Status of the Large Area Microchannel Plate Photodetector Project

for the Large Area Picosecond Photodetector Development Collaboration

Bob Wagner, Argonne National Laboratory

DOE Site Review

Wednesday 25 May 2011

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 (20-40μm pores, L/D ~60-40)
- 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

Large Area Picsecond Photodetector Collaboration

Karen Byrum, Marcel Demarteau, Henry Frisch, Seon Woo Lee, Edward May, Alexander Paramonov, Mayly Sanchez, Robert G. Wagner, Hendrik Weerts, Matthew Wetstein, Junqi Xie, Zikri Zusof

High Energy Physics Division, Argonne National Laboratory, Argonne, IL

Bernhard Adams, Klaus Attenkofer, Mattieu Chollet

X-ray Science Division, Argonne National Laboratory, Argonne, IL

Zeke Insepov

Mathematics and Computer Sciences Division, Argonne National Laboratory, Argonne, IL

Jeffrey Elam, Joseph Libera, Anil Mane, Qing Peng

Energy Systems Division, Argonne National Laboratory, Argonne, IL

Slade Jokela, Michael Pellin, Igor Veryovkin, Alexander Zinovev

Materials Science Division, Argonne National Laboratory, Argonne, IL

Dean Walters

Nuclear Engineering Division, Argonne National Laboratory, Argonne, IL

Neal Sullivan, Ken Stenton

Arradiance Inc., Sudbury, MA

Mircea Bogdan, Henry Frisch, Jean-Francois Genat, Herve Grabas, Mary Heintz, Richard Northrop, Eric Oberla, Matthew Wetstein

Enrico Fermi Institute, University of Chicago, Chicago, IL

Erik Ramberg, Anatoly Ronzhin, Greg Sellberg

Fermi National Accelerator Laboratory, Batavia, IL

Matt Andrew, Michael Cooney, Kurtis Nishimura, Gary Varner, Andrew Wong

University of Hawaii, Honolulu, HI

Rich Hemphill, Sharon Jelinsky, Jason McPhate, Oswald Siegmund, Joe Todesco, Anton Tremsin

Space Sciences Laboratory, University of California, Berkeley, CA

Valentin Ivanov

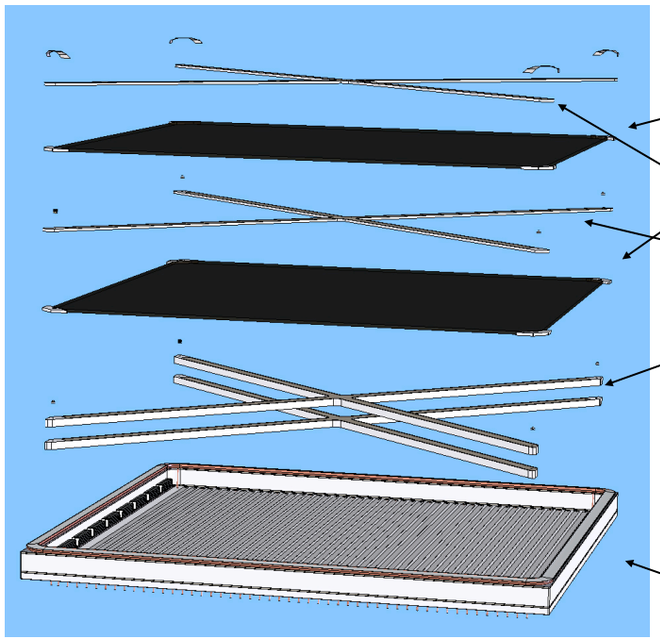
- 2 National Labs
- 3+ Universities
- 5 Divisions at Argonne
- 3 US small companies;
- Electronics expertise at Universities of Chicago and Hawaii

Goals:

- **Exploit advances in material science and nanotechnology to develop new, batch methods for producing cheap, large area MCPs.**
- **Develop path to a commercializable product on a three year time scale (approaching the end of year 2 – this summer)**

Parallel MCP-PMT Designs -- The Portfolio of Risk

- Two Complementary Designs for Photodetector
  - Ceramic packaging, evaporative photocathode -- SSL/Berkeley
    - Proven in years of fabrication in small format – high confidence of success
    - More expensive body fabrication
    - >Time/Tube construction – verify success at each step
  - All-Glass packaging, novel photocathode fabrication -- Argonne, U. Chicago
    - New design, needs development of most fabrication techniques
    - Less expensive borosilicate glass packaging
    - Target rapid production of multiple units

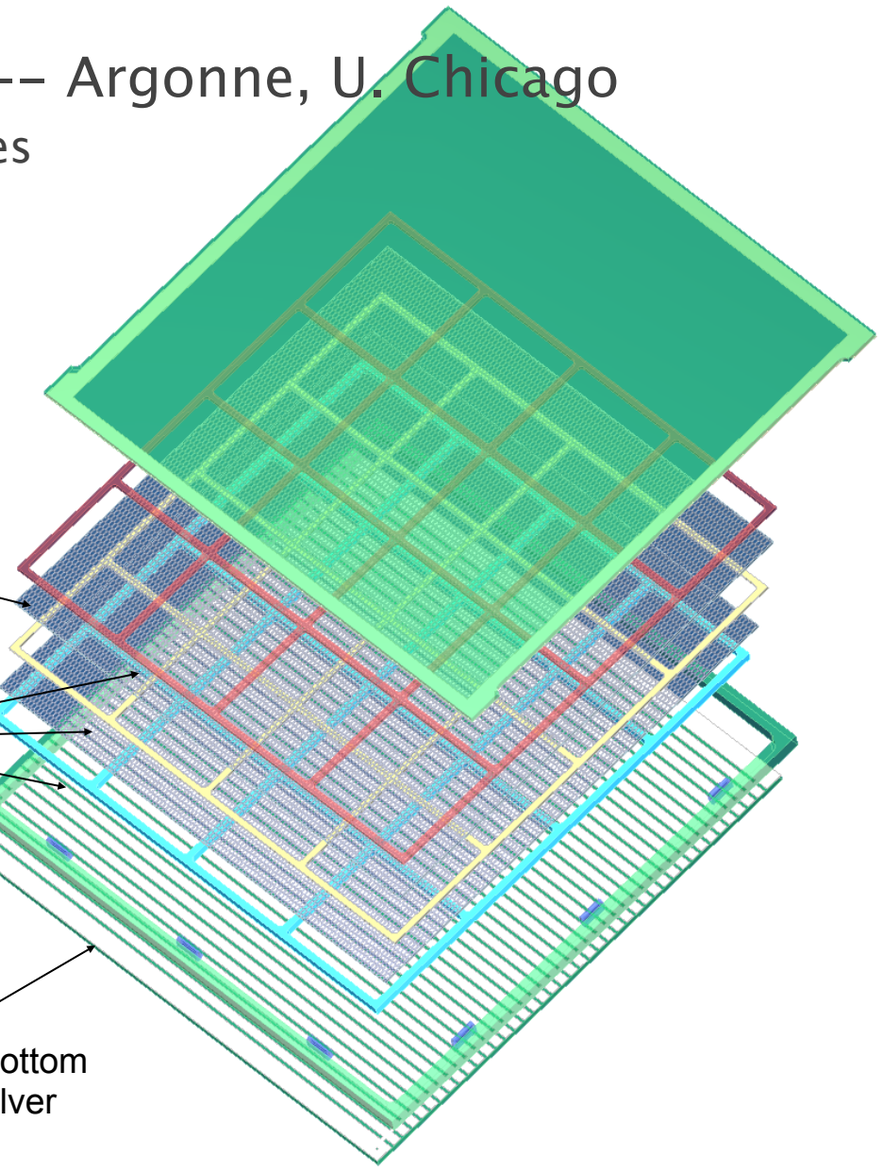


Micro-Channel Plates common to both designs

Ceramic Cross Spacers

Ceramic Sidewall/Bottom with embedded strip line. Copper chan. for indium seal

Ceramic body & spacers - SSL



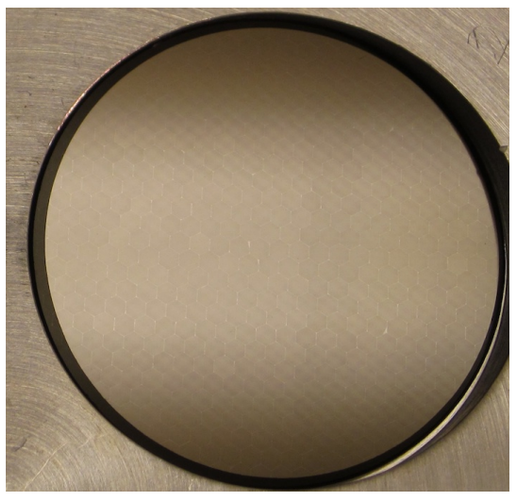
Glass Grid Spacers

Glass Sidewall/Bottom Screen printed silver anode strips

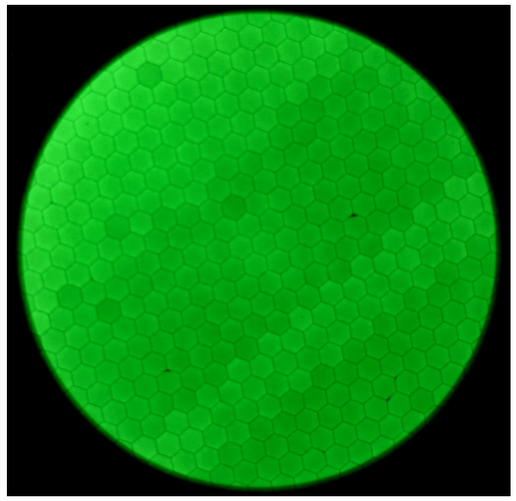
Borosilicate glass body & spacers - Argonne/UC

