Development of Large Area Fast Microchannel Plate Photodetectors

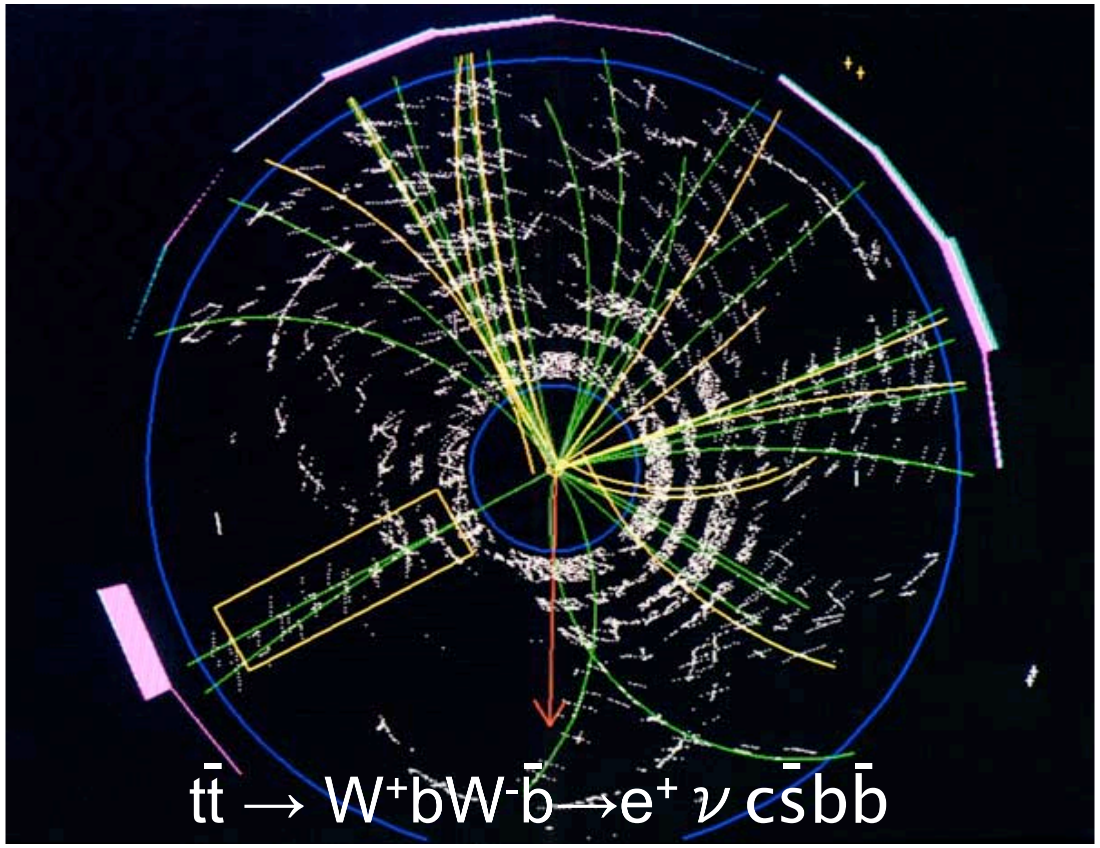
for the Large Area Picosecond Photodetector Development Collaboration
Bob Wagner, Argonne National Laboratory
SORMA XII
Thursday 27 May 2010

LAPPD Project Scope

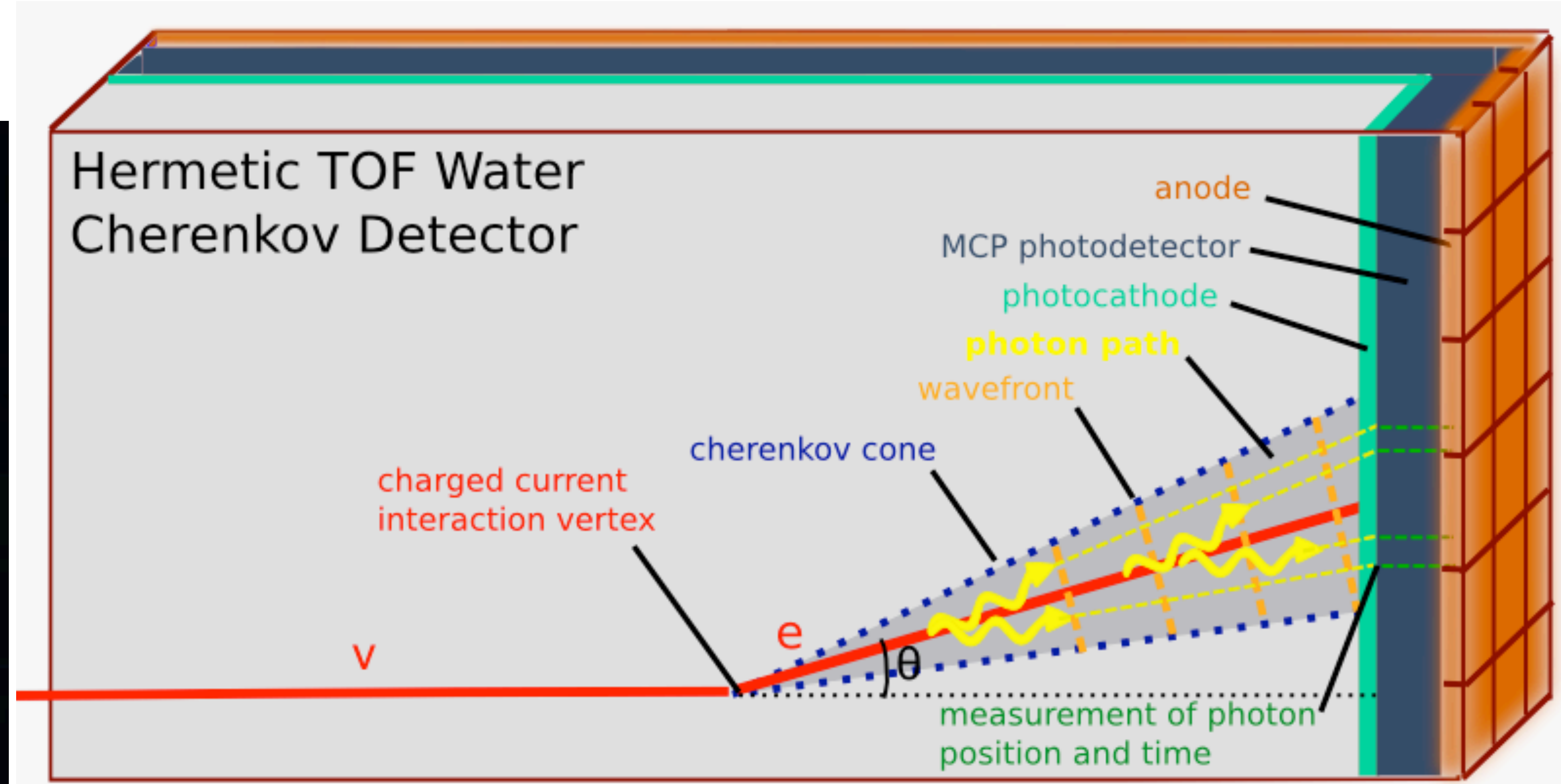
Large, Cheap, Fast Microchannel Plate Photomultiplier

- 20×20 cm^2 active area (development on 3.3cm diam. disk)
- Novel, inexpensive MCP substrate
  - Borofloat glass capillary substrates (10-20 μm pores, L/D ~60)
  - Anodic aluminum oxide (AAO) -- ceramic
- Pore activation via Atomic Layer Deposition (ALD)
  - Separate material for resistive and secondary emission layers
  - Optimize resistive and emissive layers via study of range of materials
- Customized anode readout
  - Strip line double-ended readout for picosecond timing & water Cherenkov
  - Pad readout for energy and/or coarse spatial resolution -- gamma-ray telescope camera, dual readout calorimeters, medical imaging
- High quantum efficiency photocathode --- ≥25% (1st gen. >10%)
  - Bialkali (baseline), multialkali
  - “III-V” materials, e.g. GaAs, GaN
  - Systematic program of photocathode development and analysis
- Waveform sampling switched capacitor array ASIC for readout
- Use simulation to vet and tune design

Motivation



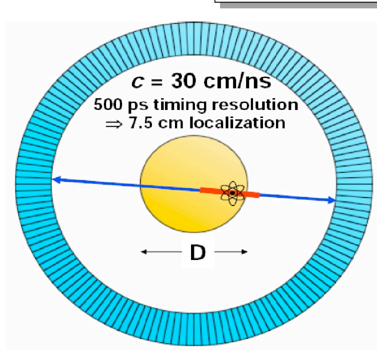
Complete particle measurement: E, p + m(PID)
1ps time & 1mm space resolution, \$100k/m^2



Water Cherenkov neutrino detector (DUSEL) ~80-90% coverage and 3-d photon vertex reconstruction
100ps time & 10mm space resolution, \$10k/m^2

Bill Moses (LBNL)
Large Area Picosecond Photodetector Workshop,
Clermont-Ferrand, Jan 2010

Time-of-Flight in PET



- Can localize source along line of flight.
- Time of flight information reduces noise in images.
- Variance reduction given by 2D/$c\Delta t$.
- 500 ps timing resolution ⇒ 5x reduction in variance!

