University of Chicago

Argonne NATIONAL LABORATORY

LAPPD

Atomic Layer Deposition in HEP:
Lessons and Opportunities

Matt Wetstein
University of Chicago/ANL

presenting work of

Jeff Elam and Anil Mane
Argonne National Laboratory, Material Science Division

material borrowed heavily from
Mike Pellin
Argonne National Laboratory, Material Science Division

and on behalf of the Large Area Picosecond Photodector (LAPPD) Collaboration

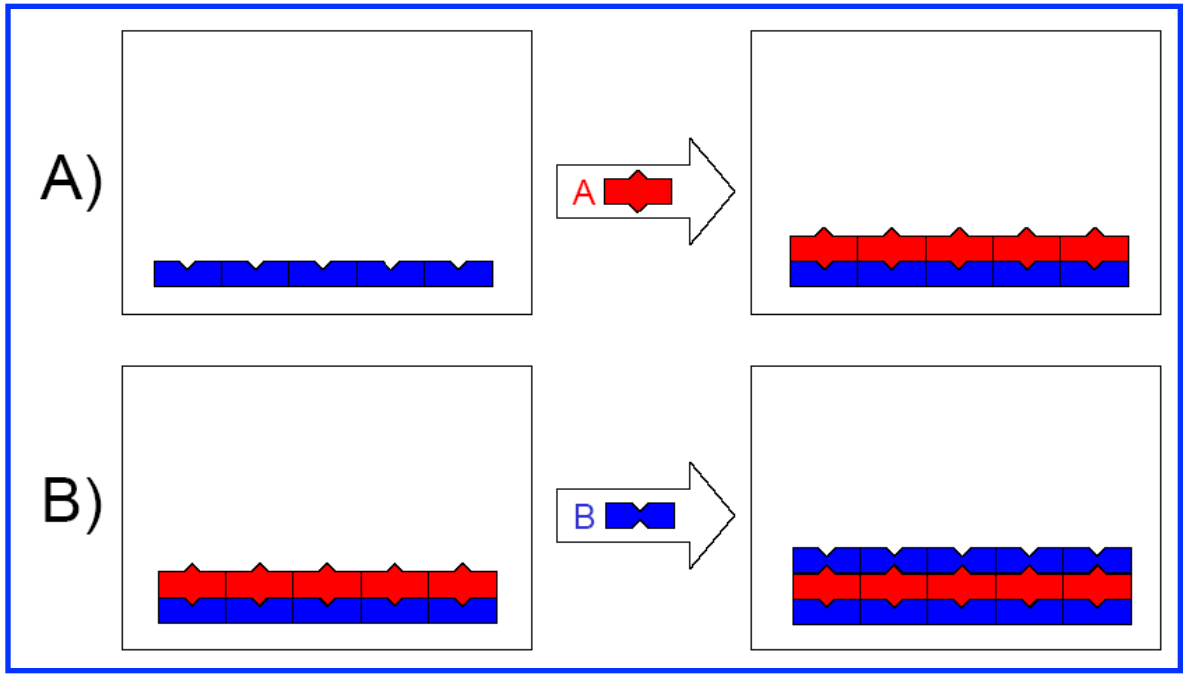
Snowmass on the Mississippi

Aug 2, 2013

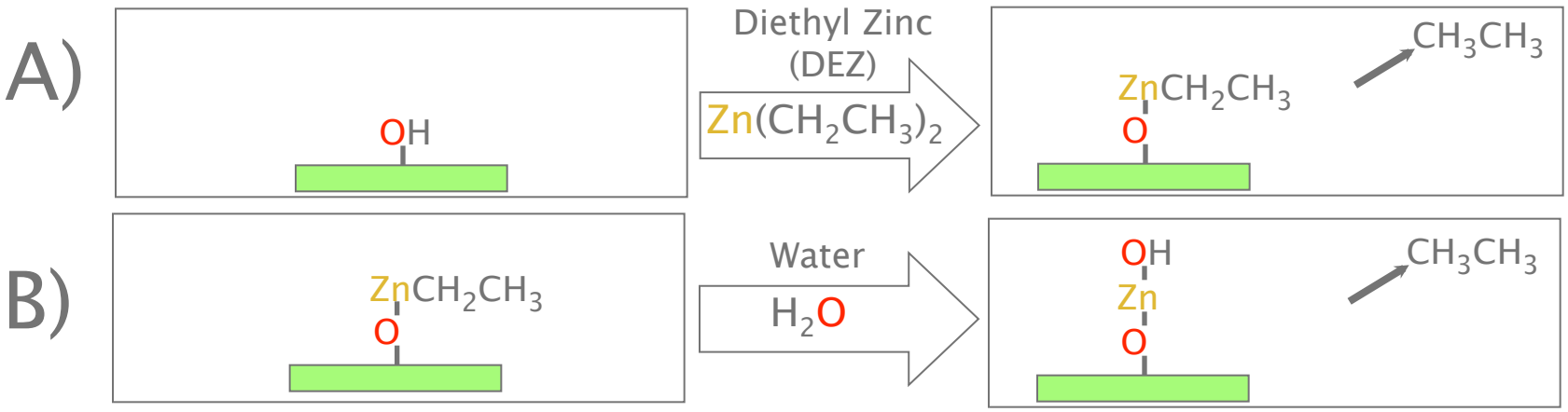
U.S. DEPARTMENT OF ENERGY

What is Atomic Layer Deposition (ALD)?

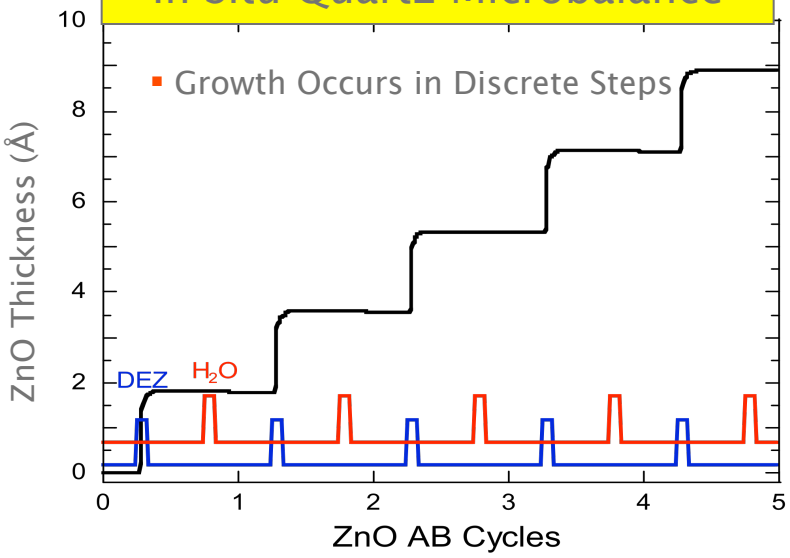
Atomic Layer Deposition is a chemical vapor deposition technique based on the sequential application of two or more chemicals (precursors) that undergo self-limiting reactions with solid surfaces. This allows the application of materials, one atomic mono-layer at a time.



