Development of Large Area Fast Microchannel Plate Photodetectors

for the Large Area Picosecond Photodetector Development Collaboration

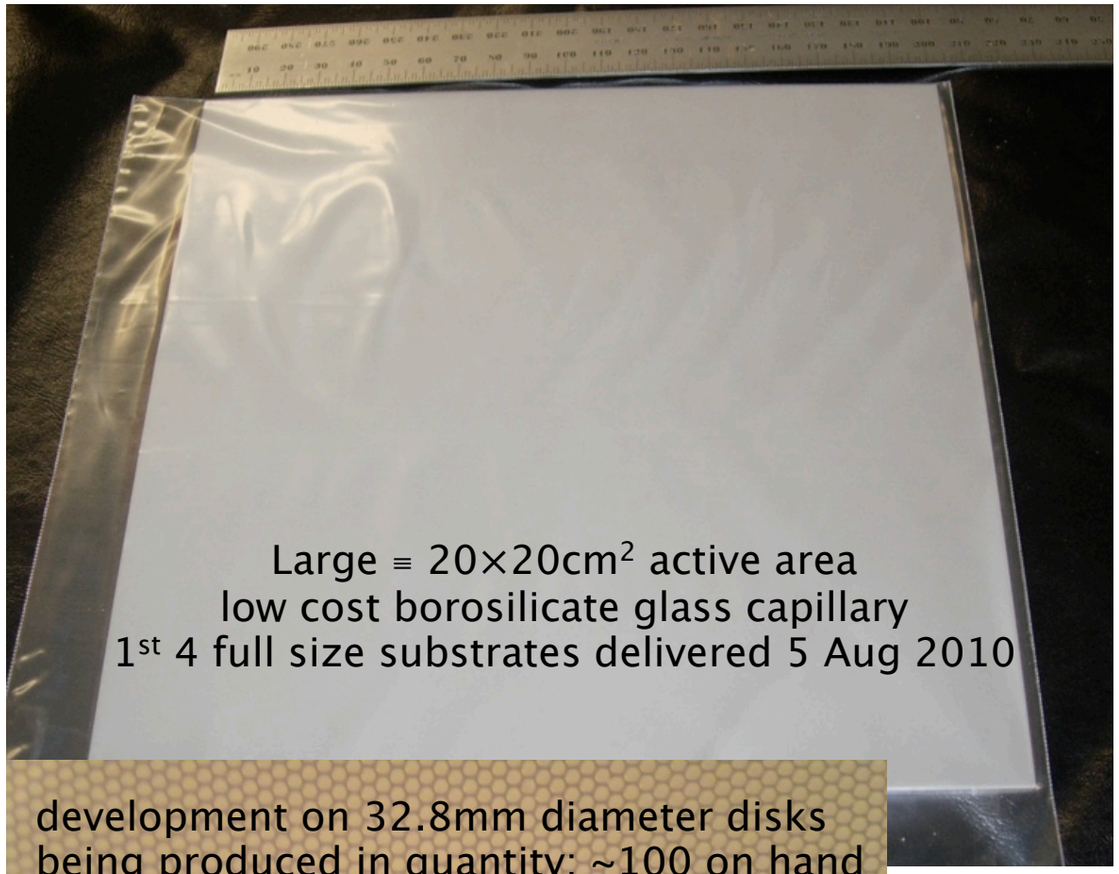
Bob Wagner, Argonne National Laboratory

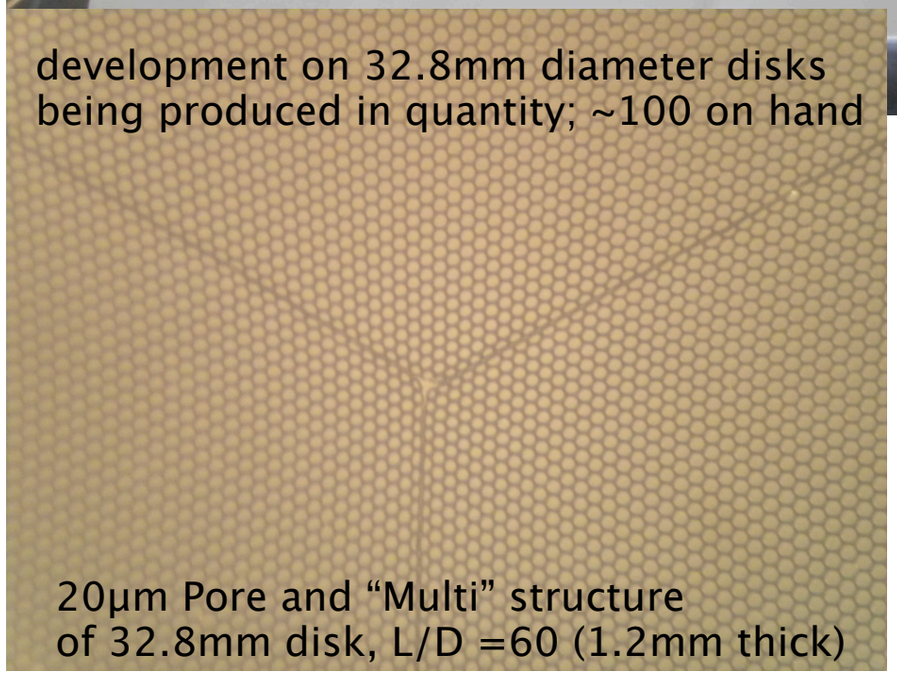
DOE Site Visit

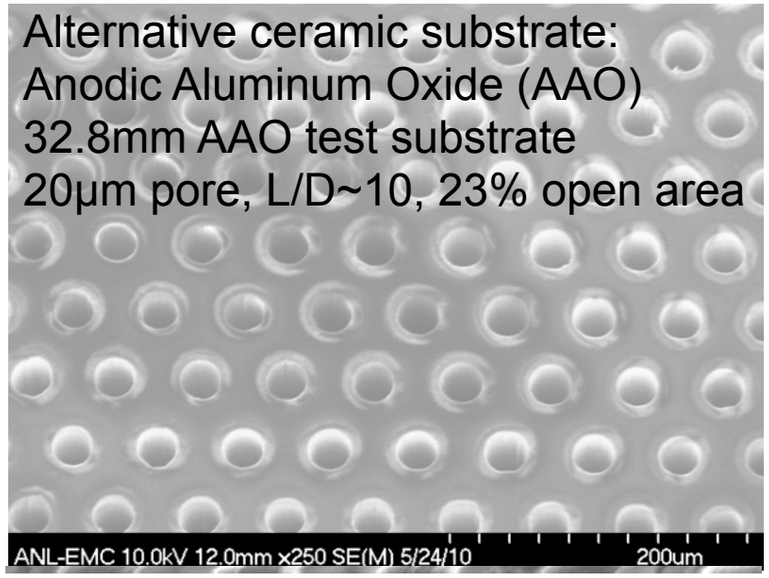
Wednesday 25 August 2010

LAPPD Project Scope

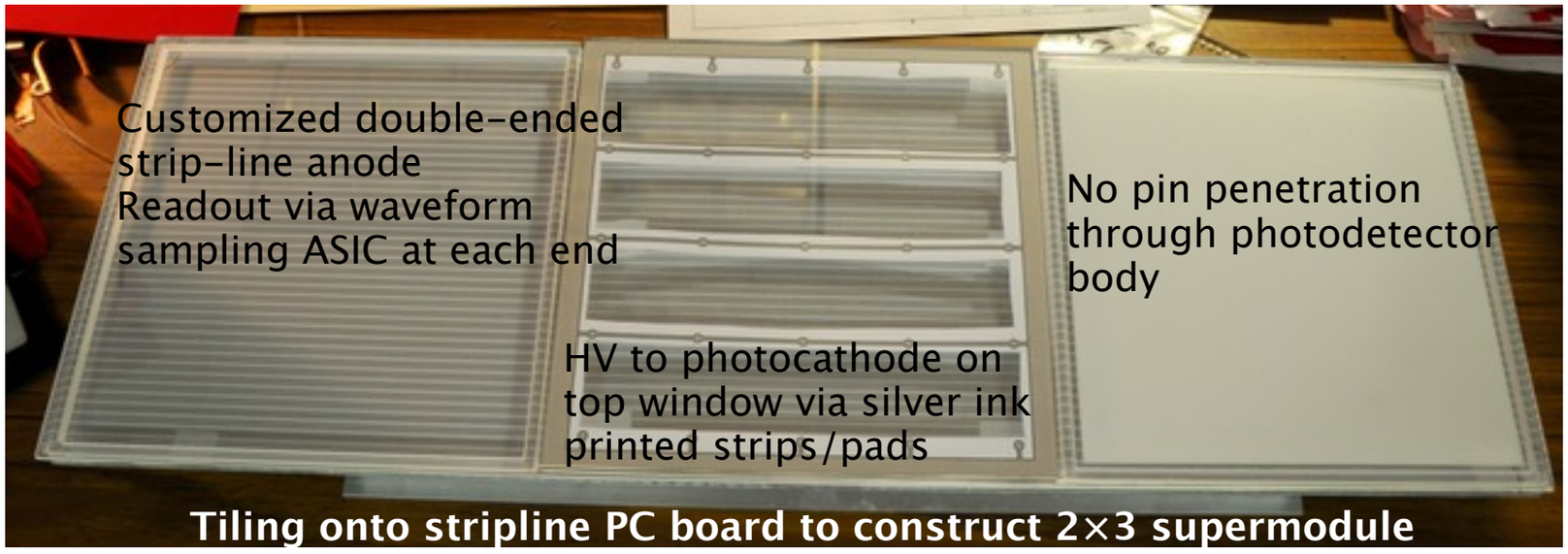
Large, Cheap, Fast Microchannel Plate Photomultiplier







- Pore activation via Atomic Layer Deposition (ALD)
  - Separate material for resistive and secondary emission layers
  - Optimize resistive and emissive properties separately via study of range of materials



Tiling onto stripline PC board to construct 2×3 supermodule

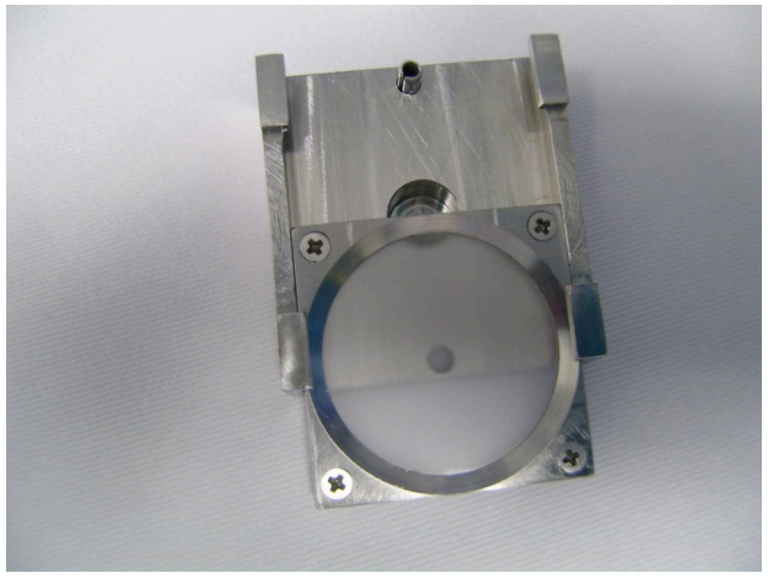
Large Area Photodetector Development Collaboration

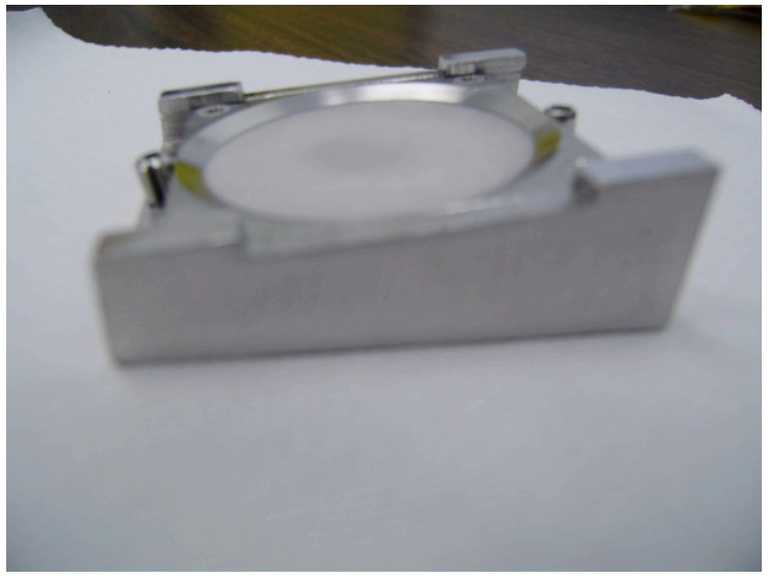
- Project Management
  - Univ. of Chicago/Argonne HEP – Henry Frisch (PI)
  - Argonne HEP – Karen Byrum (PI), Bob Wagner
  - Argonne Nuclear Engineering Div. – Dean Walters
- Atomic Layer Deposition
  - Argonne Energy Systems Div. – Jeff Elam, Qing Peng, Anil Mane, Joe Libera
  - Argonne Materials Science Div. – Mike Pellin
  - Arradiance, Inc. – Neal Sullivan, Ken Stenton
- MCP Materials Characterization
  - Argonne MSD – Igor Veryovkin, Alex Zinovev, Slade Jokela (HEP)
- MCP Testing & Performance Characterization
  - Argonne HEP – Matt Wetstein
  - Argonne APS – Bernhard Adams, Matthieu Chollet
  - Space Sciences Lab (SSL) UCB – Ossy Siegmund, Jason McPhate
- Anodic Aluminum Oxide (AAO)
  - Argonne MSD – Hau Wang, Seon Woo Lee (HEP)
  - Synkera Technologies – Dmitri Routkevitch
- Mechanical Assembly
  - Argonne HEP – Allen Zhao
  - Argonne NE – Dean Walters
  - Argonne Glass Shop – Joe Gregar
  - Univ. of Chicago – Rich Northrop
  - Fermilab – Eirk Ramberg, Anatoly Ronzhin, Greg Sellberg
- Photocathode Development
  - Argonne HEP – Zikri Yusof, Seon Woo Lee, Sasha Paramonov, Junqi Xie (new postdoc)
  - Argonne APS – Klaus Attenkofer
  - SSL – Ossy Siegmund, Jason McPhate, Anton Tremsin, Sharon Jelinsky
- Electronics DAQ
  - Univ. of Chicago – Jean-François Genat, Herve Grabas, Eric Oberla, Mircea Bogdan, Mary Heintz
  - Univ. of Hawaii – Gary Varner, Larry Rucker, Kurtis Nishimura
  - Argonne HEP – Ed May
- Simulation
  - Argonne HEP – Matt Wetstein
  - Argonne Math & CS Div – Zeke Insepov
  - Univ. of Chicago – Jean-François Genat
  - Muons, Inc. – Valentin Ivanov
  - Arradiance, Inc.