- Time of Flight Provides a *Huge* Performance Increase!
- Largest Improvement in Large Patients

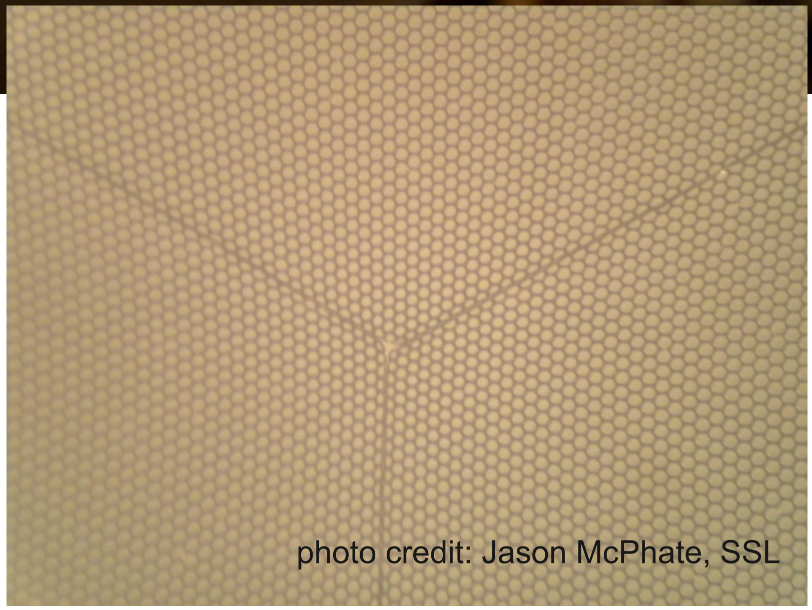
TOF (Effective Efficiency) Gain for Whole-Body PET (35 cm)

Hardware	Δt (ps)	TOF Gain
BGO Block Detector	3000	0.8
LSO Block (non-TOF)	1400	1.7
LSO Block (TOF)	550	4.2
$LaBr_3$ Block	350	6.7
LSO Side Coupled	250	9.3
LSO Small Crystal	210	11.1
LuI_3 Small Crystal	125	18.7
$LaBr_3$ Small Crystal	70	33.3

- *Incredible* Gains Predicted
- *Nothing* Else Can Give Us Gains of This Size!

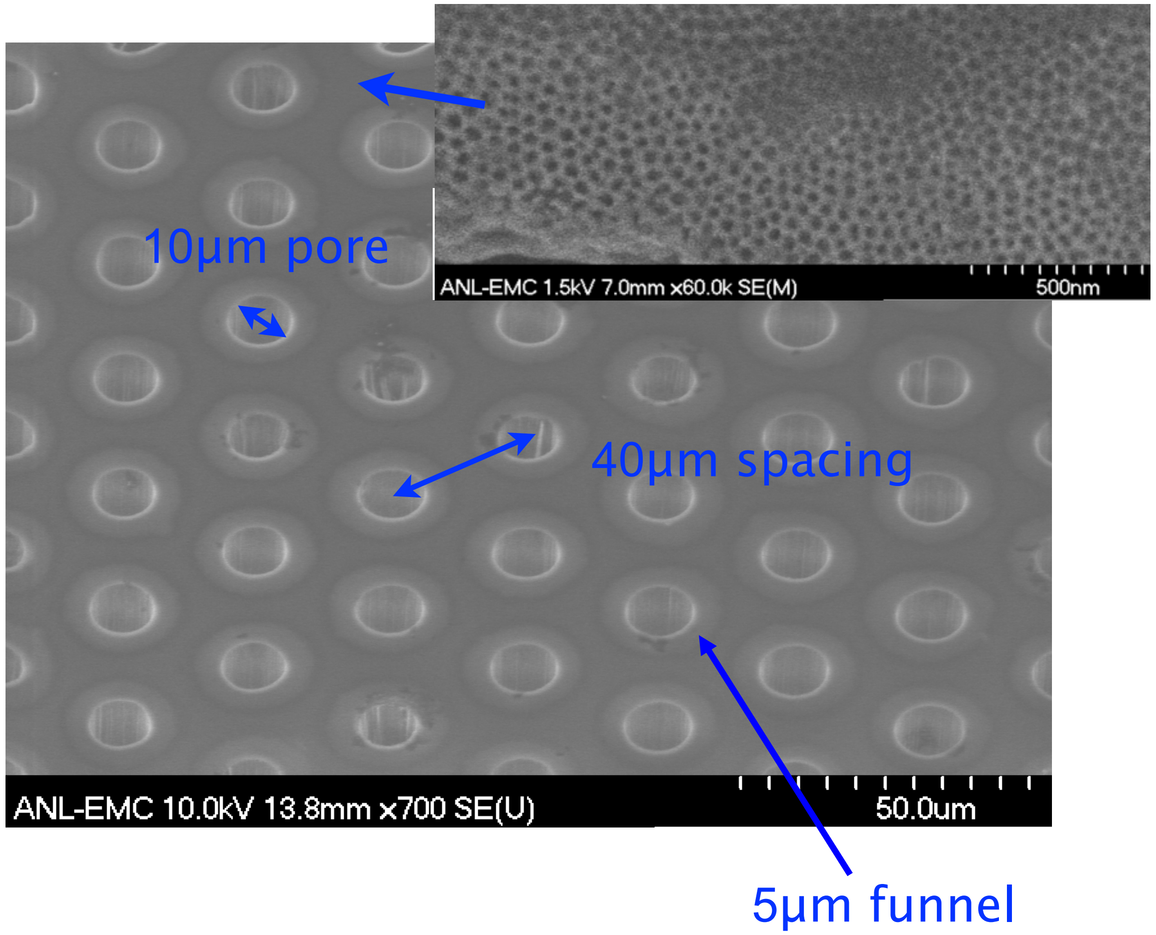
Glass Capillary Substrate Development

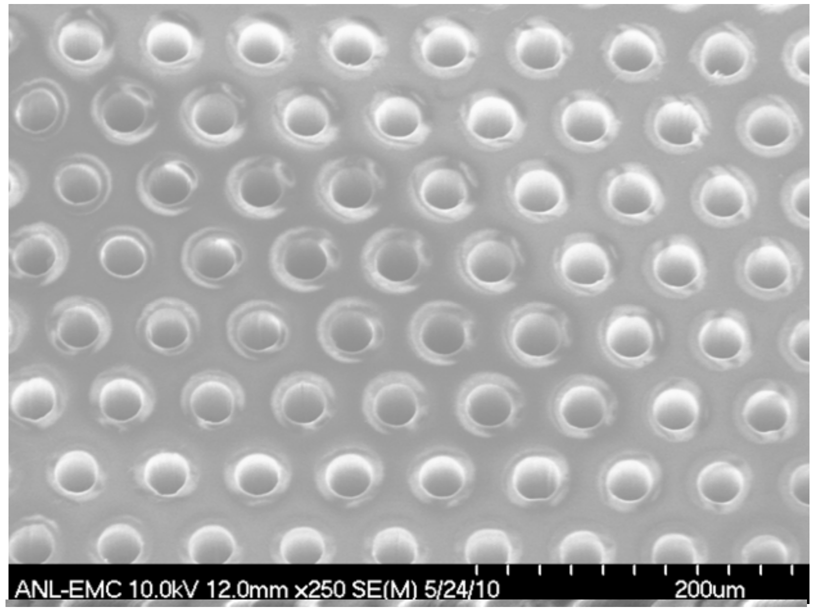
- Glass substrate development, fabrication, slicing by Incom, Inc. (Charlton, MA, USA)
  - Borosilicate glass capillary
- Disk development substrates in production
  - 32.8mm diameter
  - 20μm pore L/D=60 pieces being produced and delivered now; default working size
- 8”×8” 20μm pore substrate in fabrication at Incom.
  - Shipment of first pieces targeted for July, 2010
- All substrate pores have 8° bias w.r.t axis ⊥ to substrate
  - Used in pair chevron configuration to reduce positive ion feedback damage to photocathode



Anodic Aluminum Oxide (AAO) Development

- Self-ordering fabrication of pore structure in aluminum by anodization
- Alternative to glass capillary MCP
- Argonne AAO fabrication is 2-step
  - Form 10nm pore matrix through anodization (more “natural” size for process)
  - Pattern and etch 2-10μm pore via photolithography
    - Initial 10nm pore structure enables uniform etch larger diameter pores
- Development at Argonne is very successful
  - Now producing pores with funneled pores
    - Potential for large effective open area ratio
    - Addresses first-strike problem
    - Possible future generation of MCP with Photocathode coated on funnel via ALD