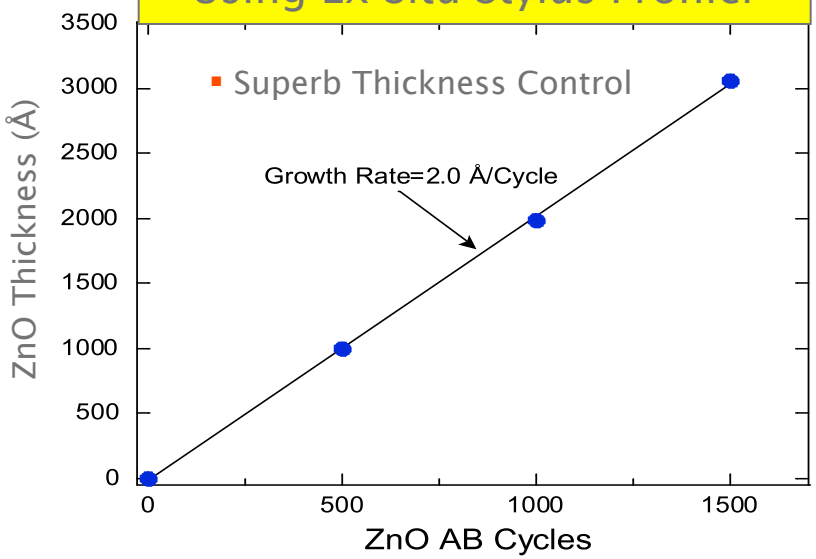
What is Atomic Layer Deposition (ALD)?



ZnO ALD Monitored Using In Situ Quartz Microbalance



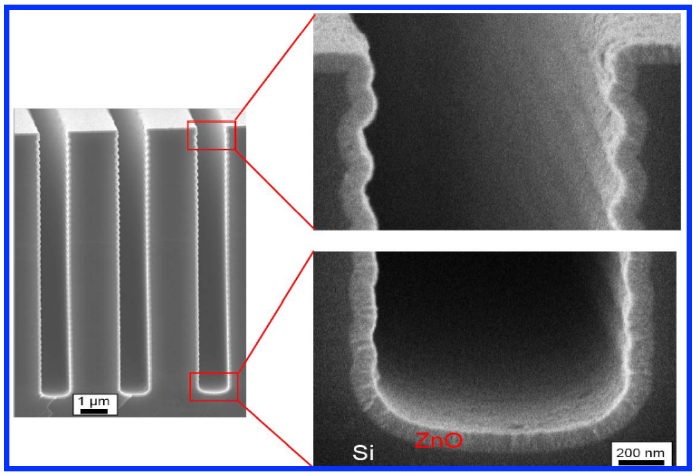
ZnO ALD Thickness Measured Using Ex Situ Stylus Profiler



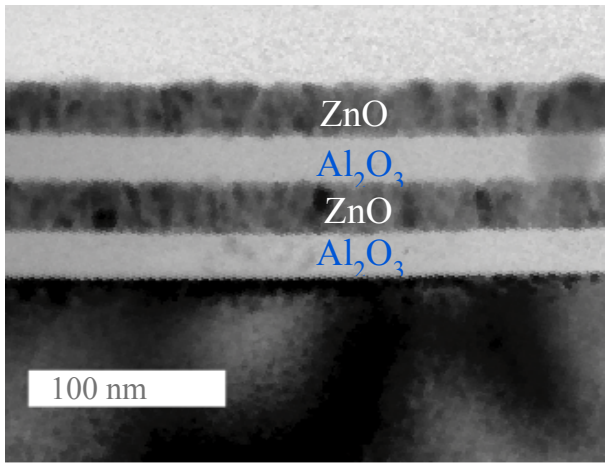
Pellin

What is Atomic Layer Deposition (ALD)?

