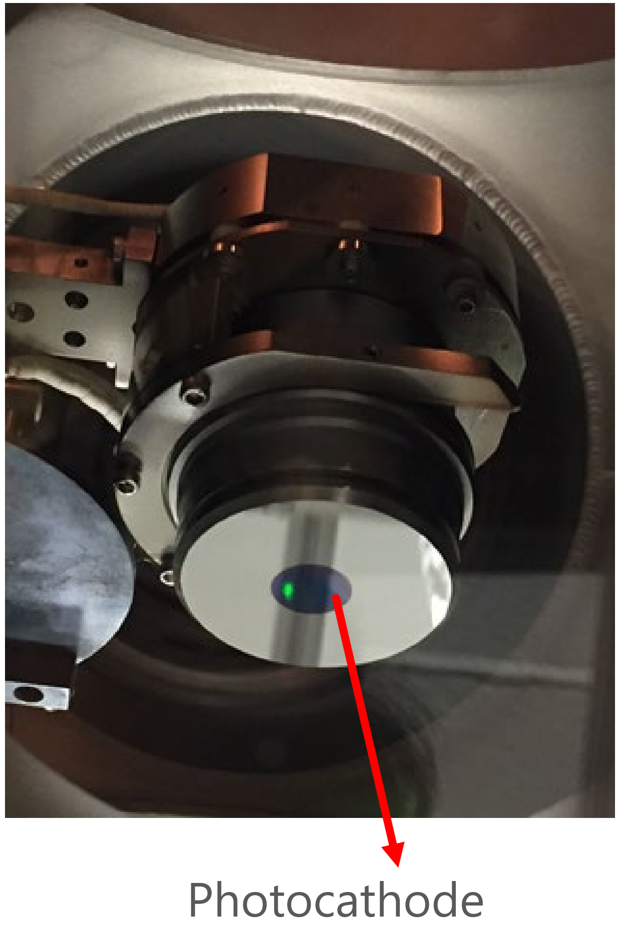
Cathode puck on a heater stage



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

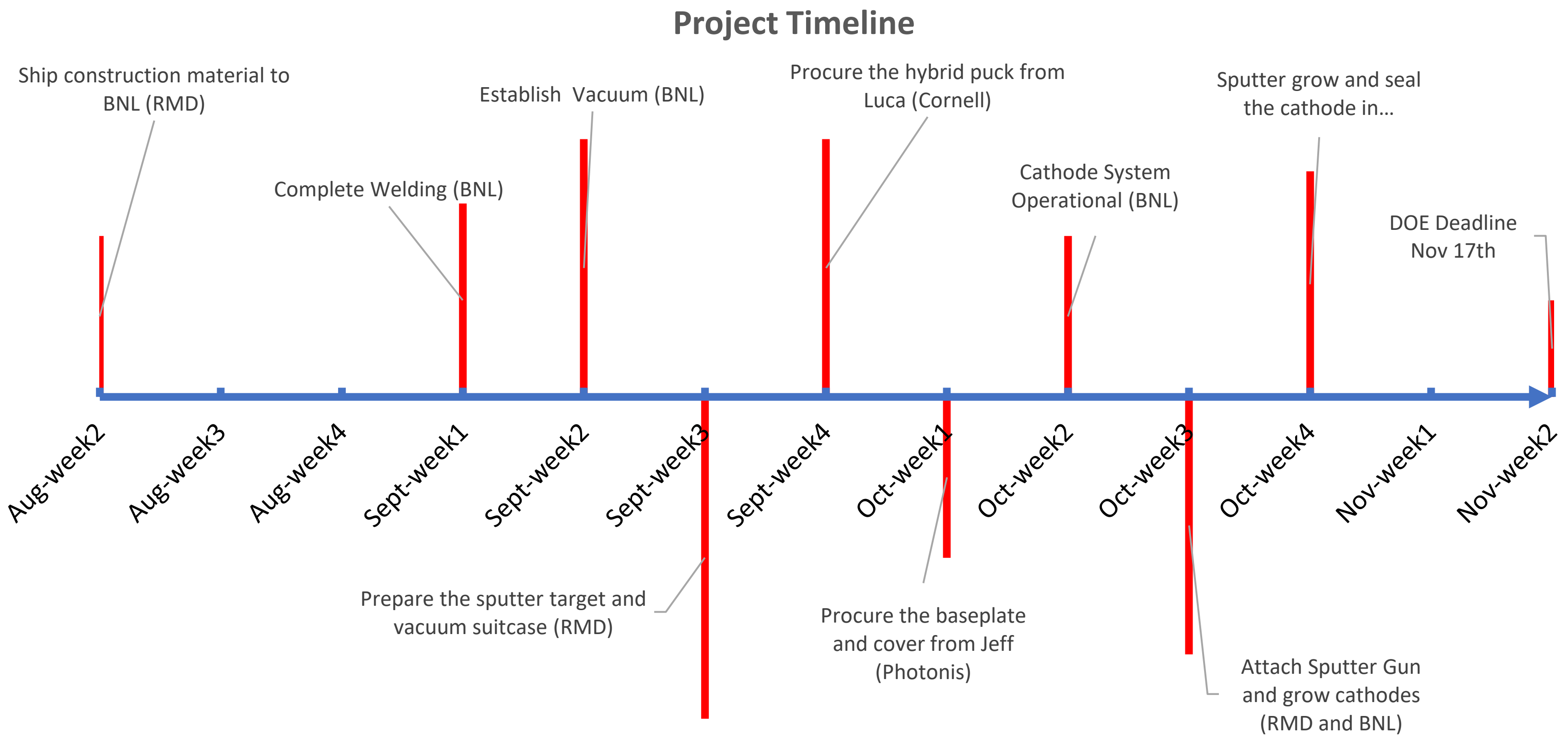
Masking the Cathode



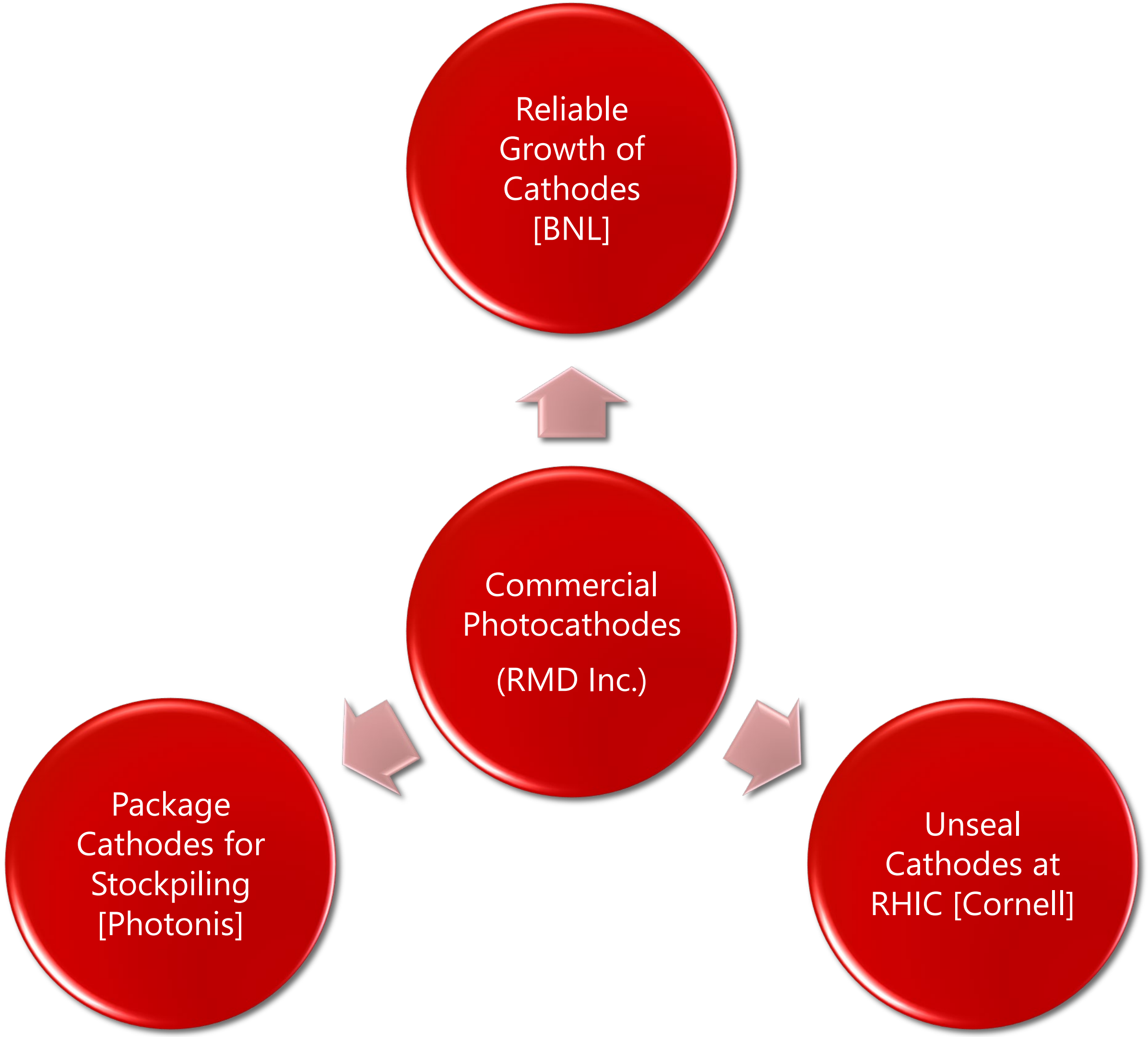


Deposition Chamber Under Construction (BNL)

- Progress has been delayed by COVID-19 shutdown