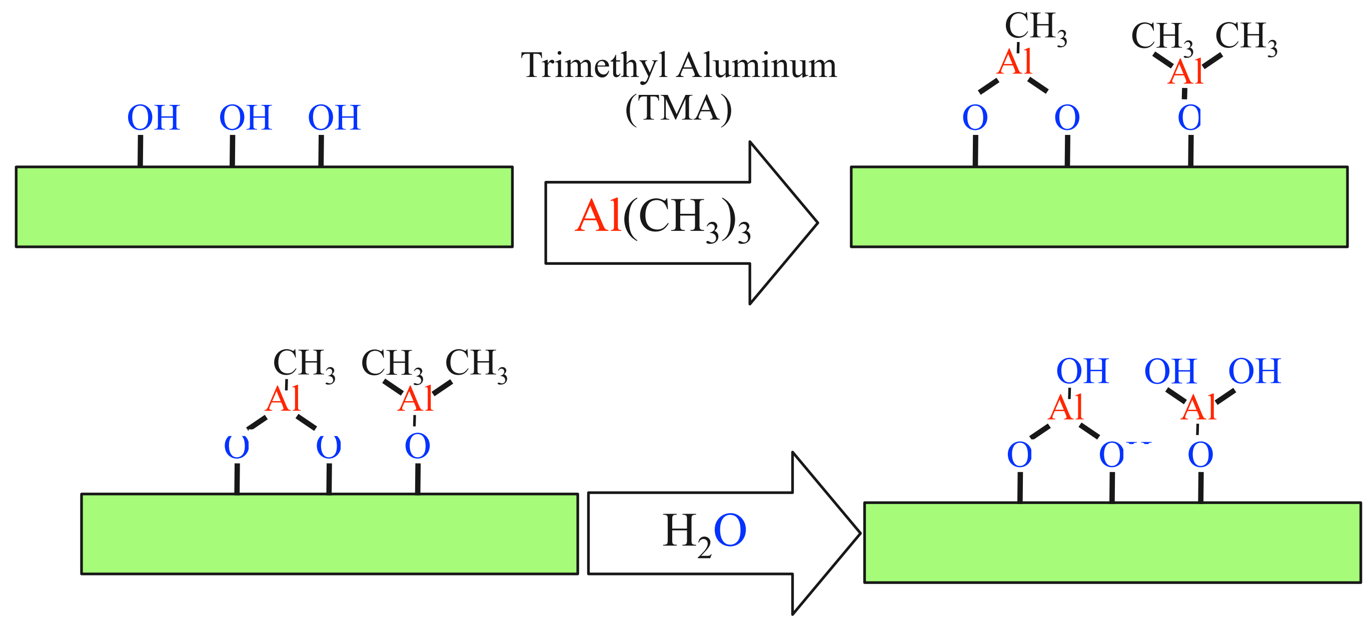


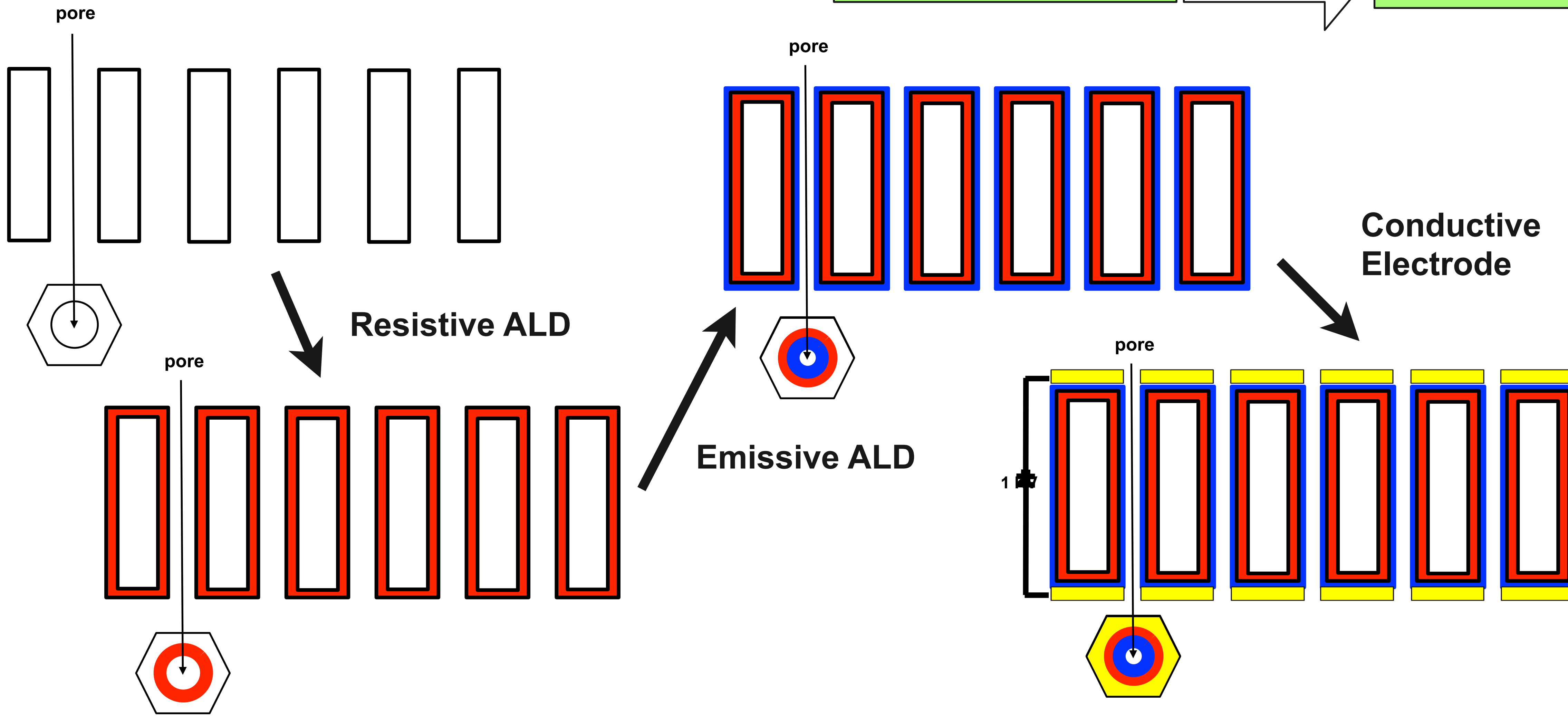
32.8mm AAO test substrate
20μm pore, L/D~10, 23% open area

Pore Activation via Atomic Layer Deposition (ALD)

Example:

- OH on surface provide reaction sites
- Trimethyl aluminum reacts liberating methane, forms Al_2O_3 layer. Leaves methyl group inhibiting further reaction on surface
- Exposure to H_2O removes methyl group. Leaves OH sites for next reaction





