Development of a Lower Cost Large Area Microchannel Plate Photodetector

for the Large Area Picosecond Photodetector Development Collaboration
Bob Wagner, Argonne National Laboratory

Workshop on the Latest Developments of Photon Detectors
Ringberg Castle, Tegernsee, Germany
Tuesday 01 Nov 2011

Introduction & Outline

- Parallel Efforts at SSL/Berkeley and Argonne/Univ. of Chicago
  - Many results from SSL presented by Ossy Siegmund
  - Electronics and timing covered by Henry Frisch
  - Photocathode science discussed by Klaus Attenkofer
- This Talk
  - Details of substrate and atomic layer deposition (ALD) functionalization development
  - All glass packaging for low cost production
  - Results from Argonne
    - MCP testing
    - Photocathode fabrication
    - Detector vacuum sealing

MCP-PMT Module & Readout Concept

2×3 array of MCP Tiles for paneling detector, e.g. water Cherenkov tank

Strip readout pattern
3.8mm strips, 5mm pitch (40 strip anode)
4.6mm strips, 6.8mm pitch (30 strip anode)
Coordinate readout:

- Time difference along strip
- Charge division for ⊥ direction

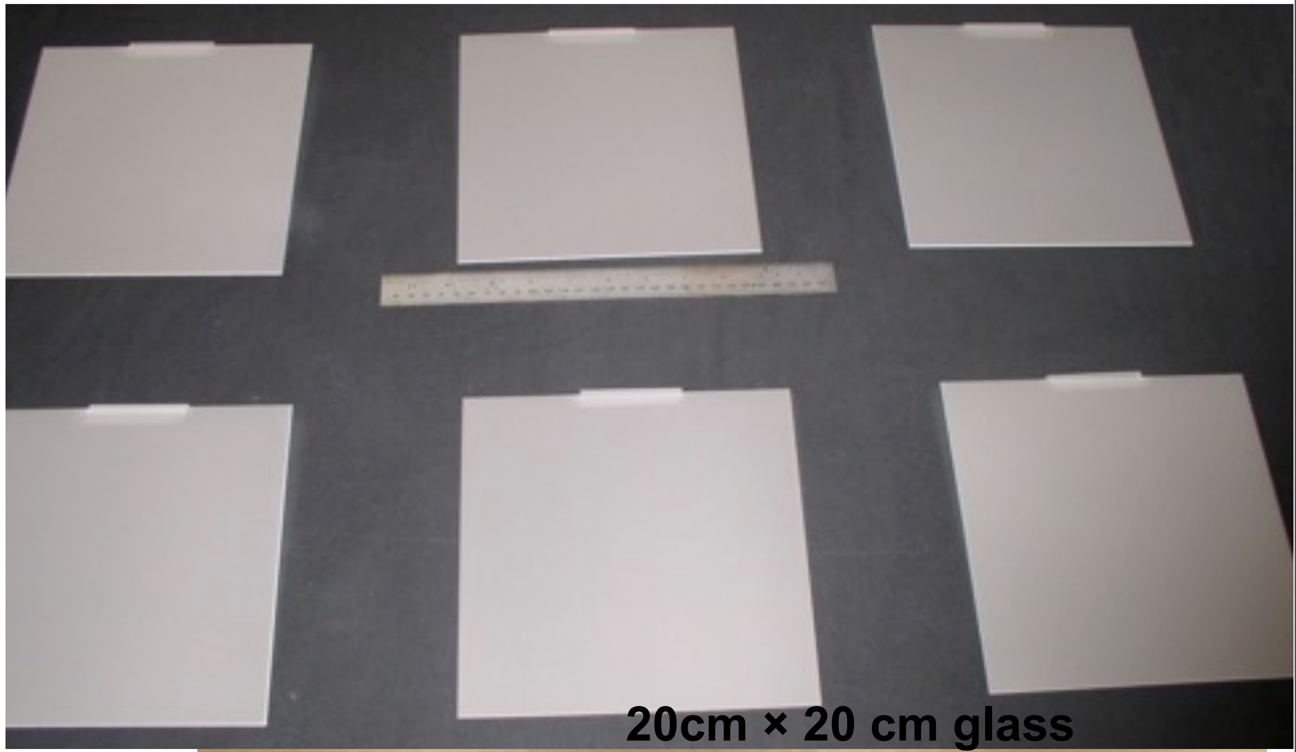
LAPPD Project Scope

Large, Low Cost, 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)
  - Anodic aluminum oxide (AAO) (research concluded) -- ceramic
- Pore activation via Atomic Layer Deposition (ALD)
  - Separate glass substrate, resistive layer, and secondary emission layer
  - Optimize resistive and emissive behavior 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%
  - Bialkali (baseline), multialkali
  - "III-V" materials, e.g. GaAs, GaN, InGaN
  - Systematic program of photocathode development and analysis
- Waveform sampling switched capacitor array ASIC for readout

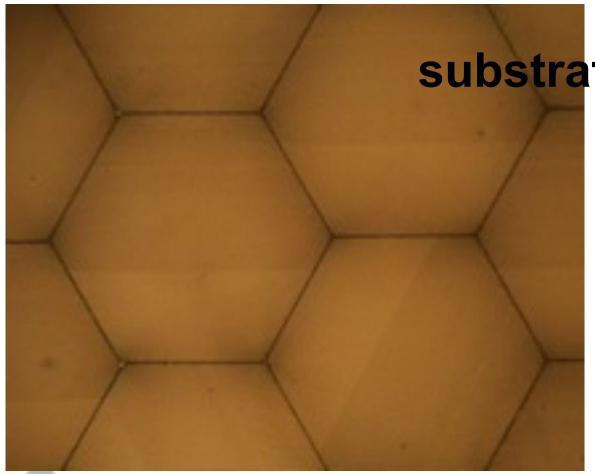
Glass Capillary Substrate Development

- Borosilicate glass capillary substrates from Incom, Inc. (Charlton, MA, USA)
- Technology development on 32.8mm diameter disk substrates
  - 20µm (L/D=60) & 40µm (L/D=40) pore size
- 20cm × 20cm plates for working detector
  - (18) 40µm pore substrates delivered
  - (35) 20µm pore substrates delivered
  - Baseline is 20µm pore
- 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

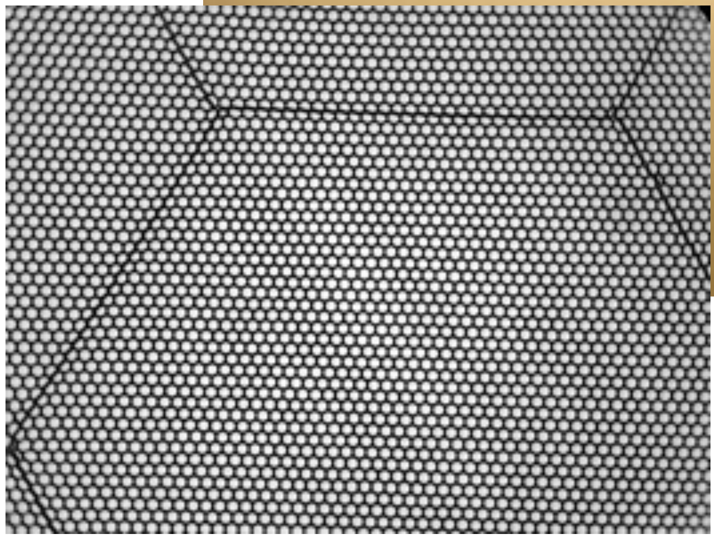


20cm × 20 cm glass substrates October, 2011

photo credit: Joe Gregar, Argonne



substrate detail 2010



substrate detail August, 2011

photo credit: Jason McPhate, SSL

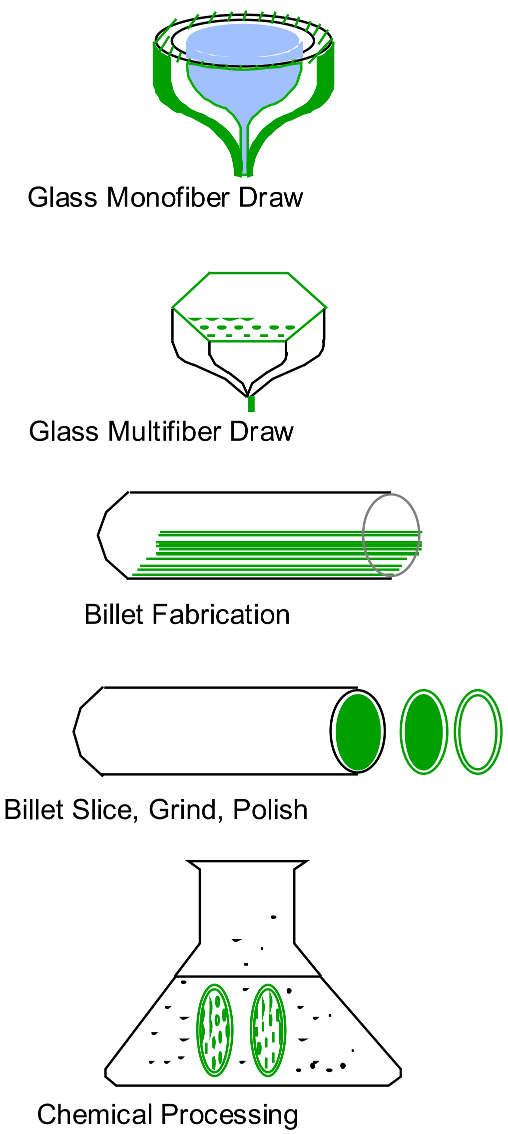
Commercial Microchannel Plate Fabrication

Graphic Credit: B. Laprade & R. Starcher, Burle (2001)

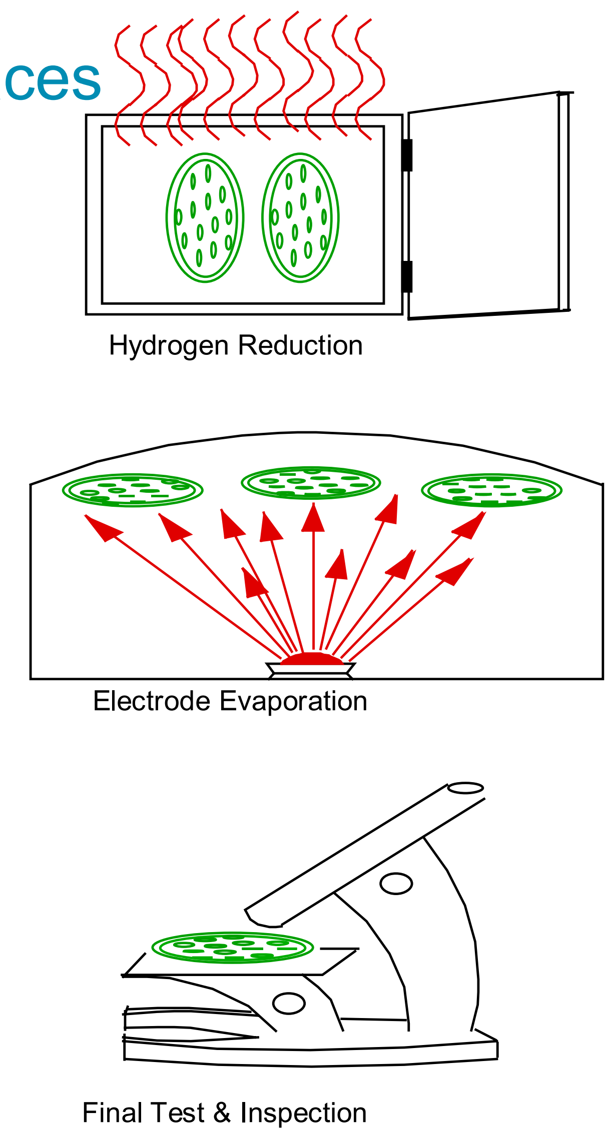
Glass is gravity-fed via cylindrical furnace

Glass is typically lead glass tube with solid soft glass core
Borosilicate glass capillaries are hollow core

Chemical processing to remove soft core glass
hollow core glass capillaries skip this step