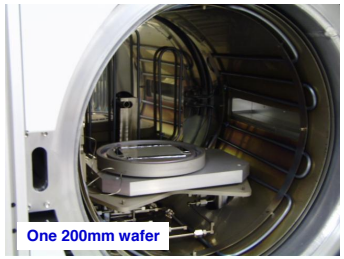
Conformal

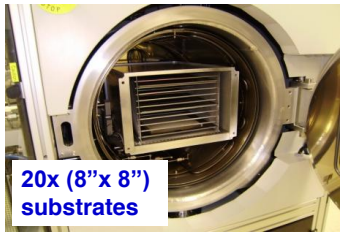


Can produce hybrid, layered materials

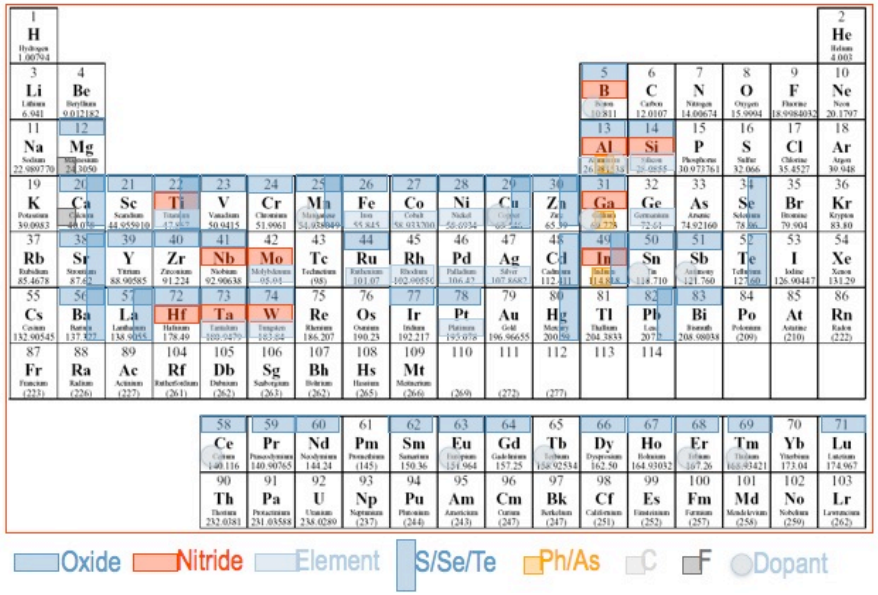


Scalable



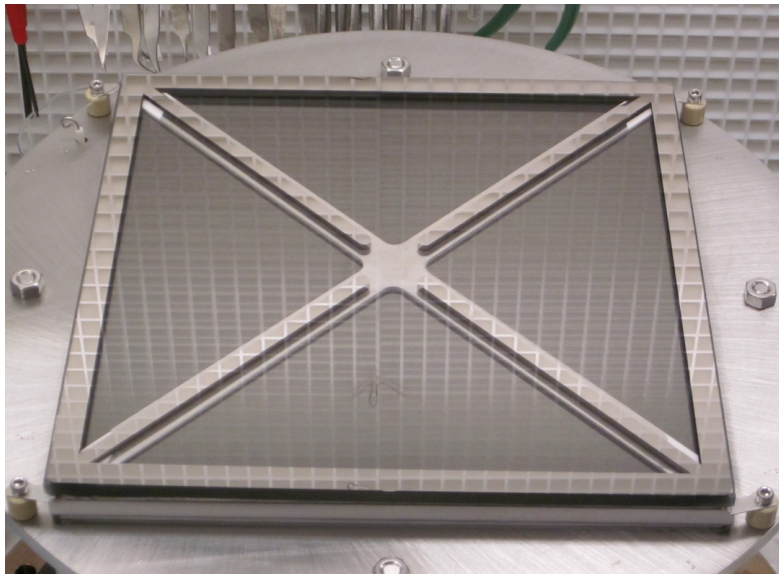


Compatible with a large number of elements and compounds

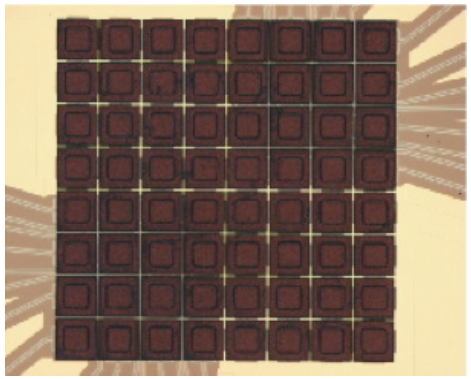


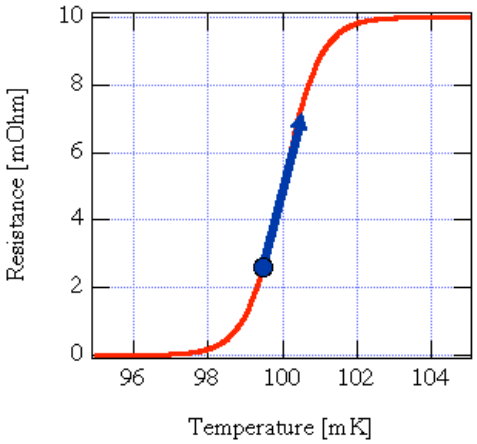
ALD is very useful for HEP!

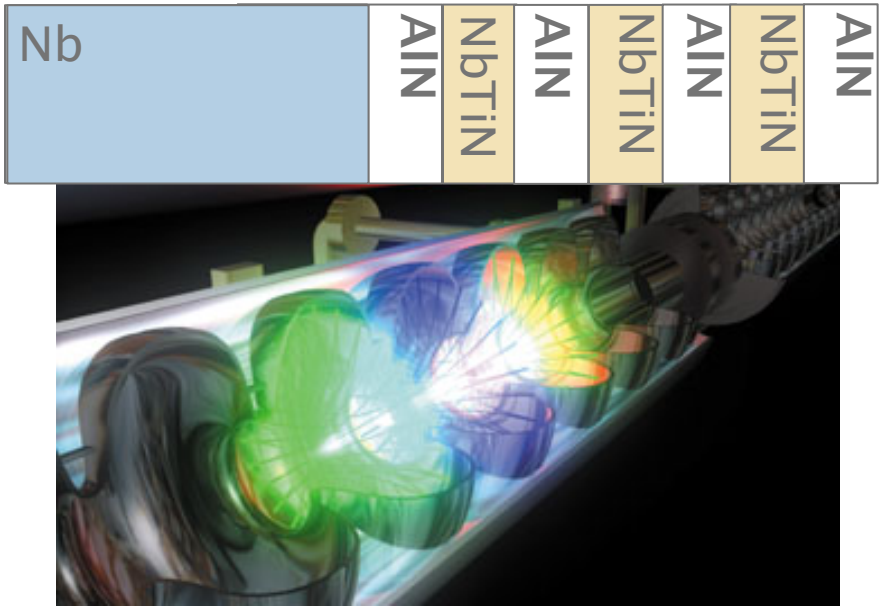
Large Area Picosecond Photodetectors



Transition Edge Sensors





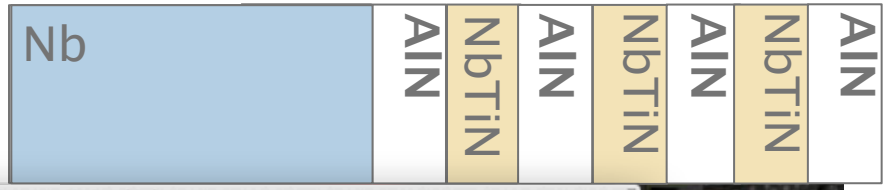


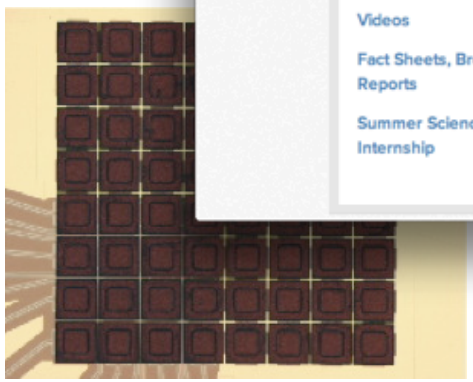
Superconducting RF cavities

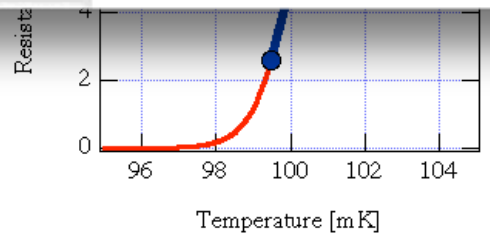
- Layered structures raise the critical magnetic field at which vortex losses form.

ALD is very useful for HEP!

Large Area Picosecond Photodetectors





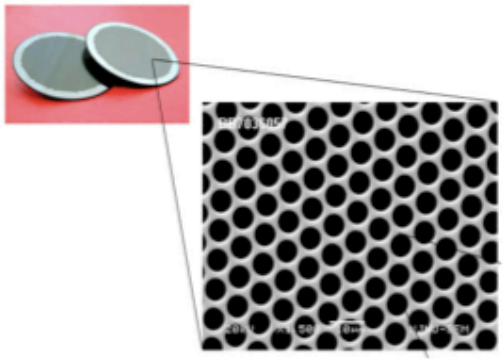


LAPPD Collaboration
Reinventing the unit-cell of light-based neutrino detectors

- single pixel (poor spatial granularity)
- nanosecond time resolution
- bulky
- blown glass
- sensitive to magnetic fields

- millimeter-level spatial resolution
- <100 picosecond time resolution
- compact
- standard sheet glass
- operable in a magnetic field

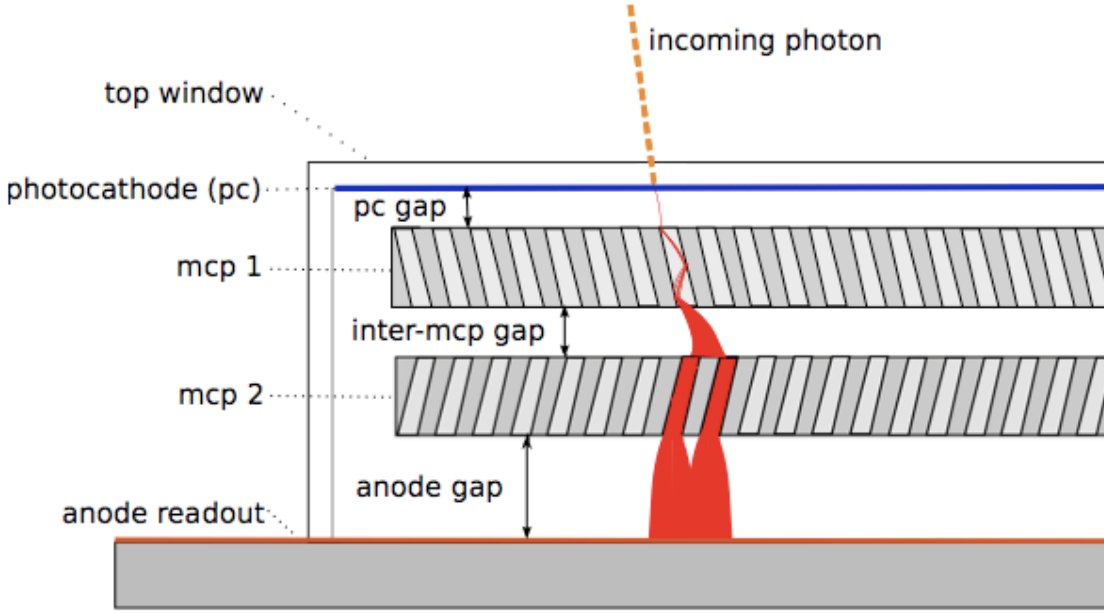
What is an MCP-PMT?