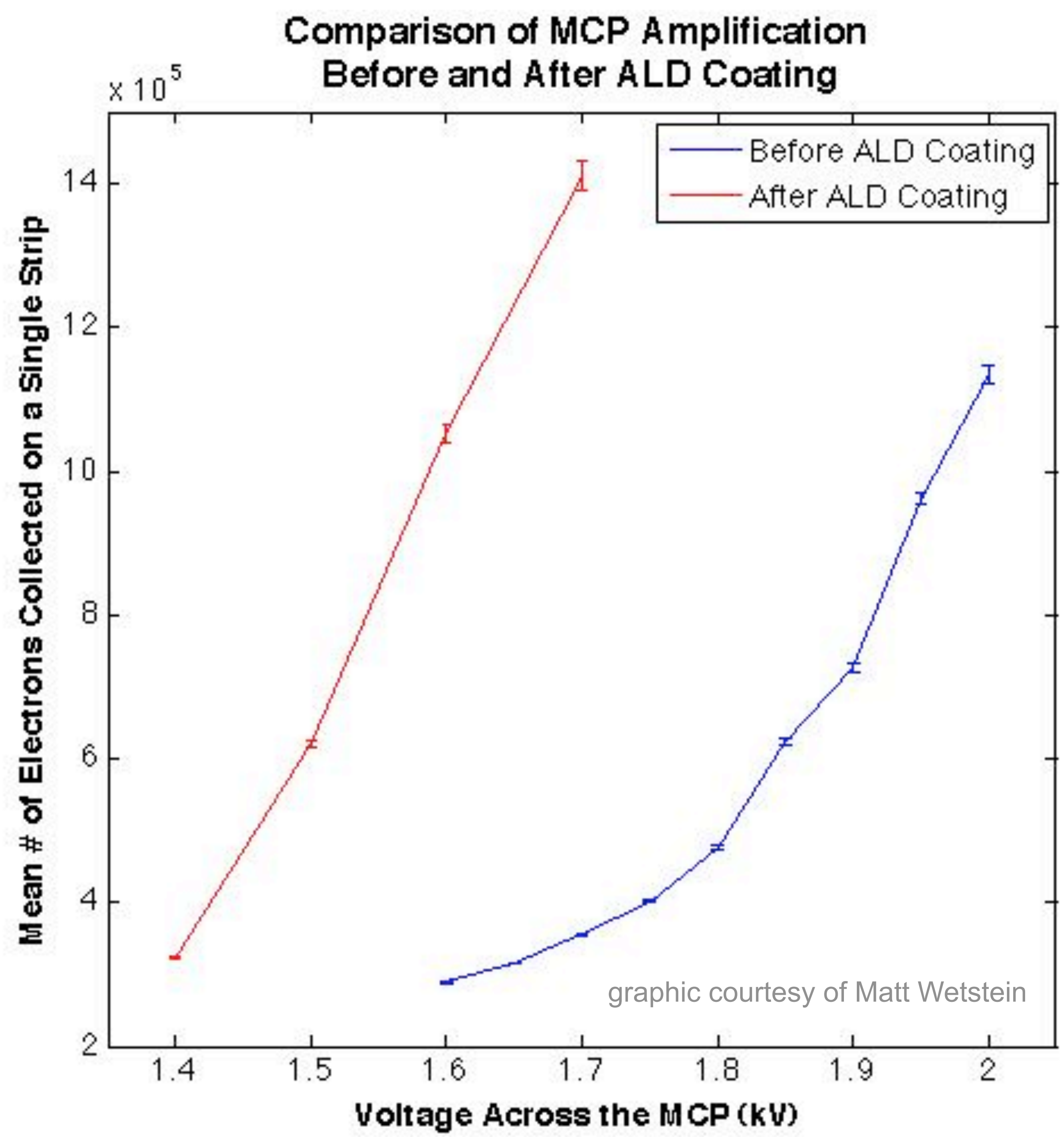
Wednesday, May 26, 2010

Functionalization of Commercial MCP

First test of ALD coating

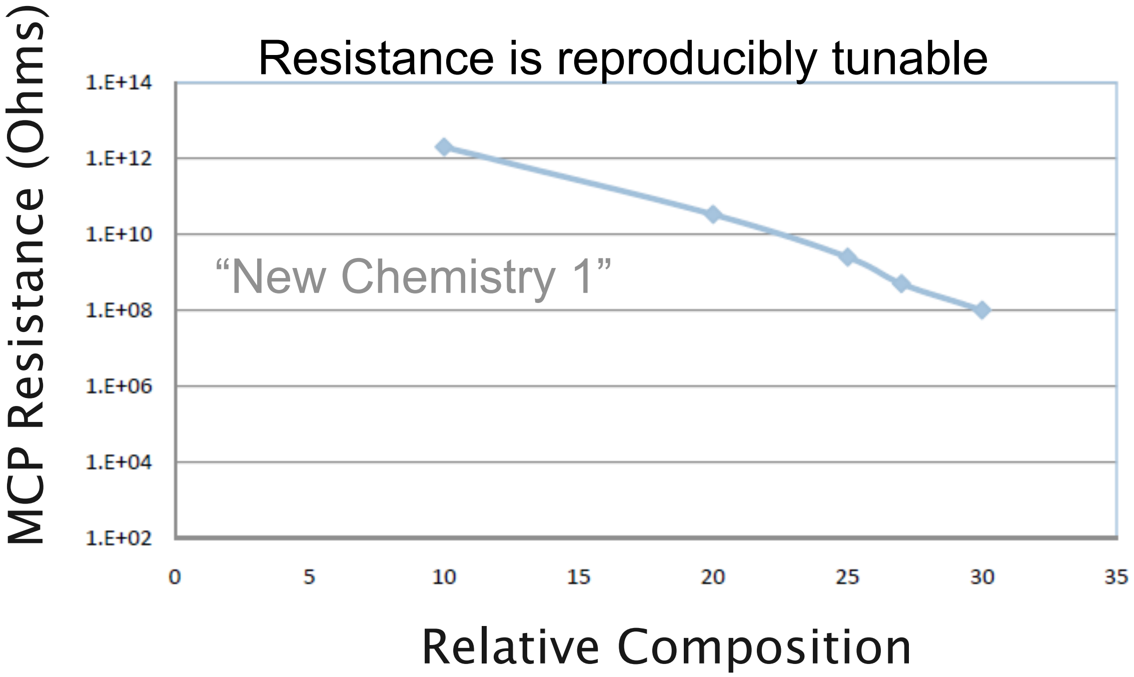
Commercial Pb-Glass MCP with existing functionalization

ALD of Al_2O_3 coating improves gain

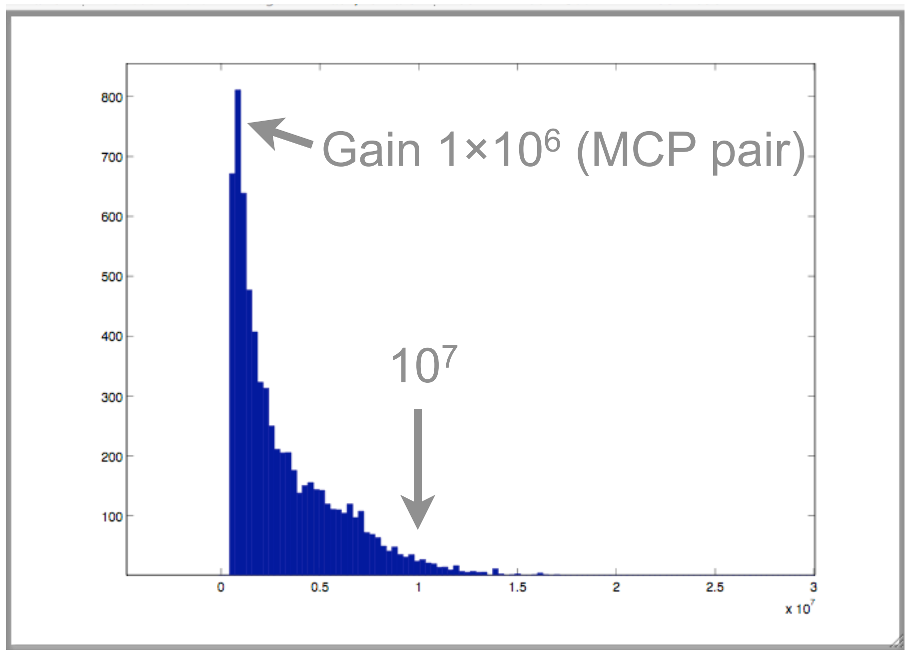


ALD Functionalization of Micro-Channel Plates

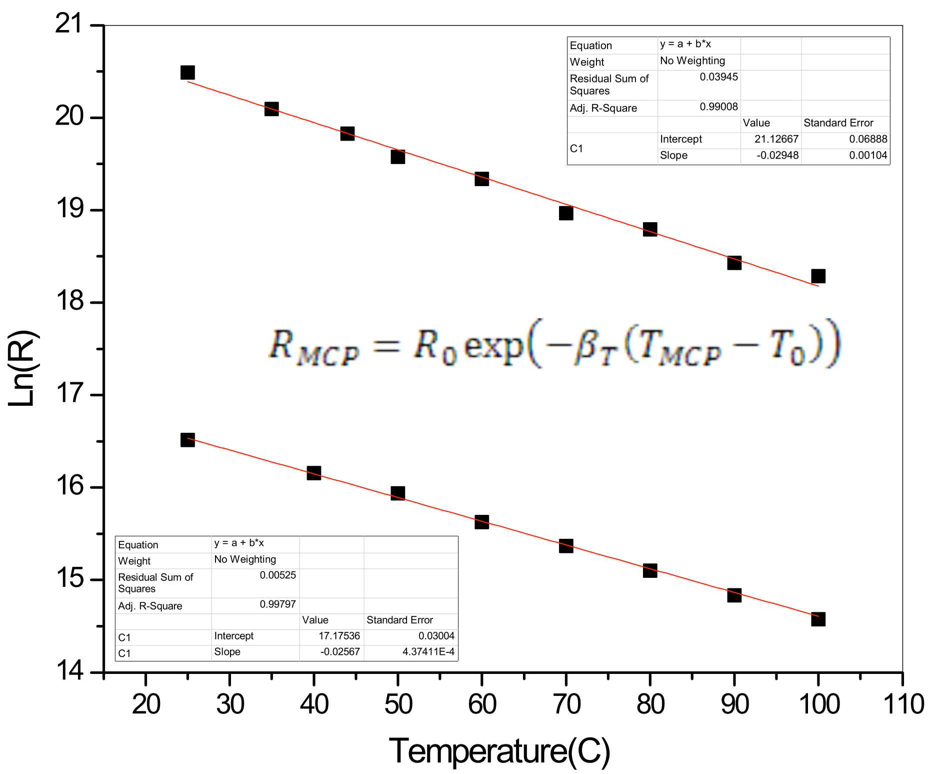
New ALD chemistries for resistive coating developed at Argonne



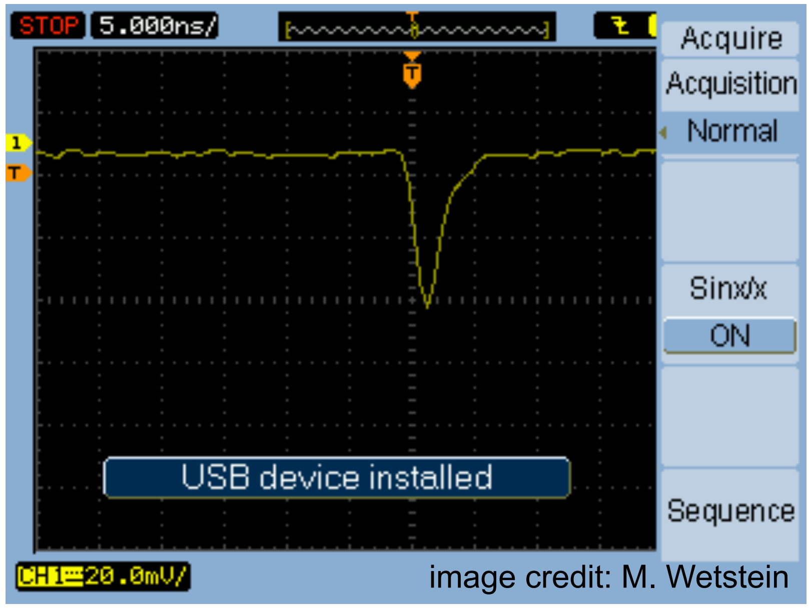
MCP 72/78 Amplification: 1.3/1.2 kV



Al_2O_3 Secondary Emission Layer



β_T = -0.02 for commercial MCP (literature)
= -0.027 "New Chemistry 1"