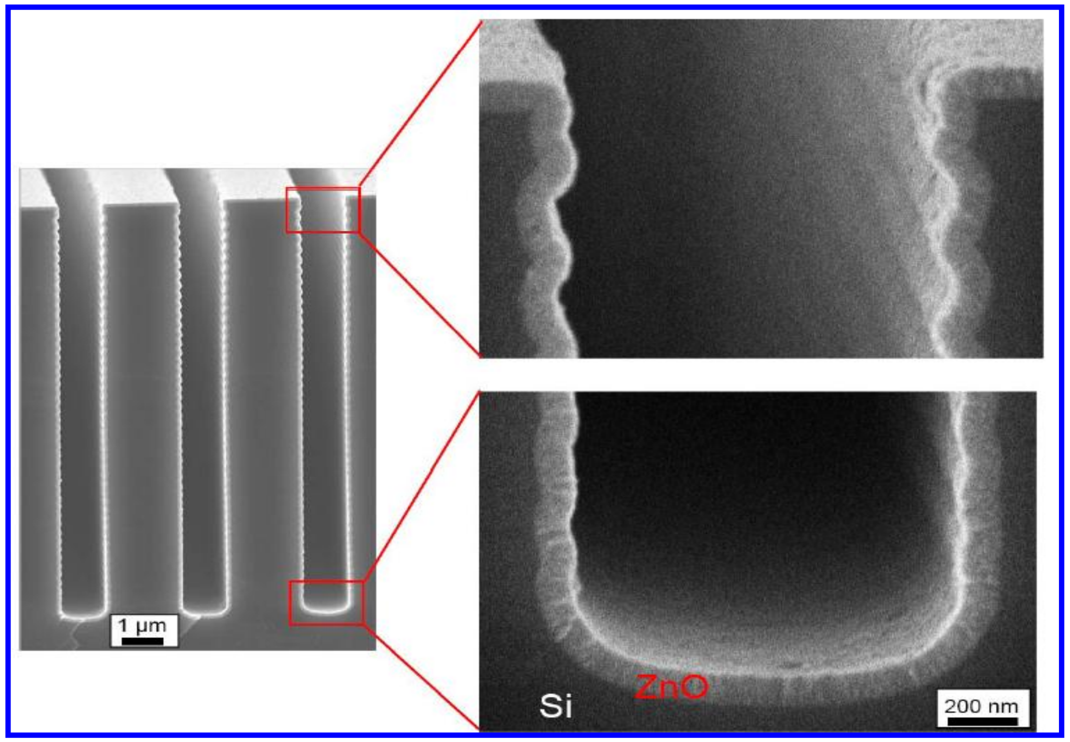


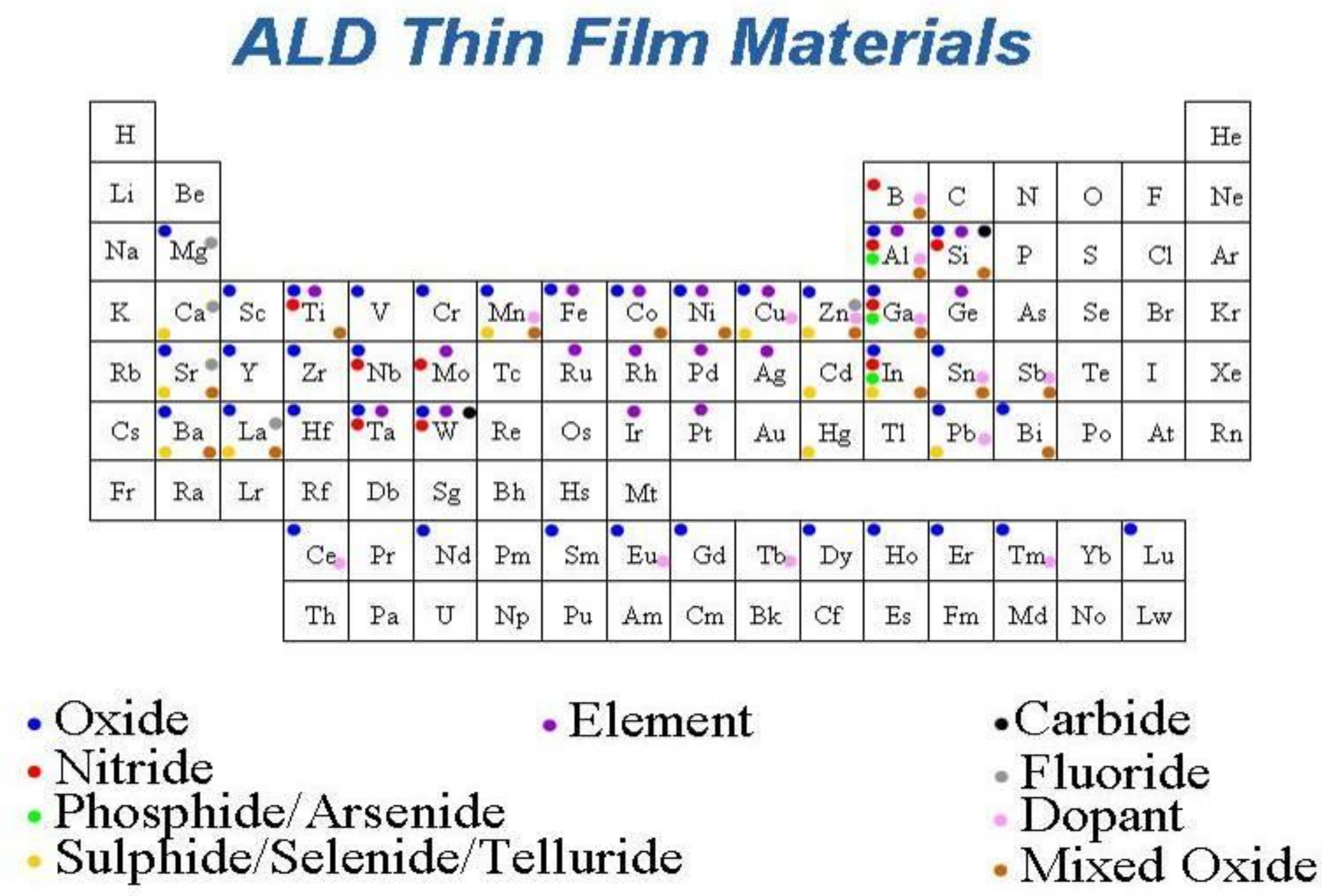
ALD replaces this step



Before sealing in tube, plate must be subjected to prolonged exposure to electrons at low voltage to outgas H_2 and other material
ALD process greatly reduces scrub time

Pore Activation via Atomic Layer Deposition



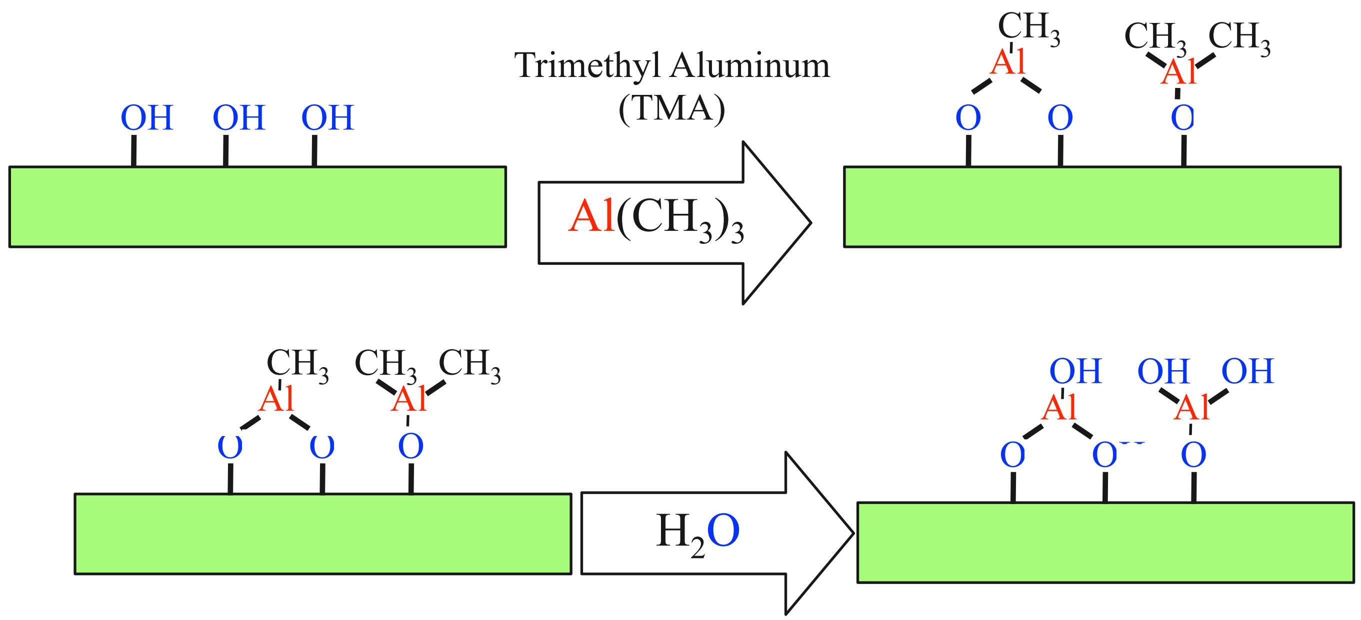


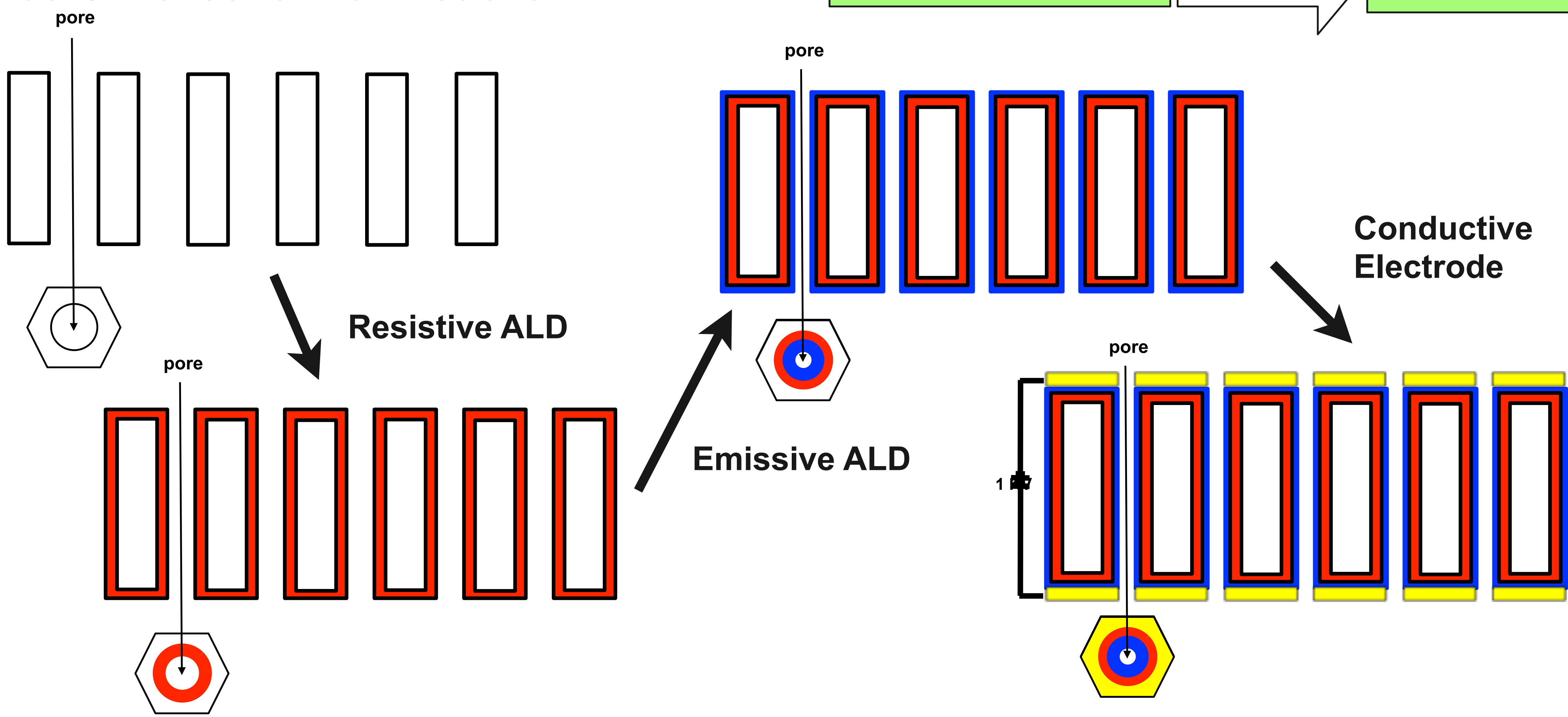
- Conformal, self-limiting process
- Molecular mono-layer thickness control
- Large variety of applicable materials

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



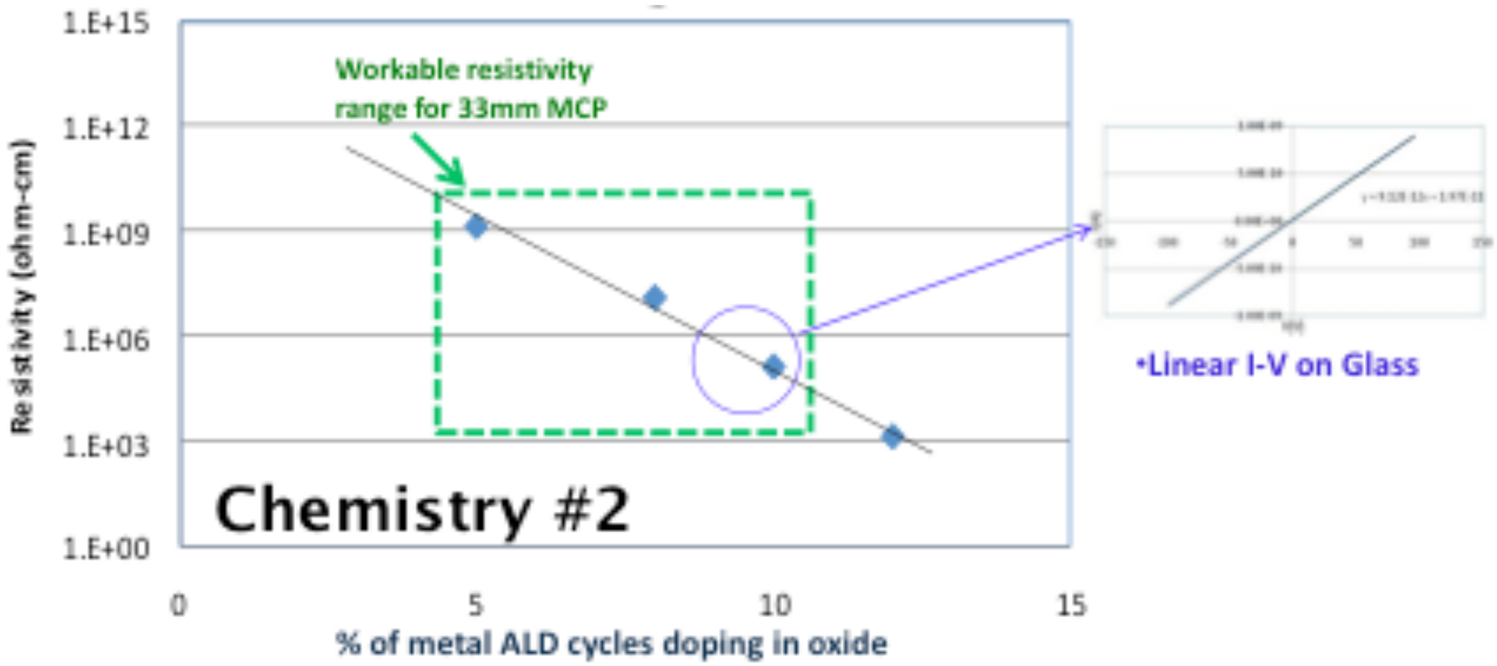


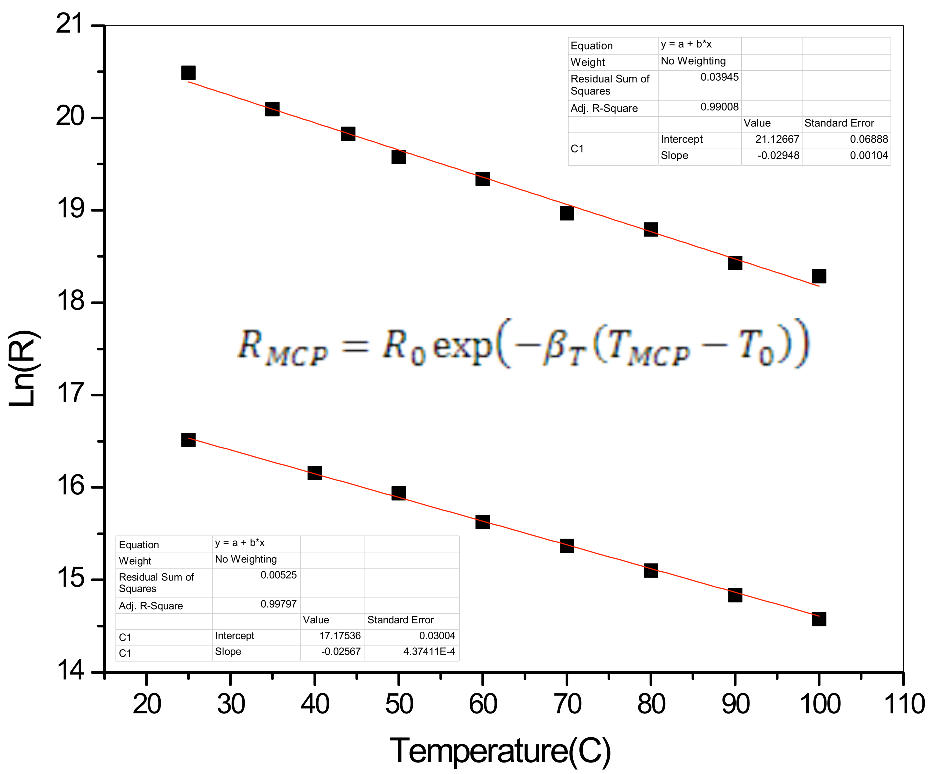
Development of Lower Cost Large Area MCP Photodetector, R. Wagner, Argonne, LIGHT11, Ringberg Castle, 20111101