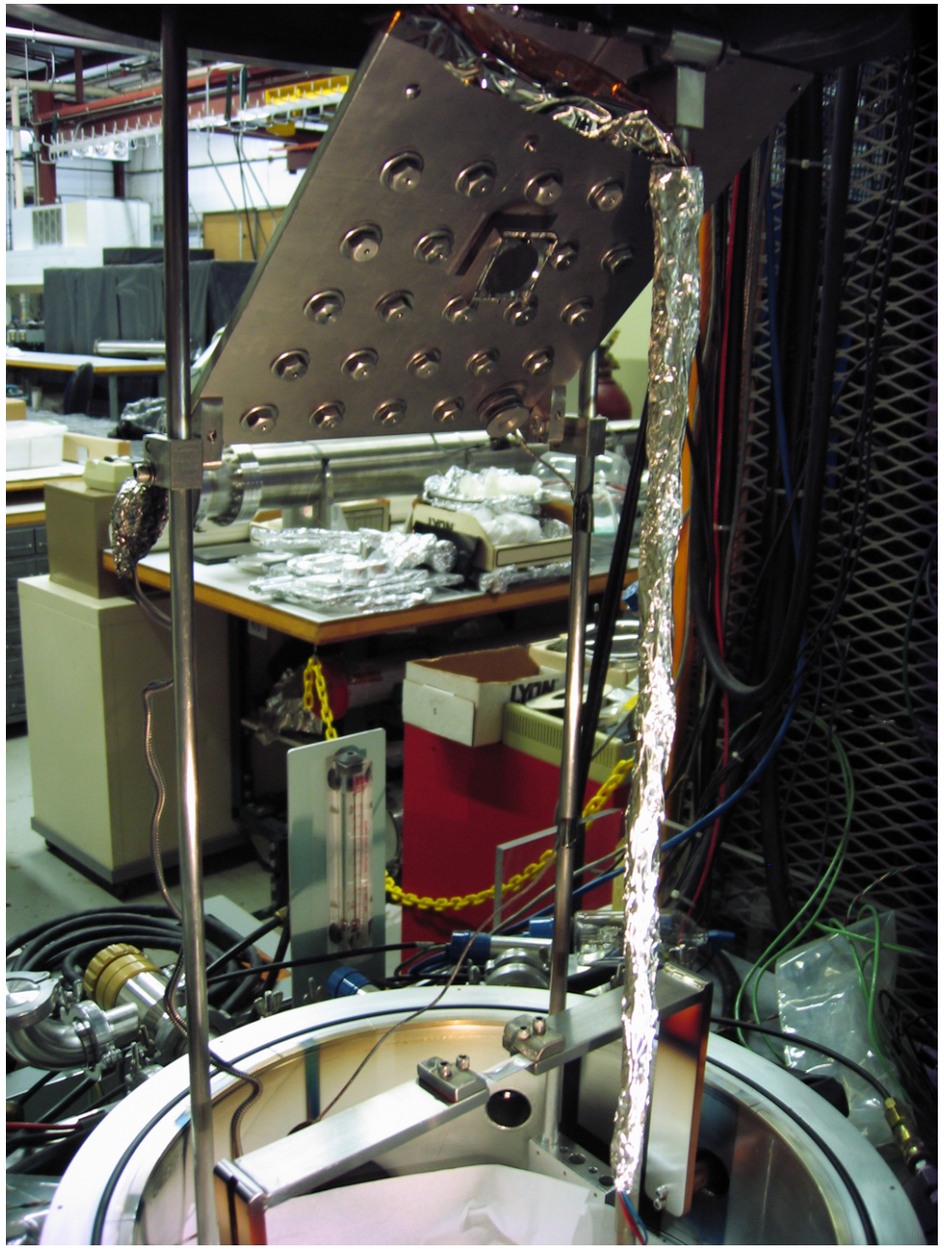
Electrode Evaporation onto MCPs - Endspoiling

Work performed at Fermilab Thin Film Facility
(E. Hahn, G. Sellberg, Q. Peng (ANL), Allen Zhao(ANL))

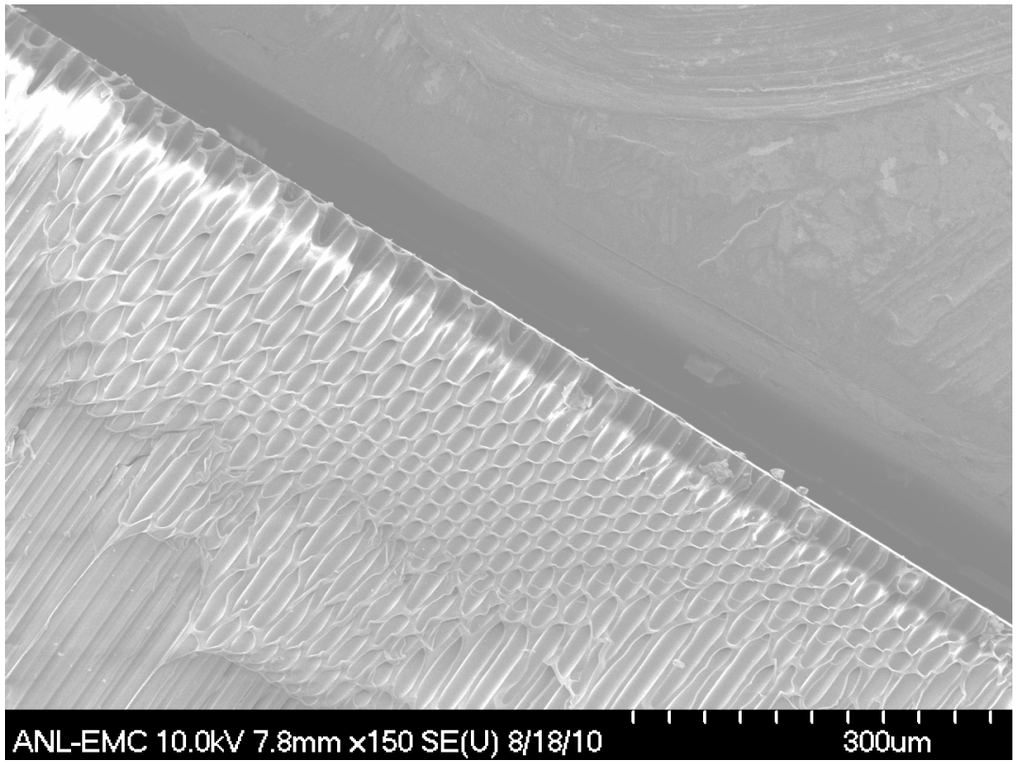
- Metallization for electrical contact applied to bare glass capillary before ALD
- Nichrome evaporation performed at Fermilab Thin Film Facility
- Fixture must rotate MCP about 8˚ bias of pores
- Penetration of electrode into pores should be 1 diameter, i.e. 20μm (endspoiling)
- Modified design and producing 5 fixtures

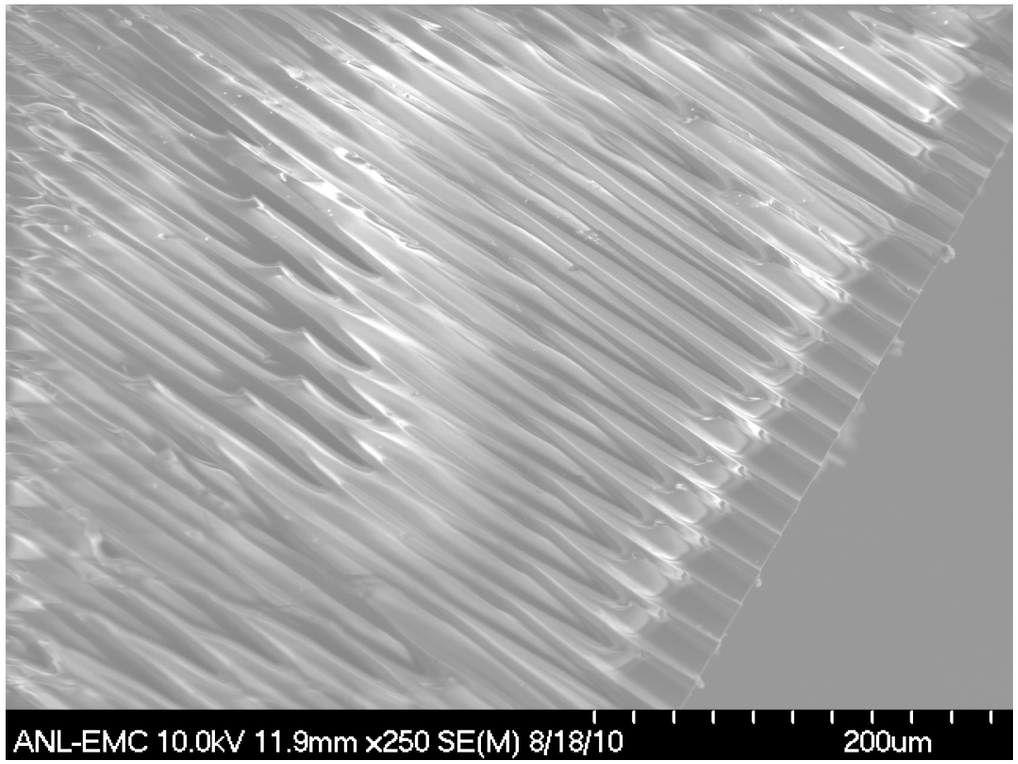






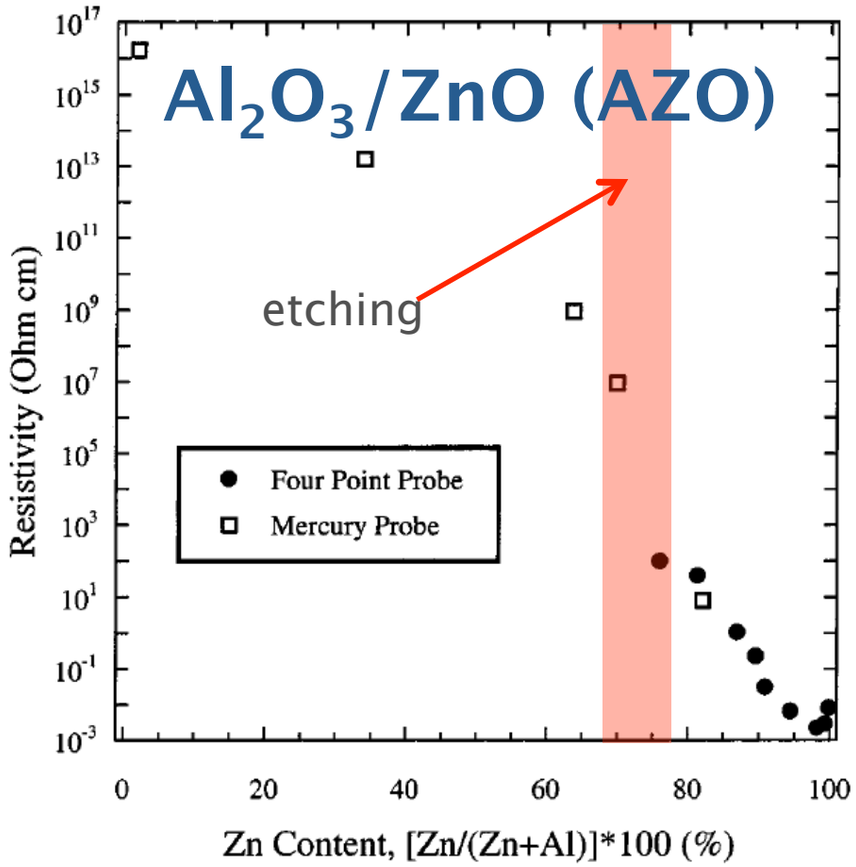
Electrode Evaporation -- Endspoiling Results





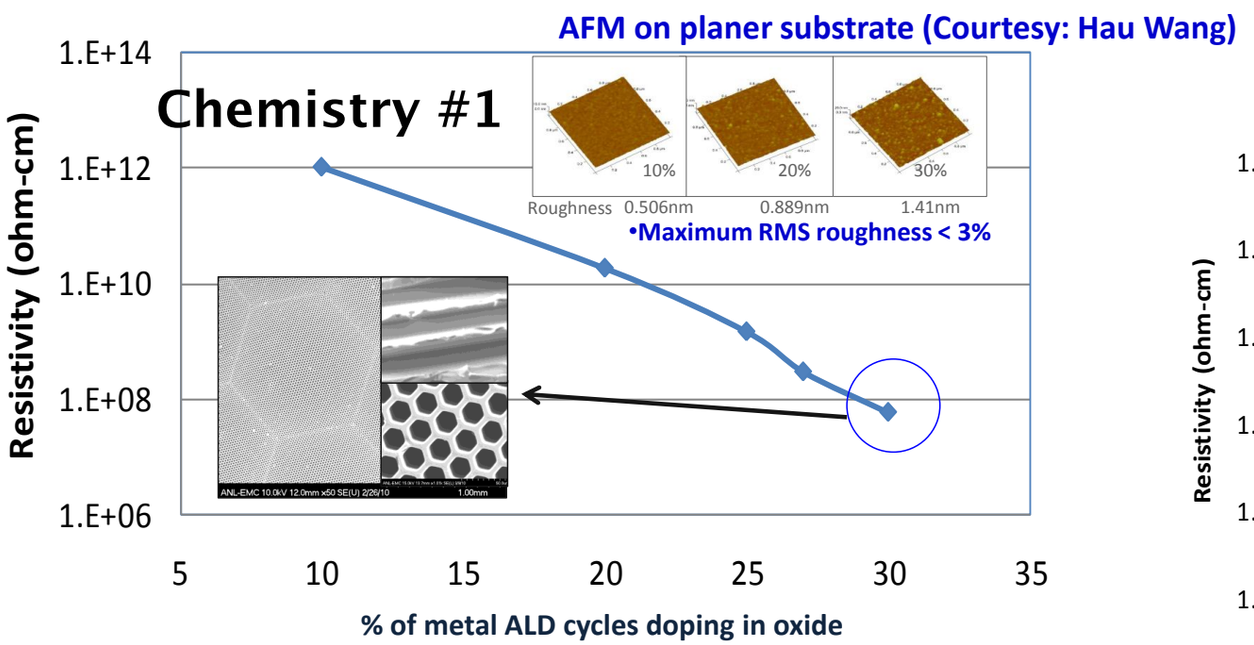
- SEM photos of endspoiling from first use of fixture
- Penetration of electrode into capillary pores is ~30μm is acceptably good

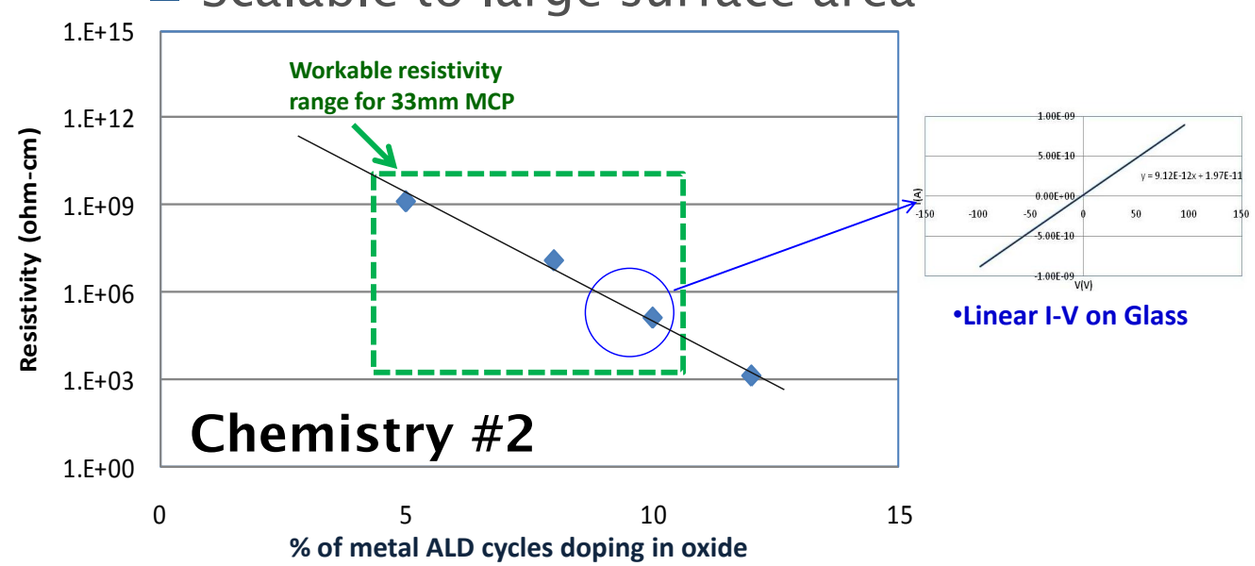
ALD Resistive Coating Development



- First resistive coating tested at Argonne
- Good:
  - Existing process
  - Functionalized MCPs exhibited high gain
- Bad:
  - etching of ZnO by trimethyl aluminum
  - 10^5 resistance change over 10% composition change