Signal from MCP pair coated with new resistive layer + Al_2O_3 emissive layer

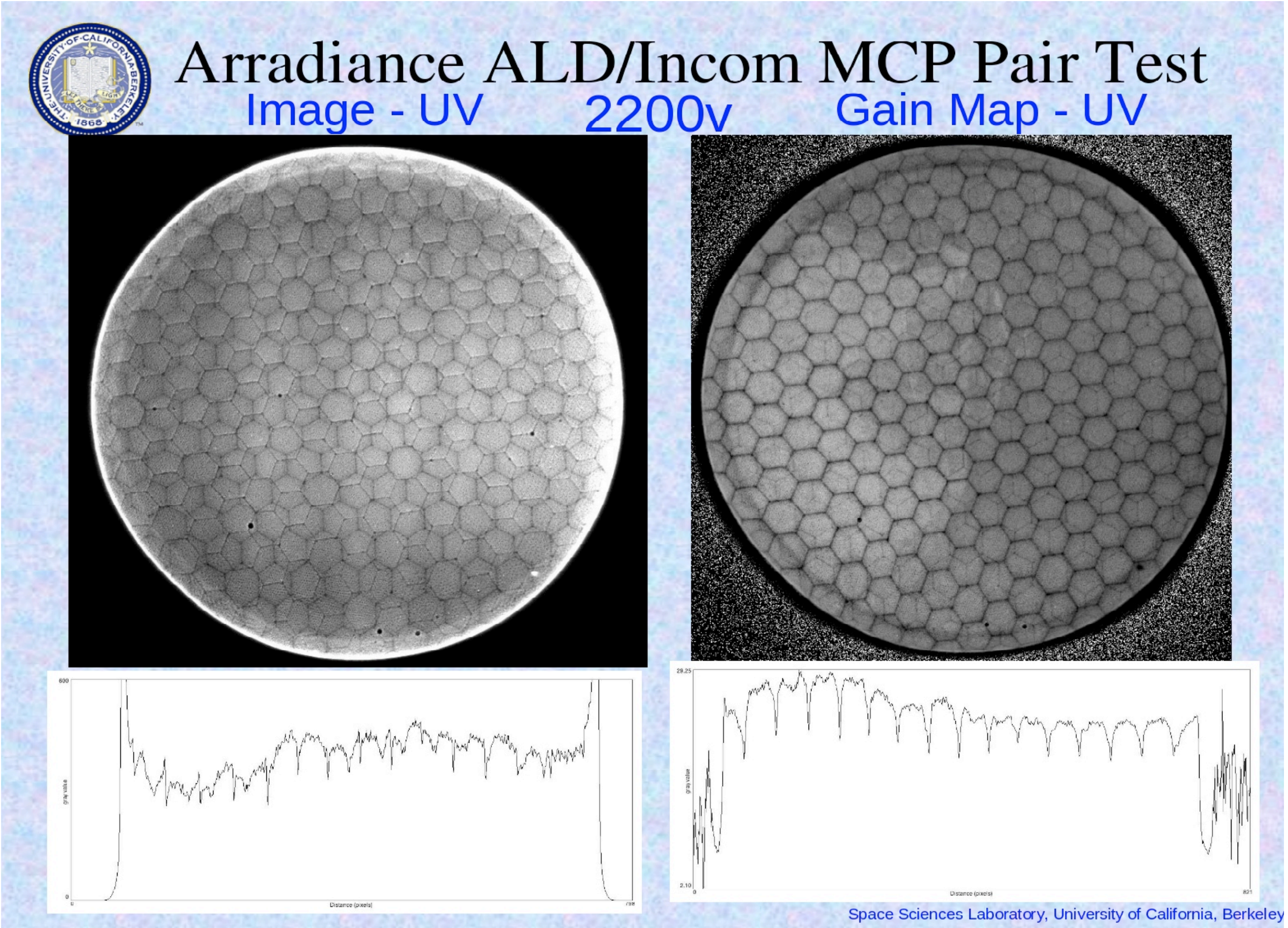
Visual Study of ALD Coated MCP

Glass capillaries coated by Arradiance, Inc.

Pair test at Space Sciences Lab/UC-Berkeley

Electron map of MCP

“Multi” boundaries visible, fade at higher gain



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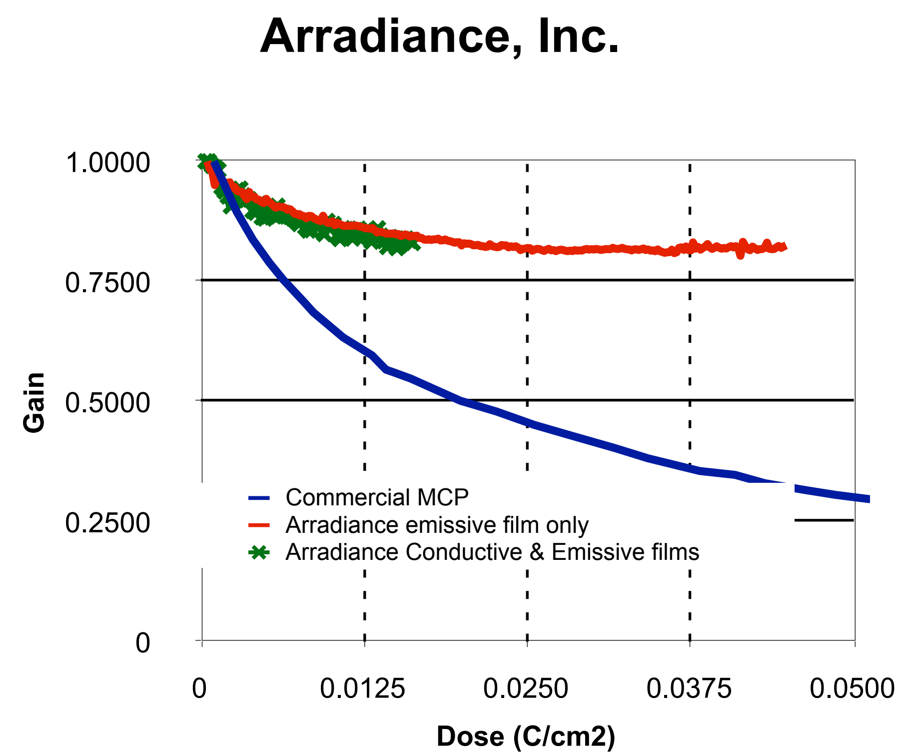
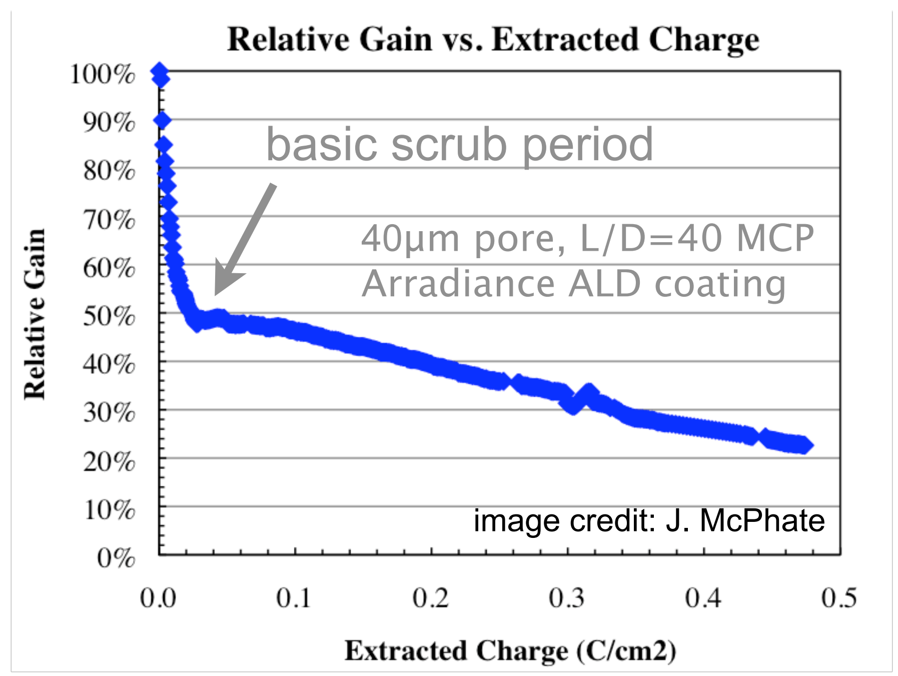
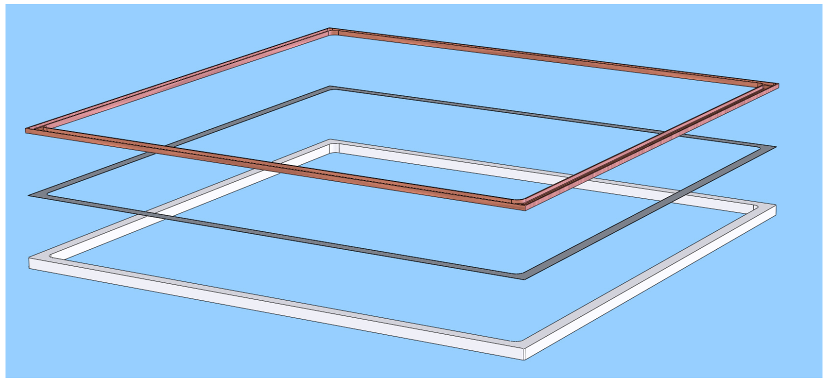
Advantages of ALD vs Conventional Pb Glass MCP

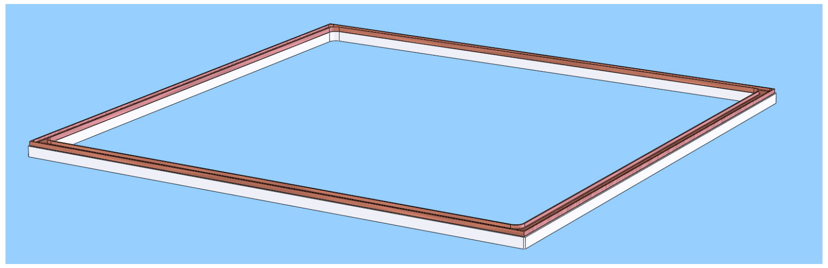
- Conventional lead-oxide MCPs have single composition for resistive/emissive material
  - Functionalized in H-furnace requiring long "scrubbing" time (removal of volatiles)
- ALD allows separate control of resistive and emissive layers
  - separately optimize each layer for best overall performance
  - Scrub time reduced by up to ×10

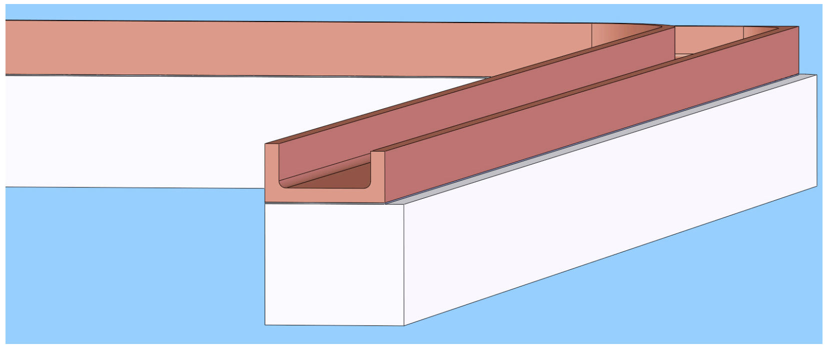




MCP Photomultiplier Packaging -- Ceramic Body (Space Science Laboratory/UC-Berkeley)