ALD Functionalization of Micro-Channel Plates

Three new ALD chemistries for resistive coating developed at Argonne

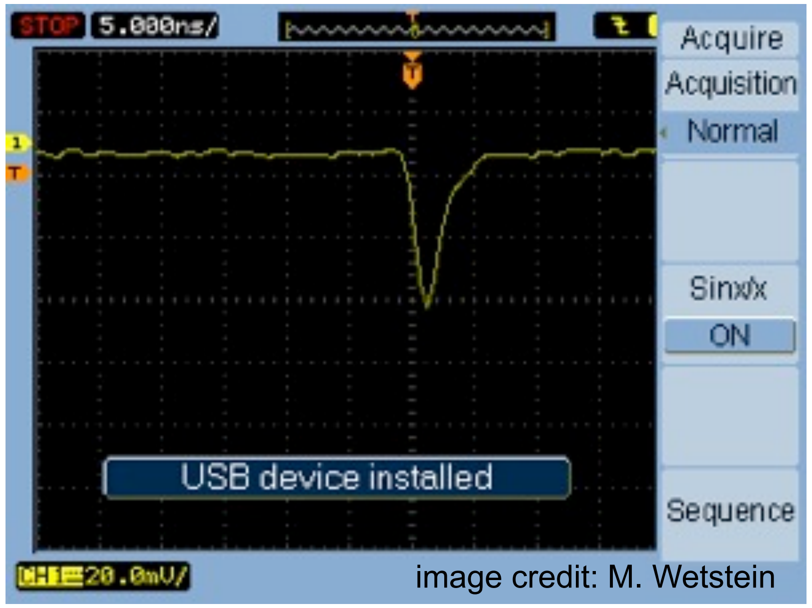
Resistance is reproducibly tunable





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

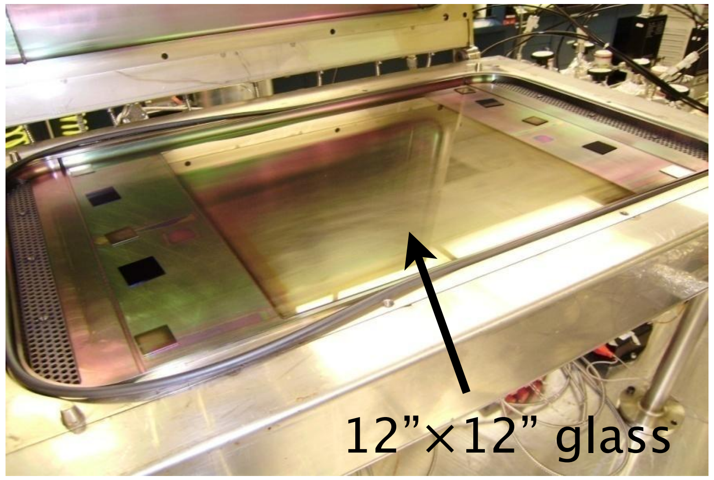
Al_2O_3 Secondary Emission Layer

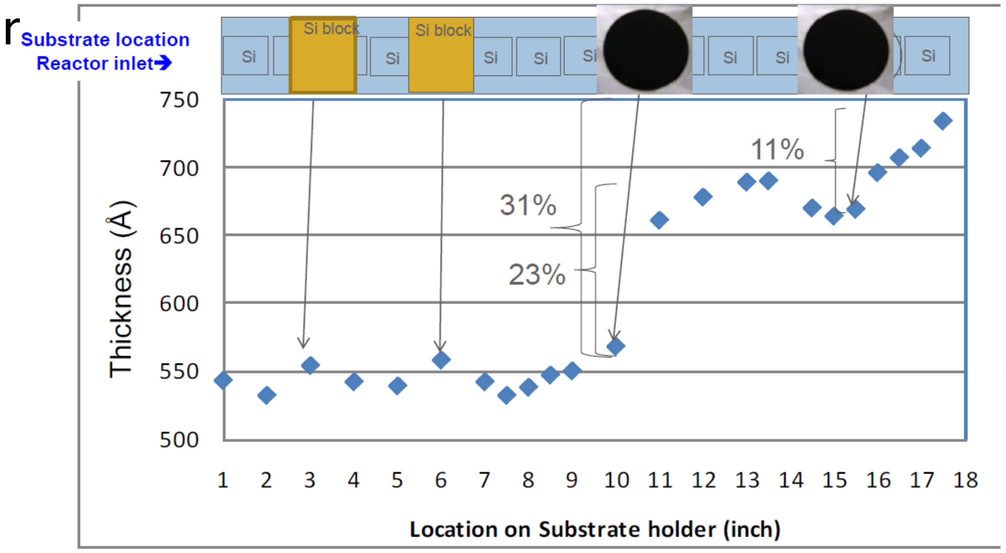


Signal from MCP pair coated with Chem. 2 resistive layer + Al_2O_3 emissive layer

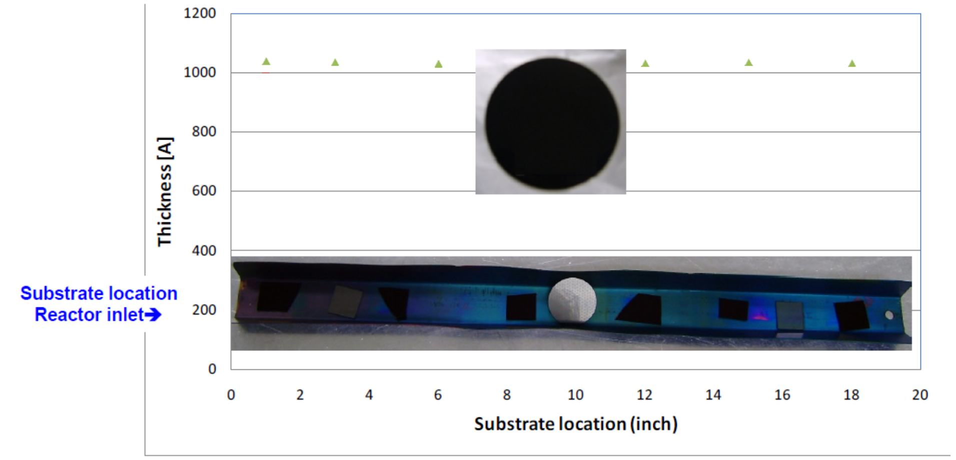
Scale-up to Large Surface Area

Process scale-up on large reactor

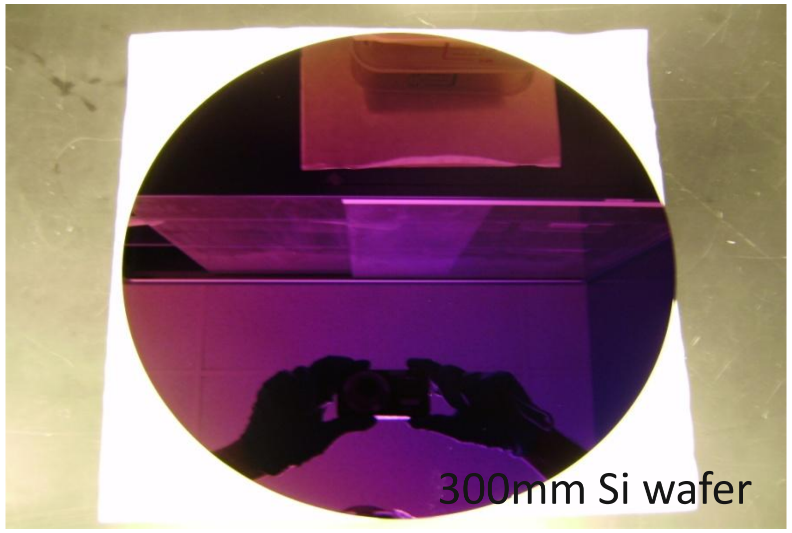




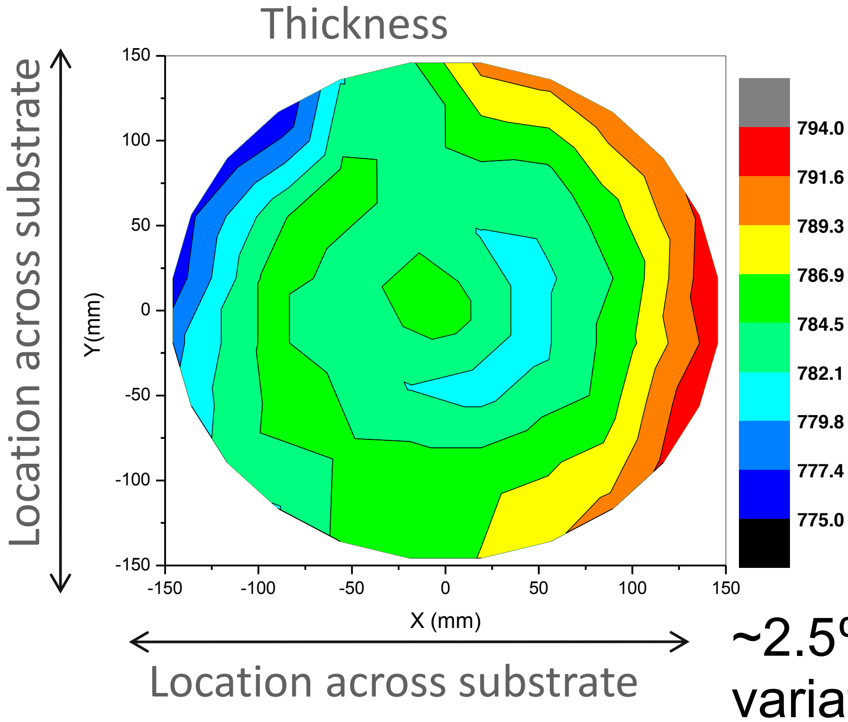
Chemistry #1:
1% thickness increase across Si wafers
Up to 30% increase after MCP locations