Microchannel Plate (MCP):

- a thin plate with microscopic (typically <50 μm) pores
- pores are optimized for secondary electron emission (SEE).
- Accelerating electrons accelerating across an electric potential strike the pore walls, initiating an avalanche of secondary electrons.

- An MCP-PMT is, sealed vacuum tube photodetector.
- Incoming light, incident on a photocathode can produce electrons by the photoelectric effect.
- Microchannel plates provide a gain stage, amplifying the electrical signal by a factor typically above 10^6.
- Signal is collected on the anode



Key Elements of the LAPPD Detector

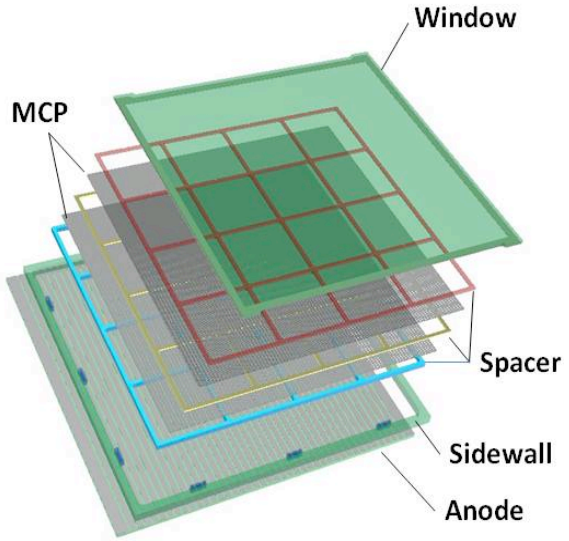
Glass body, minimal feedthroughs

MCPs made using atomic layer deposition (ALD).