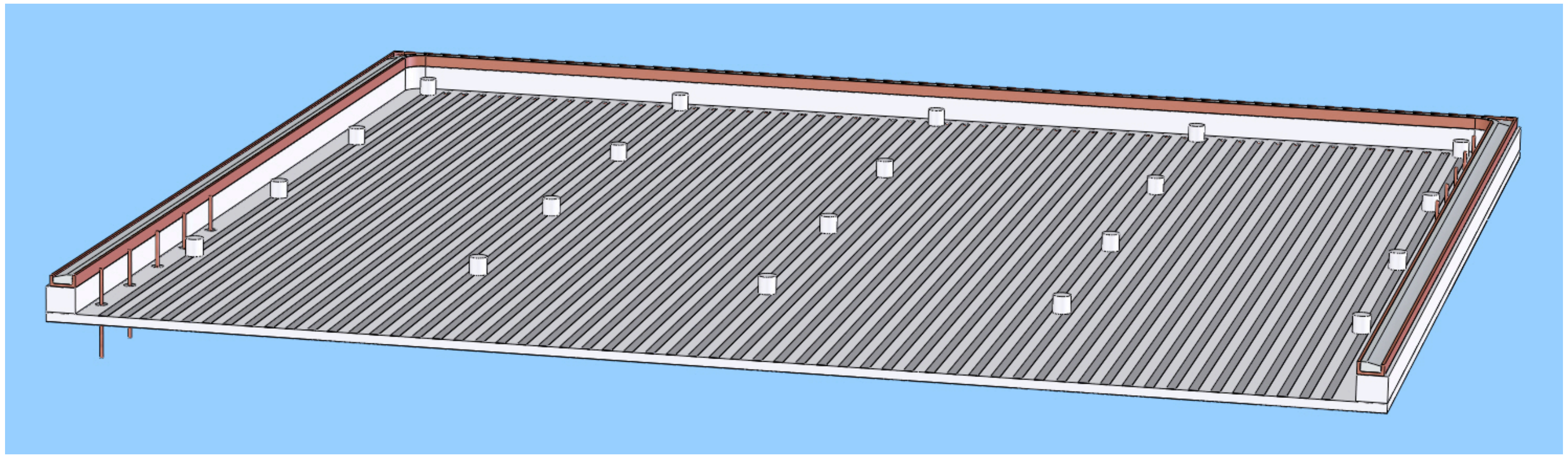




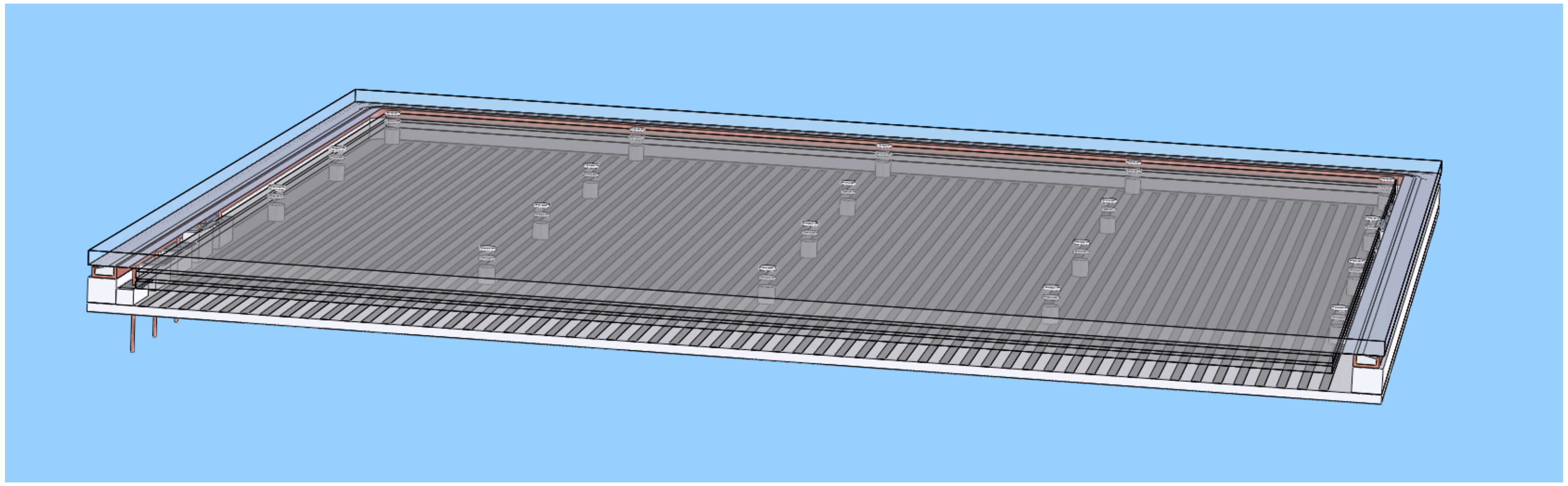


Single Joint Brazed Body
Tray for Indium top seal

- Kovar
- Ni plated/sintered
- Cu plated for Indium wetting



SSL/UC-Berkeley Ceramic Body Design

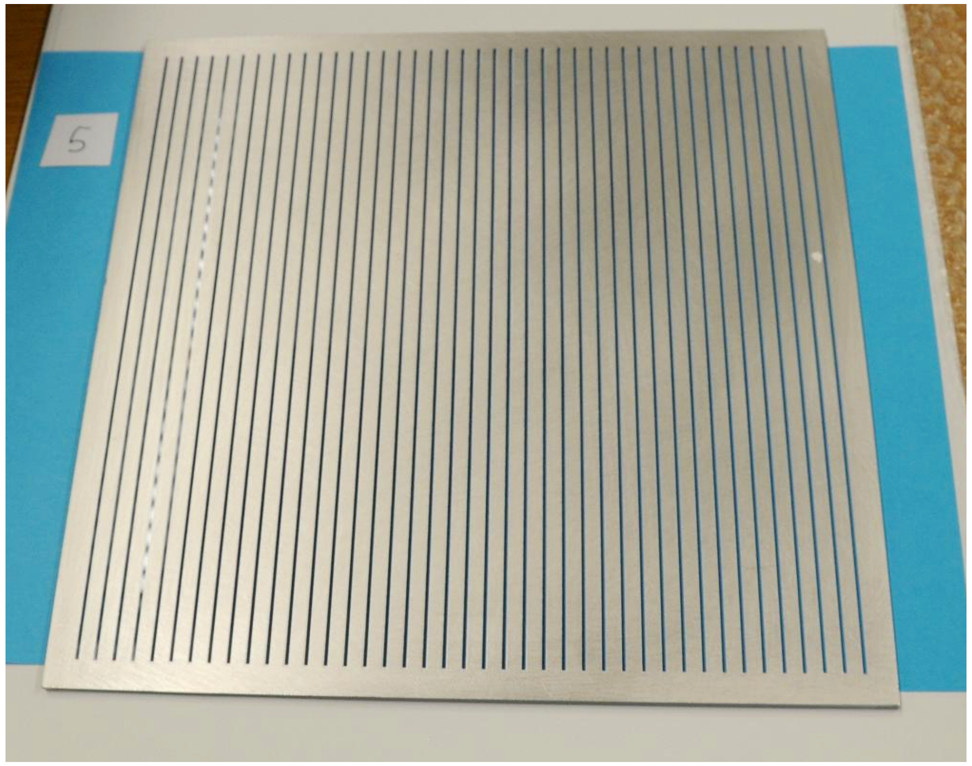


Final assembly with MCP, photocathode top plate, anode strip line, HV pins

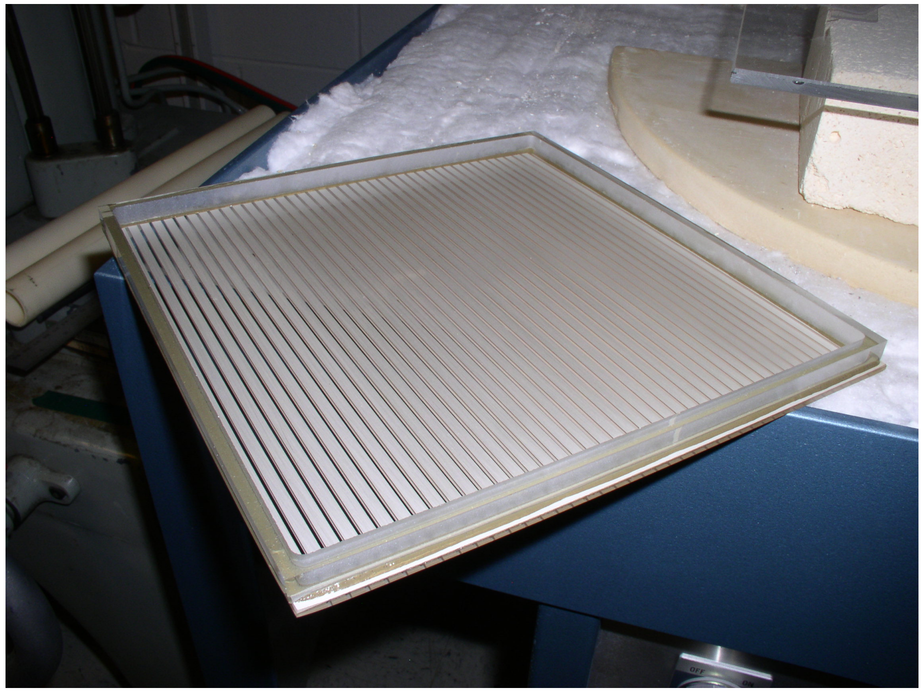
design drawings courtesy J. McPhate, SSL

MCP Photomultiplier Packaging -- Borofloat Glass Body (Univ. of Chicago/Argonne Natl. Lab.)

Ceramic body is proven method. Design by SSL group with years of experience. Relatively expensive.
UC/Argonne alternative design with inexpensive glass & bonding methods. Untested.