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



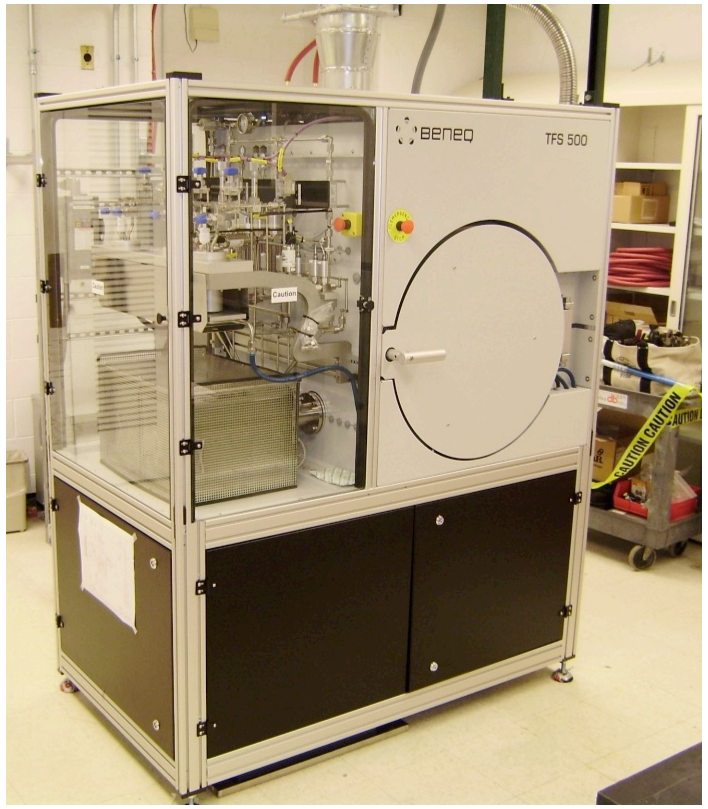
300mm Si wafer coated with Chemistry #2



~2.5% thickness variation across wafer

Scale-Up of ALD Processing -- Beneq Reactor

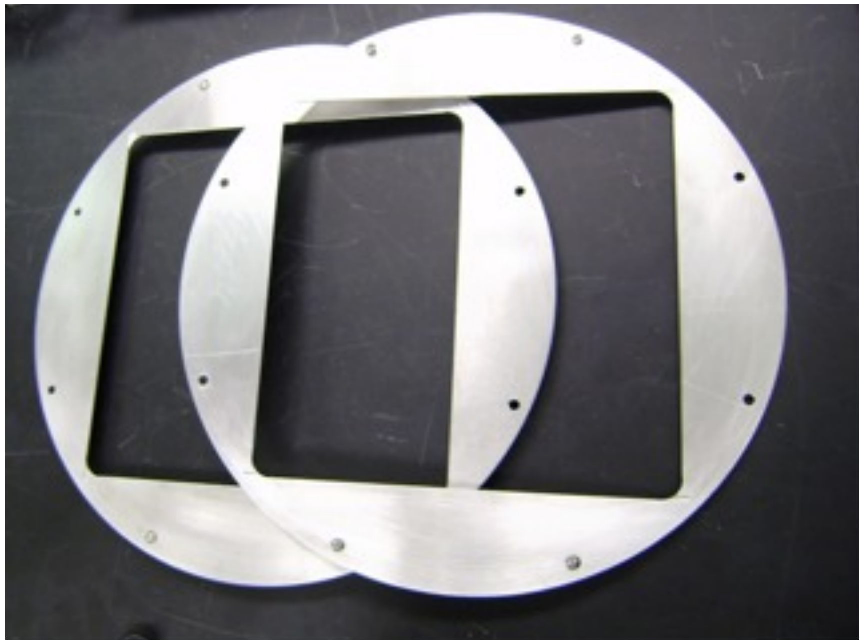
Arrived 18 May 2010



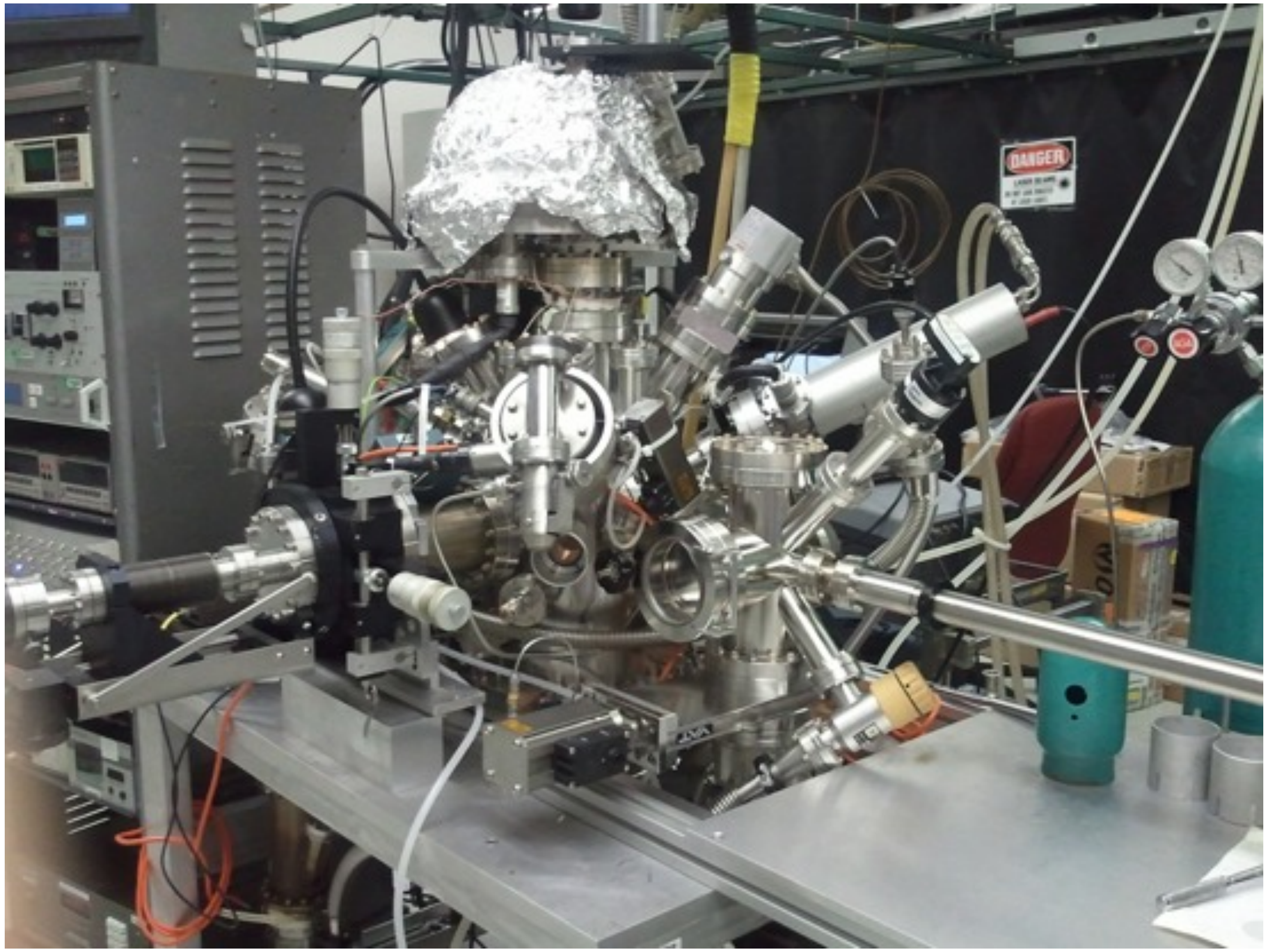
Studying ALD on Large Surface Areas

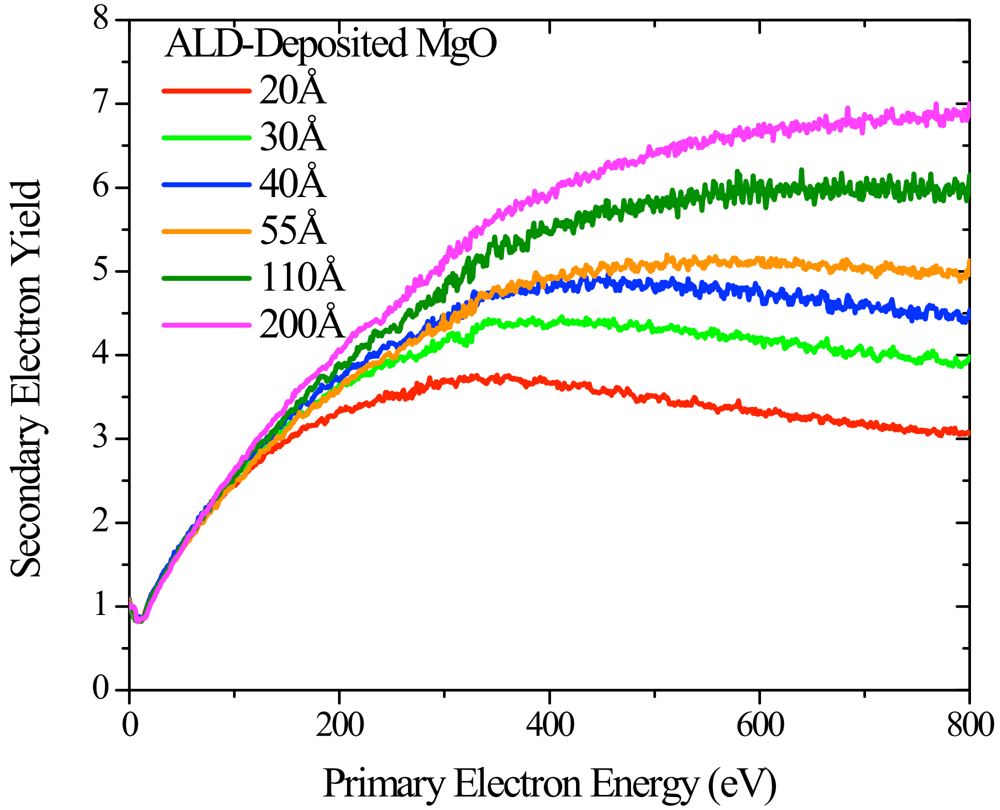
- 33mm disk surface area is $0.13m^2$
- 8”x8” surface area is $6.4m^2$
- 20 MCPs area is $129m^2$

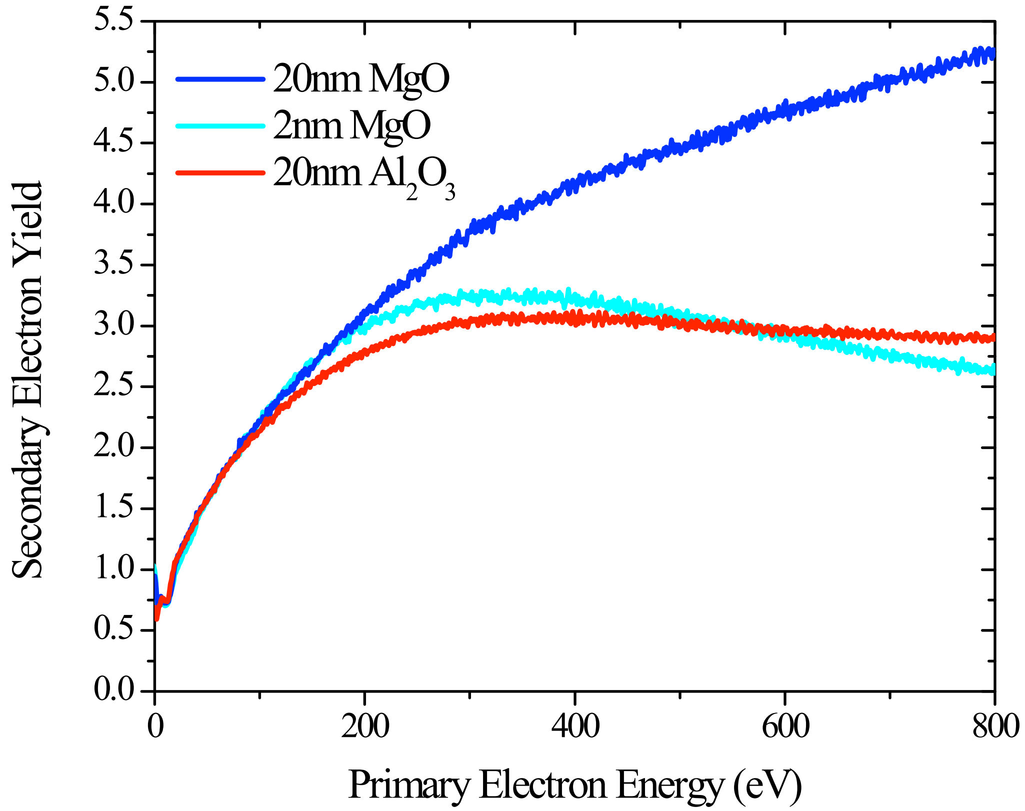
Stackable 20cm × 20cm plate holders for multiple plate coating in Beneq Reactor



Secondary Emissive Materials Characterization



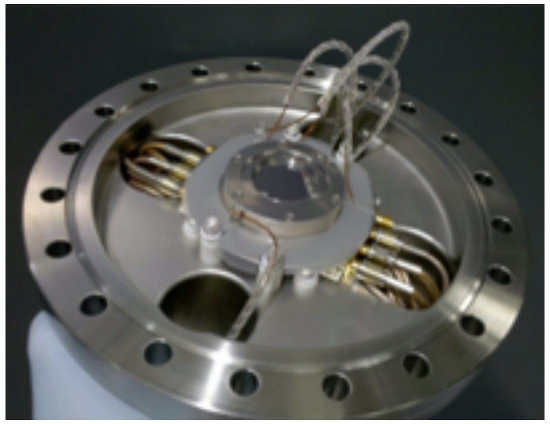


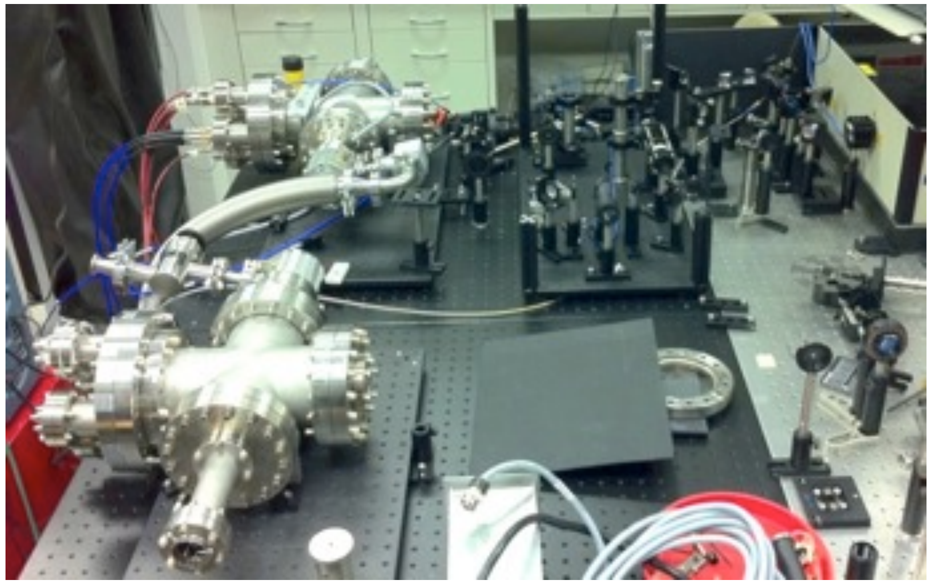


Characterization Chamber

- UV Photoelectron Spectrometer
- X-ray Photoelectron Spectrometer
- Low Energy Electron Diffraction

MCP Testing at Argonne -- APS UV Laser Facility

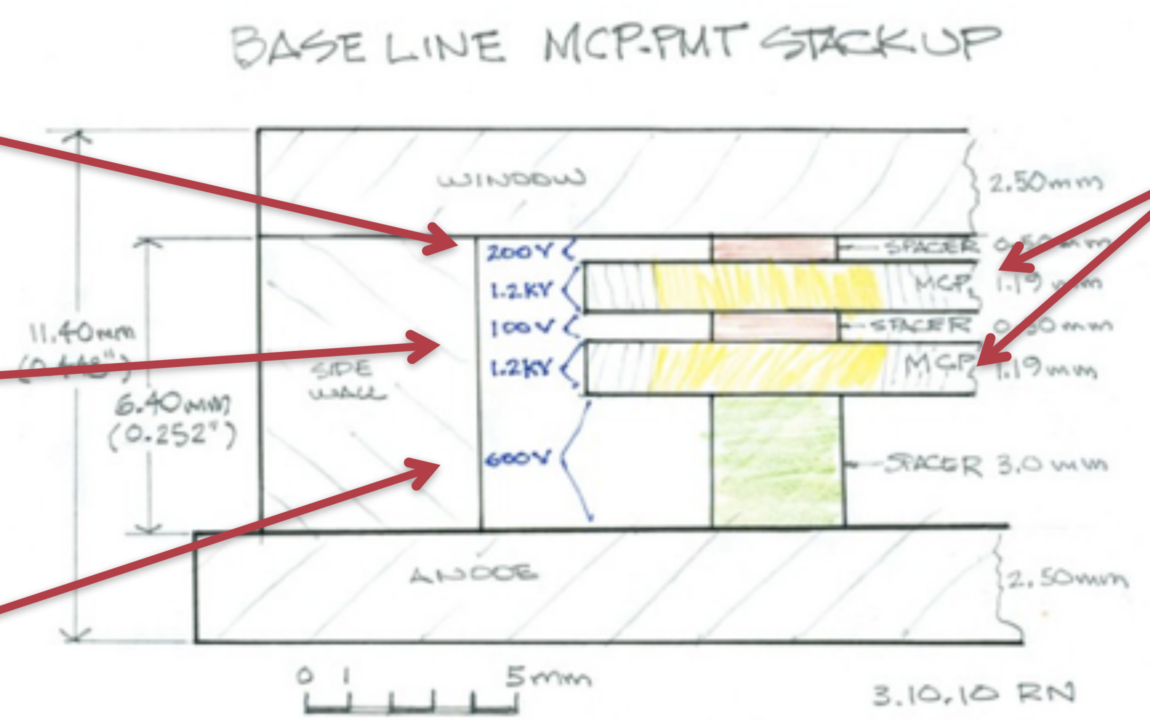




Gap 1: “first strike”
Impacts on variability of transit time and amplification

Gap 2: Impact on saturation of MCP pair, spatial spread of signal

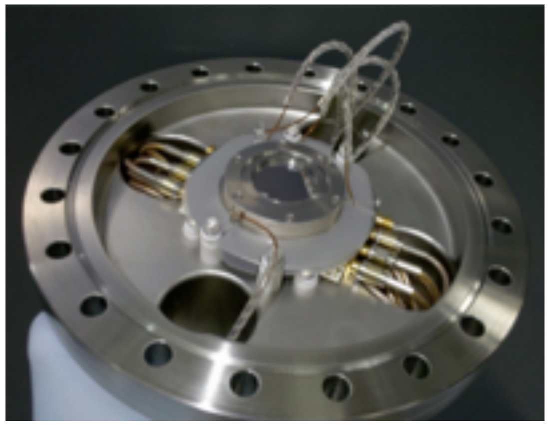
Gap 3:spatial and temporal spreading of the charge cloud. Space charge effects. Interface with anode.