- **3 Alternative Resistive Chemistries developed by Argonne ALD group**
- Good:
  - Good control of resistivity
  - Uniform, smooth coating, no etching
  - Functionalized MCP pair exhibited high gain
  - Scalable to large surface area

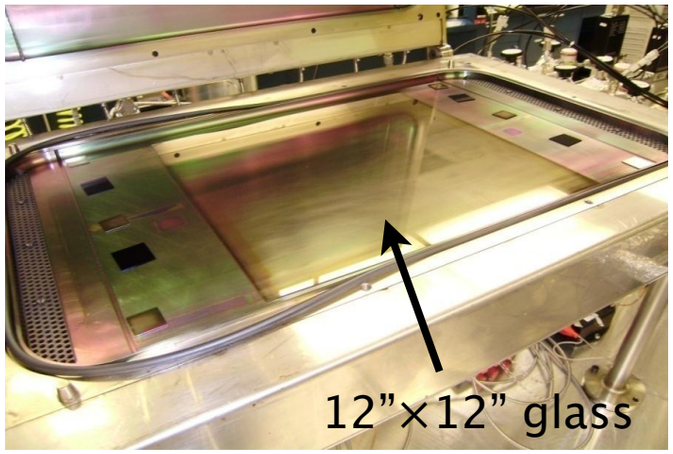


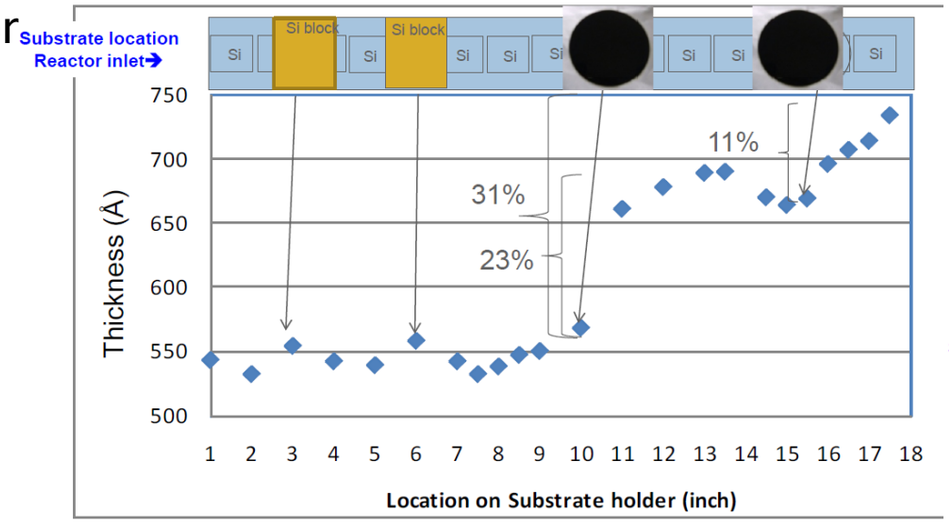


- **Uniform and smooth ALD coating pores of MCP**

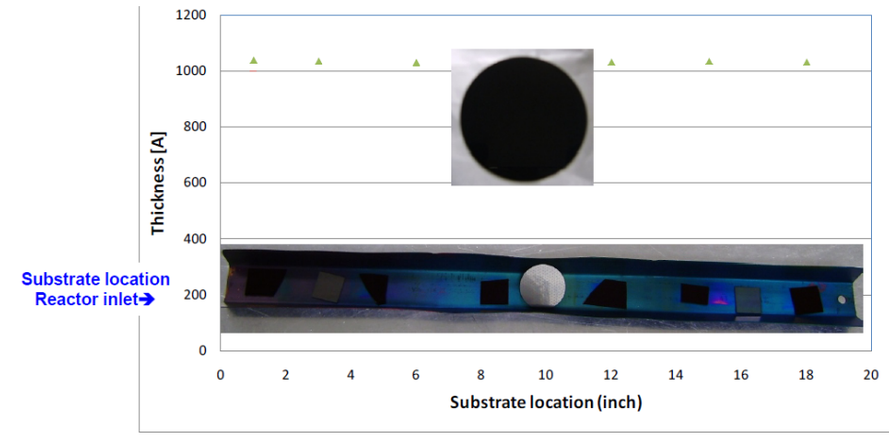
Scale-up to Large Surface Area

Process scale-up on large reactor

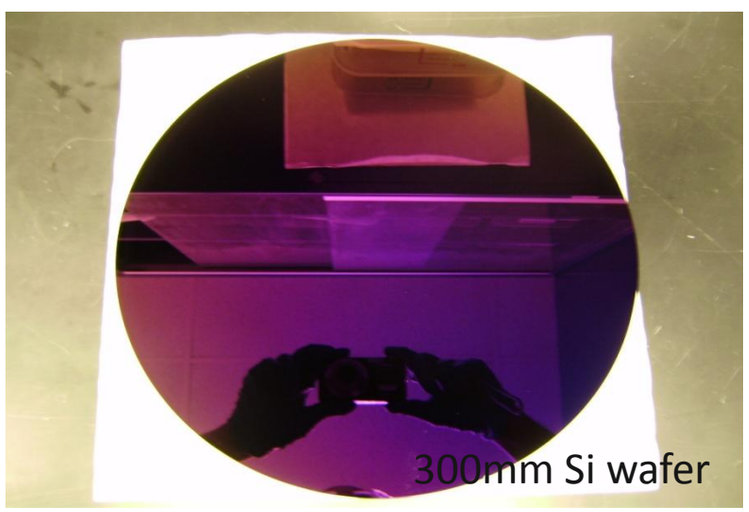




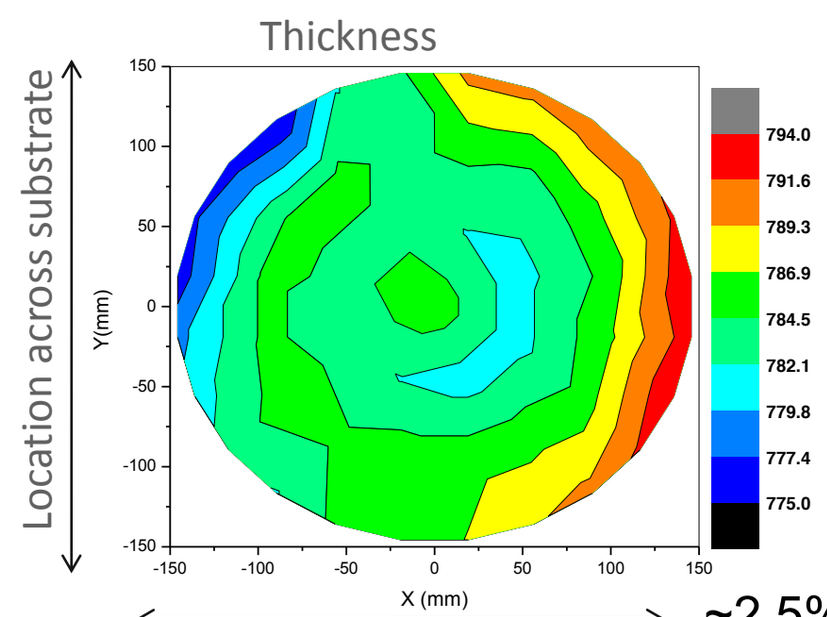
Chemistry #1:
1% thickness increase across Si wafers
Up to 30% increase after MCP locations



Chemistry #2:
No thickness increase near MCP
Uniformity, scaling ease in ALD are process dependent



300mm Si wafer coated with Chemistry #2



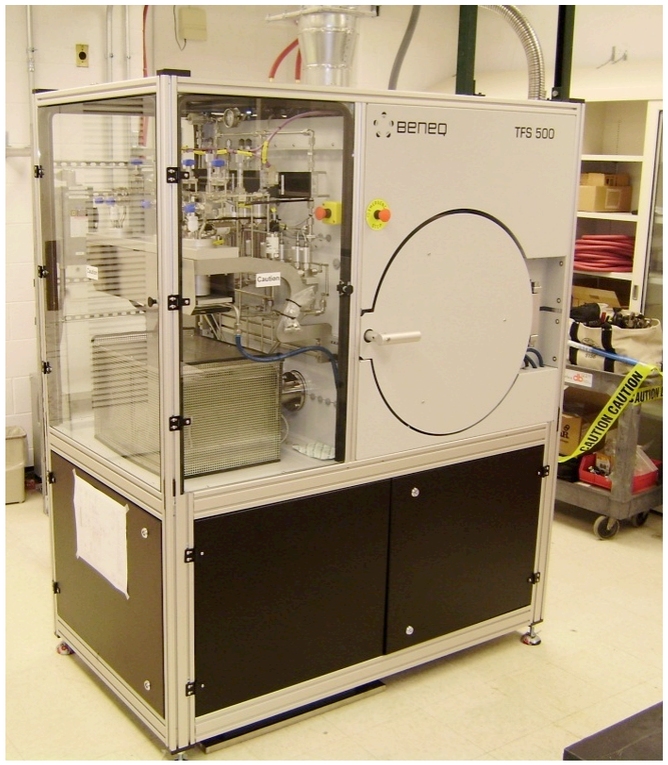
~2.5% thickness variation across wafer

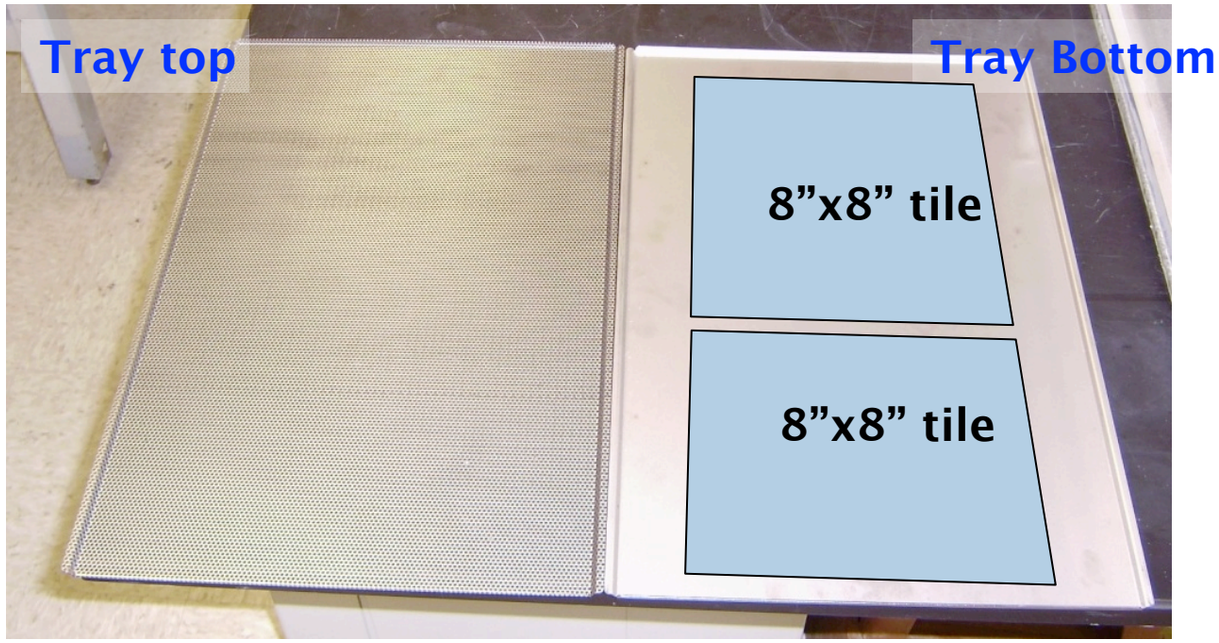
Scale-Up of ALD Processing -- Beneq Reactor

Arrived 18 May 2010

Studying ALD on Large Surface Areas

- 33mm disk surface area is $0.13m^2$
- 8”x8” surface area is $6.4m^2$
- 20 MCPs area is $129m^2$