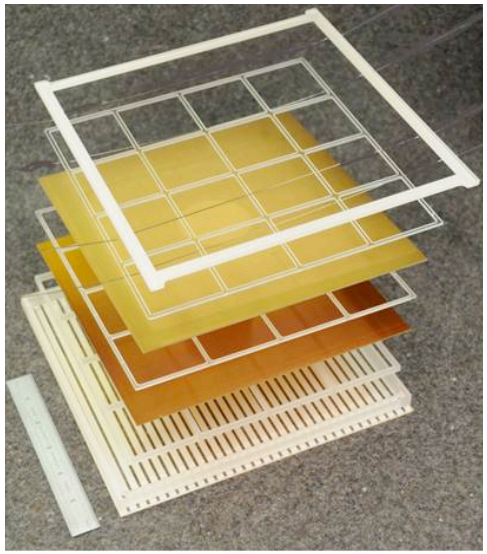
transmission line anode

fast and economical front-end electronics

large area, flat panel photocathodes

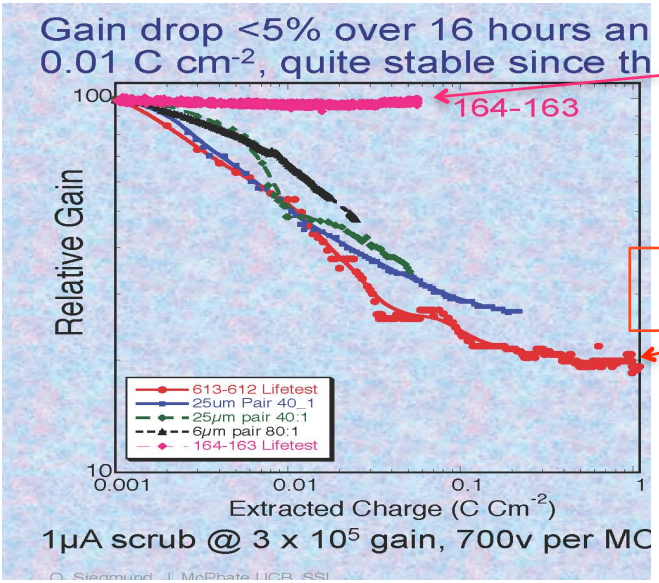


Design Drawing - September 2010



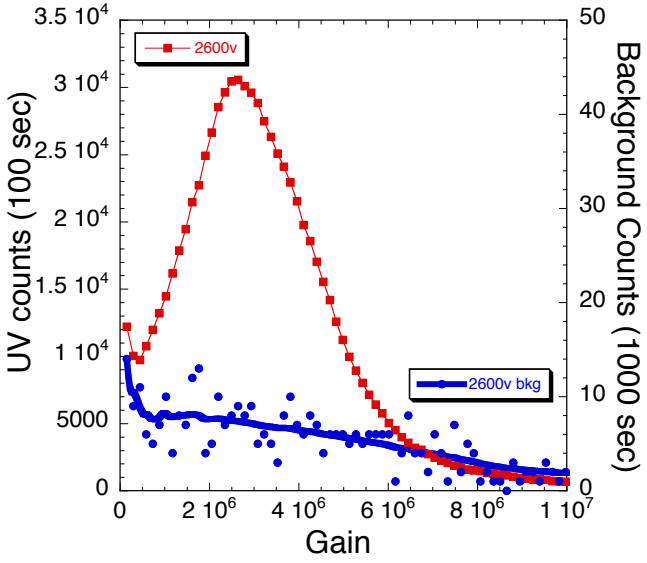
Actual Glass Parts - April 2012

The Wonders of Pure Materials



Measured ANL ALD-MCP behavior

Typical MCP behavior- long scrub-times



Lifetime of latest generation Microchannel Plate PMT's

A. Britting, W. Eyrich, A. Lehmann†, F. Uhlig, and PANDA Cherenkov group

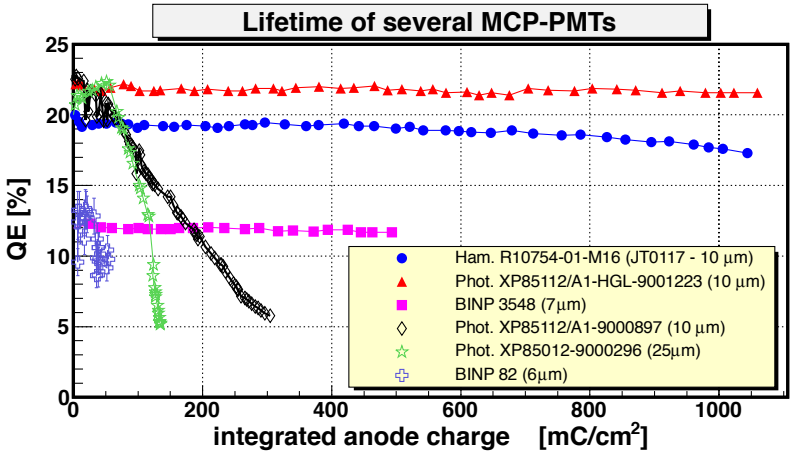
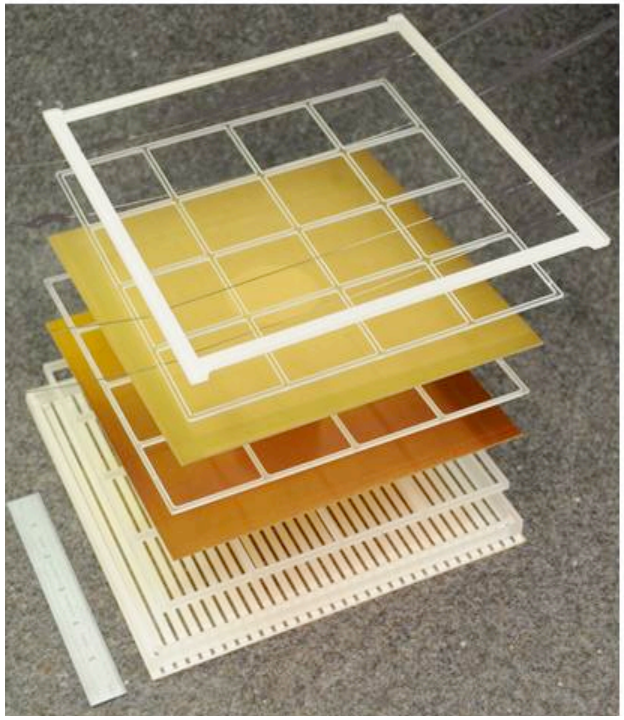


Figure 1: QE at 400 nm for old (open) and new generation (solid dots) MCP-PMTs as function of the anode charge.

Same Thing in New Ways

Moving From Capabilities to Cost



LAPPD detectors:

- Thin-films on borosilicate glass
- Glass vacuum assembly
- Simple, pure materials
- Scalable electronics
- Designed to cover large areas

Conventional MCPs:

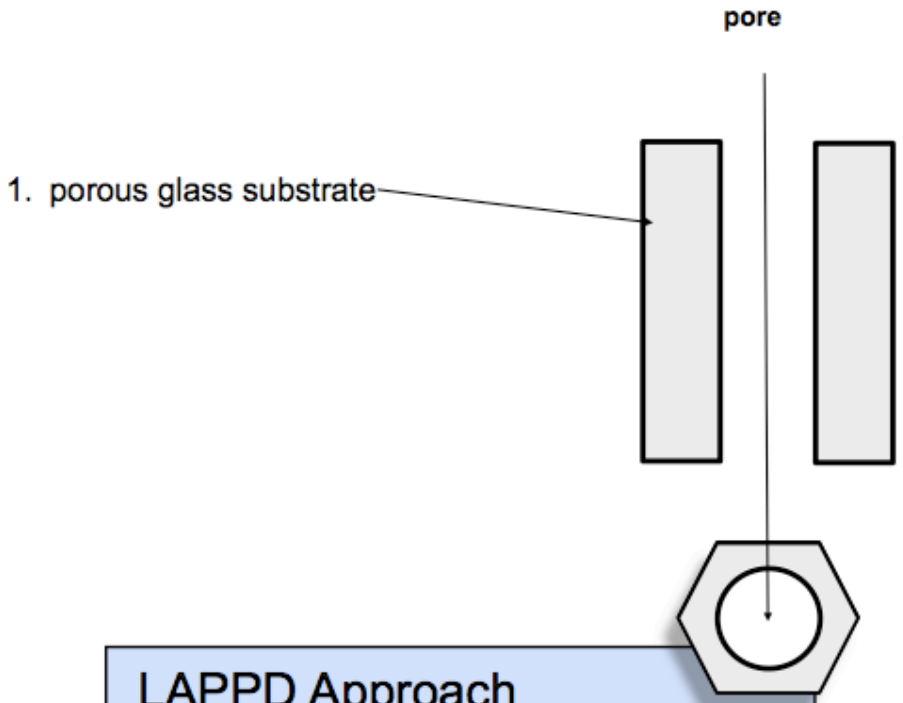
- Conditioning of leaded glass (MCPs)
- Ceramic body
- Not designed for large area applications

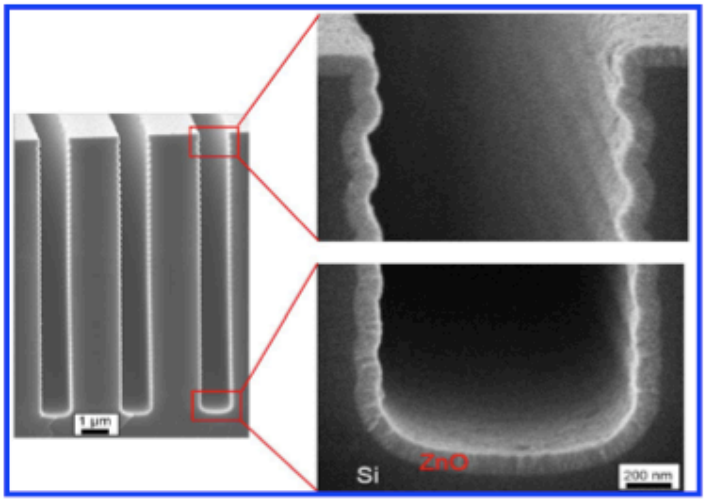
Separating Functionality

J. Elam, A. Mane, Q. Peng (ANL-ESD),
N. Sullivan (Arradiance), A. Tremsin (Arradiance, SSL)

Conventional MCP Fabrication

- Pore structure formed by drawing and slicing lead-glass fiber bundles. The glass also serves as the resistive material
- Chemical etching and heating in hydrogen to improve secondary emissive properties.
- Expensive, requires long conditioning, and uses the same material for resistive and secondary emissive properties. (Problems with thermal run-away).





LAPPD Approach

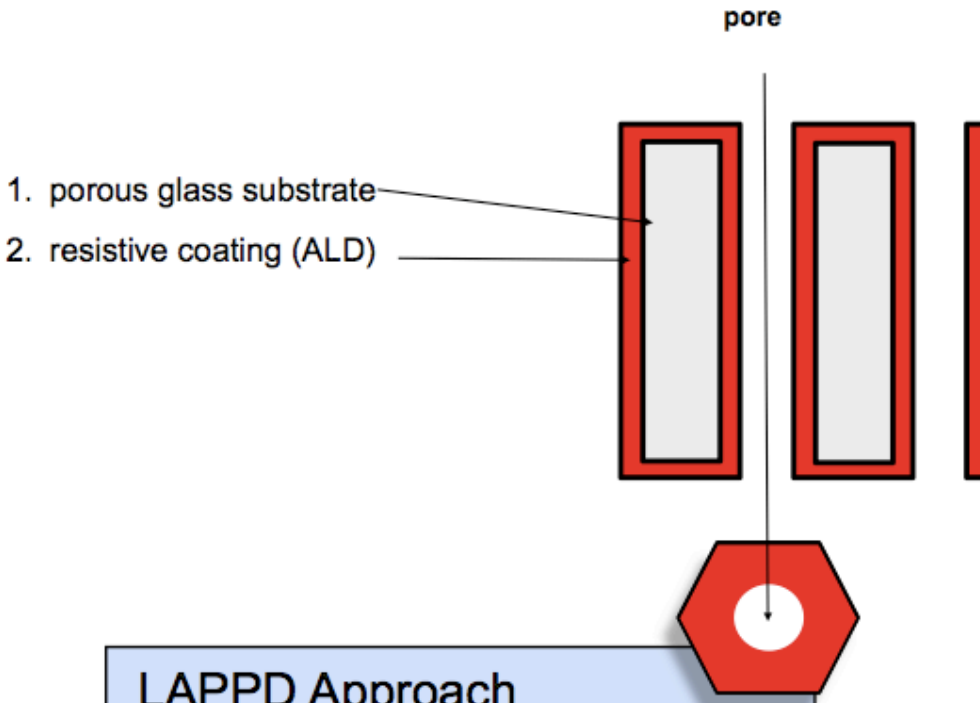
- Separate out the three functions
- Hand-pick materials to optimize performance.
- Use Atomic Layer Deposition (ALD): a cheap industrial batch method.
  - ALD is diffusive, conformal and allows application of material in single atomic monolayers