Micro-Channel Plate Development Status

- Glass capillary array quality has been dramatically improved
  - Extensive development work by Incom, Inc.
- ALD functionalization has established baseline process. Materials development continuing
  - Chemistry #2 resistive layer; Al_2O_3 or MgO secondary emissive layer
  - Alternative ALD materials studies planned for secondary emission
  - Tuning of process technique ongoing
- Electroding at Fermilab & SSL
  - Fermilab routinely coating multiple 33mm disks/run
  - Small numbers of 8" plates at SSL; Fermilab completing 8" evaporation chamber

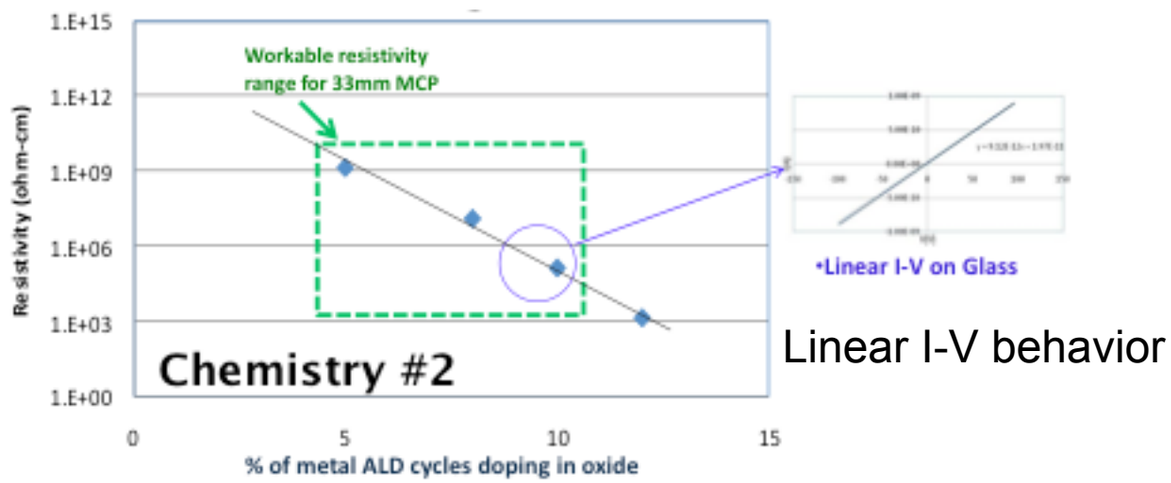


Photograph



Phosphor Image

Latest batch of 33mm capillary disks

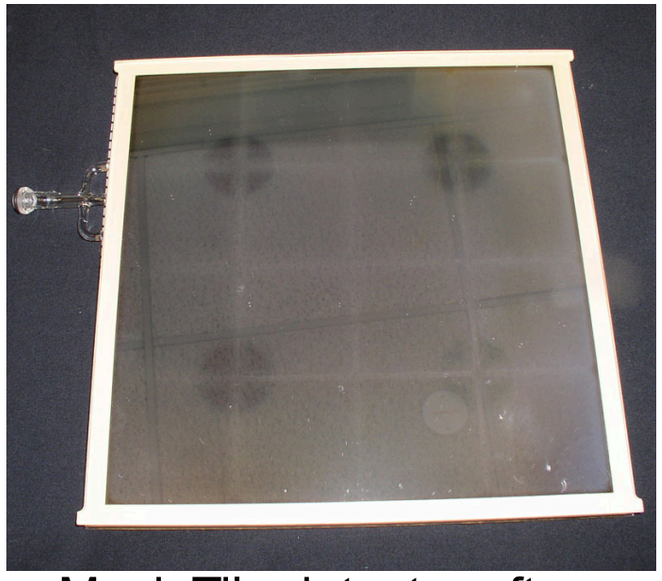


Linear I-V behavior

Resistance vs. ALD Doping Cycles for Chemistry #2

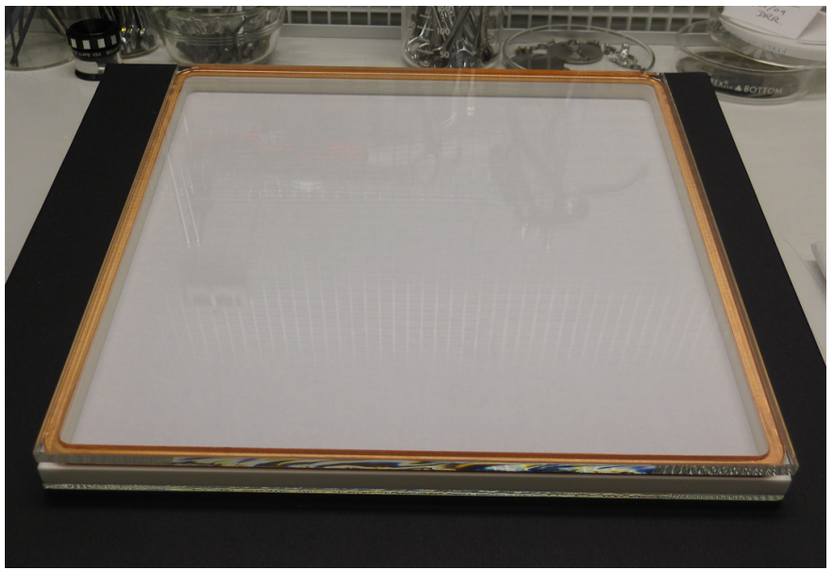
Hermetic Packaging Status

- All-Glass Packaging
  - Fabricated one sealed box with internals (dummy MCPs)
  - Mock Tile fabricated with 4 working 33mm MCP pairs
    - Successful initial pump down showing leak tight seal
    - Crack in top plate developed during extended vacuum pumping for electrical testing
  - Thermopressure indium seal in development
- Ceramic Packaging
  - Most pieces for body assembly in hand
  - Indium seal standard, although larger than past
  - 8” fabrication chamber nearing completion



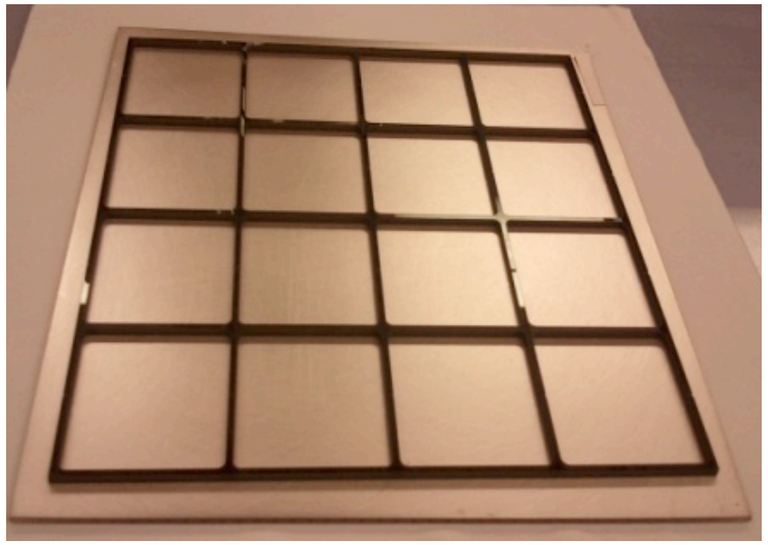
Mock Tile detector after final top plate frit firing