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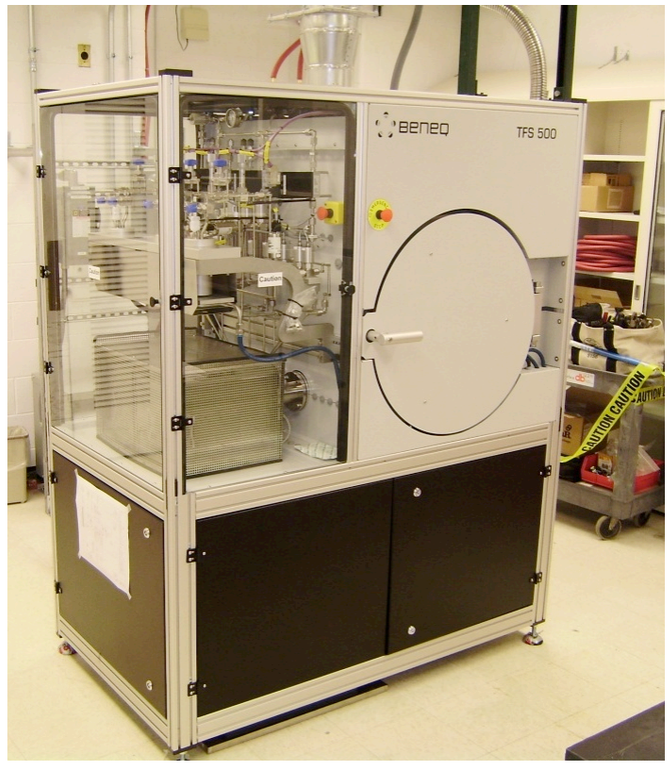
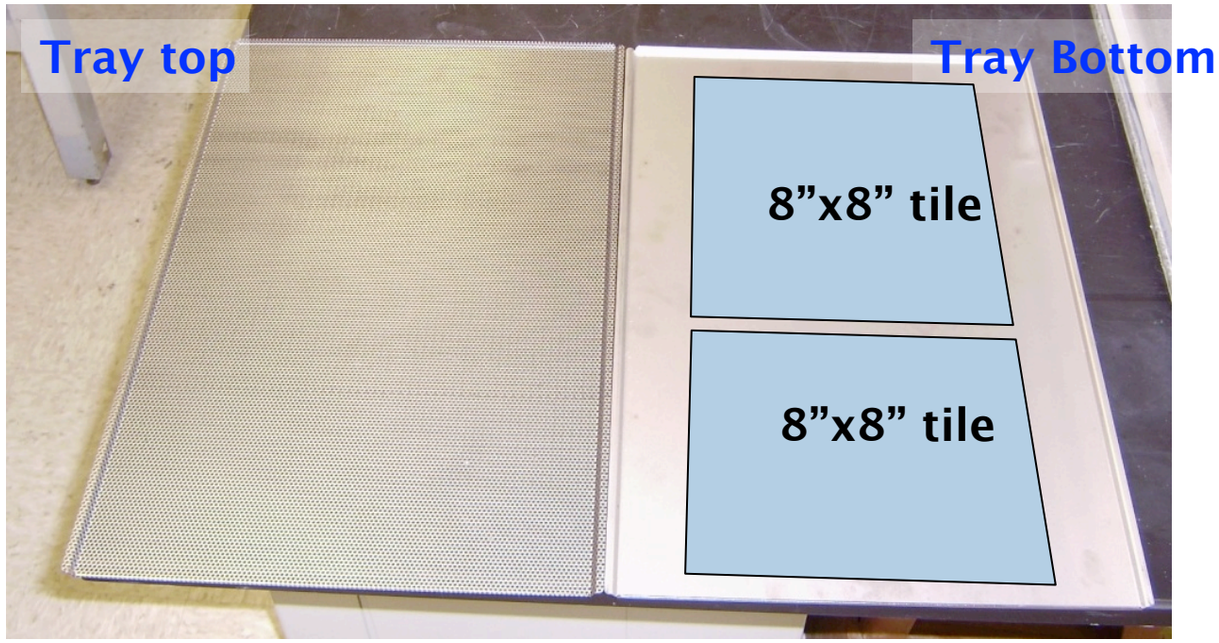
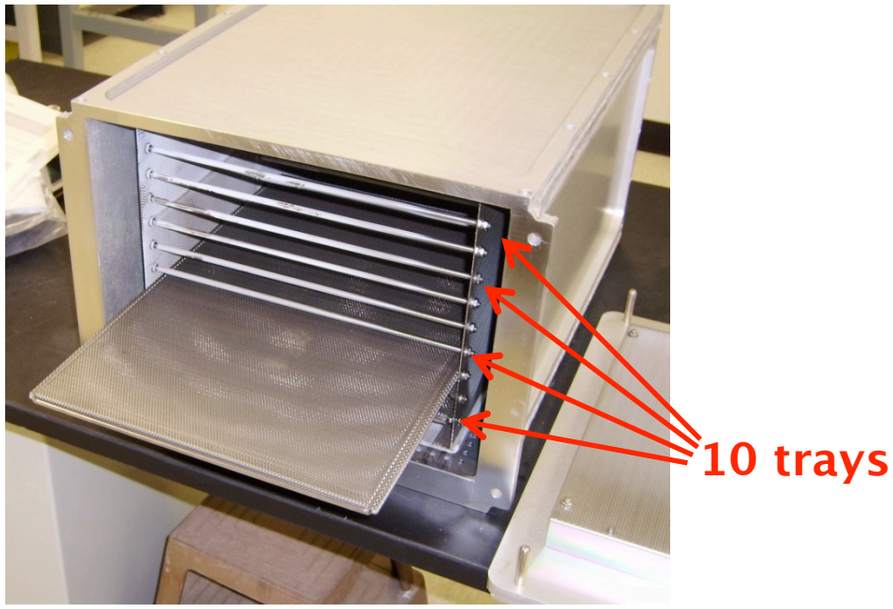
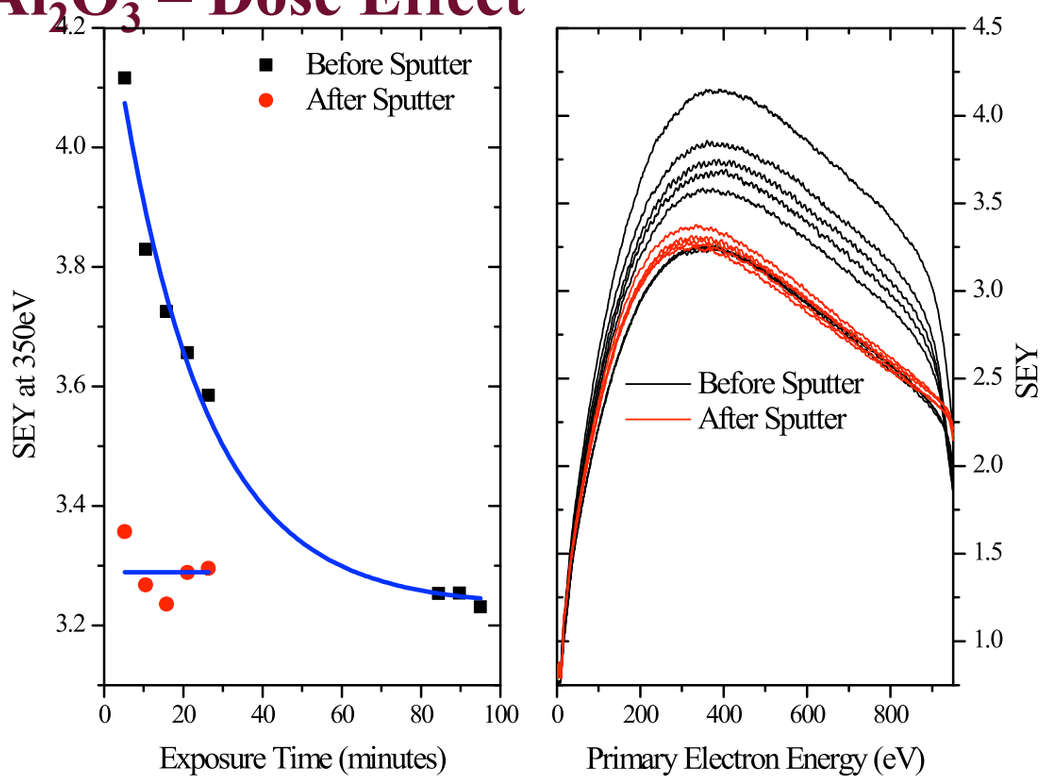


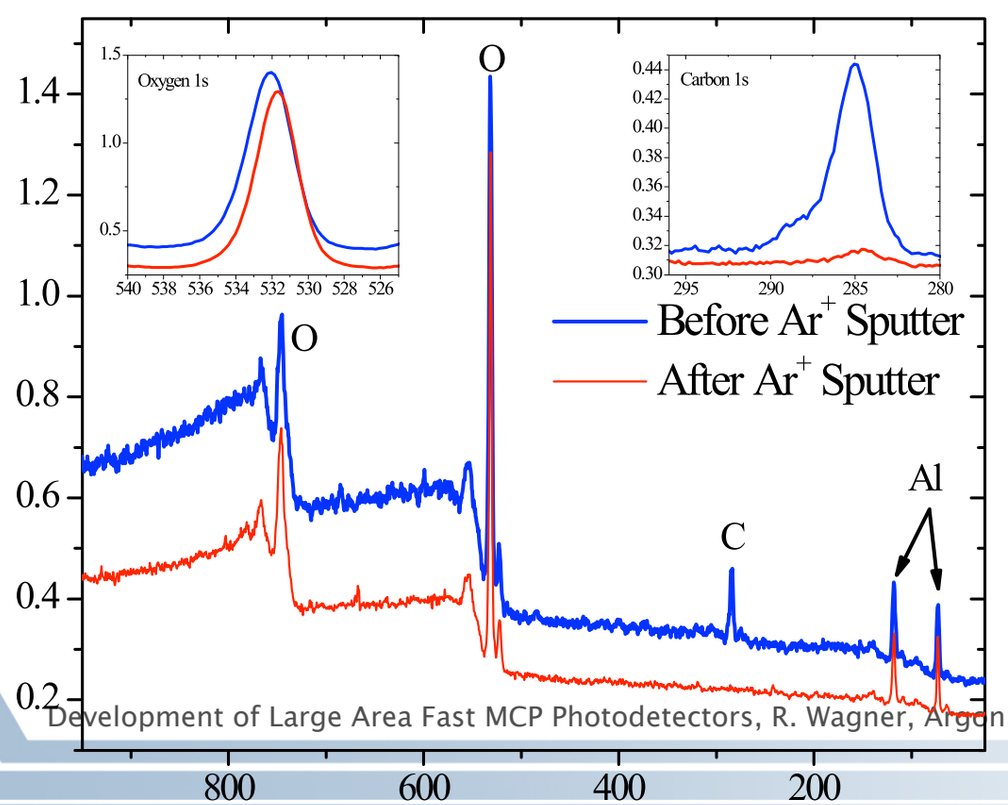




Secondary Emission Coating Development

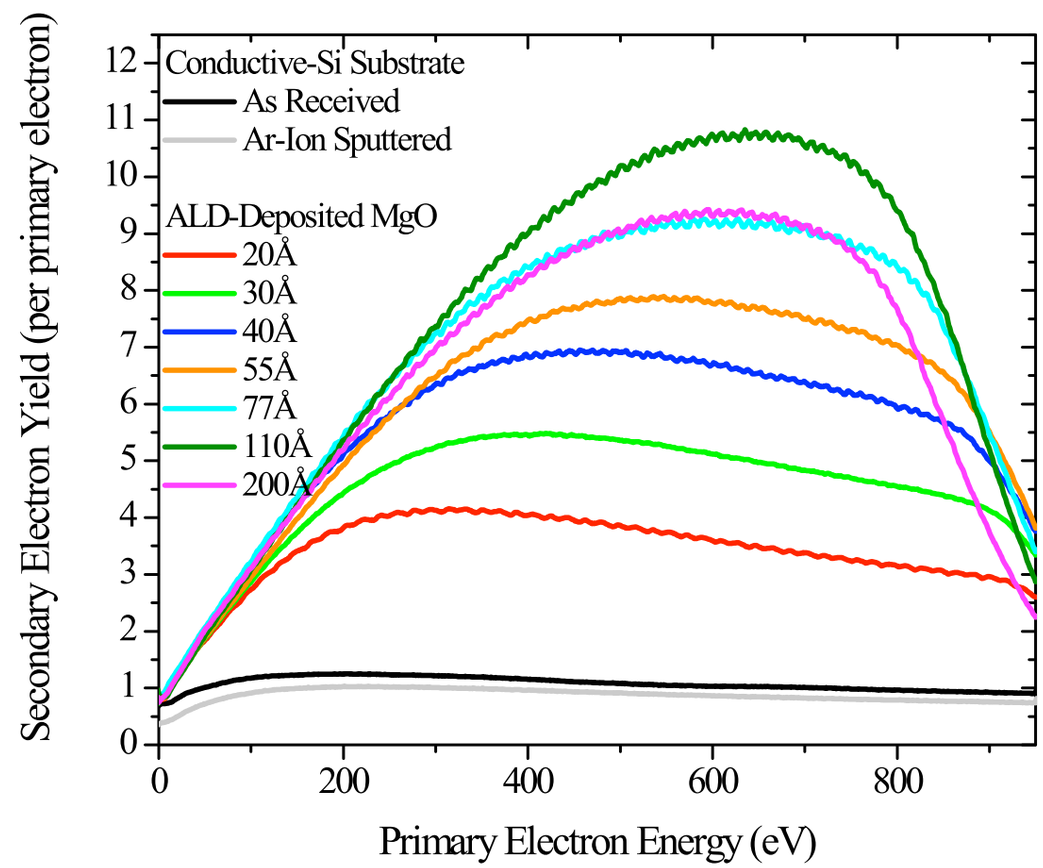
Al_2O_3 – Dose Effect





Studies of Al_2O_3 and MgO at Argonne Characterization Facility indicate both are improved alternatives to commercial Pb-glass MCPs

MgO Secondary Electron Emission vs. Film Thickness

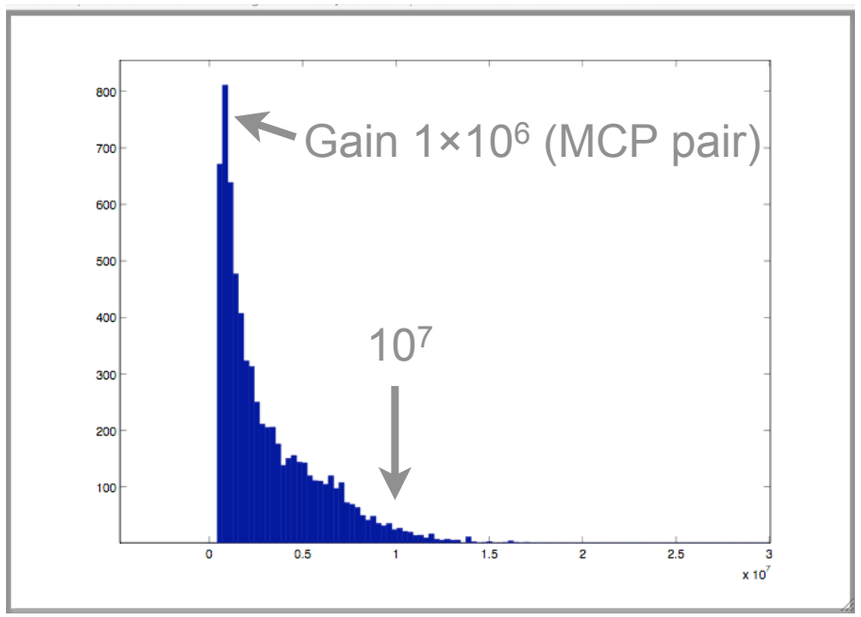


Graphics courtesy Slade Jokela

Functional Testing of Micro-Channel Plates

Test MCPs pairs with new ALD resistive chemistries

MCP 72/78 Amplification: 1.3/1.2 kV



Al_2O_3 Secondary Emission Layer

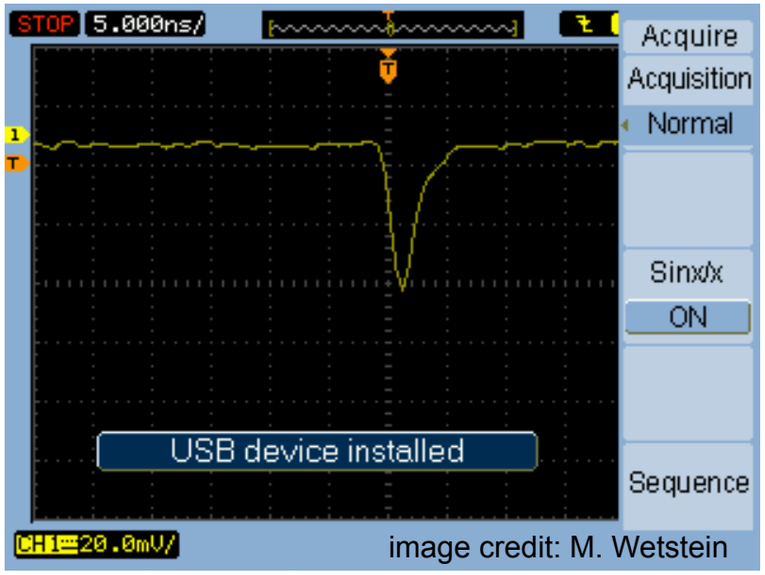
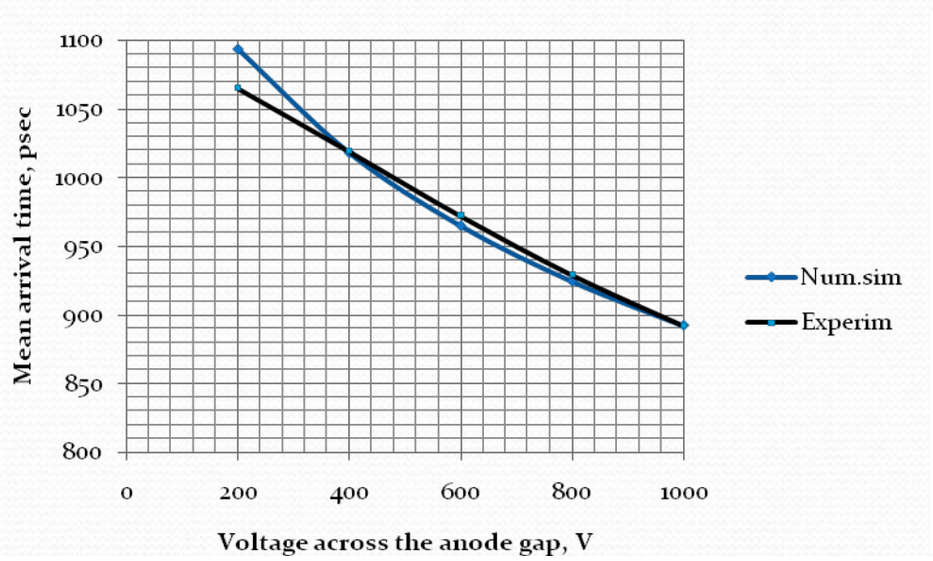
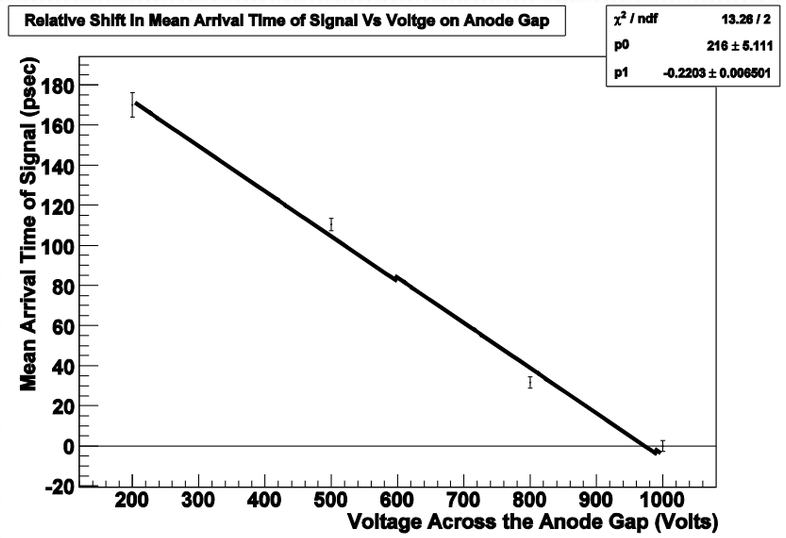