- Received a 6-month no-cost extension from DOE Contracts Office
- RMD is supplementing the current SBIR R&D effort with internal funding (~$250k)

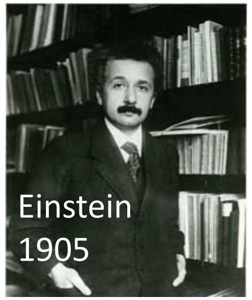


A Team Effort - SBIR

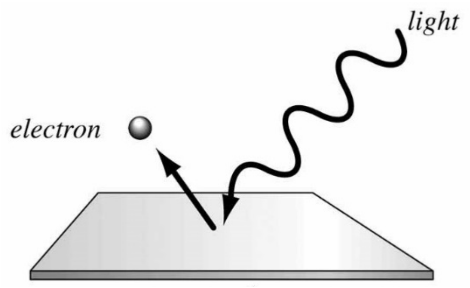


Questions ?

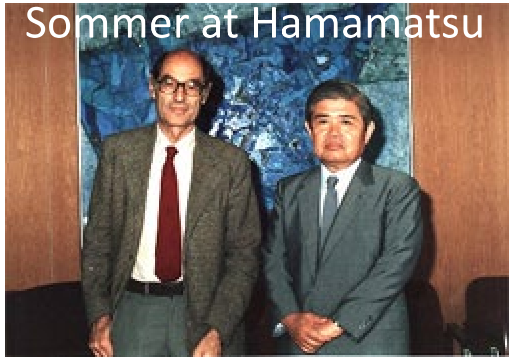
What is a Photocathode?



Nobel prize for photoelectric effect - 1921



Photocathode

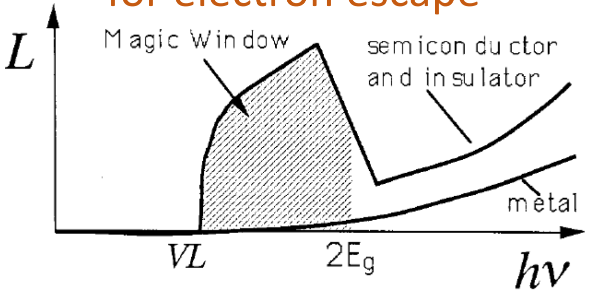


- In 1951 Dr. Alfred Sommer discovered a process for "alkali antimonides" (M_3Sb) preparation that performed better than metal photocathodes
- Hamamatsu uses Sommer's process in PMT's (1980's)
- Process involves reactive evaporation of alkalis' on Sb

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