Deflection of Mock Tile top plate at vacuum

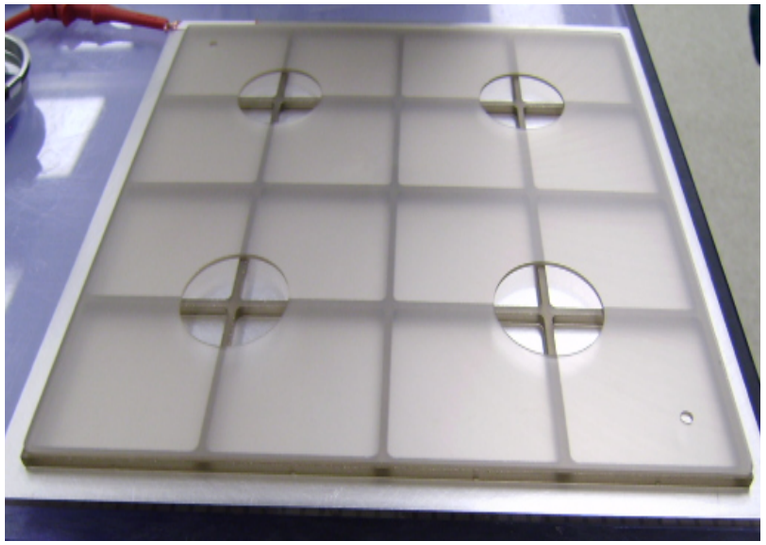


Ceramic body illustrative stack-up

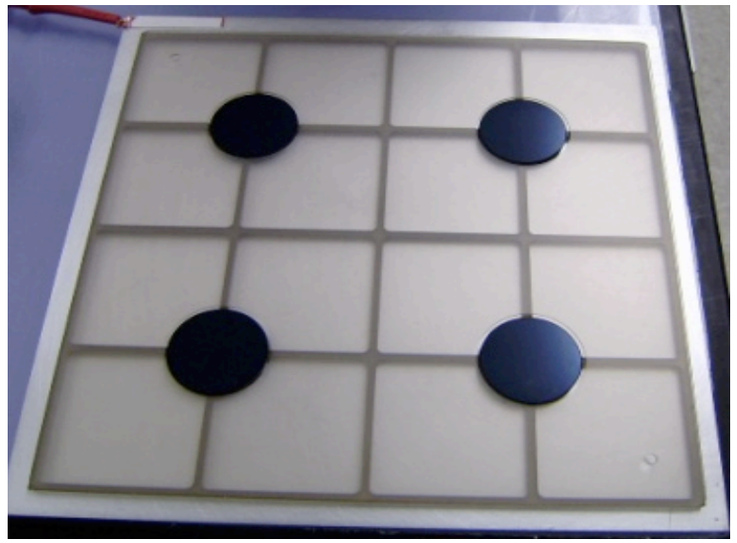
Mock Tile Fabrication -- Assembly



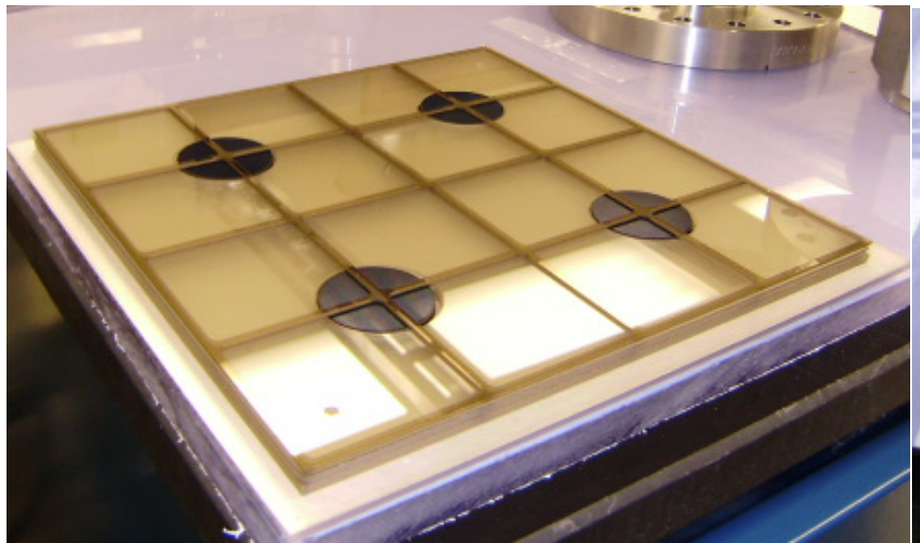
2.97mm bottom Grid Spacer



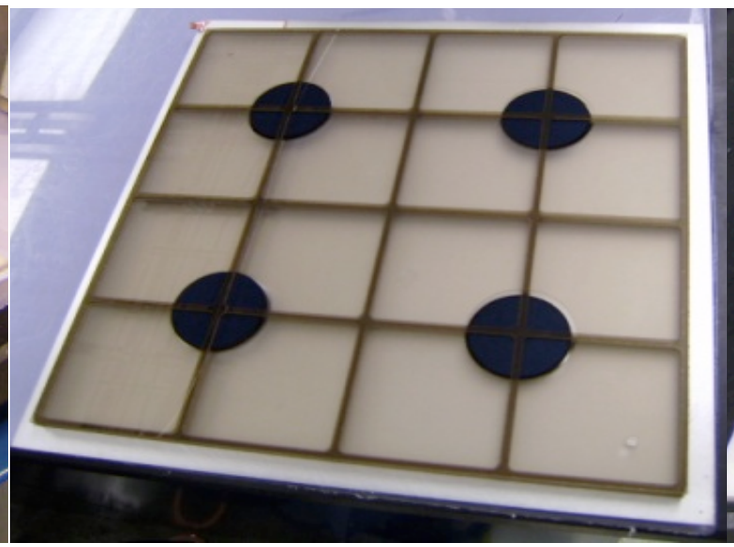
Add Mock MCP



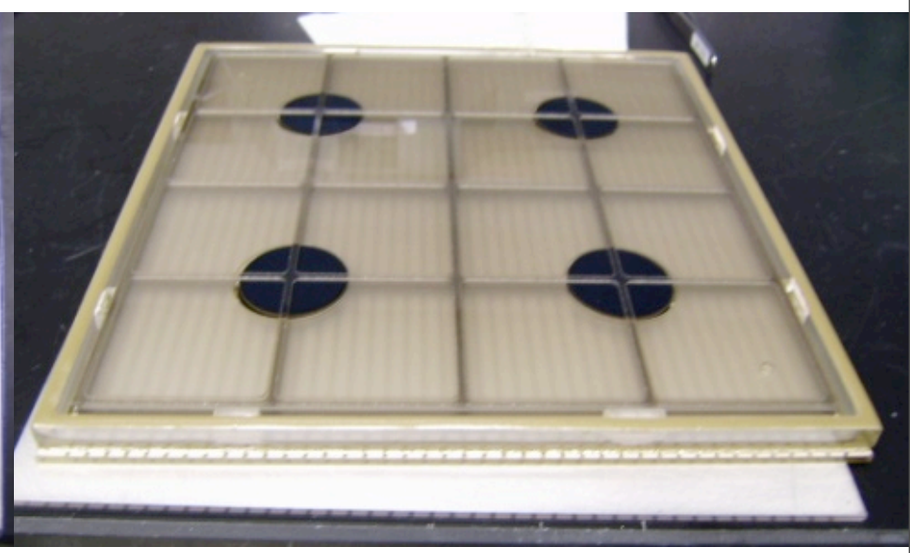
Add 33mm Functionalized MCPs



Add 1.1mm Grid Spacer



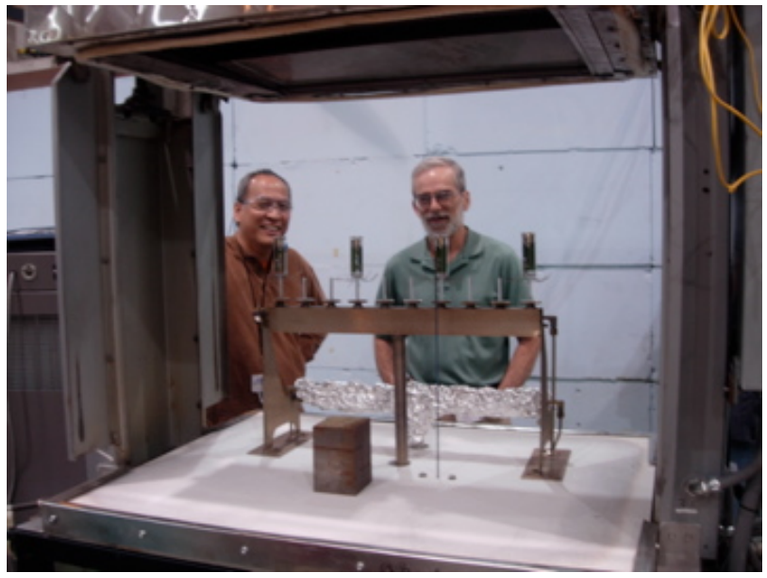
Add Mock MCP,
33mm MCPs and top
1.1mm Grid Spacer



Full stack in Tile Base

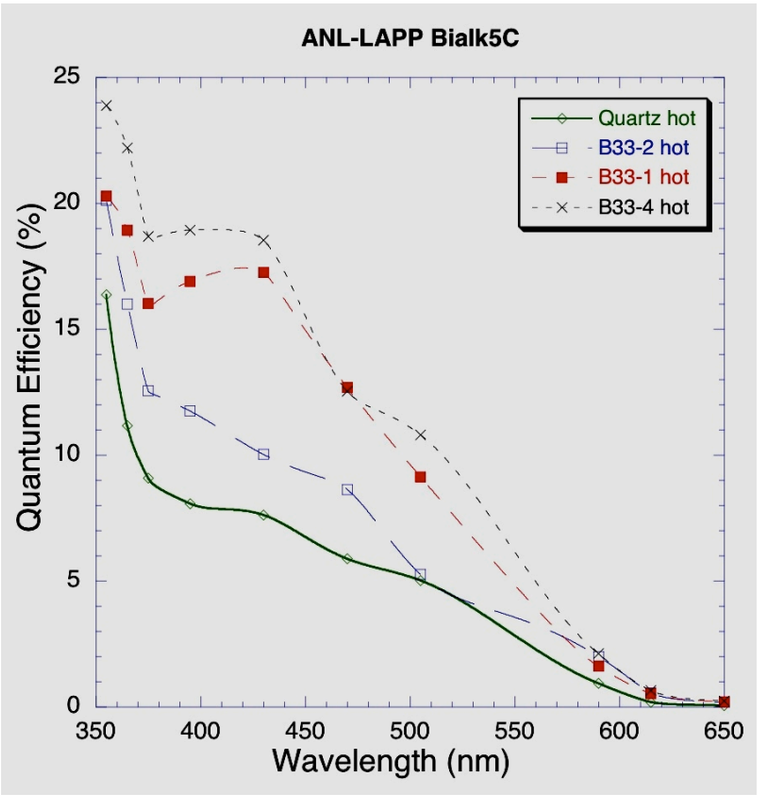
Photocathode Status

- "Shooting" bialkali photocathode samples at SSL
  - Have obtained 25% QE on borosilicate glass
- Photocathode techniques progressing well at Argonne
  - Produced first photocathode on small test PMTs using Burle equipment
  - Development vessel (Chalice) for 4"×4" photocathode using Burle equipment well advanced