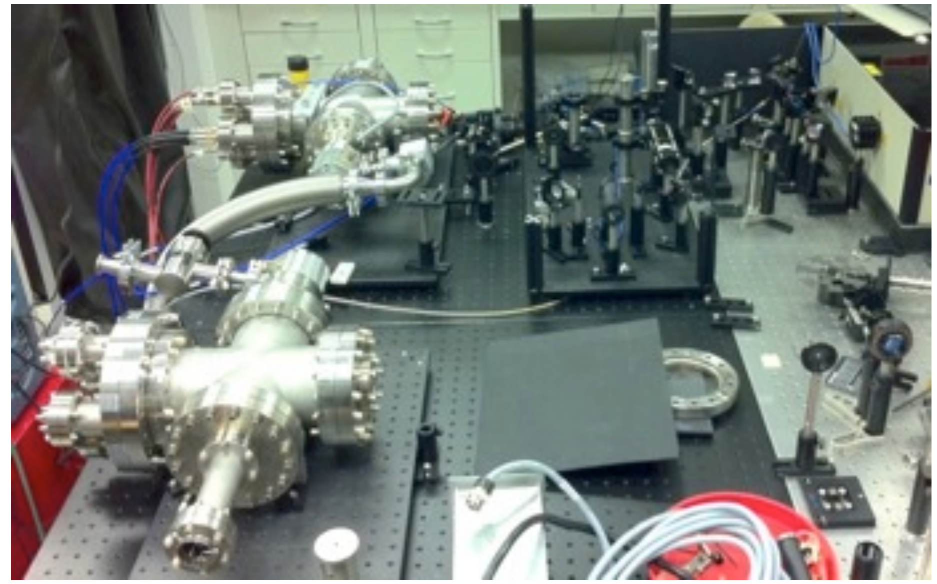


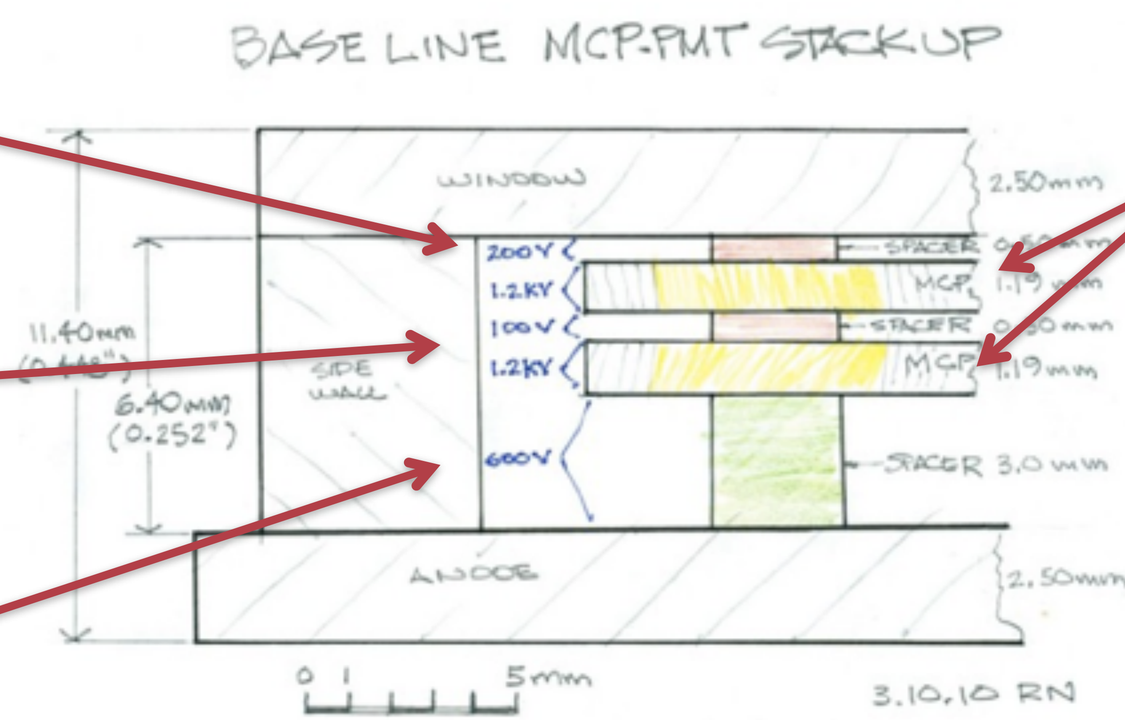
Operational voltages
Plate geometry (pore size, L/D)
Chemistry (SEE, resistive layer)
- Plate quality
- Uniformity
- Noise
- Stability

Plate resistance
- Saturation
- Relaxation time

MCP Testing at Argonne -- APS UV Laser Facility







Gap 1: "first strike"
Impacts on variability of transit time and amplification

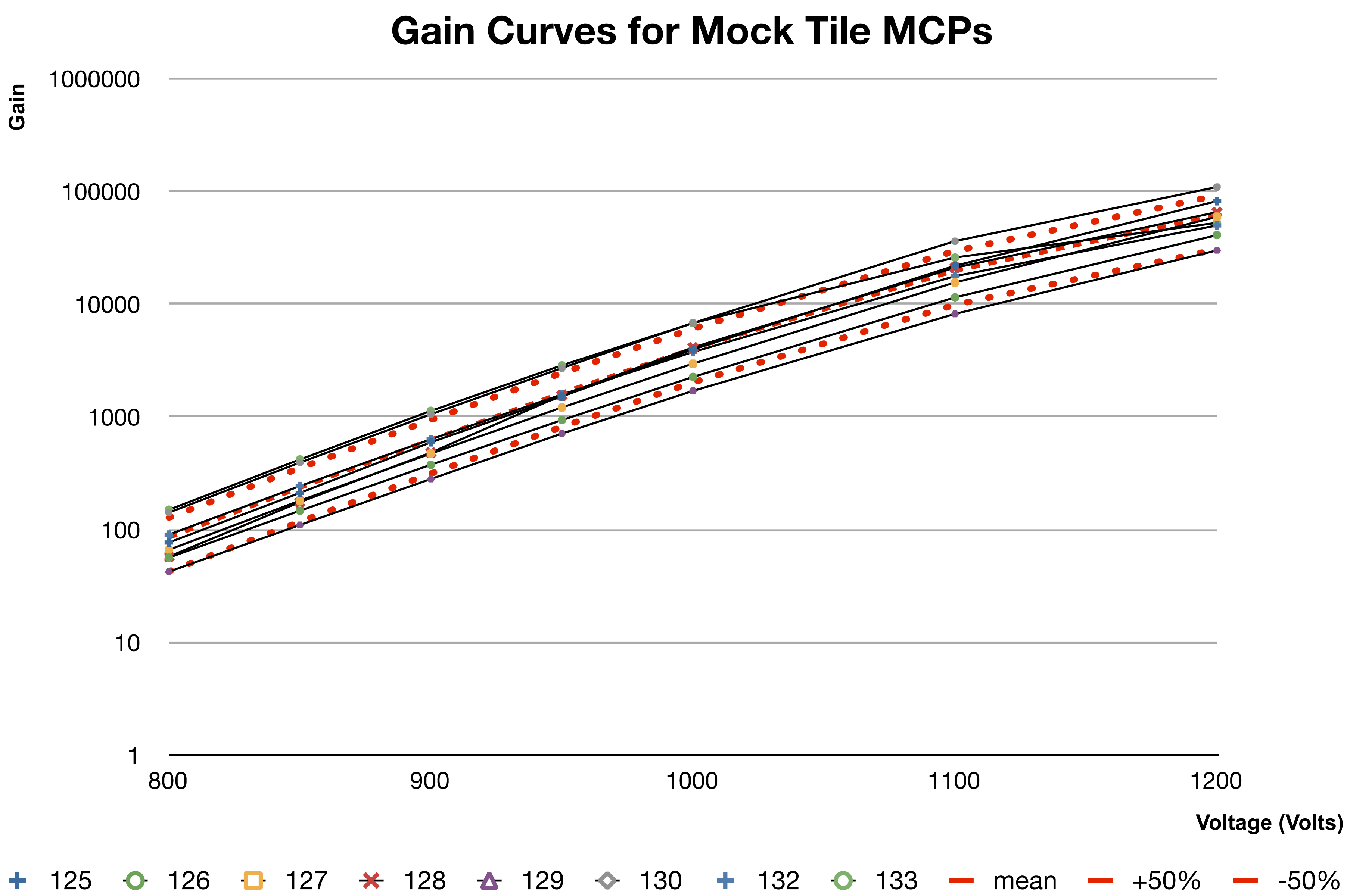
Gap 2: Impact on saturation of MCP pair, spatial spread of signal

Gap 3:spatial and temporal spreading of the charge cloud. Space charge effects. Interface with anode.

Operational voltages
Plate geometry (pore size, L/D)
Chemistry (SEE, resistive layer)
- Plate quality
- Uniformity
- Noise
- Stability

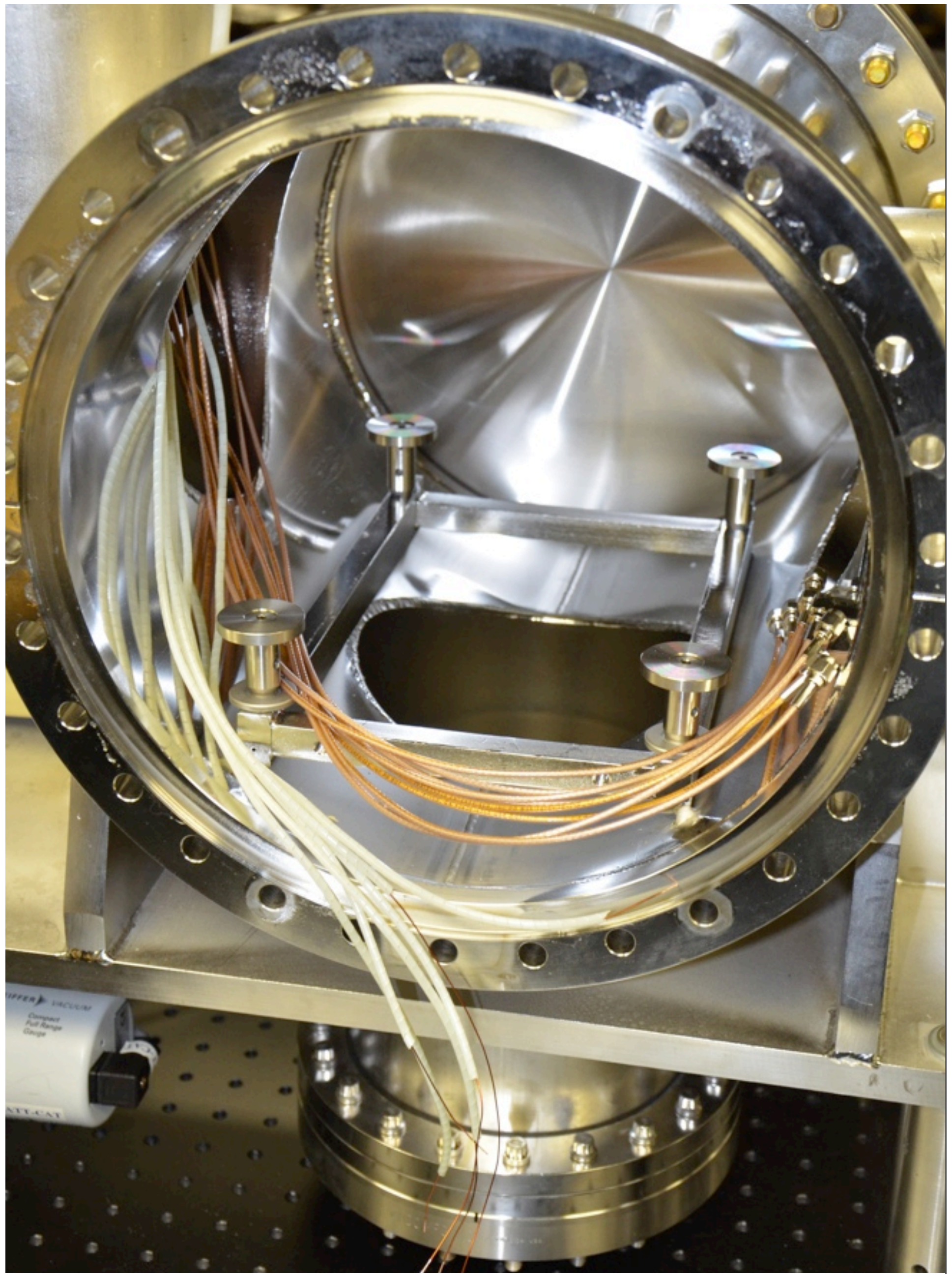
Plate resistance
- Saturation
- Relaxation time