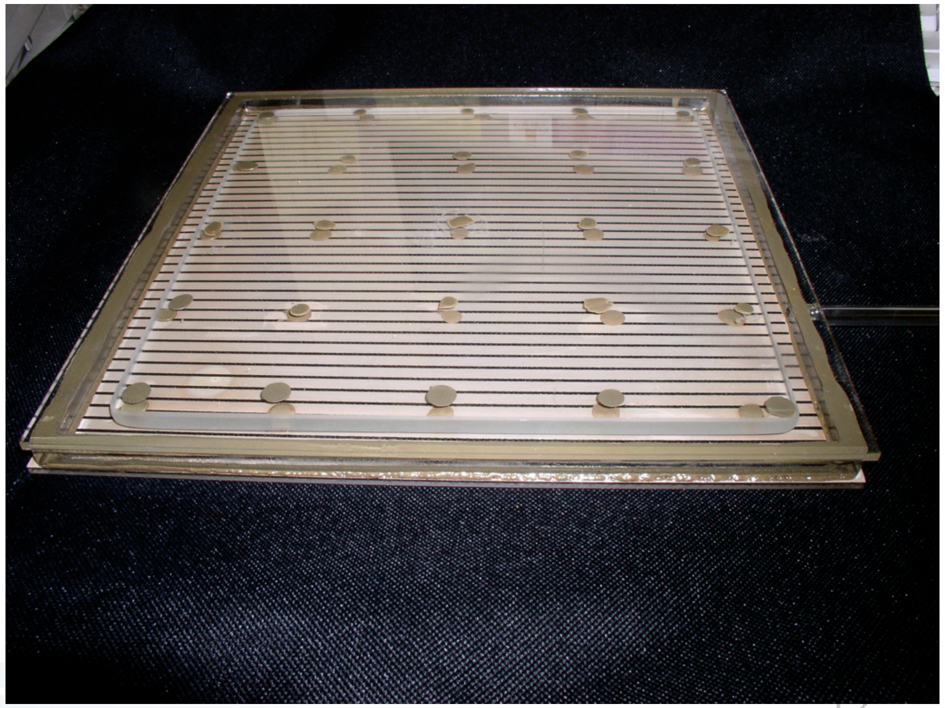


Silk-screen printing of anode ground plane on B33 glass



Sidewall bonded to bottom plate with glass frit

First "sealed box". No internals.
Glass "drop piece" for internal support.
Top seal is glass frit in this test.
Will ultimately use Indium or Indium alloy

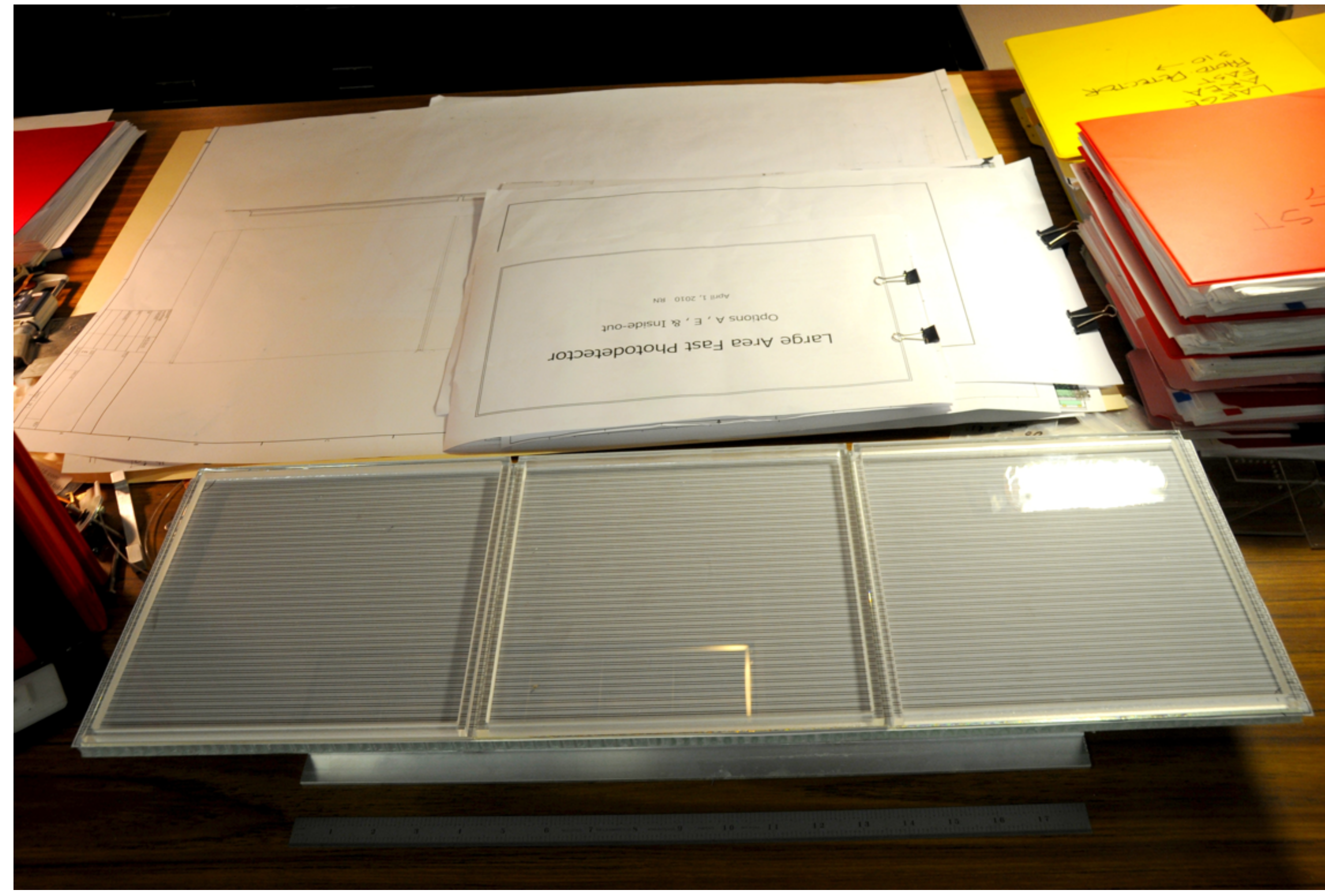


“Inside-Out” Supermodule Design for Tiling Photodetectors

Ground plane on vacuum side of detector. Provides even silver surface for sidewall bonding.

Silver signal strip lines on separate board positioned beneath photodetector

Differential readout at either end allows tiling of MCPs onto supermodule board



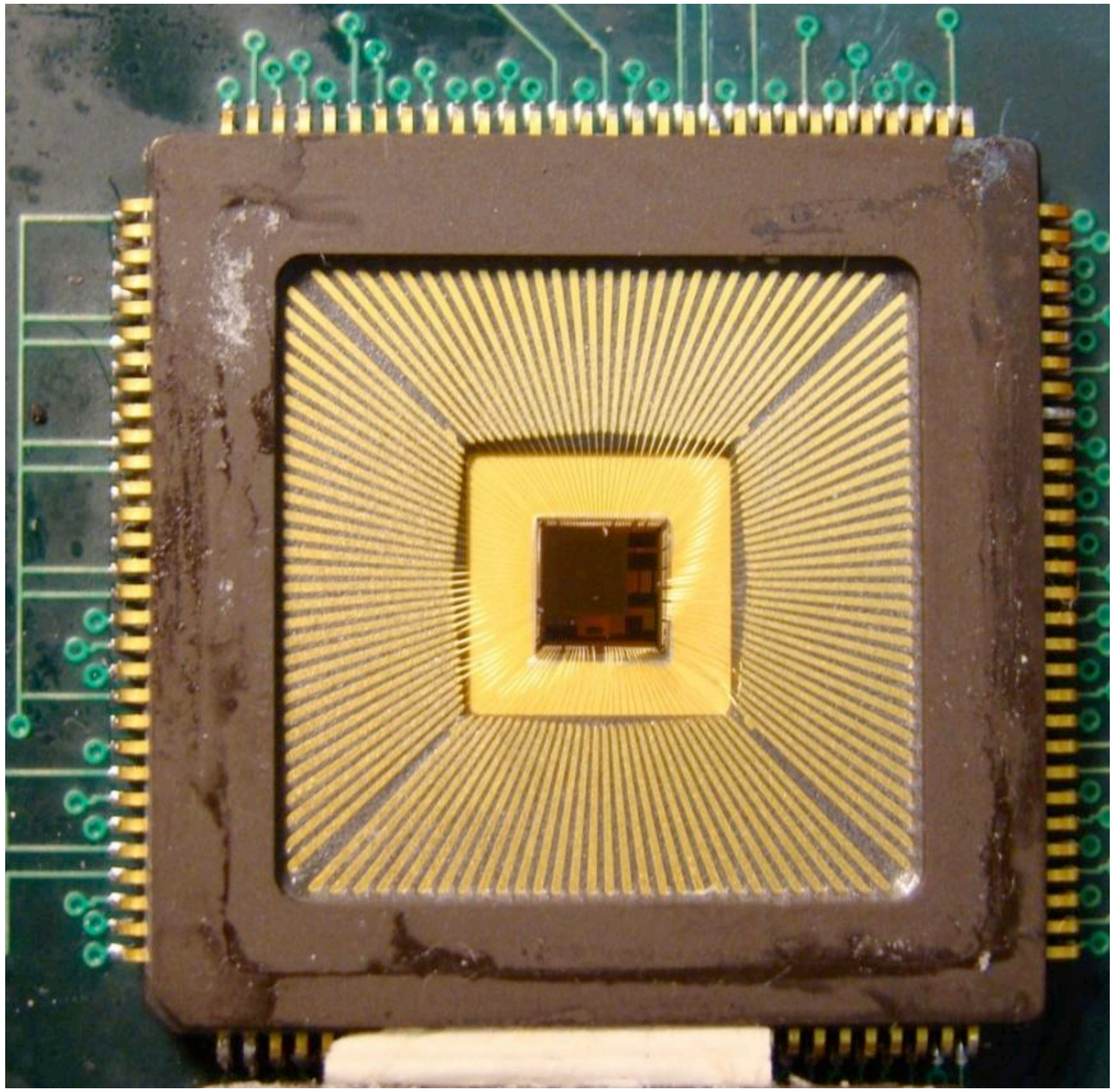
Mockup of three tile supermodule

Signal testing of supermodule board beginning at Univ. of Chicago

Differential readout at either end allows

Picosecond Timing Readout ASIC

- Univs. Chicago/Hawaii ASIC design for readout using switched capacitor array in 130nm CMOS
- 1st round chips delivered in Oct, 2009
  - 4 channels of full sampling
  - 10-15 Gsamples/s
  - 256 cells @ < 100ps/cell
  - 1-2 GHz bandwidth, 50Ω
- Have tested:
  - DC power vs. bias
  - Sampling cell response vs input
  - ADC's comparator
  - Leakage
  - Digital readout
- AC testing board in preparation
- 2nd generation design submitted with many improvements: input trigger disc., phase lock, higher bandwidth, increased sampling rate,...
  - Chips due from foundry June, 2010