Photocathode fabrication with Burle equipment at Argonne

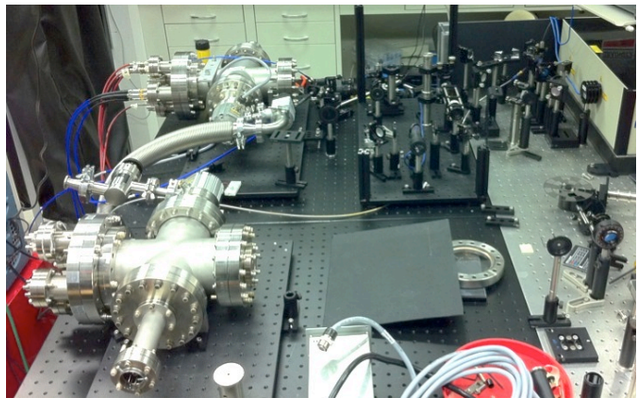
Chalice for 4"×4" photocathode test pieces

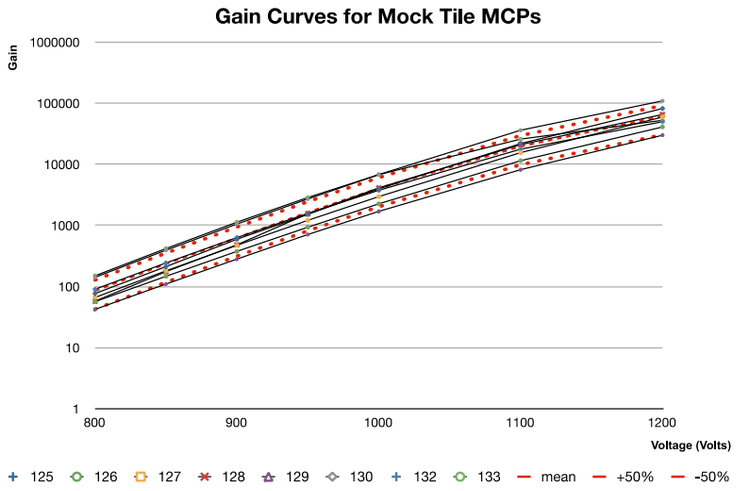


Run #5 test KCsSb Bialkali Cathodes at SSL

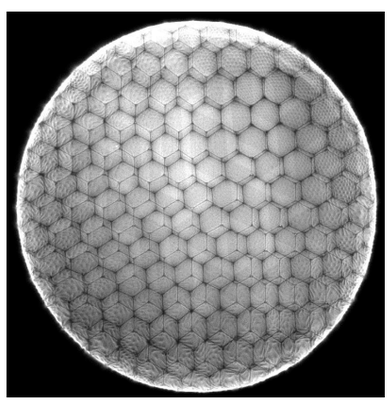
MCP Testing Status

- UV laser setup at Argonne APS
  - Two test stations for 33mm MCPs
  - 8” plate test chamber nearing completion
  - Routinely testing 33mm MCPs for gain, stability, timing, pair configurations
- Dual test station at SSL for 33mm MCPs
  - Crossed strip delay readout + phosphor readout
  - 8” test station ready

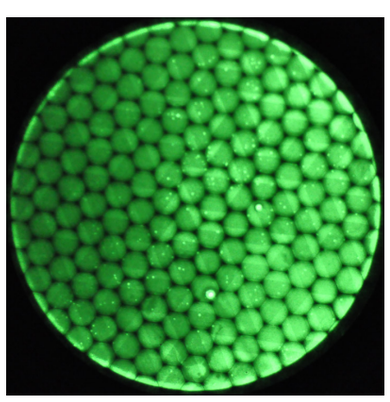




Gain curves as measured at Argonne laser test station



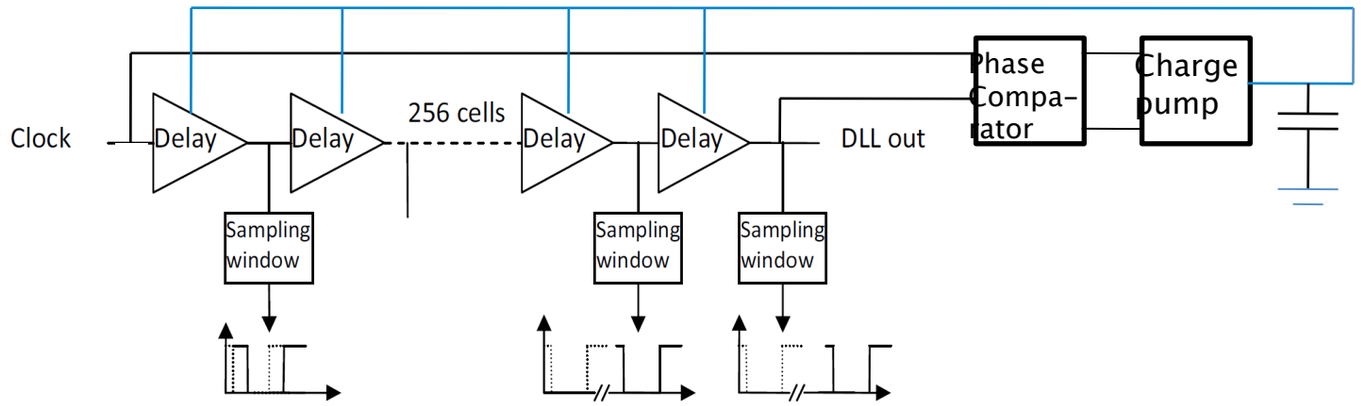
Pair MCP XDL Image at SSL



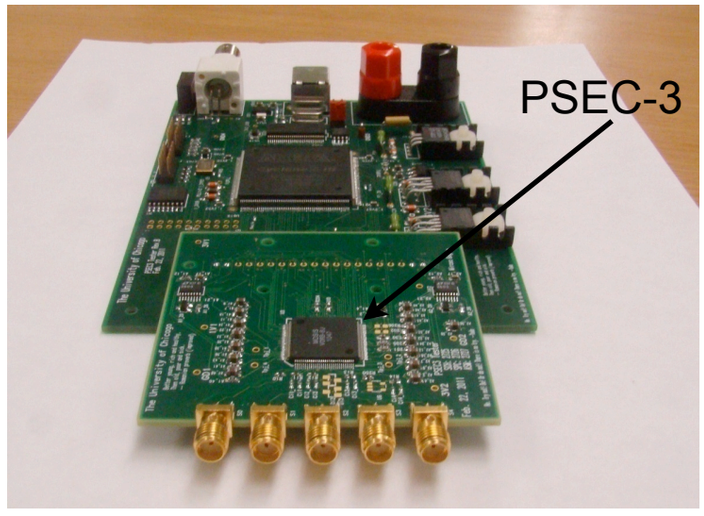
Single MCP Phosphor Image at SSL

Electronics Readout

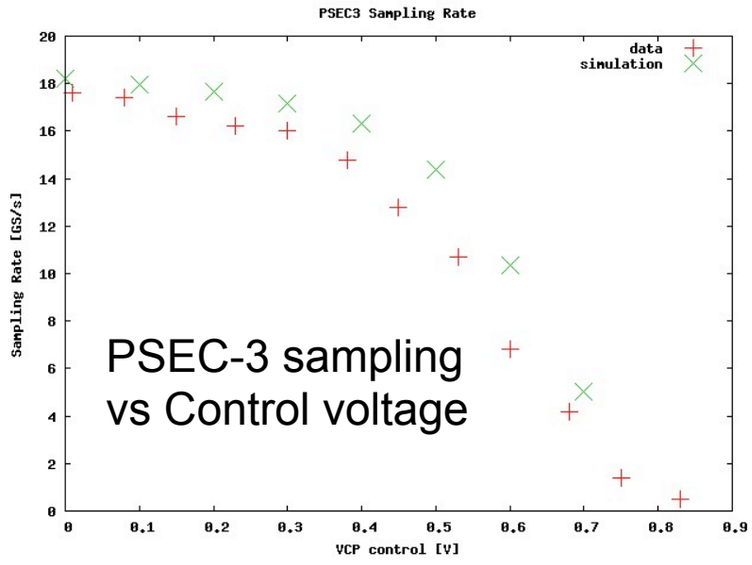
- Switched capacitor array waveform sampling ASIC
  - digitize on chip; 12 bit ADC
  - >10 GSa/s capability
  - Analog bandwidth > 1 GHz
  - Event rate ~ 100 kHz