MCP Testing at Argonne -- “Mock Tile” MCPs

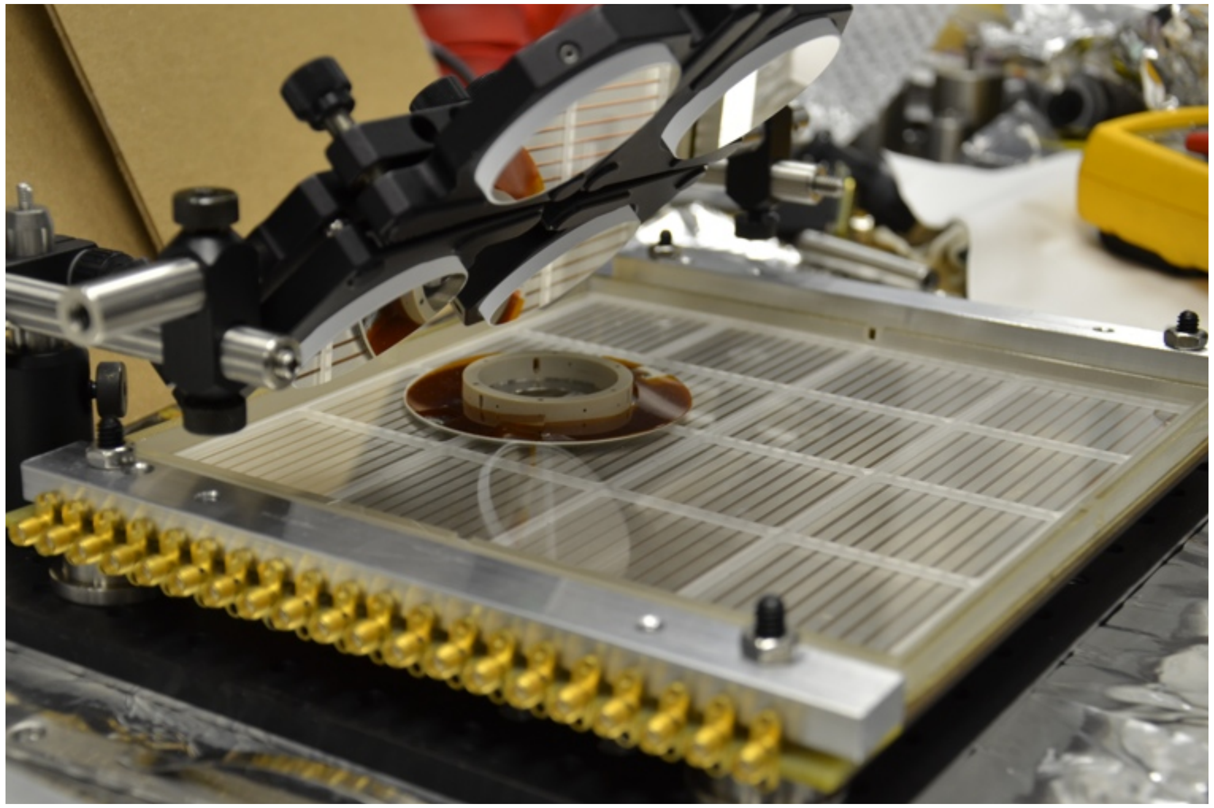


Eight 33mm MCP disks functionalized with identical “Chemistry 2” resistive coating and Al_2O_3 SEE layer

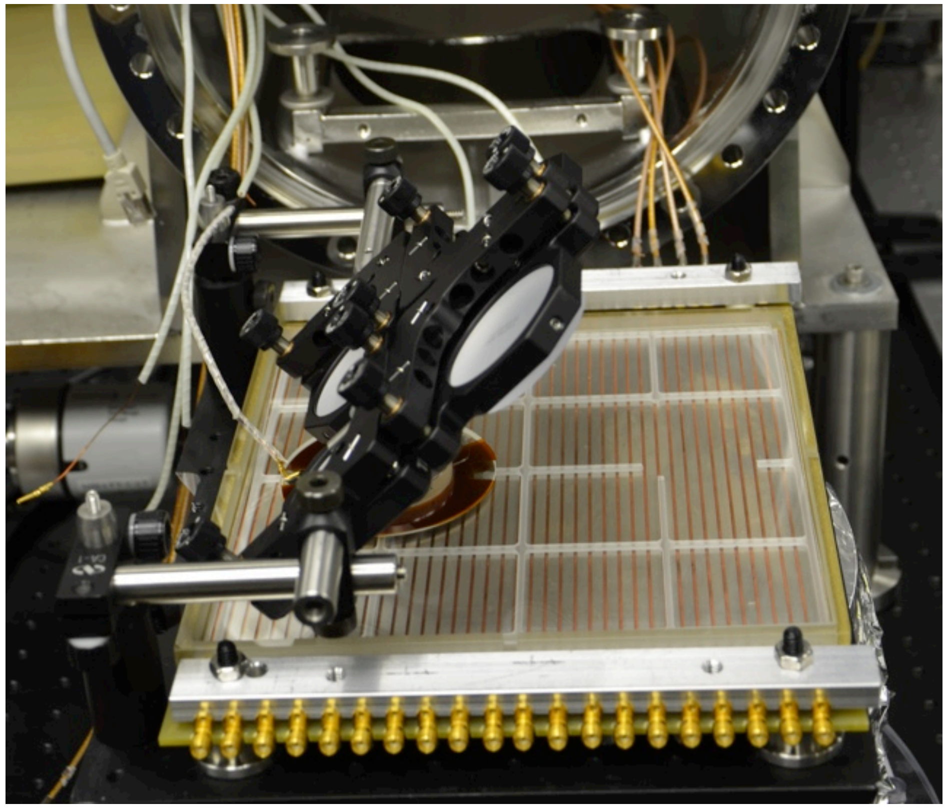
Commissioning of 8” Test Chamber at Argonne APS