image credit: M. Wetstein

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

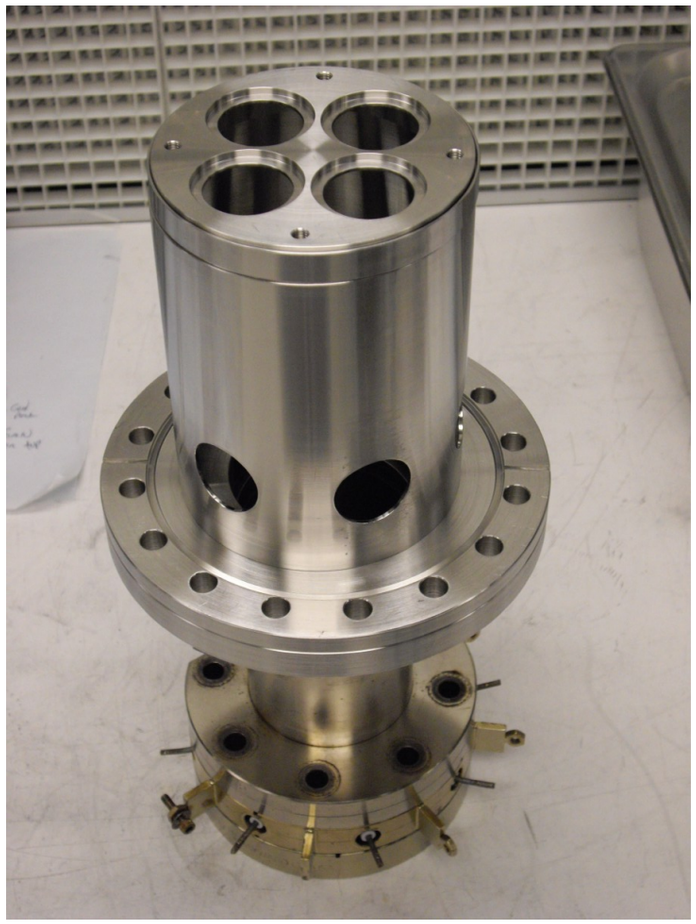
Detailed comparison of simulation & experiment in progress

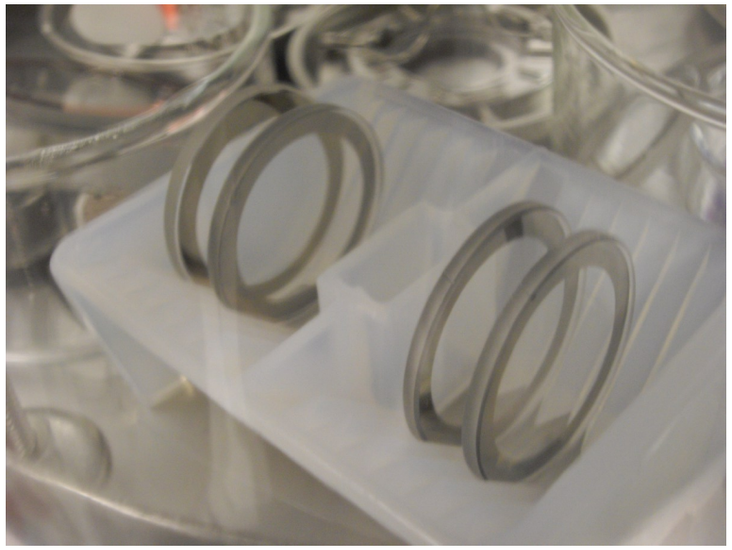




Photocathode Deposition Development

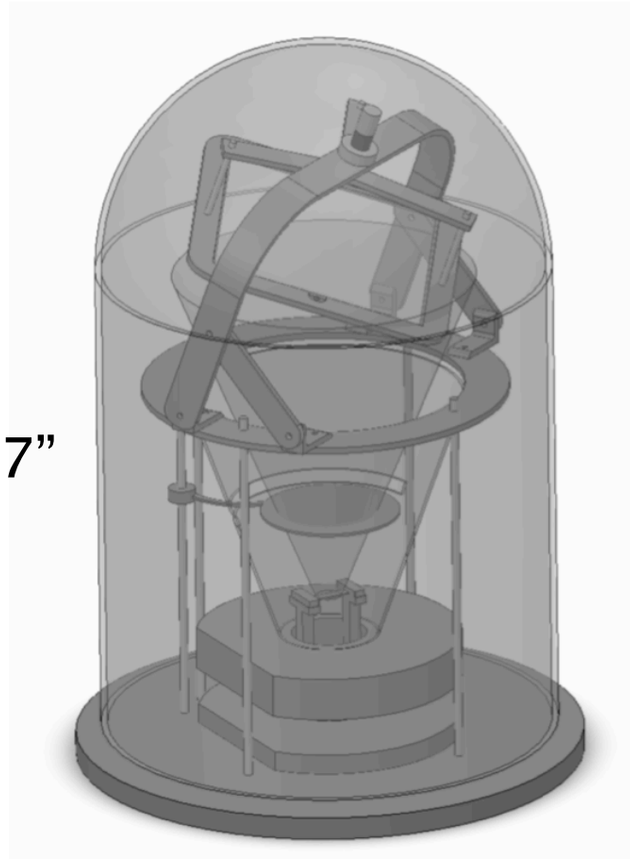
Work performed by Space Sciences Lab, UC-Berkeley
(O. Siegmund, J. McPhate, A. Tremsin, S. Jelinsky)





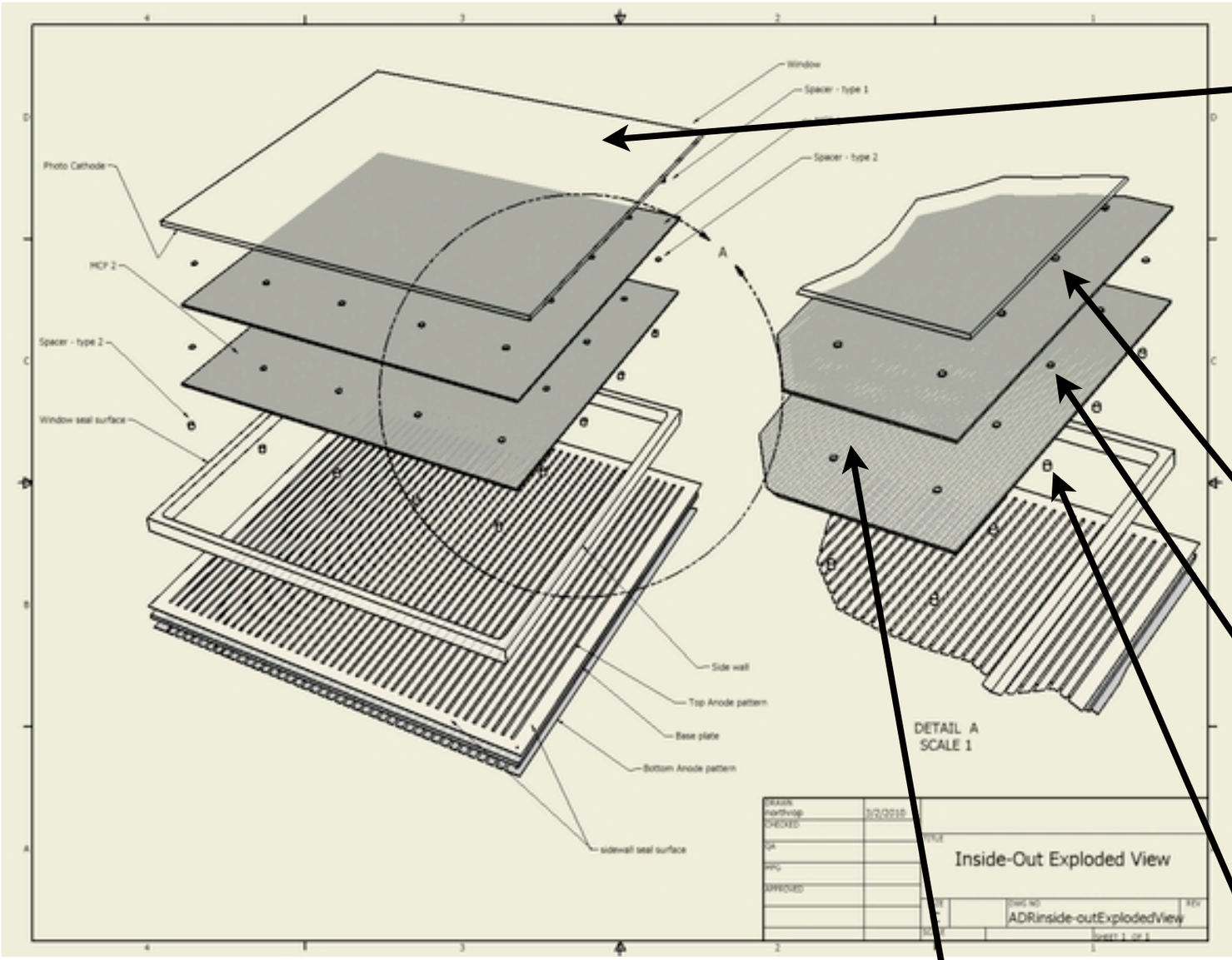
Small tank for 1.22” test run samples
Test runs with Fused Silica, Borofloat glass
ITO & MgO coated ALD layers on glass

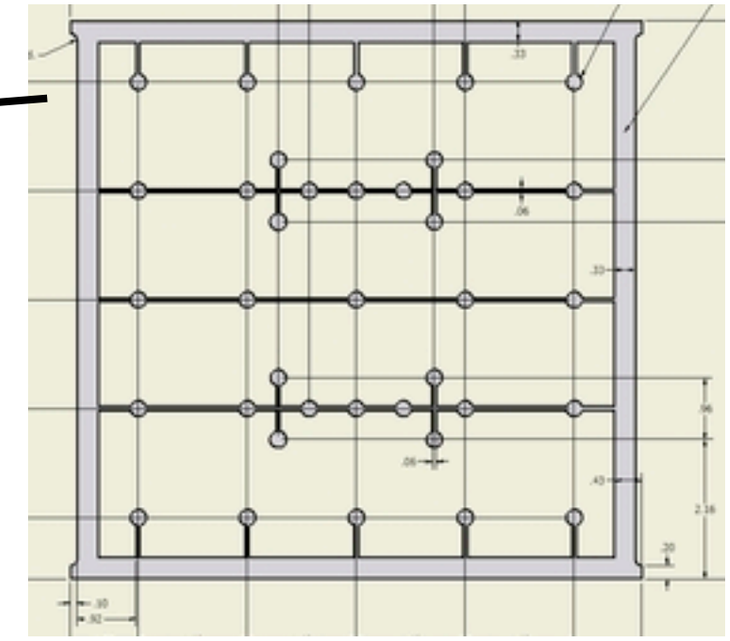
Evaporation tooling for 8.7” windows



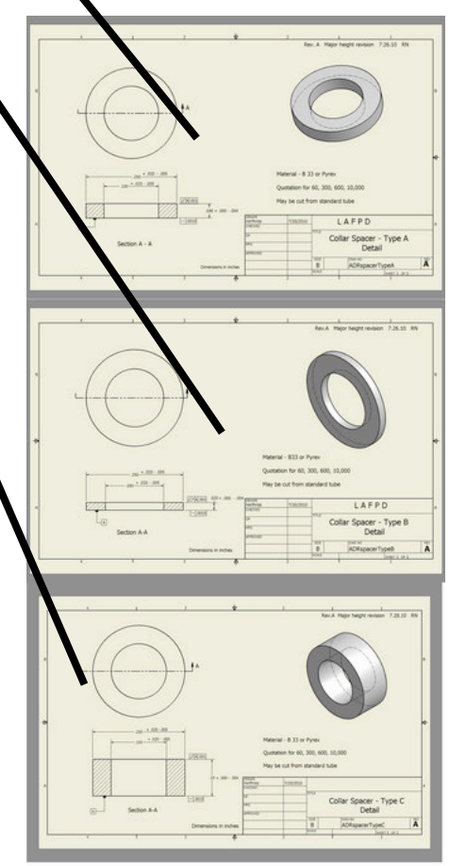
16” tank for full-sized 8.7” windows

Mechanical Assembly of Tiles -- Overview

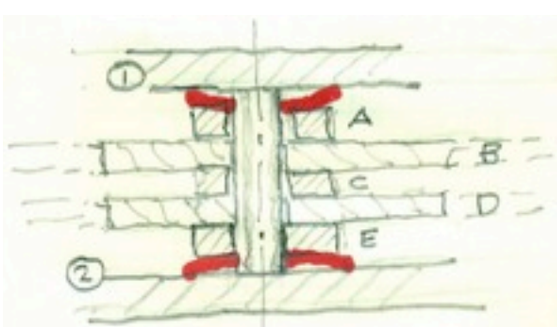




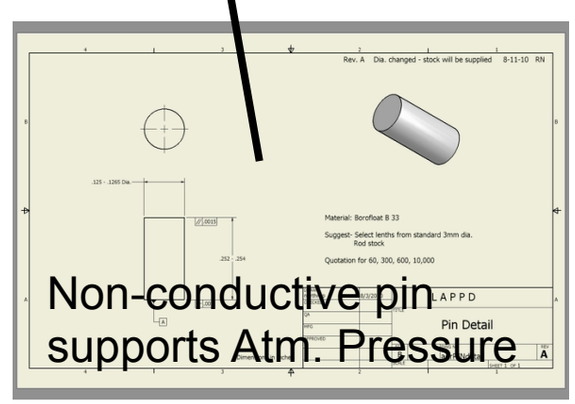
Photocathode Top Window
HV distribution through strip pattern