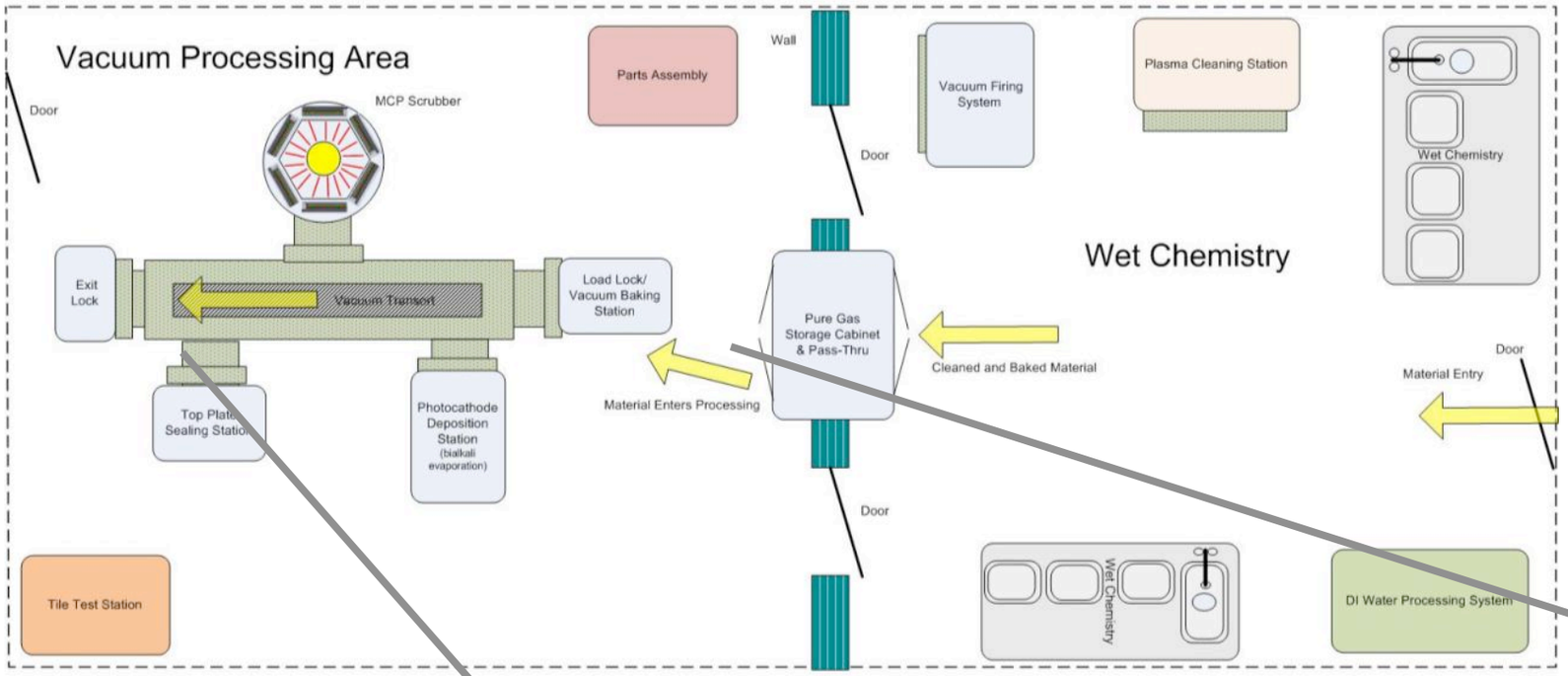
- PSEC-3
  - 4 channel
  - Submitted 11 Aug 2010, 40 pieces delivered 16 Dec 2010
  - Addressed several issues with generation 2 PSEC
- PSEC-4
  - 6 channel; two test channels converted to readout
  - Submitted 9 May 2011 to MOSIS
  - Improve analog bandwidth

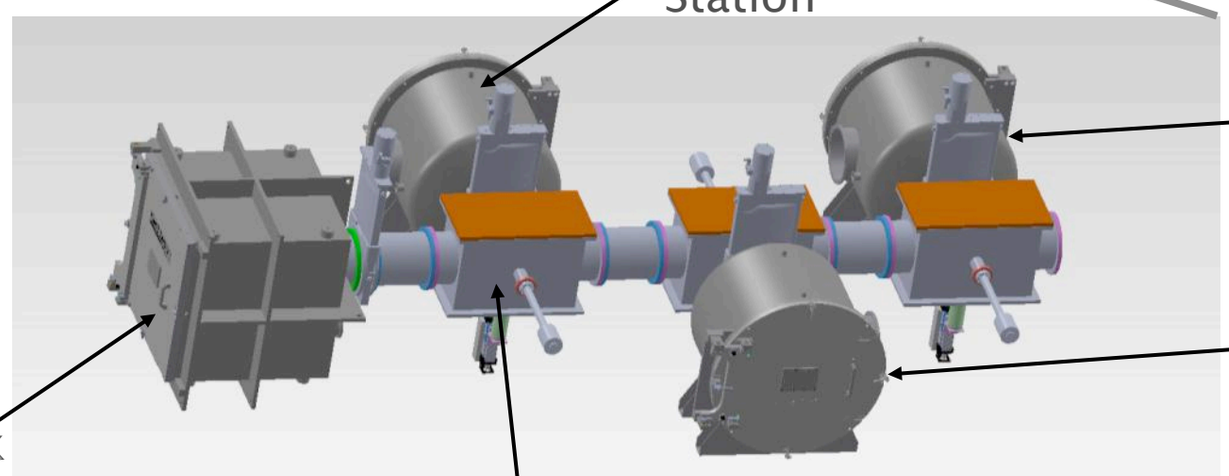


PSEC-3 Evaluation Board



MCP Tile Production Facility





- Double lab at Argonne
- Designing layout of lab based on process requirements
- Build up facility over next couple years as process steps vetted

ARRA Goal Summary -- Year 1

- Year 1
  - Identify & characterize photoelectron emission properties of materials for photocathode development complete
  - Demonstration of amplification with gain ≥ 300 with ALD-functionalized MCP complete
  - Achieve differential time resolution < 10 ps and space resolution ≤ 1mm in vacuum with 50Ω transmission-line anode complete
  - Upgrade existing collaboration vacuum transfer facilities to match 8”-square module assembly just completing
  - Design including costing & interfacing with vendors of production sealed-glass tubes, for vacuum-transfer/assembly facility for 8”-square module complete
  - Design prototype 2 channel ASIC with sampling ≥ 20 GSa/s, analog bandwidth ≥1.5GHz, and capacitor-sampling-chain and timing blocks complete
  - Demonstration of operational 8”-square photocathode in progress at SSL
  - Demonstration of vacuum seal of 8”-square window to body complete
  - Summary report on Year 1 progress including technical achievements and knowledge gained complete

ARRA Goal Summary -- Year 2

- Year 2
  - Demonstration of gain 10^6 and aging performance comparable to or better than commercial MCPs with pair of ALD-functionalized plates complete
  - Development of MCP test facility capable of handling 8" plates complete
  - Functionalization of 8"×8" glass capillary substrate with ALD done; process optimization in progress
  - Design and costing of photocathode characterization facility operational and continuing
  - Design and costing of 8" glass tile assembly facility in progress

Visit our web site for more information:
http://psec.uchicago.edu
("Blog" and "Library" links are a good starting place)

Future Work

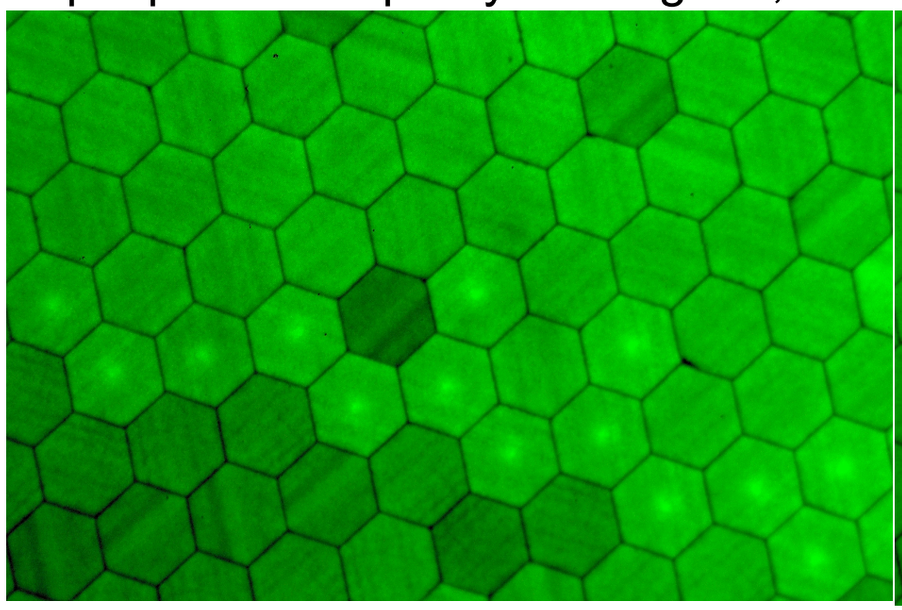
- Photocathode
  - Produce 8”×8” photocathode with QE ≥ 25% with acceptable dark current
  - Continue characterization survey of novel materials for photo/secondary emission
- Glass Substrate
  - Evaluate process economics for large picosecond timing & medical applications
  - Setup for multiple plate production optimized for ALD coating process & robust mechanical assembly
- Atomic Layer Deposition
  - Evaluate process economics for large picosecond timing & medical applications
  - Achieve single resolution out to 4 pe’s
  - Continue characterization of materials for resistive and secondary emissive properties
- Testing
  - Transition to large volume testing
  - Continue to test innovations on small scale
- Simulation
  - Complete end-to-end simulation package
- Mechanical Assembly
  - Build quantity of 8”×8” tiles and 3×2 tile modules
  - Design & optimize assembly procedures
- Electronics
  - Design production generation clock distribution
  - Design production FPGA DAQ/control card
  - 6 Channel PSEC chip