8” MCP Vacuum Test Assembly

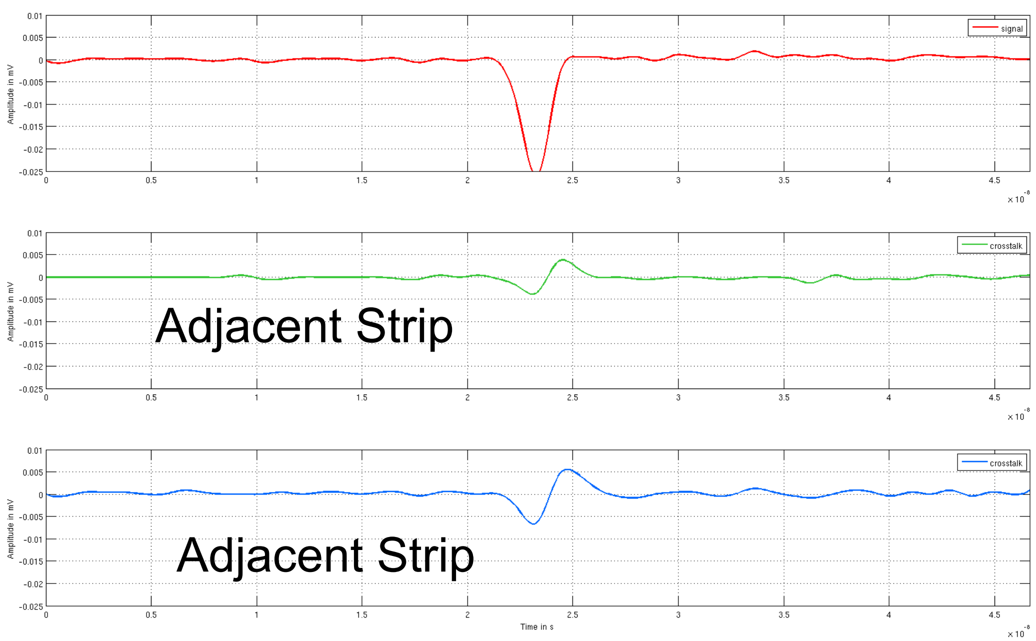


8” Tile base with 33mm MCP pair ready for insertion into chamber



First Pulse Measurements with 8” Anode Strip Line

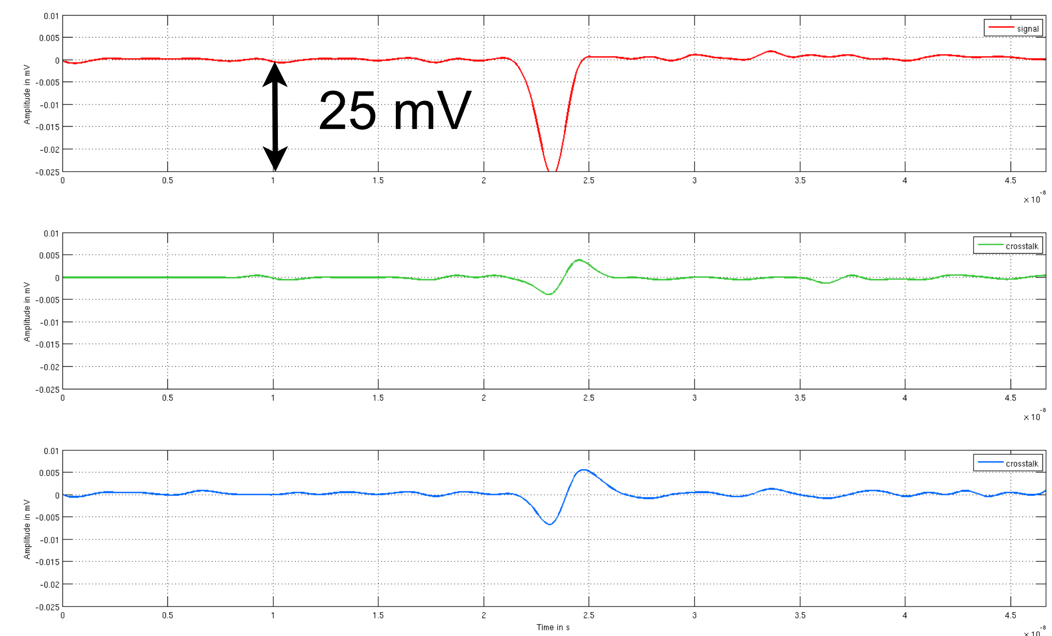
5 ns



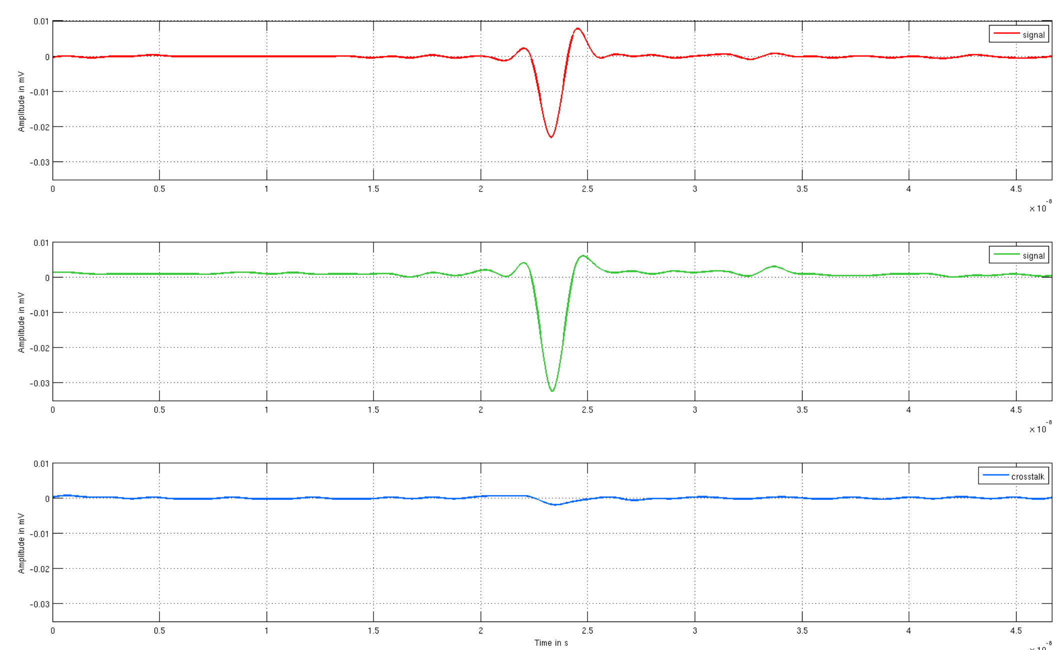
Signal

Crosstalk

Crosstalk



30 mV

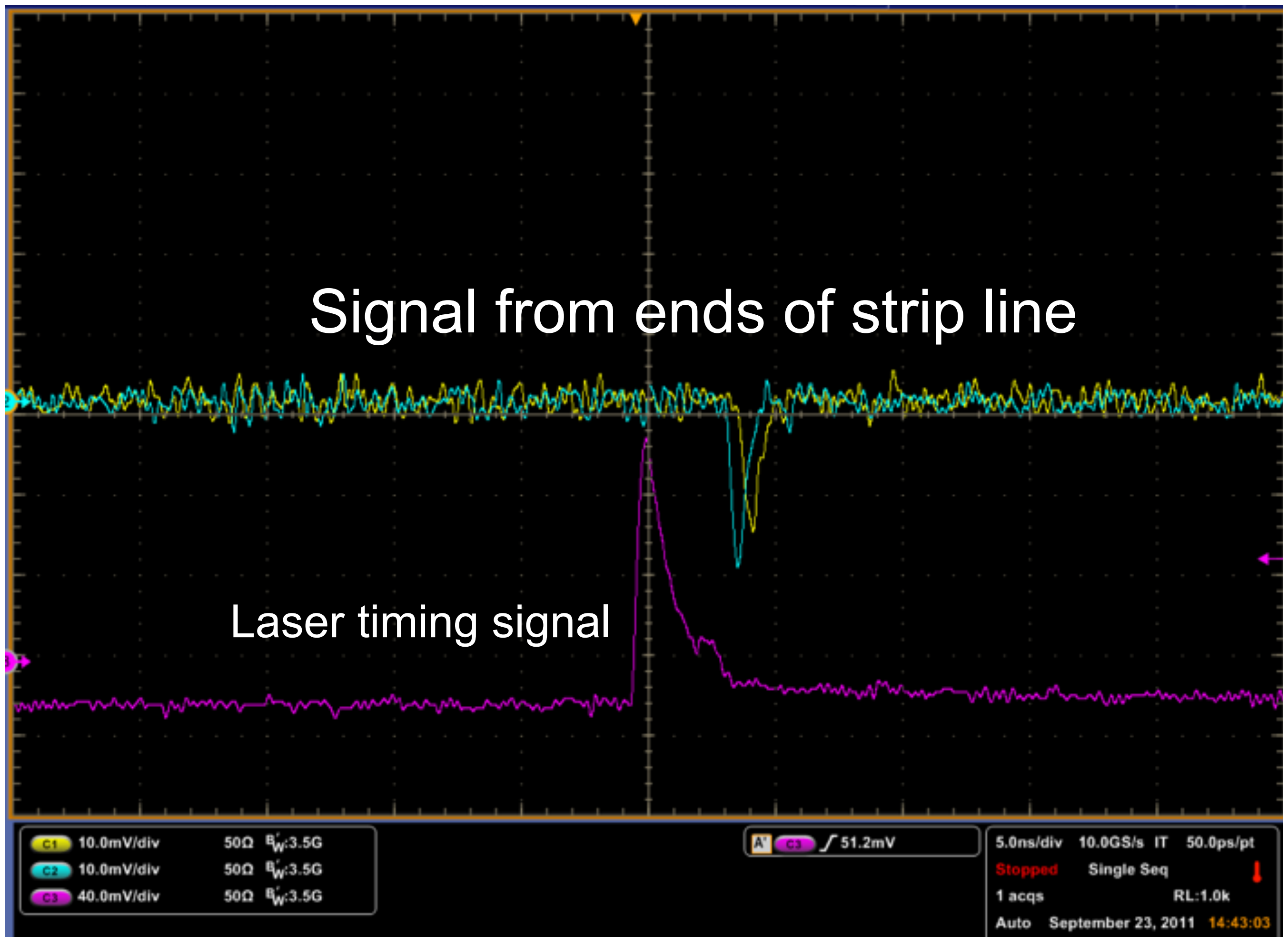


Signal

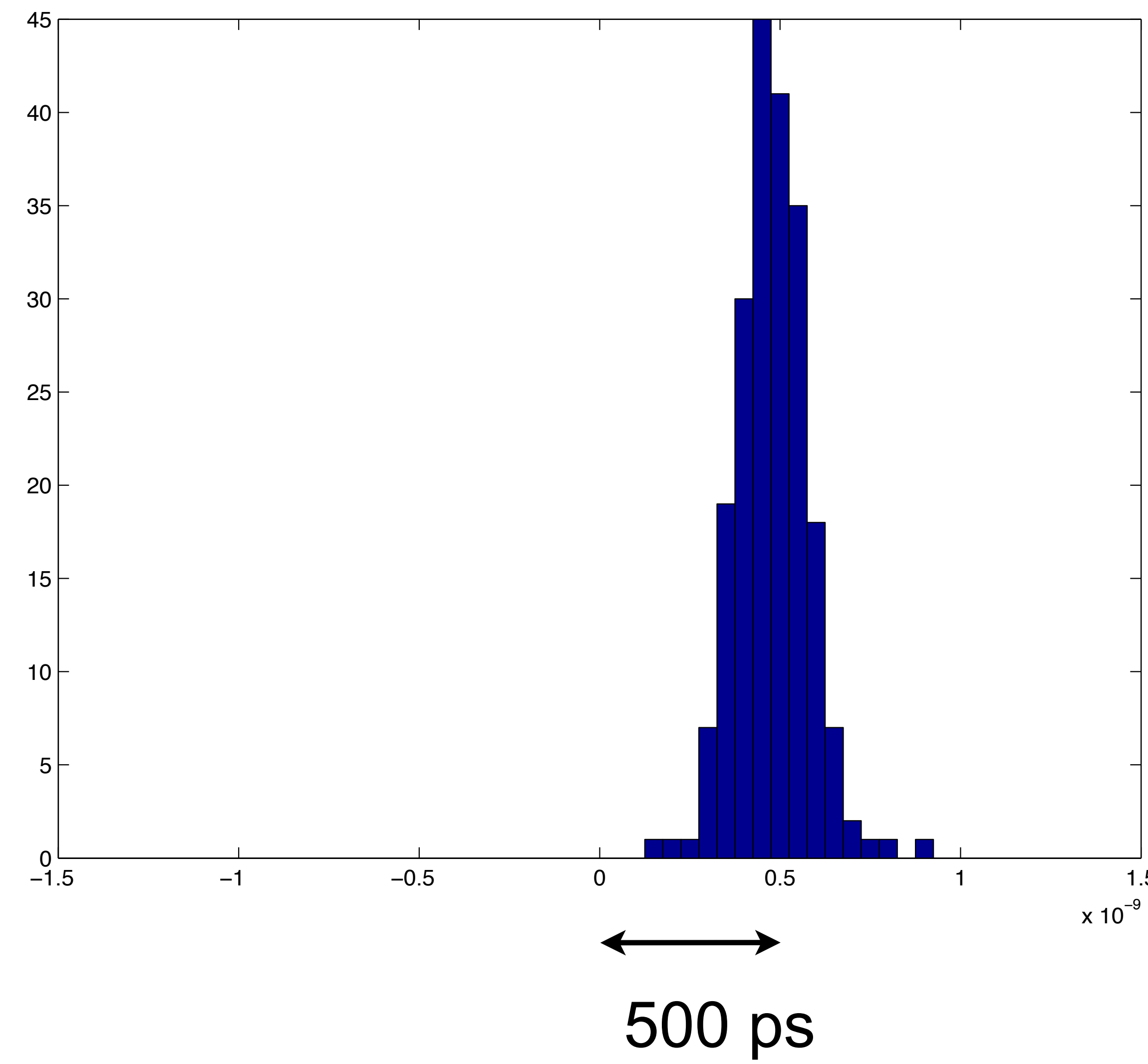
Signal

Crosstalk

First Pulses on 20cm × 20cm MCP Plate



differential arrival time distribution

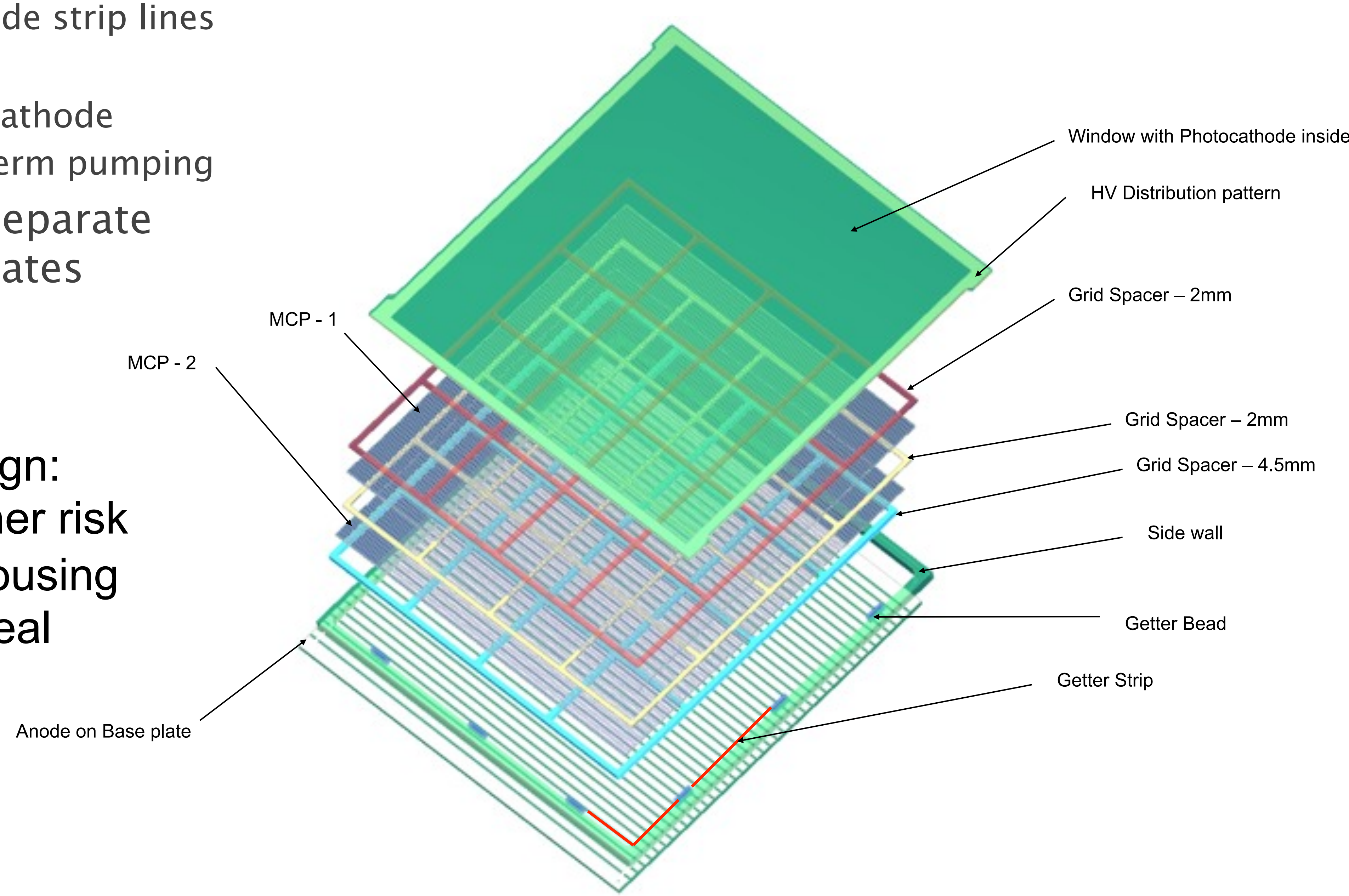


Simple soldered wire connection to strip line
Readout and differential timing with fast scope

Hermetic Packaging

- For working MCP Photodetector, need to provide
  - Functionalized, Scrubbed MCP Plates
  - Vacuum tight housing
    - Bottom plate with anode strip lines
    - Sidewall
    - Top plate with photocathode
    - Getter strip for long term pumping
  - Support/Spacers to separate MCPs, bottom/top plates

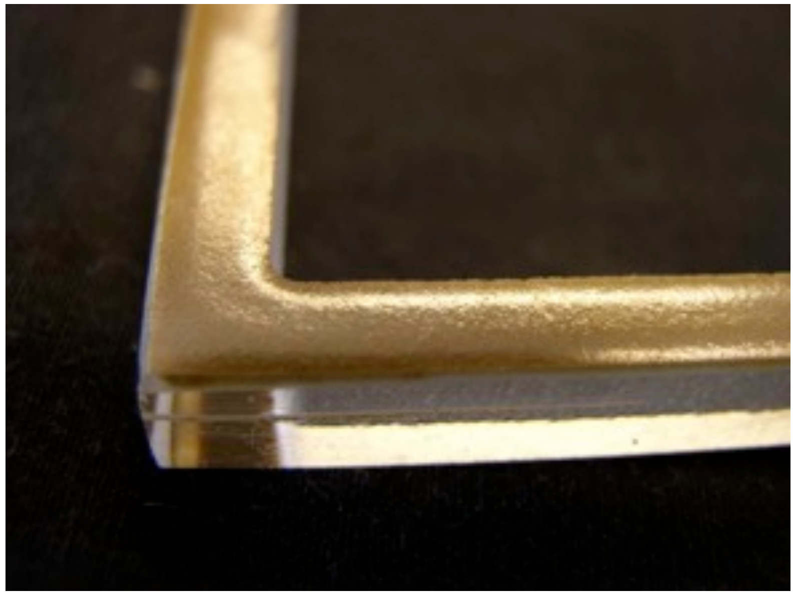
Borosilicate all glass design:
Frugal, innovative ⇒ higher risk
No pin penetration into housing
Cold/Warm top window seal development needed