Conductive spacer collars set HV distribution through MCPs & to anode ground

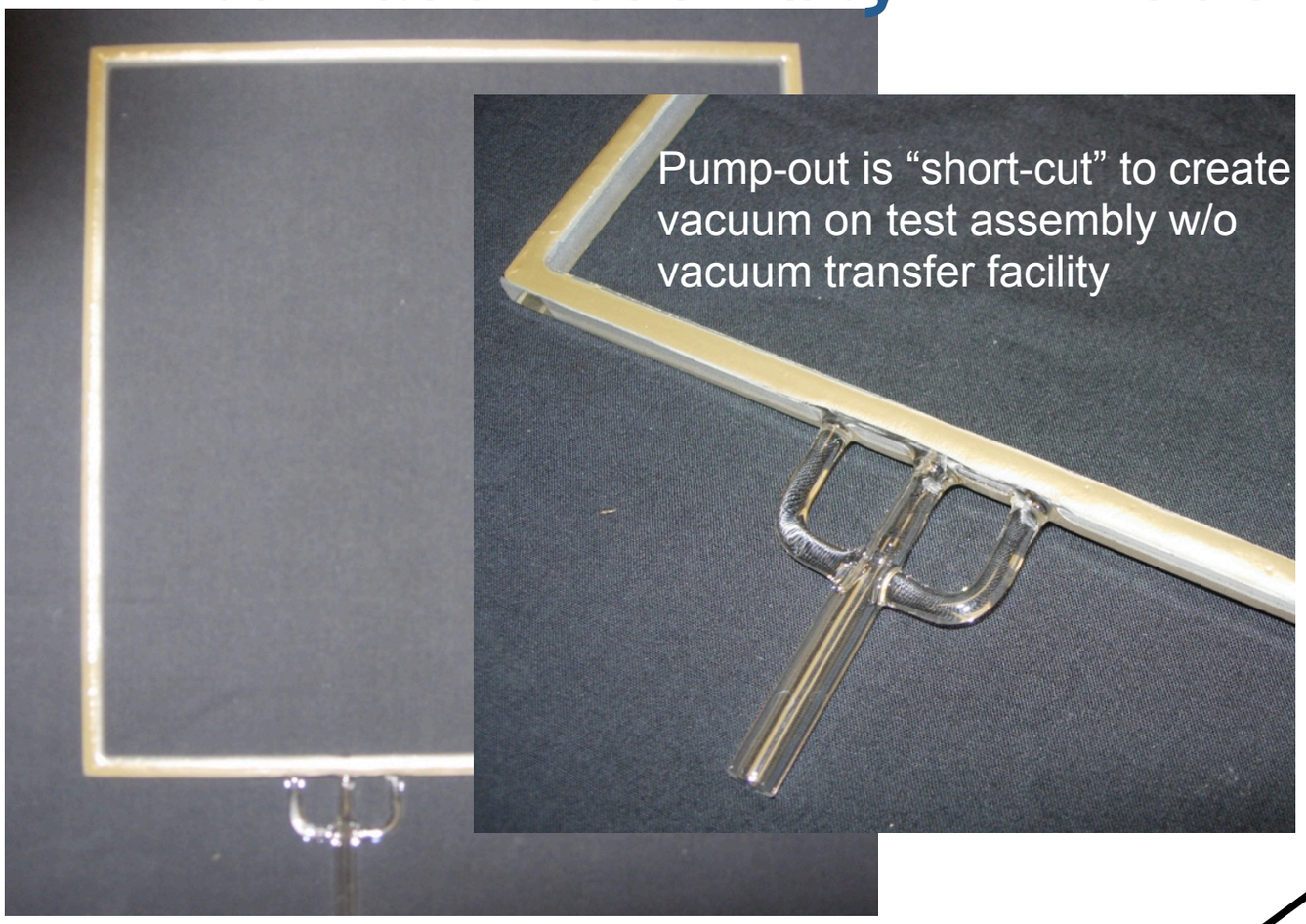


Spacer detail

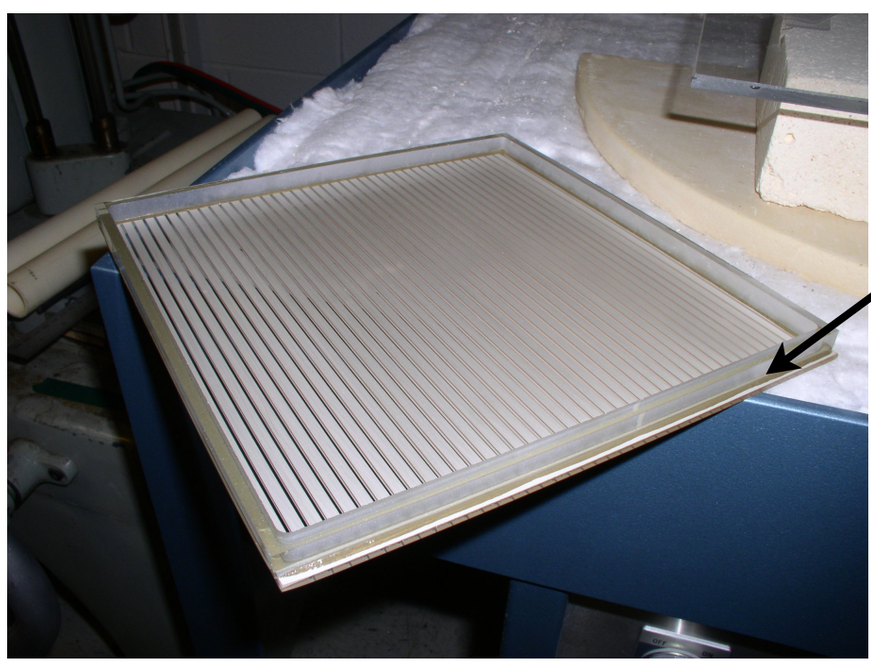


Non-conductive pin supports Atm. Pressure

Tile Base Assembly -- Anode Bottom Plate & Sidewall



- **Develop technique to reproducibly bond sidewall to bottom anode plate**
  - Center sidewall frame w.r.t. bottom plate; 2 sides flush, equal overhang on anode ground strips



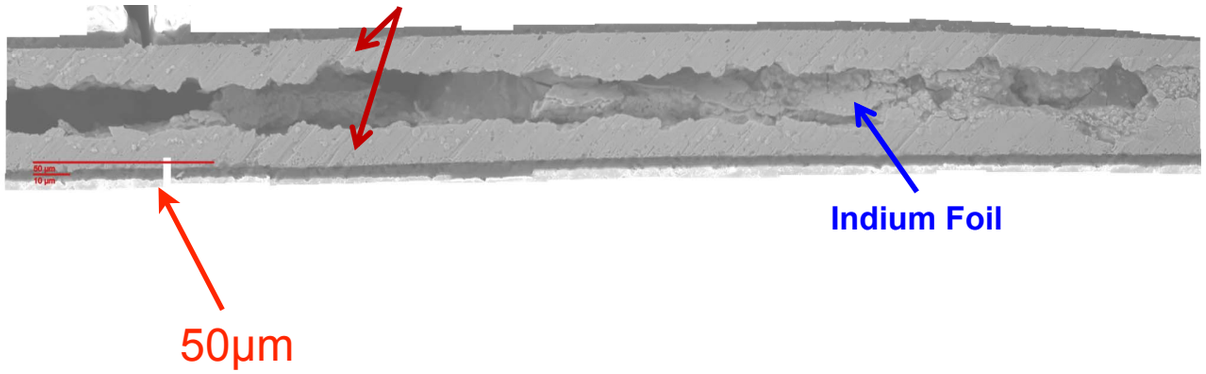
Sidewall bonds along thin silver strip
Extension of strip past sidewall for bridging grounds between tiles

Indium Thermopressure Top Window Seal Development

- Collaborative effort with Univ. of Illinois- Chicago (Ernesto Indacochea, Alcides Raraz, Marc Kupfer)
- **Bonding of top plate to sidewall must be low temperature (≤150˚C) to avoid damage to photocathode**
  - Test indium cold/warm press seal to silver, chromium, or nichrome films on glass

	Temperature (ºC)	5 Minutes			15 minutes		
		Pressure (psi)					
		800	1000	1200	800	1000	1200
Ag coated	25				*		
	100	✓	✓	✓		*	
	125					*	
	150	✓	✓			*	
Cr coated	25						
	100		✓			*	
	125						
	150						
Cr/In coated	25						
	100						
	125		✓				
	150						

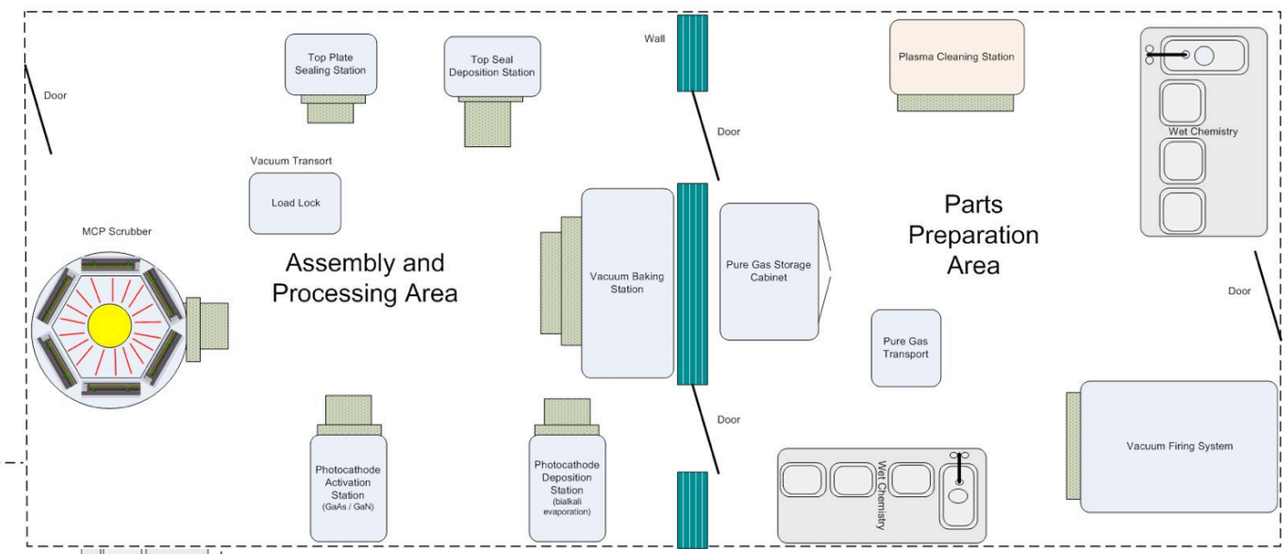
Successful Glass-Ag-In-Ag-Glass seal
1”×1” silver ink printed glass coupons
1000psi for 5 min., 160˚C



Tile Production Facility Development

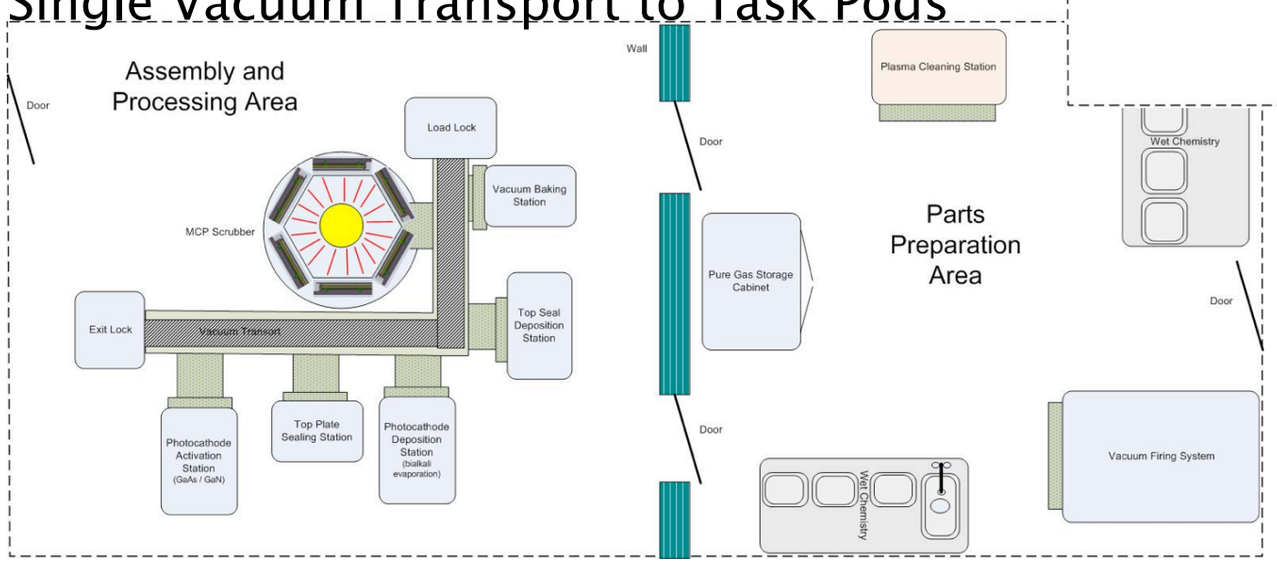
- **Goal: Produce all glass MCP photodetector tiles in quantity; ultimately want to produce one supermodule/week (2×3 tiles)**
- **Demonstrate beginning-to-end process technology**
- Initially pursuing two alternatives for vacuum handling in parallel
- Wet chemistry area identical & common to PC Growth Facility

Lab Layout #1



Lab Layout #2

Single Vacuum Transport to Task Pods



Instrumentation "Islands" serviced by Vacuum Transport Cart

Summary

Successes:

- Achieved all goals from Year 1 except deposition of photocathode on 8" window. Delay from funding start in Aug, 2009, photocathode work at SSL is progressing satisfactorily
- ALD coatings of 33mm glass capillary disks produce gain $>10^6$ in MCP pairs
- Developed 3 ALD resistive + 2 ALD emissive chemistries
- Designs for hermetically sealed tube
  - Proven design in ceramic by SSL
  - Well-advanced inexpensive glass design -- first hermetic box completed

Challenges:

- Photocathode growth at Argonne
- Test mechanical support and HV distribution collars
- Move to reliable and reproducible fabrication of sealed tubes in quantity
- Beginning design of tile production facility at Argonne
  - Lab space for tile facility identified
  - Beginning layout design of labs for wet chemistry and vacuum handling

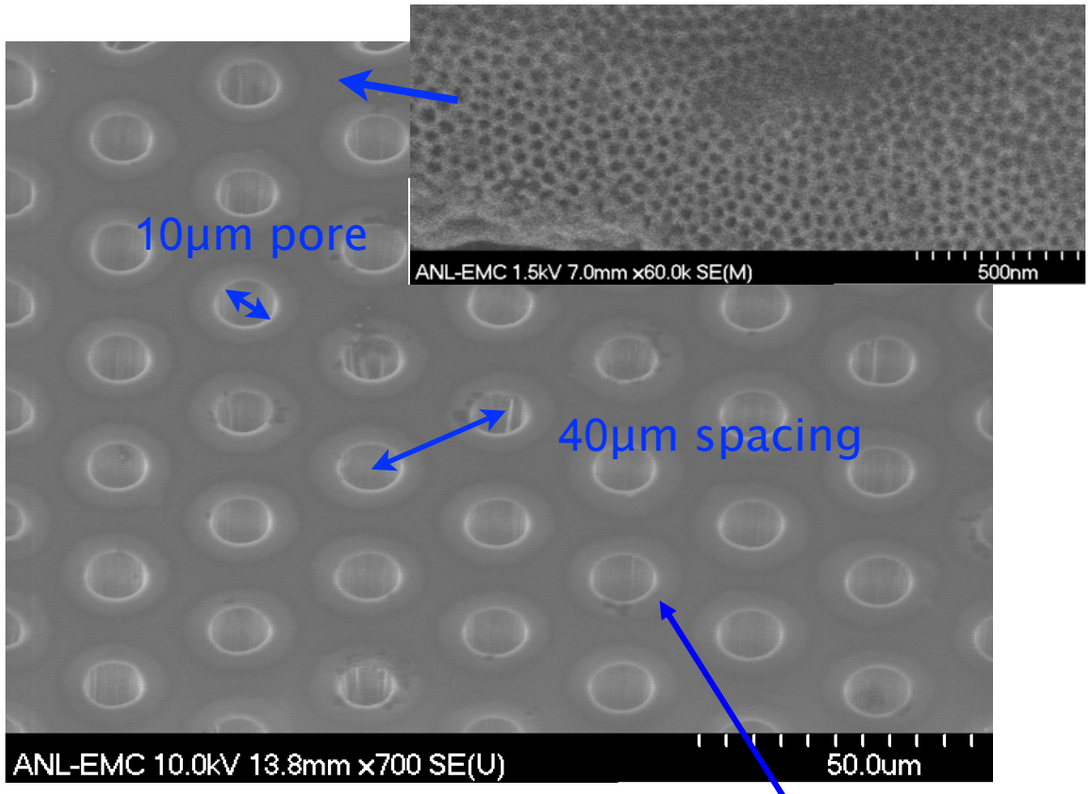
Future Work -- Year 2

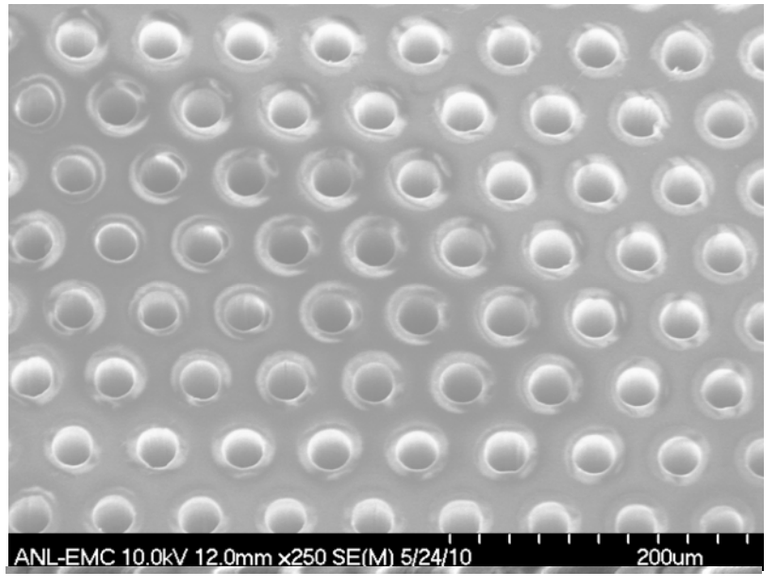
- Fabrication of photocathode on 8”×8” borosilicate glass
- Delivery and ALD of first 8”×8” glass capillary plates
- Fabrication of hermetically sealed “photocathodeless” full size MCP
  - MCP plates, spacers, anode readout; no photocathode on top plate (or possibly thin gold photocathode)
- Testing of 2nd generation sampling ASIC
- Design and construction of Tile Production Facility at Argonne
- Commissioning of Photocathode Growth and Characterization Facility adjacent to Tile Facility
- Vetting of supermodule design