BACKUP SLIDES

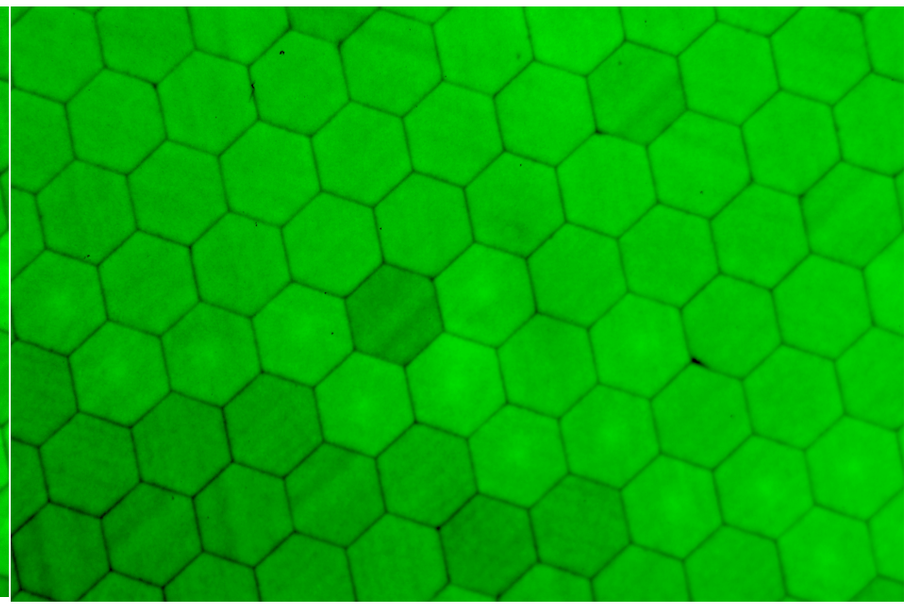
Improvements & Issues in Glass Capillary Arrays

Issues:-
We still have linear striations inside the multifibers
There seem to be 4 types of multifiber
- Most are pretty good, low striation
- Some are darker – low gain – smaller open area ratio
- Some pretty good but with bright spot in middle
- 3 extra bright multifibers

Triple points are pretty much gone, multifiber boundaries are thin and uniform!

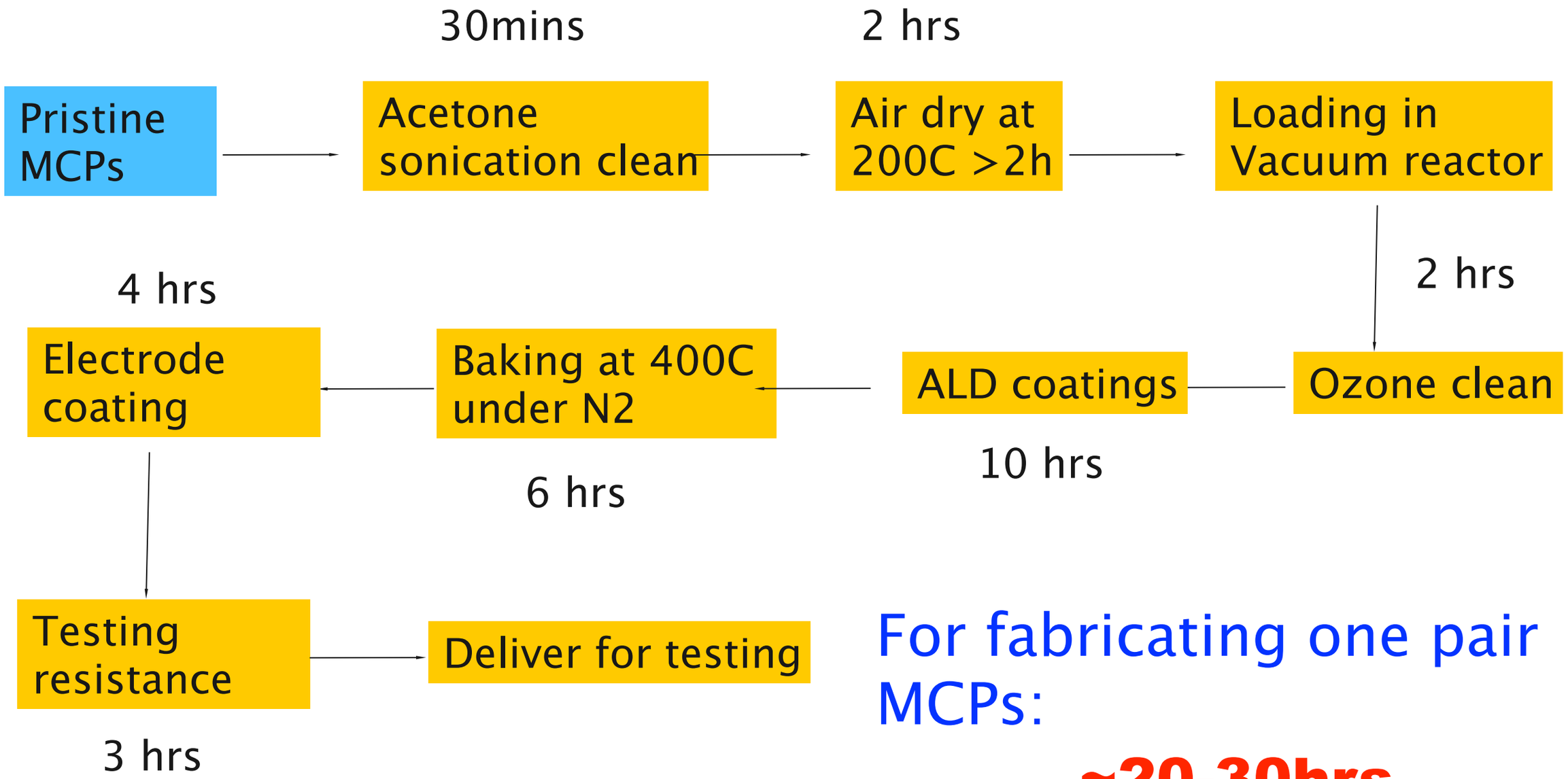


800v MCP



1000v MCP

General procedures for Fabrication of MCPs



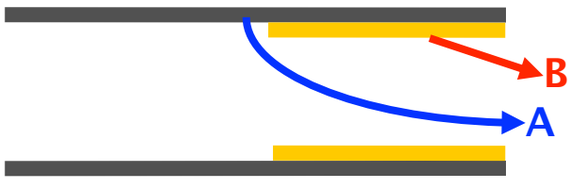
courtesy Qing Peng, Argonne ALD Group

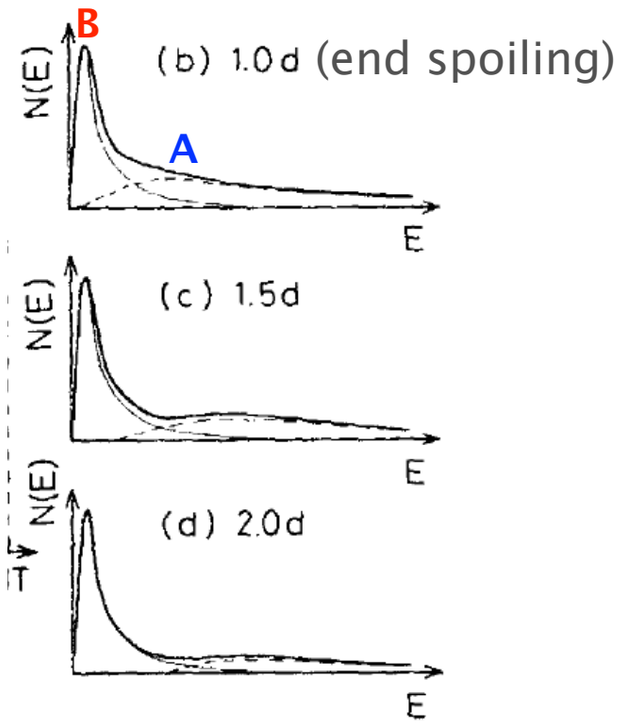
For fabricating one pair MCPs:

~20-30hrs

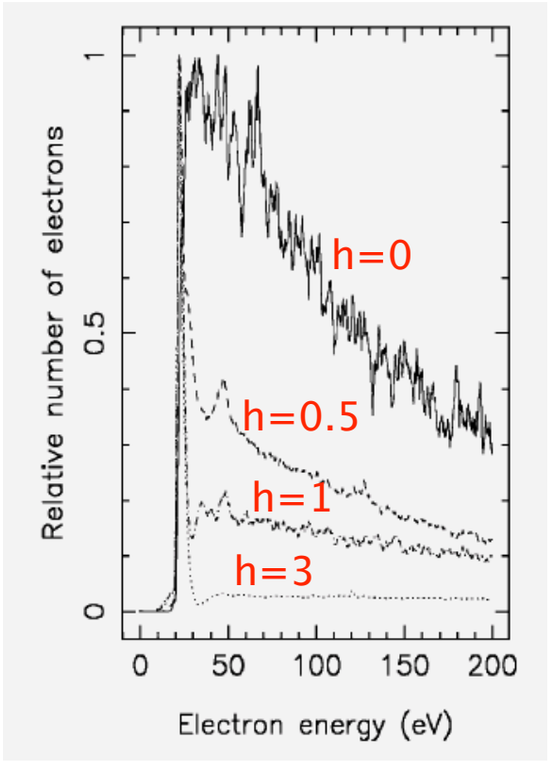
if everything is right

End-spoiling Details





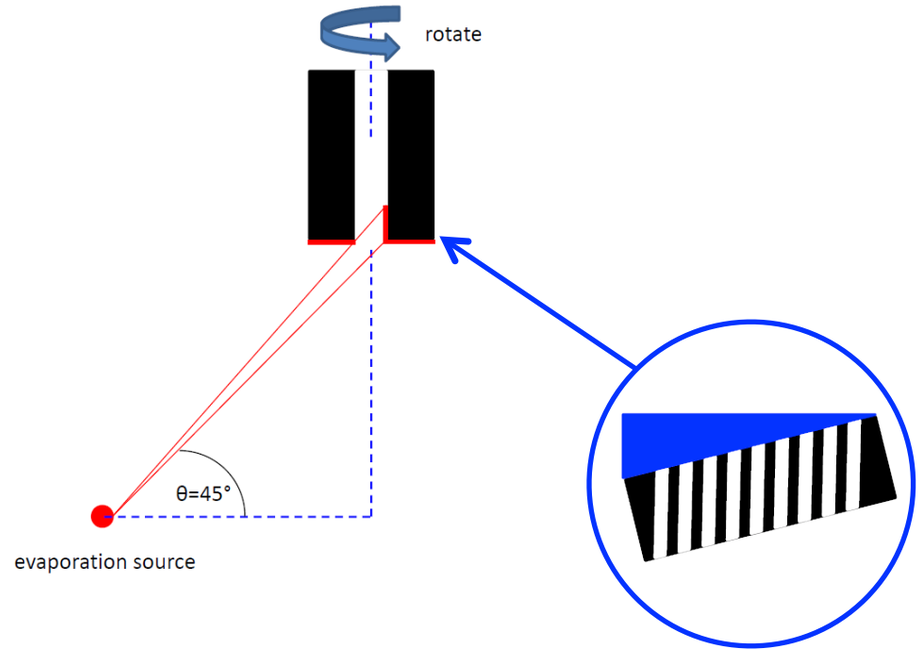
Simulations:



- N(E) becomes more narrow as end spoiling increases

Gain ~ (SEC) $^{(L/z)}$

SEC=secondary electron coefficient
L=pore length
z=distance between collisions



Gain ~ (SEC) $^{(L/z)}$ exp(−0.65h) ⇒ Gain decreases

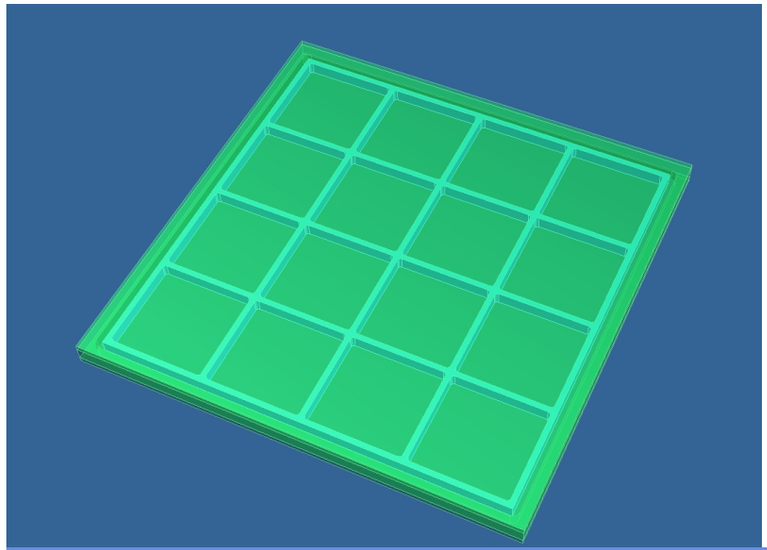
Argonne Processed 20µm Substrates
Summary of Parts

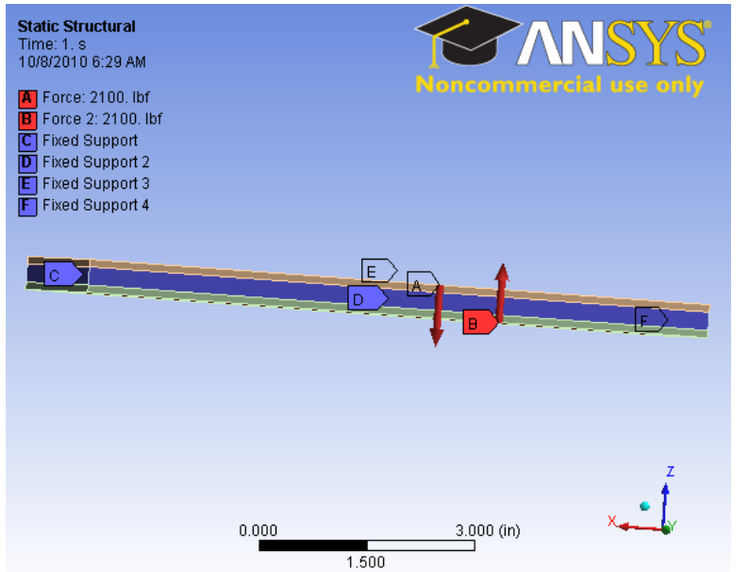
MCP 160

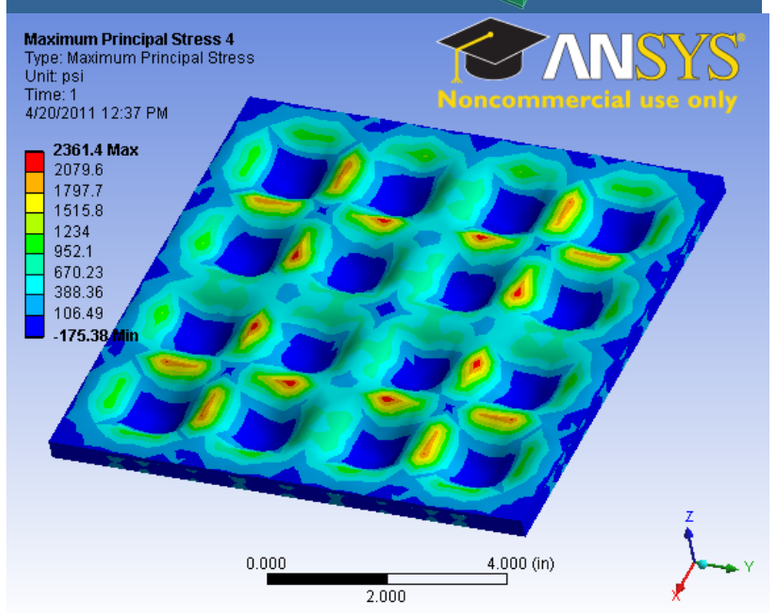
A	C	L	M	N	O	R	S	T	U	V	W	X
	Incc											
Id		Resistive Layer		SEE Layer		Electroding				Annealing	Resistance	
Serial Number	Incom Batch No.	Chemistry	Thickness (Å)	Chemistry	Thickness (Å)	Material	Thickness (Å)	Location	End Spoiling	400C	Air Resistance (Mohm)	Vacuum Resistance (Mohm)
MCP 102	0A-47499	Chem-1	650	Al2O3	55	NiCr	2000	Over	1d	after electrode		
MCP 103	0A-47499	Chem-1	650	Al2O3	55	NiCr	2000	Over	1d	after electrode	40	360
MCP 112	0A-47499	Chem-1	650	Al2O3	55	NiCr	2000	Over	1d	no		
MCP 114	0A-47499	chem-2	800	Al2O3	55	NiCr	2000	Under	1d	no	100	112
MCP 116	0A-47499	chem-2	800	Al2O3	55	NiCr	2000	Under	1d	no		31
MCP 136	1A-31445	chem-2	800	Al2O3	55	NiCr	2000	Over	1d	before electrode	179	185
MCP 137	1A-31445	chem-2	800	Al2O3	55	NiCr	2000	Over	1d	before electrode	164	175
MCP 140	1A-31445	chem-2	850	MgO	75	NiCr	2000	Over	1d	before electrode	99	
MCP 143	1A-31445	chem-2	850	MgO	75	NiCr	2000	Over	1d	before electrode	86	
MCP 145	1A-31445	chem-2	900	MgO	75	NiCr	2000	Over	1d	before electrode	25	25
MCP 146	1A-31445	chem-2	900	MgO	75	NiCr	2000	Over	1d	before electrode	21	21
MCP 160	300-2734-G	chem-02	860	Al2O3	60	NiCr	2000	under	1d	no	55	40
MCP 161	300-2734-G	chem-02	860	MgO	80					before electrode		
MCP 162	300-2734-G	chem-02	860	MgO	80					before electrode		
MCP 166	300-2734-G	chem-02	860	MgO	80					no		
MCP 167	300-2734-G	chem-02	860	Al2O3	60					before electrode		
MCP 168	300-2734-G	chem-02	860	Al2O3	60					before electrode		