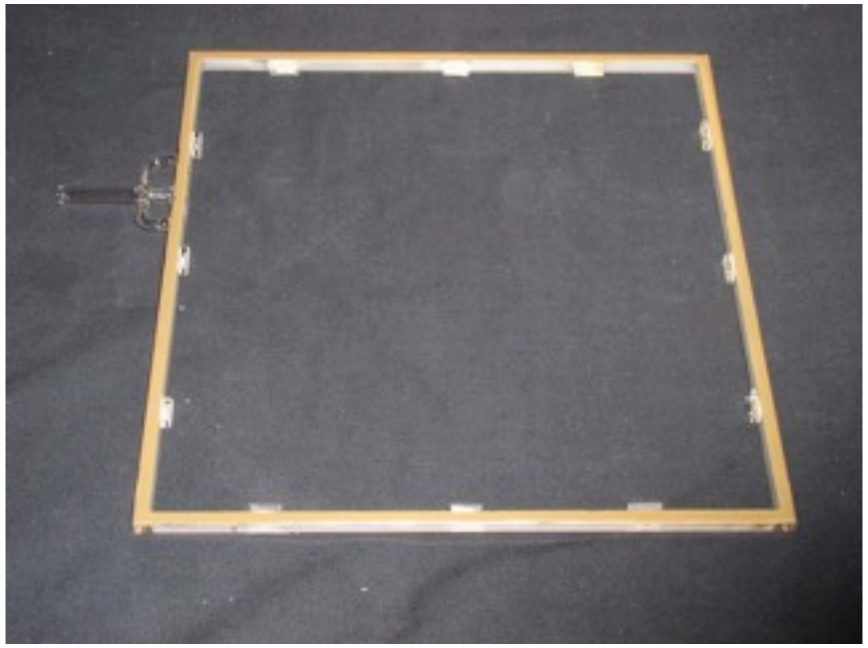
Tile Base Fabrication

Apply Frit Paste to Sidewall

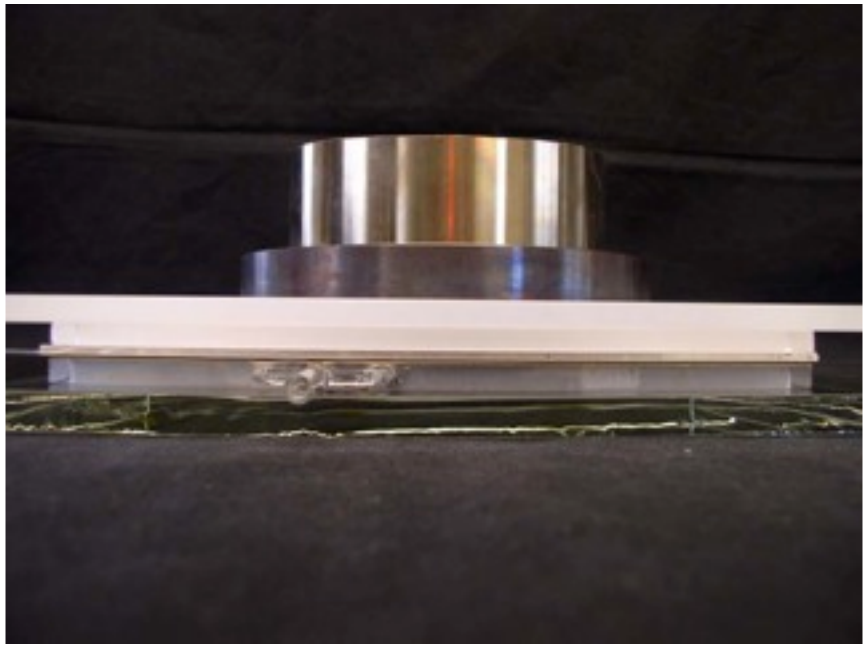
350˚C Fire to Dry Paste



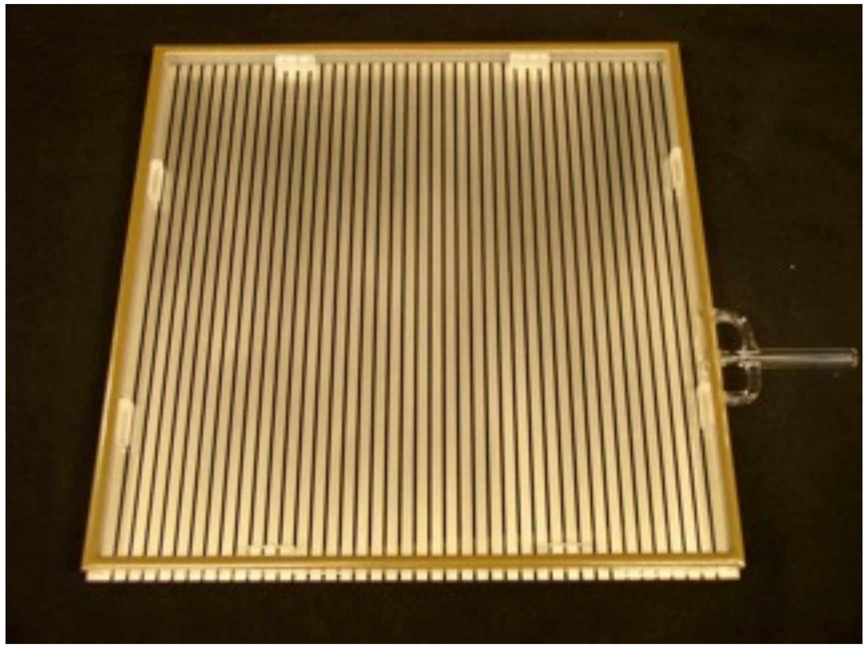
470˚C Fire to Glaze



Attach Getter Holders
Silver Ink Frit @ 350˚C



470˚C Fire to
Bond Anode Plate



Completed Tile Base
w/Vacuum Tight Bond

Demountable 8” Tile Prototype

Inner, outer retainer rings for demountable O-ring seal

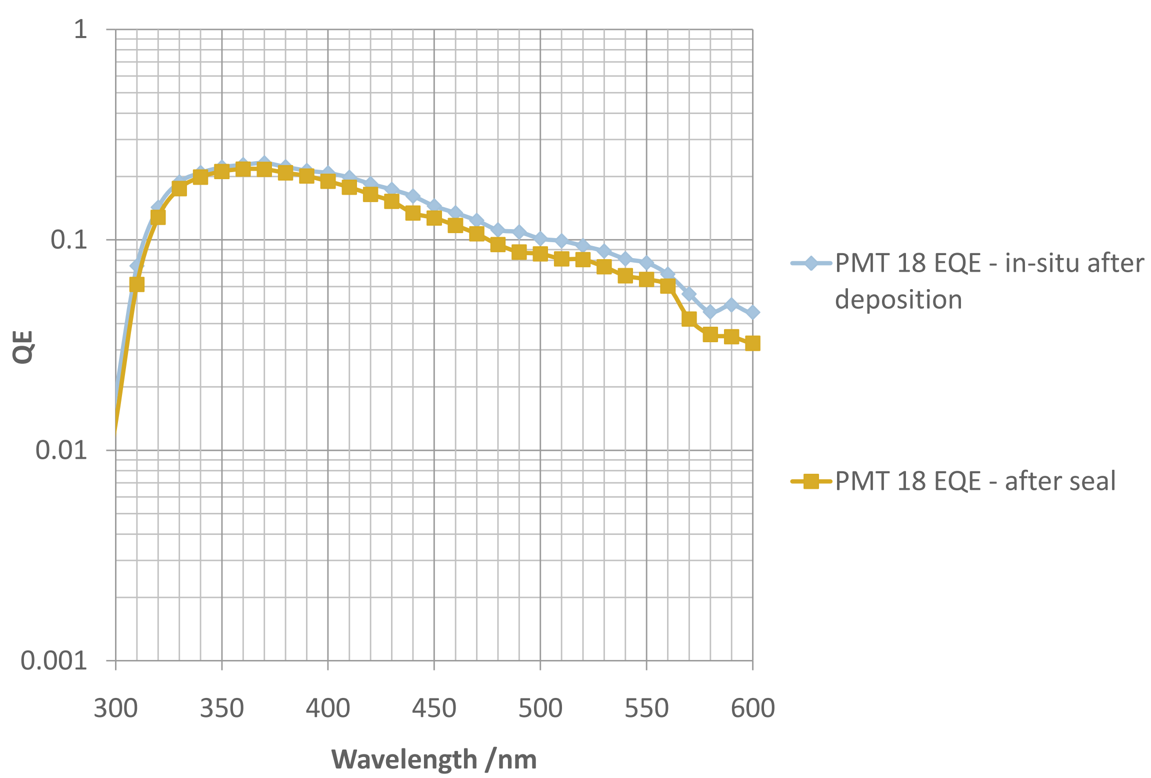
Inner, outer retainer rings for demountable O-ring seal

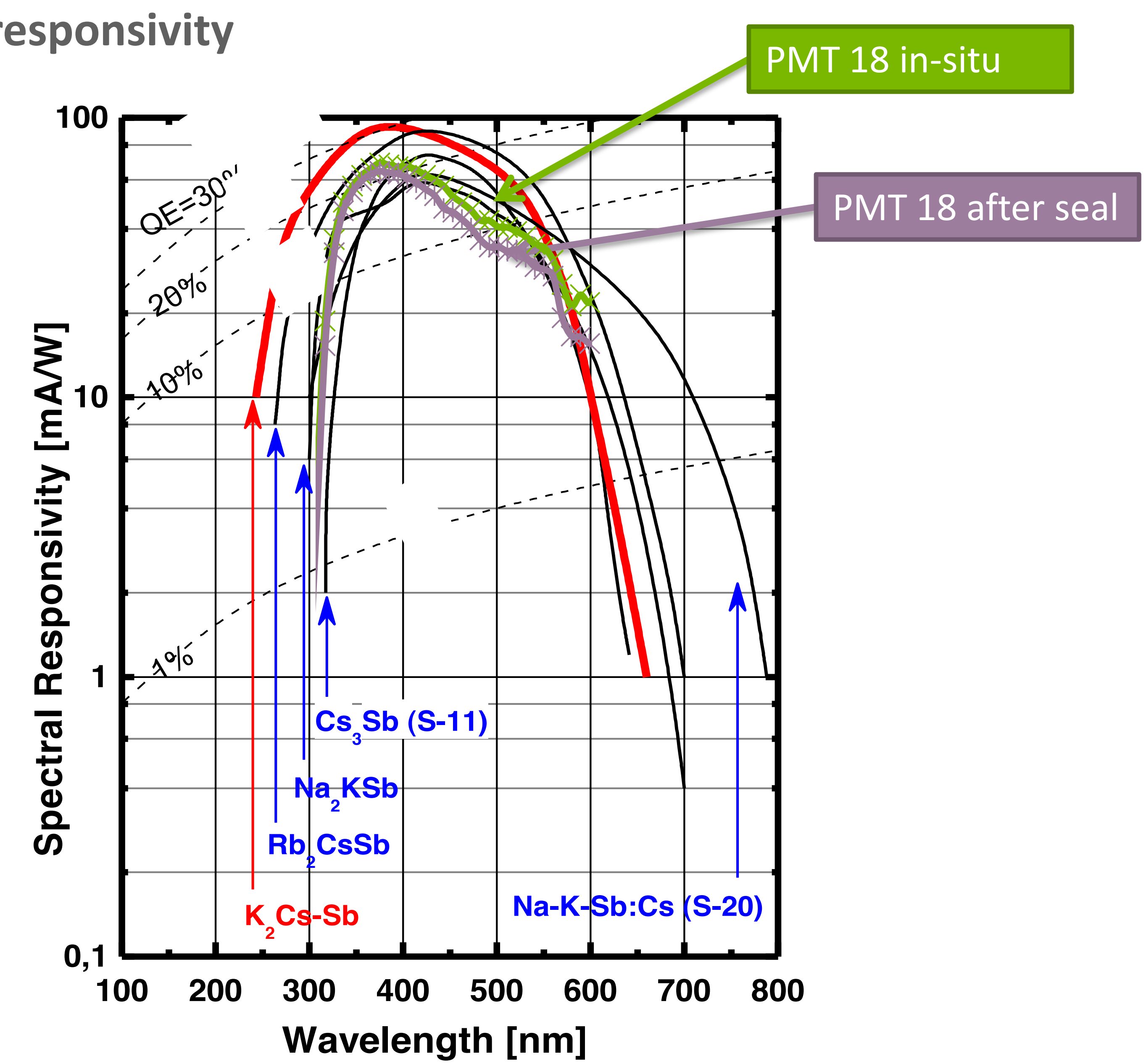
Leak checking of assembled demountable structure

Bialkali Photocathode Development at Argonne

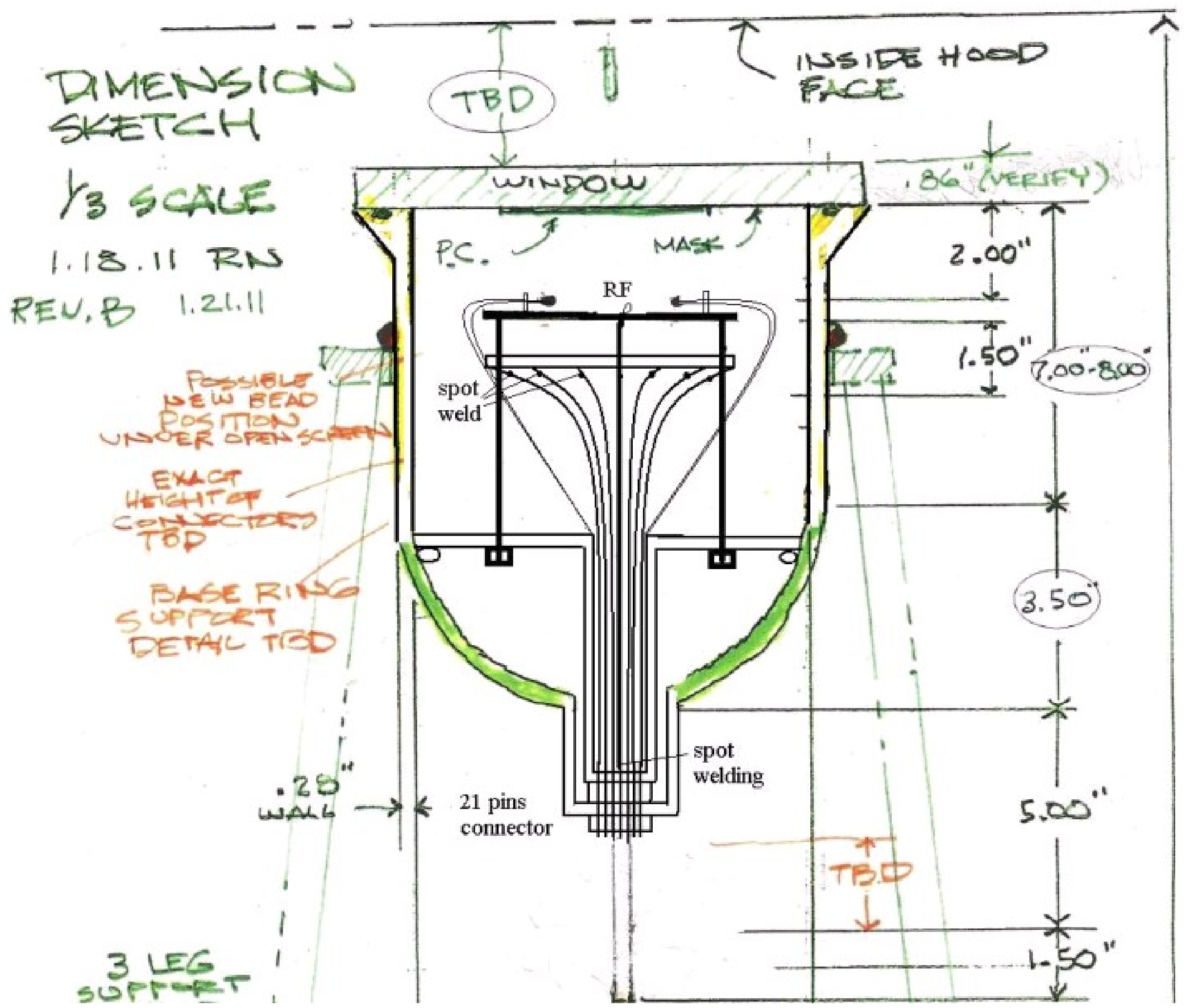
- Shoot photocathode similar to traditional PMT method
  - metal beads activated by current heating
- Use glass containment vessel with bead support structure & detachable top window
- Learn method by making photocathodes on small PMTs
  - PMT processing equipment obtained from Burle Industries

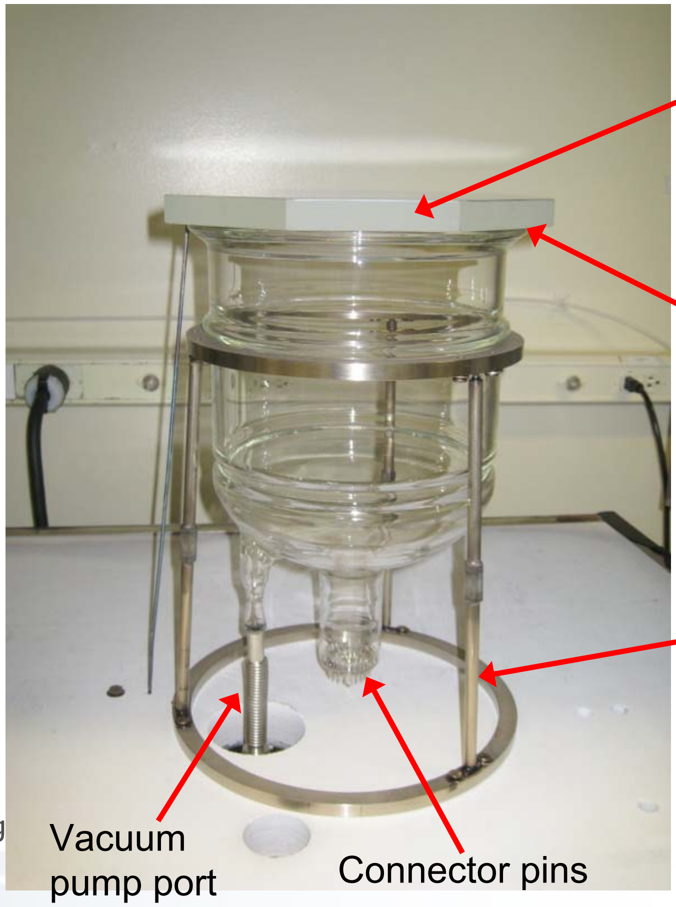
Results from Photocathode Growth in Burle Process Chamber





Bialkali Photocathode -- Scale-Up to 4” Photocathode





Summary

- Large Area Microchannel Plate Photodetector project has completed 2nd year
- Many critical milestones achieved for detector realization
  - Signals acquired from full-sized tile base with 33mm MCP pair in 8" test ch.
  - ALD coatings of 33mm glass capillary disks producing gain $>10^6$ for MCP pair
  - Observation of gain from 8"×8" single MCP and MCP pair
  - Production of detector quality 8"×8" glass capillary arrays
  - Developed 3 ALD resistive + 2 ALD emissive chemistries
  - Low temperature (120°C) In(52)Sn(48) seal made on 1" sidewall/window
  - Readout ASIC for picosecond resolution fabricated, tested, and functioning well
- Mature mechanical designs for hermetically sealed tube
  - Proven design in ceramic by SSL
  - Well-advanced inexpensive glass design -- hermetic prototypes
- Facility for 8"×8" photocathode fabrication and study near completion at SSL
  - Full-size process chamber installed, near commissioning
- Tile production facility for All-Glass MCP-PMT in design at Argonne

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