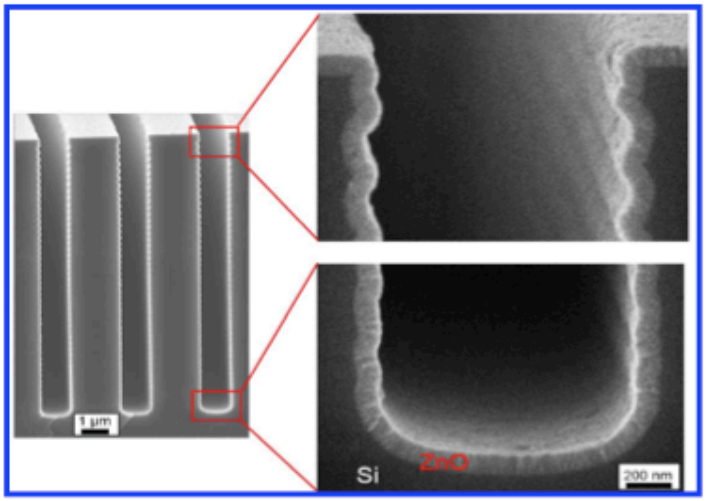
Separating Functionality

J. Elam, A. Mane, Q. Peng (ANL-ESD),
N. Sullivan (Arradiance), A. Tremsin (Arradiance, SSL)

Conventional MCP Fabrication

- Pore structure formed by drawing and slicing lead-glass fiber bundles. The glass also serves as the resistive material
- Chemical etching and heating in hydrogen to improve secondary emissive properties.
- Expensive, requires long conditioning, and uses the same material for resistive and secondary emissive properties. (Problems with thermal run-away).





LAPPD Approach

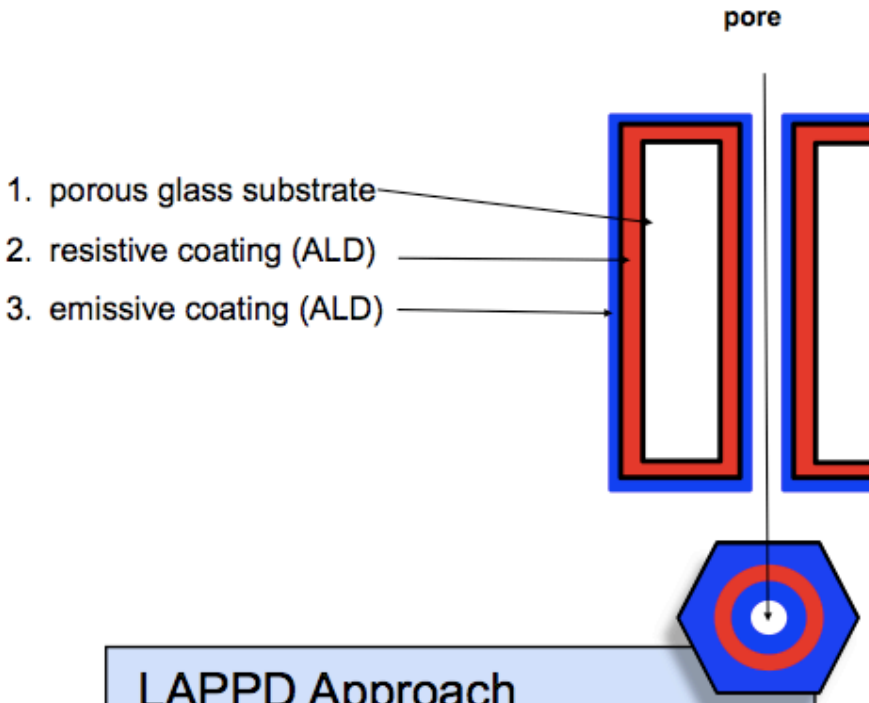
- Separate out the three functions
- Hand-pick materials to optimize performance.
- Use Atomic Layer Deposition (ALD): a cheap industrial batch method.
  - ALD is diffusive, conformal and allows application of material in single atomic monolayers

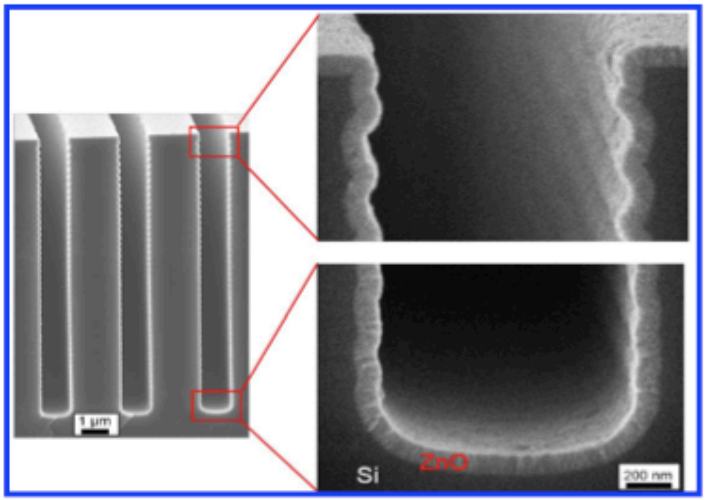
Separating Functionality

J. Elam, A. Mane, Q. Peng (ANL-ESD),
N. Sullivan (Arradiance), A. Tremsin (Arradiance, SSL)

Conventional MCP Fabrication

- Pore structure formed by drawing and slicing lead-glass fiber bundles. The glass also serves as the resistive material
- Chemical etching and heating in hydrogen to improve secondary emissive properties.
- Expensive, requires long conditioning, and uses the same material for resistive and secondary emissive properties. (Problems with thermal run-away).