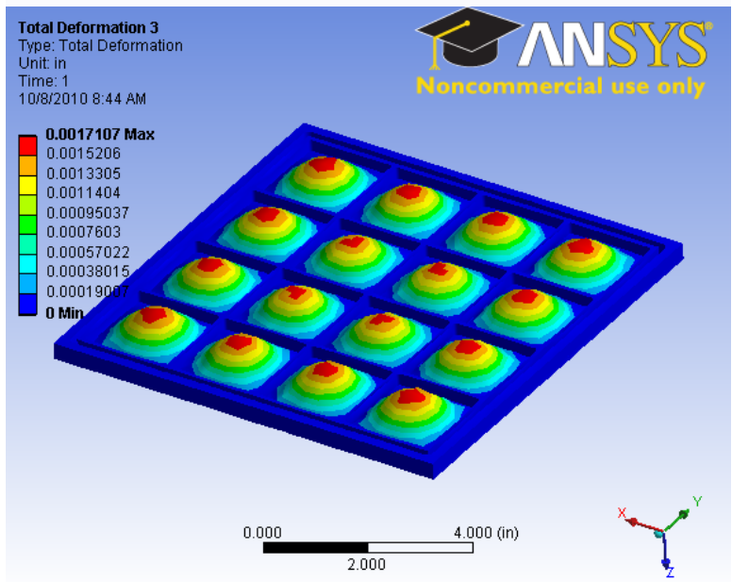
FEA Analysis of Grid Spacer Loading

Grid Spacer Stress Analysis based on 28 psi loading





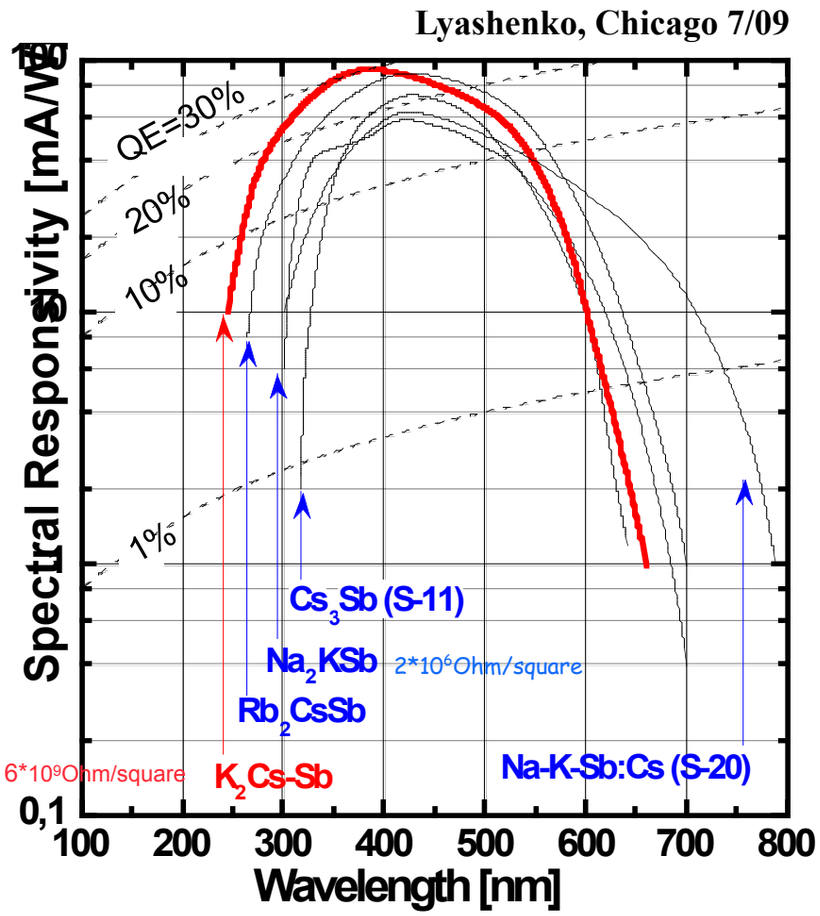


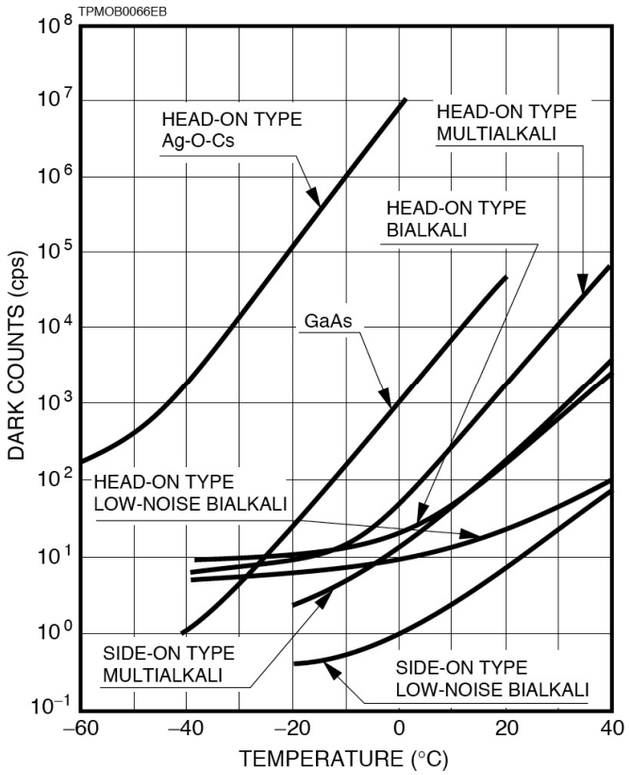


Safety factor of 2.3 (actual bending vs. ultimate) - 350 psi compressive load thru stack

Maximum bending stress for B33 is 3626 psi

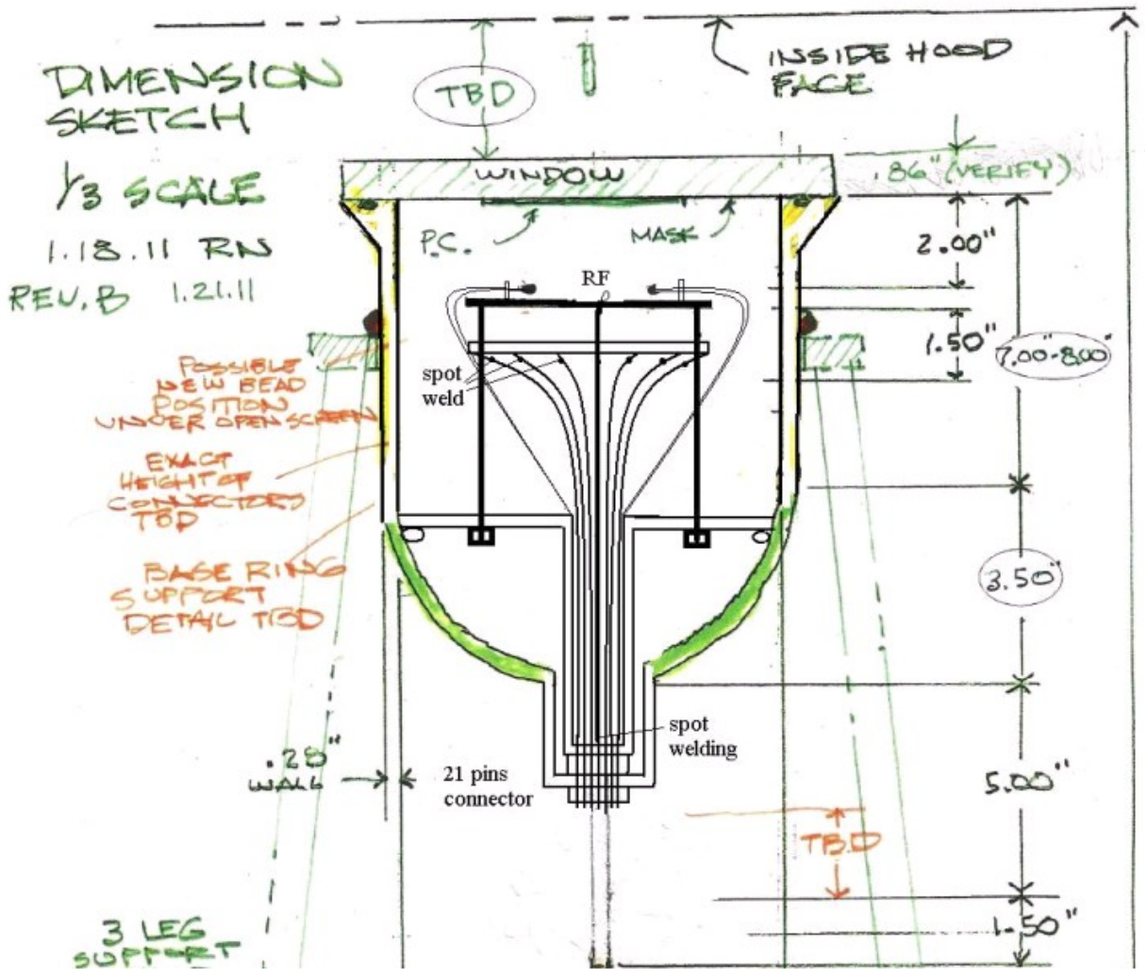
Typical Bi-Alkali Cathode Characteristics





Cathode Noise vs Temp
expect 10,000 to 40,000 events/sec for 8” tube bialkali!

Bialkali Photocathode -- Scale-Up to 4” Photocathode



Mount for alkali and Sb metal beads

“Chalice” fabrication in Argonne Glass Shop

Chamber for Testing 8”×8” MCP Plates