Summary

- Large Area Picosecond Photodetector Development collaboration is nearing end of first year having realized several initial goals.
- Atomic Layer Deposition coatings of 33mm glass capillary disks producing gain >10^6 for MCP pair
- Study of 3 ALD resistive + 2 ALD emissive chemistries
- Mature mechanical designs for hermetically sealed tube
  - Proven design in ceramic by SSL
  - Well-advanced inexpensive glass design -- close to first hermetic box
- Fast sampling ASIC has progressed through two design generations
  - Previously demonstrated ~20ps single channel resolution with commercial MCP (Photonis Planacon) and commercial electronics (Ortec 9327 Amp/Timing Disc)
- Developed alternative Anodic Aluminum Oxide substrate
- Beginning design and assembly of photocathode development facility at Argonne
- Facility for 8”×8” photocathode fabrication and study in progress at SSL

Future Work -- Year 2

- Fabrication of photocathode on 8”×8” borosilicate glass
- Delivery and ALD of first 8”×8” glass capillary plates
- Fabrication of hermetically sealed “photocathodeless” full size MCP
  - MCP plates, spacers, anode readout; no photocathode on top plate (or possibly thin gold photocathode)
- Testing of 2nd generation sampling ASIC
- Vetting of supermodule design

Visit our web site for more information:

http://psec.uchicago.edu
(“Blog” and “Library” links are a good starting place)

BACKUP SLIDES

General procedures for Fabrication of MCPs

Pristine MCPs → 30mins: Acetone sonication clean → 2 hrs: Air dry at 200C >2h → Loading in Vacuum reactor

→ 2 hrs: Ozone clean → ALD coatings (10 hrs) → Baking at 400C under N2 (6 hrs) → 4 hrs: Electrode coating

→ Testing resistance (3 hrs) → Deliver for testing

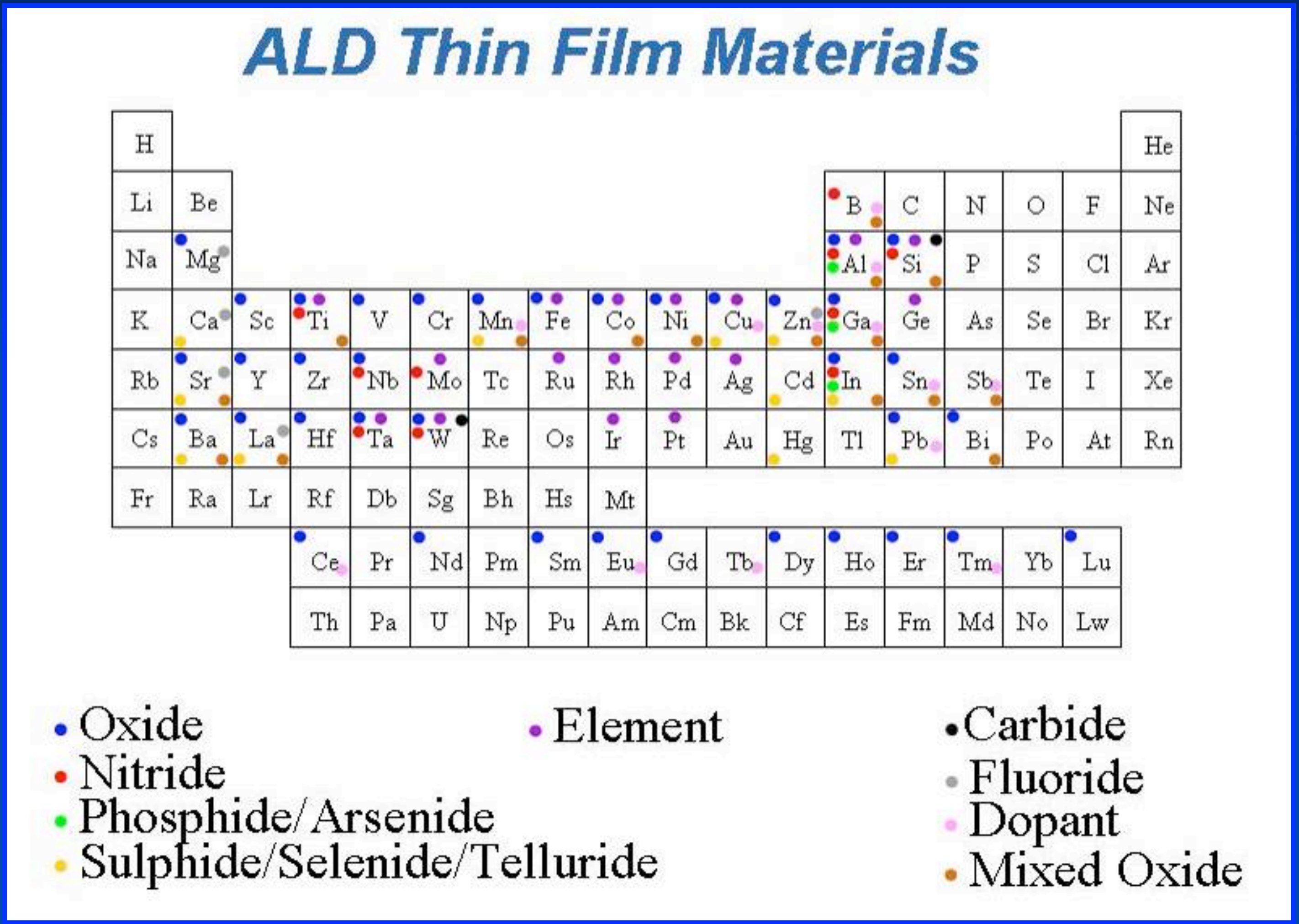
For fabricating one pair MCPs:

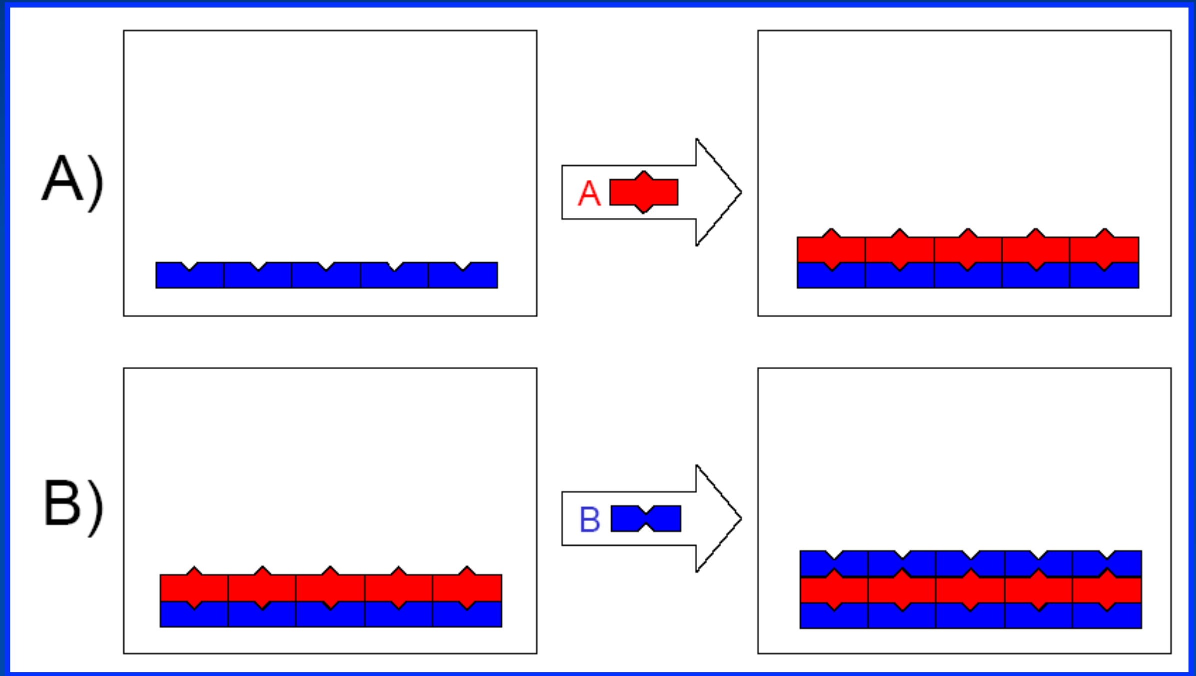
~20-30hrs

if everything is right

courtesy Qing Peng, Argonne ALD Group

Atomic Layer Deposition (ALD) Thin Film Coating Technology





- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects (JE)

•Lots of possible materials => much room for higher performance

Jeff Elam pictures