LAPPD Approach

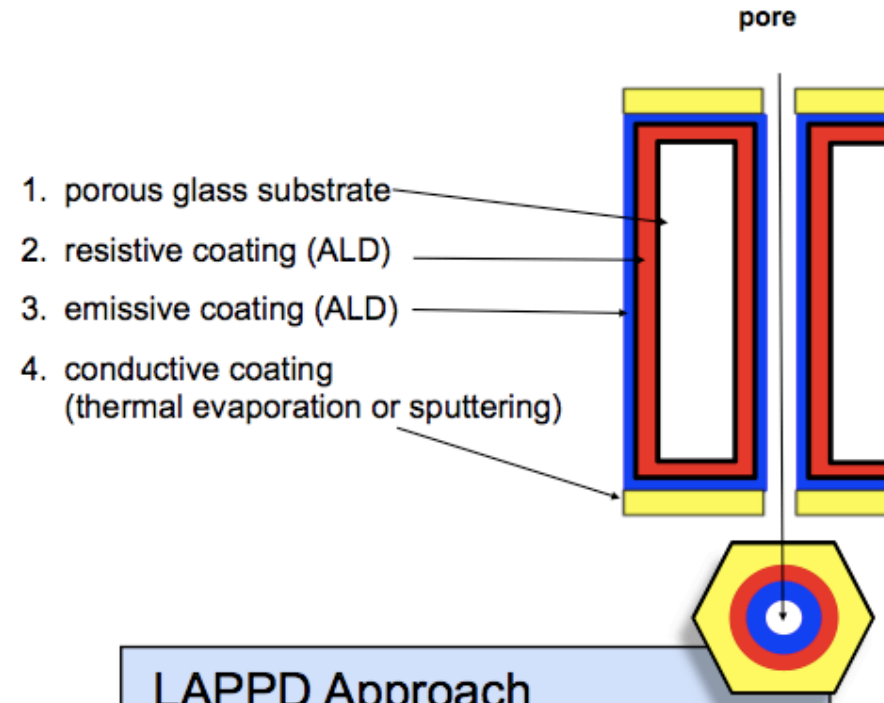
- Separate out the three functions
- Hand-pick materials to optimize performance.
- Use Atomic Layer Deposition (ALD): a cheap industrial batch method.
  - ALD is diffusive, conformal and allows application of material in single atomic monolayers

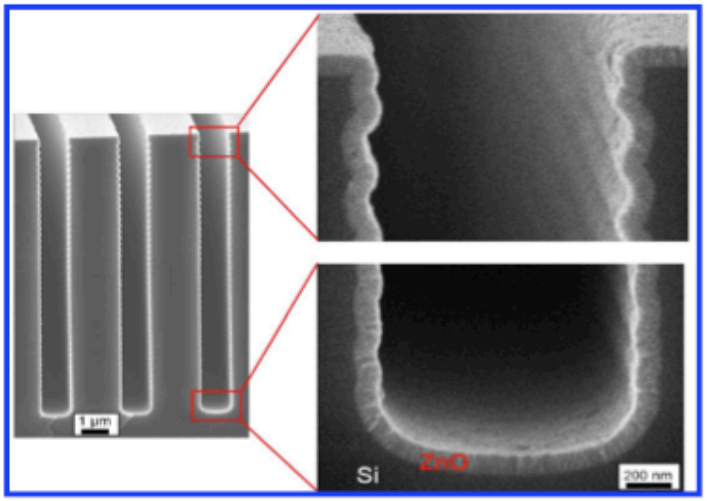
Separating Functionality

J. Elam, A. Mane, Q. Peng (ANL-ESD),
N. Sullivan (Arradiance), A. Tremsin (Arradiance, SSL)

Conventional MCP Fabrication

- Pore structure formed by drawing and slicing lead-glass fiber bundles. The glass also serves as the resistive material
- Chemical etching and heating in hydrogen to improve secondary emissive properties.
- Expensive, requires long conditioning, and uses the same material for resistive and secondary emissive properties. (Problems with thermal run-away).

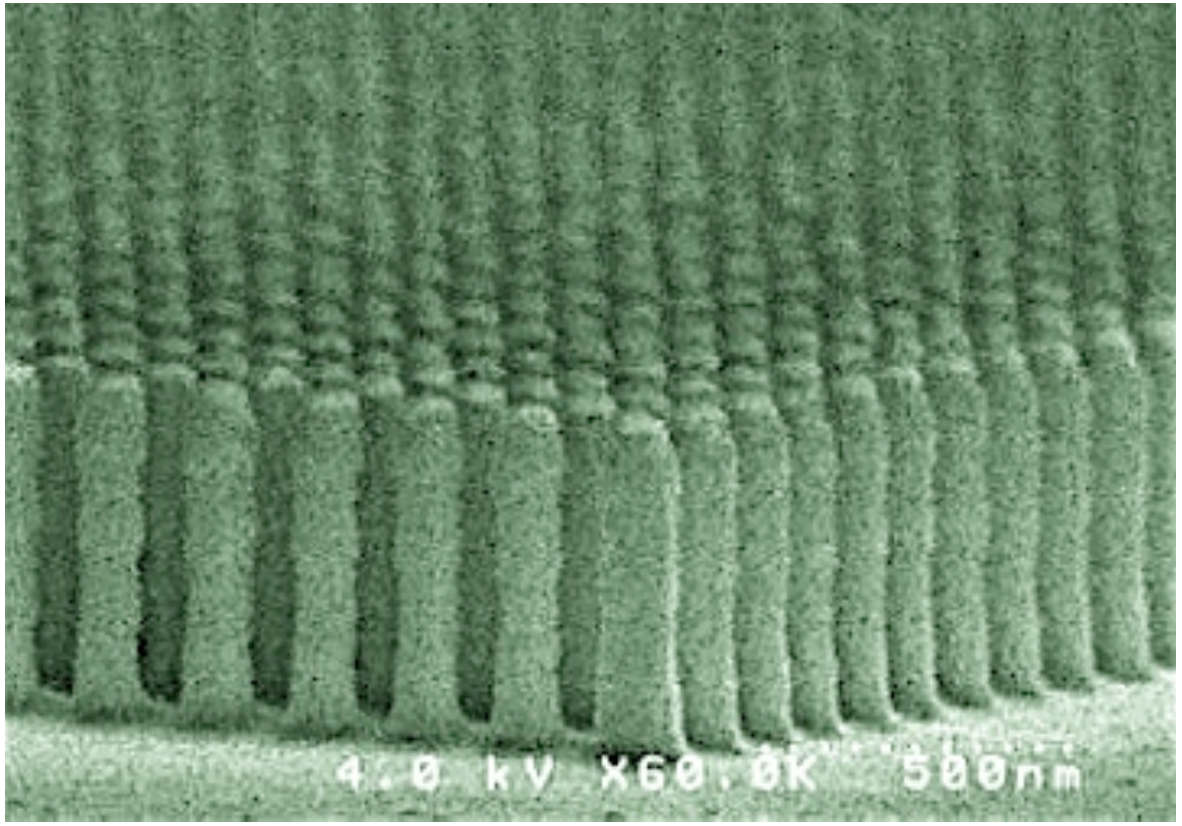




LAPPD Approach

- Separate out the three functions
- Hand-pick materials to optimize performance.
- Use Atomic Layer Deposition (ALD): a cheap industrial batch method.
  - ALD is diffusive, conformal and allows application of material in single atomic monolayers