BACKUP SLIDES

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



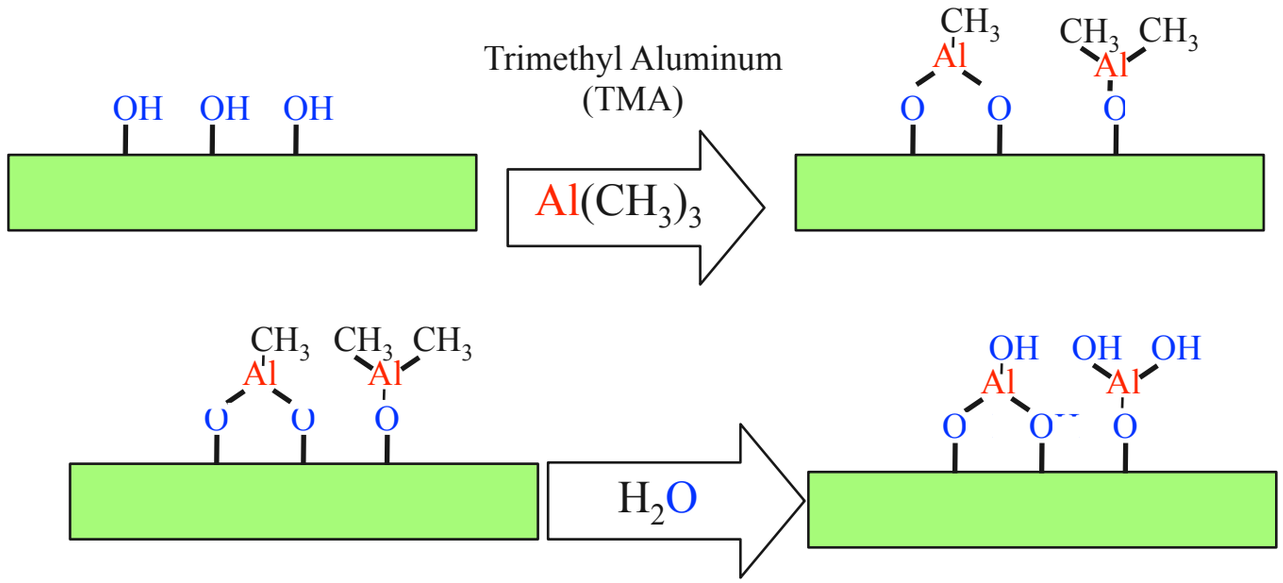


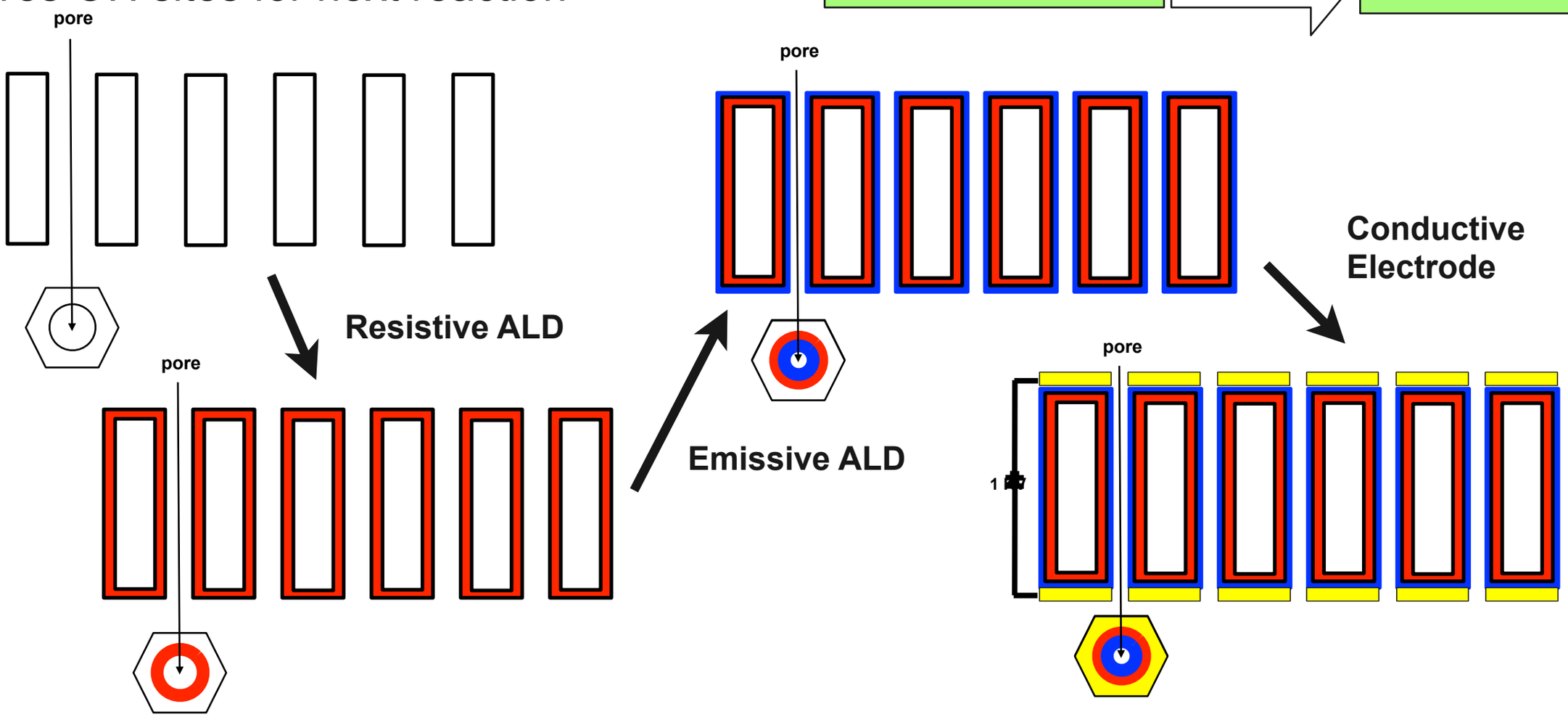
32.8mm AAO test substrate
20μm pore, L/D~10, 23% open area

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





General procedures for Fabrication of MCPs

For fabricating one pair MCPs:

~20-30hrs

if everything is right

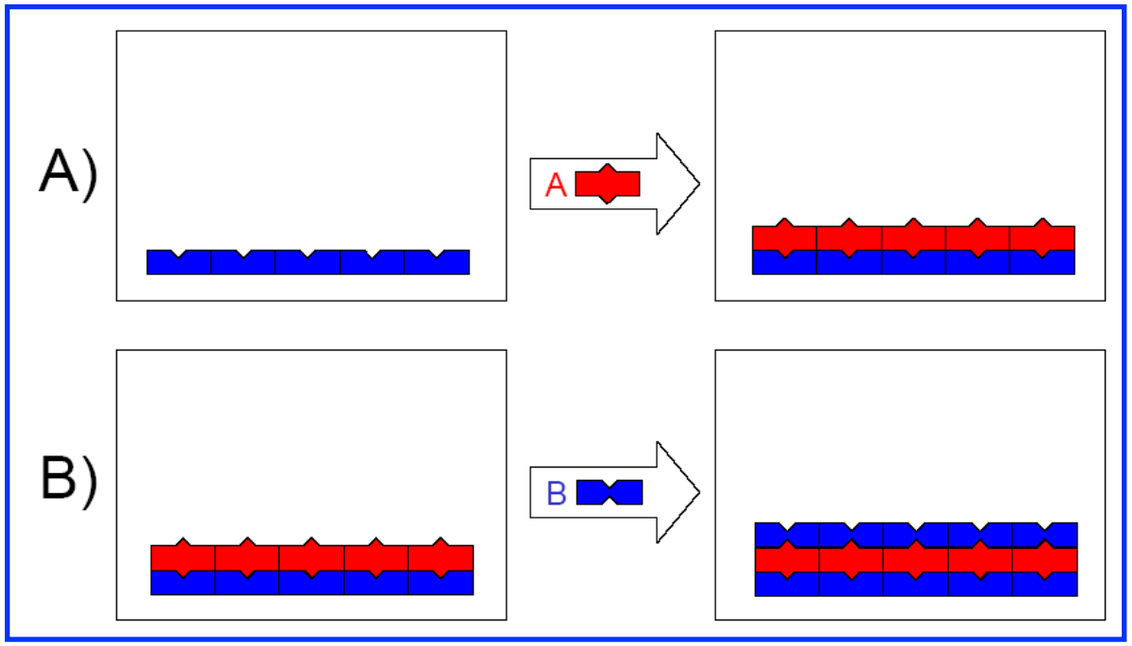
courtesy Qing Peng, Argonne ALD Group

Atomic Layer Deposition (ALD) Thin Film Coating Technology

Lots of possible materials => much room for higher performance

Jeff Elam pictures

Atomic Layer Deposition (ALD) Thin Film Coating Technology

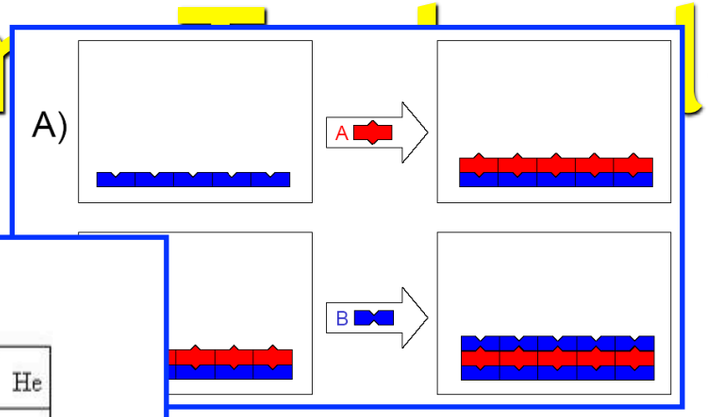


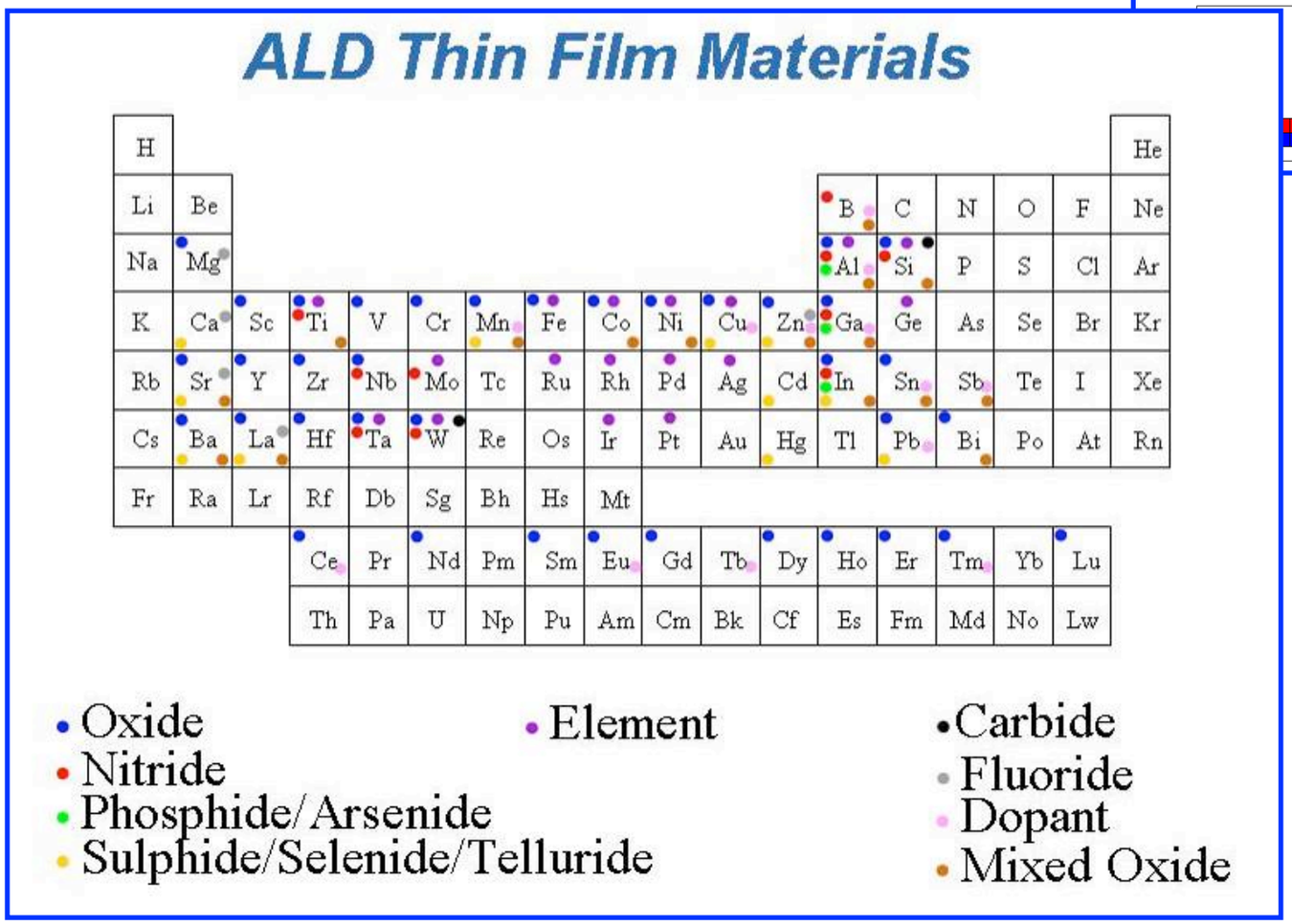
- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects (JE)