Separating Functionality

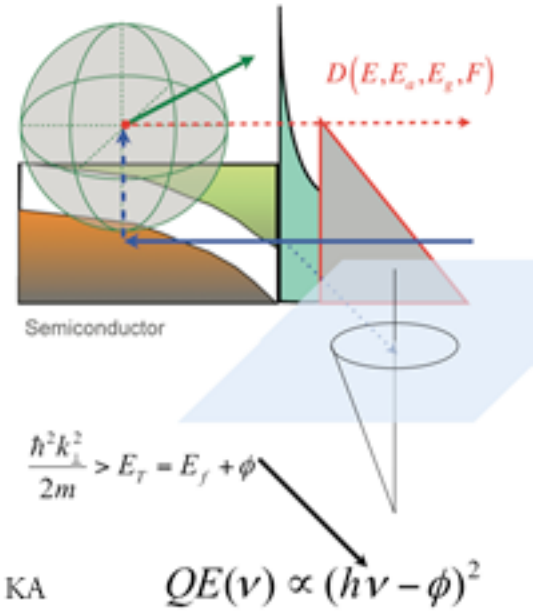


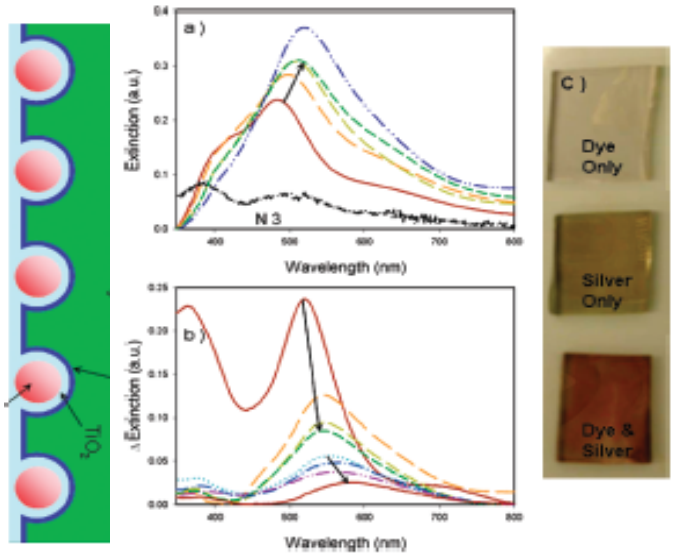
When you separate structure from other chemical processes, interesting new ideas are possible.

Material Science as Science

Photocathodes are an example of a technology, often taken for granted, where there is a lot of room to understand the basic underlying physics.

Material scientists and HEP folks are making strides in understanding the basic materials and optimizing them for ultra-high QEs.





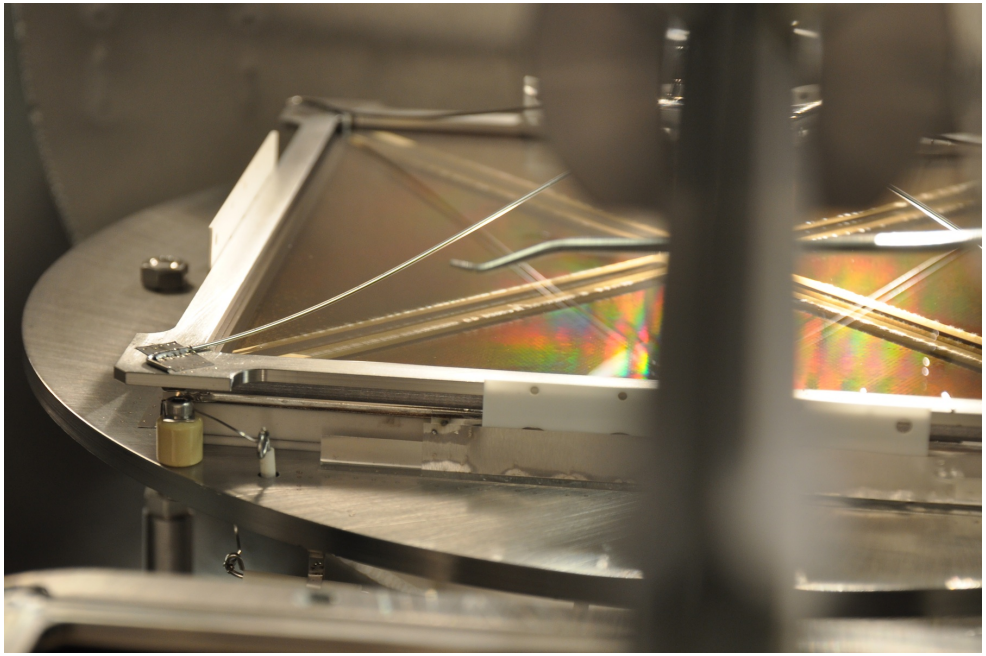
See, for example:

Second Workshop on Photocathodes – U Chicago

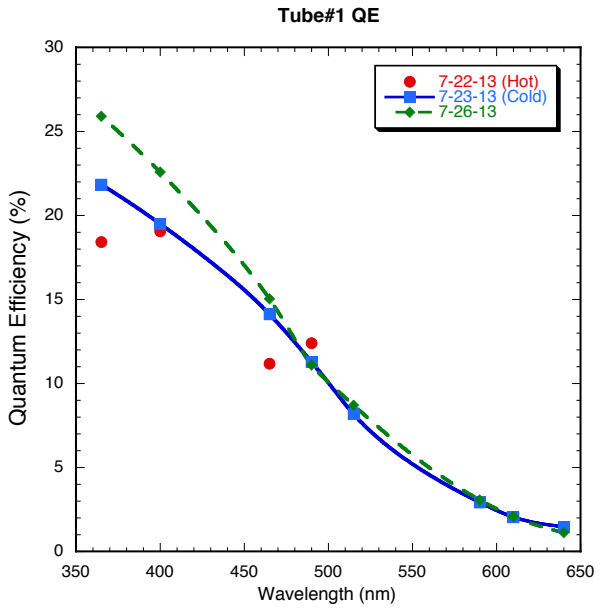
https://psec.uchicago.edu/workshops/2nd_photocathode_conference/

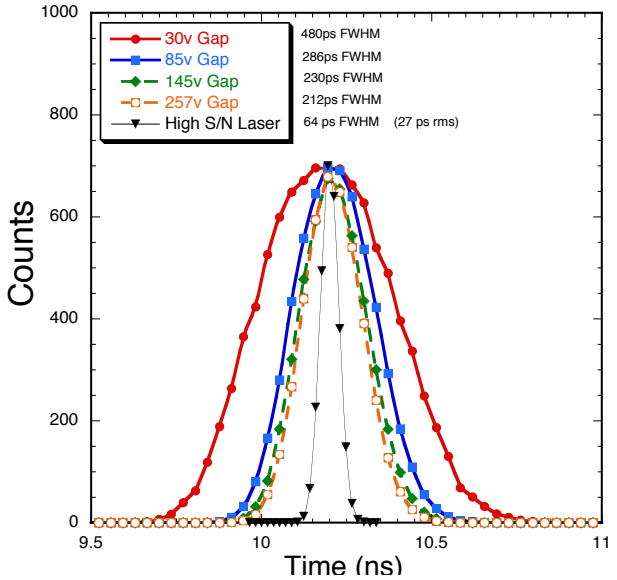
Postscript/News Flash!

- First complete LAPPD (with photocathode) has been sealed at Berkeley SSL
- Will be brought to air, any day now…possibly before Snowmass ends.



Tube with window hot indium seal completed





Importance of Cross-pollination

Reaching out to other communities can produce an unstoppable force.

Importance of Cross-pollination