Lots of possible materials => much room for higher performance

Jeff Elam pictures

Atomic Layer Deposition (ALD) Thin Film Coatin[illegible]logy





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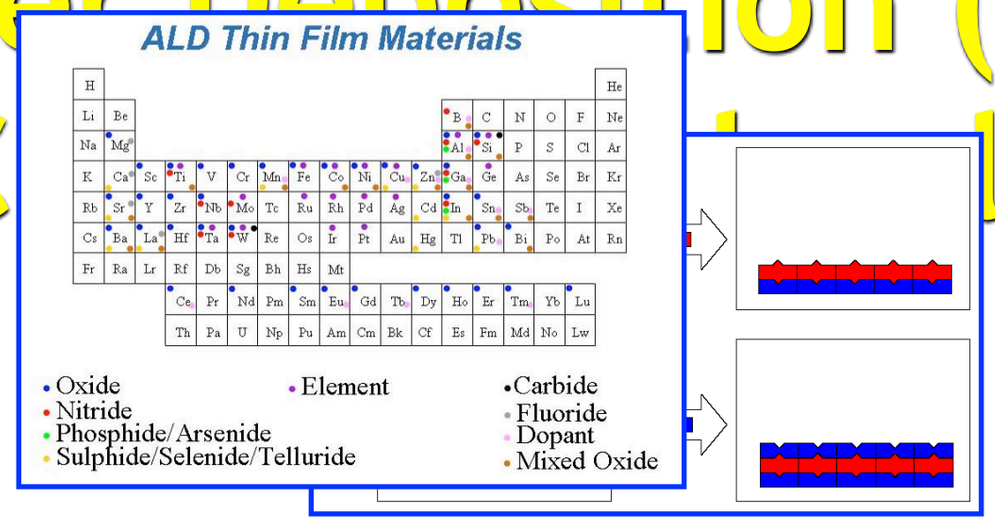
Jeff Elam pictures

Atomic Layer Deposition (ALD) Thin Film C logy



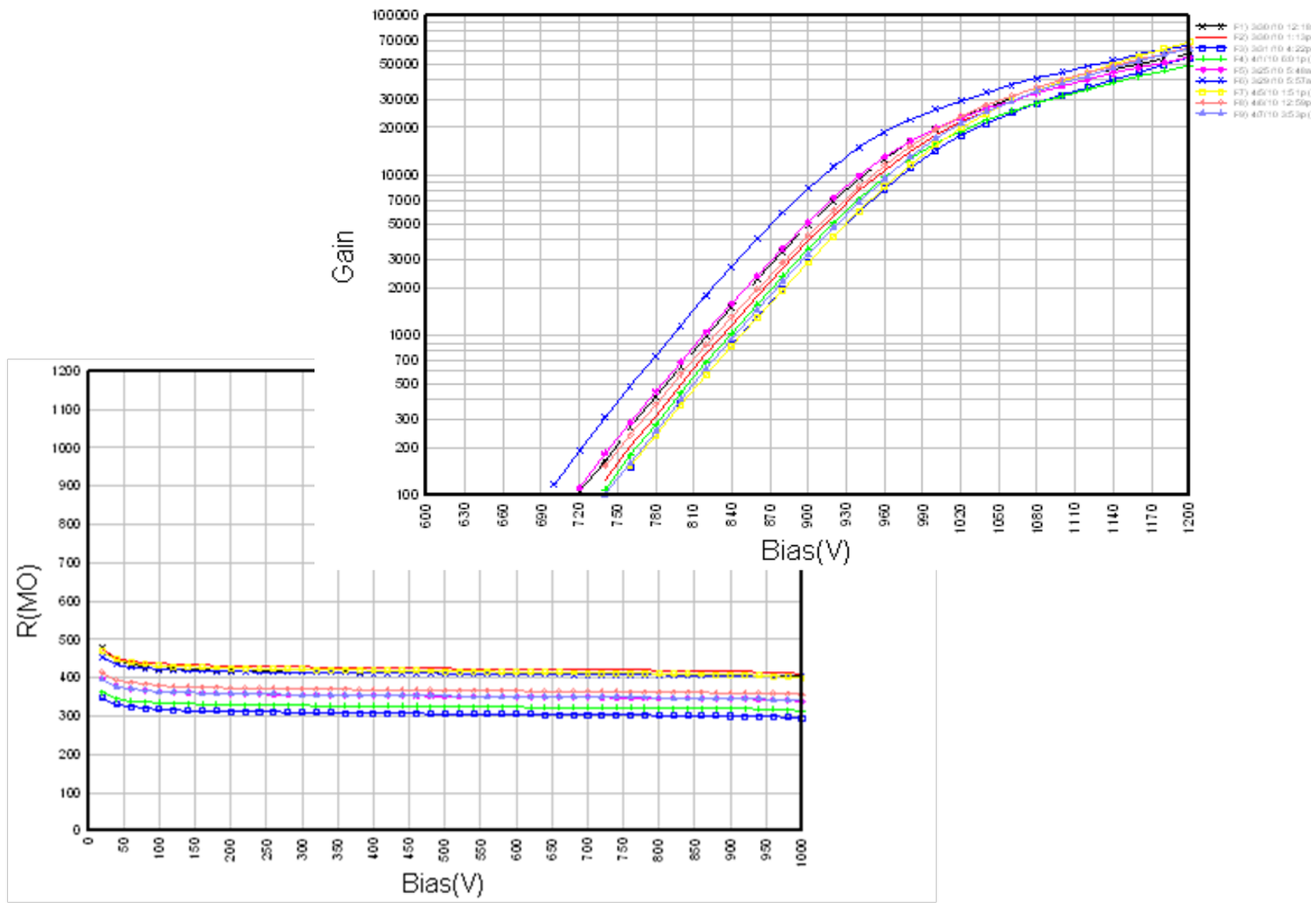
- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects (JE)

Lots of possible materials => much room for higher performance

Jeff Elam pictures

ALD at Arradiance, Inc.

Results - Incom 66:1, 20um, 60% OAR
March 2010



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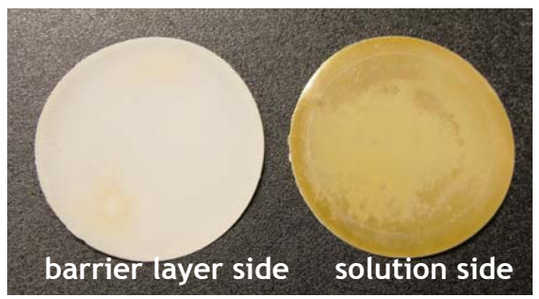
Courtesy Neal Sullivan, Arradiance, Inc.

AAO Work at Synkera Technologies, Inc.

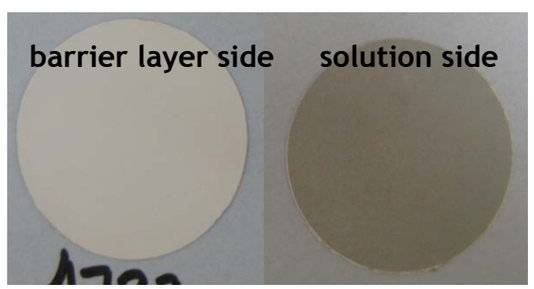
Task 2. PROTOTYPES FABRICATION

Overall size:	32.8 mm
Active area:	24.5 mm
Thickness :	100 µm
Pore Period:	1 – 1.2 µm (400V)
Pore Diam.:	0.5 µm targeted
OAR:	TBD
Annealing:	500°C

Batch 1



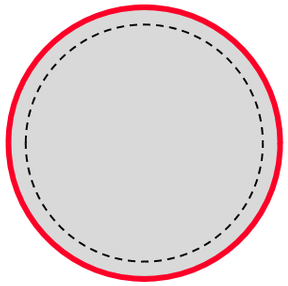
Batch 2



Batch 1: DELIVERED
- voltage ramp; surface has smaller channels
- opposite sides are different in morphology
- some discoloration from processing residue

Batch 2: DELIVERED
- improved processing
- voltage ramp eliminated
- more uniform surface than in Batch 1

Batch 3: IN PROGRESS
- Target larger pore diameter and improved surface structure
- Reduce aspect ratio for Arradiance (thickness 50 µm and 100 µm)



SYNKERA TECHNOLOGIES, INC.

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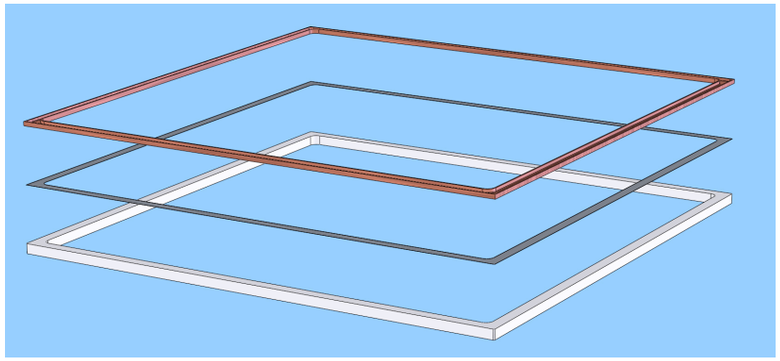
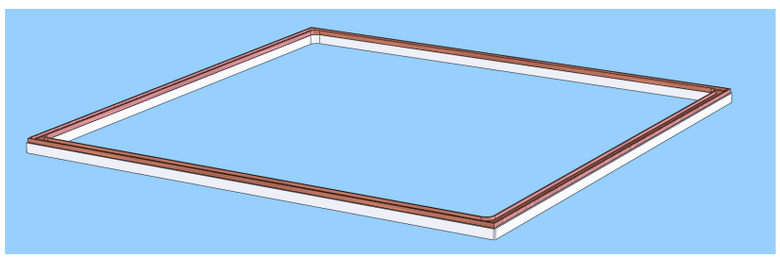
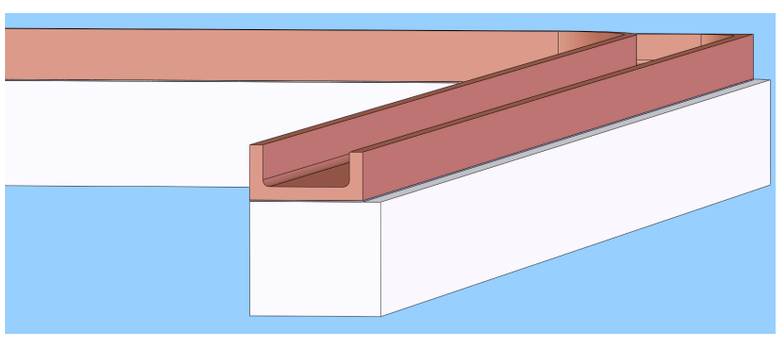
Courtesy Dmitri Routkevitch Synkera Technologies, Inc.

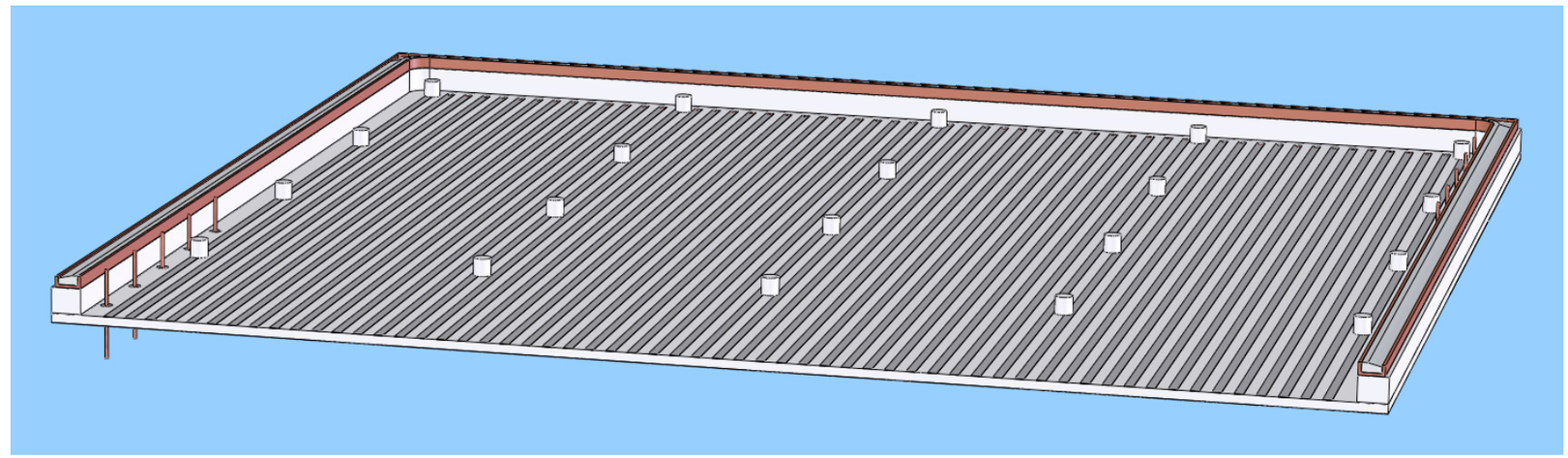
MCP Photomultiplier Packaging -- Ceramic Body (Space Science Laboratory/UC-Berkeley)



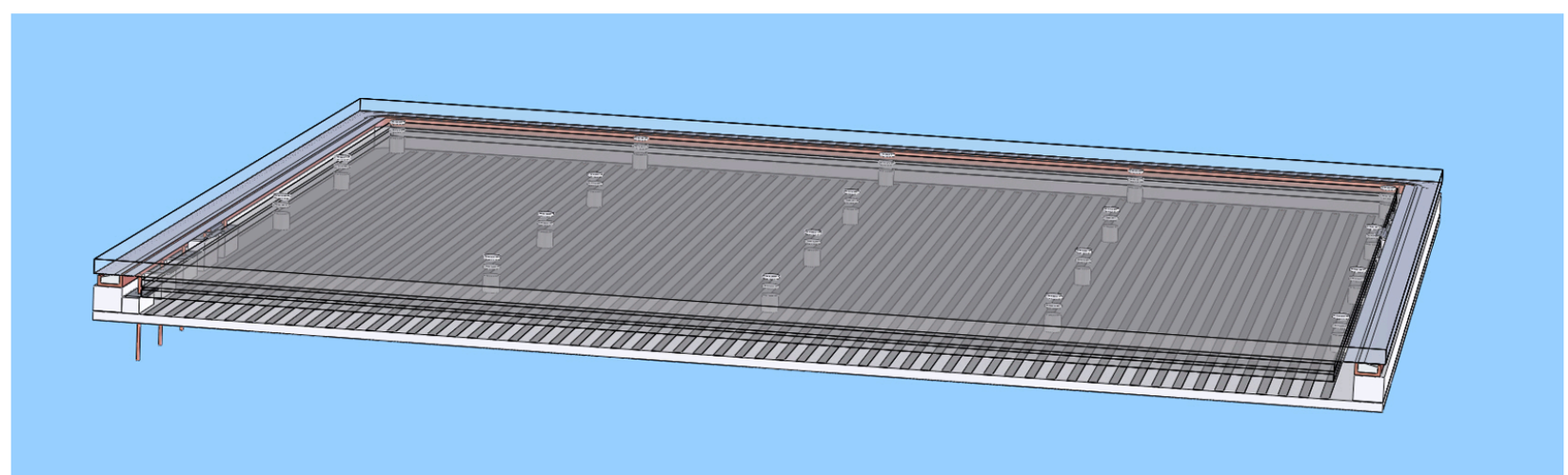




Single Joint Brazed Body
Tray for Indium top seal
- Kovar
- Ni plated/sintered
- Cu plated for Indium wetting



SSL/UC-Berkeley Ceramic Body Design



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

design drawings courtesy J. McPhate, SSL