Argonne NATIONAL LABORATORY

... for a brighter future

Large Area Photodetector Development:

Project Status

Bob Wagner, Project Physicist

for LAPD Collaboration

Work on Timing Detectors, Clermont-Ferrand

28 Jan 2010

U.S. Department of Energy

UChicago Argonne LLC

Office of Science U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

The Large Area Photodetector Collaboration

Received first funds in August, 2009

Many others have joined since original proposal:
- Argonne HEP - Slade Jokela, Seon Woo Lee, Bob Wagner
- Argonne Nuclear Science - Dean Walters
- Argonne Energy Systems - Qing Peng, Anil Mane
- Argonne Materials Science - Thomas Proslier
- U. Chicago - Erik Oberla, Sam Meehan, Hervé Grabas
- SSL - Sharon Jelinsky, Jason McPhate
- U. Illinois, Chicago - Kathleen Broughton

plus certainly others I overlooked

The Development of Large-Area Fast Photo-detectors

April 15, 2009

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[1] Joint appointment Argonne National Laboratory and Enrico Fermi Institute, University of Chicago

LAPD Project Scope

Develop and Fabricate Microchannel Plate Photodetector Incorporating:

- 20×20 cm^2 active area
- High quantum efficiency photocathode --- ≥ 25%
  - Bialkali, multialkali
  - “III-V” materials, e.g. GaAs, GaN
- Novel inexpensive MCP substrate
  - Bare Glass Capillary Substrates - borofloat glass
  - Anodic Aluminum Oxide (AAO) - ceramic
- Pore activation via Atomic Layer Deposit (ALD)
  - Separate material for resistive and emissive layer
  - Evaporative metallization for high voltage electrical contact
- Customized anode readout
  - Double-ended strip line readout for picosecond timing
  - Conventional pad readout for energy and/or coarse spatial location
    - *Gamma-ray telescope camera (see K. Byrum talk)*
    - *Dual readout calorimeters*
    - *Medical imaging?*
- Possibly novel front-end electronics, e.g. picosecond timing ASIC chip (see J-F. Genat talk)
- Design by vetted and tuned simulation

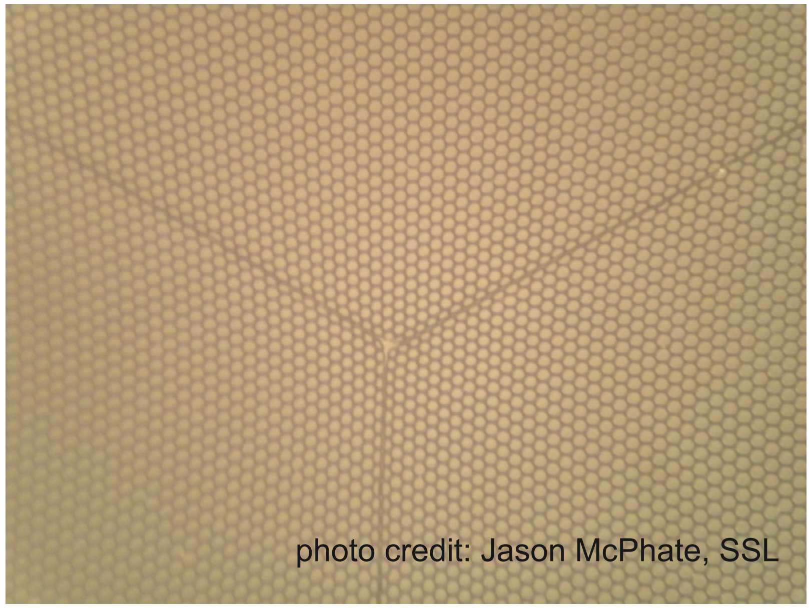
Photocathode Development

- Initial photocathode will be bialkali: Na-K-Sb
  - Univ. California - Space Science Lab has many years experience with fabrication
  - Current facilities not adequate for 8”×8” photocathode fabrication (and vacuum assembly of MCP-PMT)
- First year milestone is upgrade of SSL facilities for large area MCP-PMT assembly
- Need to study/develop large area photocathode deposition technique
  - Largest photocathode to be made by evaporation deposition on flat glass
- Photocathode development at Argonne beginning
  - Interest in III-V materials for X-ray source work
  - Bi/multialkali work also
  - Plan for Argonne facility near completion
- First make working photocathode, then worry about increasing QE
  - Small sample work on Borofloat 33 & 270 glass starting at SSL

Glass Substrate Status

- Glass substrate development, fabrication, slicing by Incom, Inc. (Charlton, MA, USA)
- Disk development substrates in production
  – 32.8mm diameter
  – 40µm pore size L/D=40 samples on hand at Argonne. Used in first ALD coatings
  – 20µm pore L/D=60 pieces being produced and delivered now. This is our default working size
- 8”×8” 20µm pore fabrication starting at Incom.
- All substrate pores have 8˚ bias

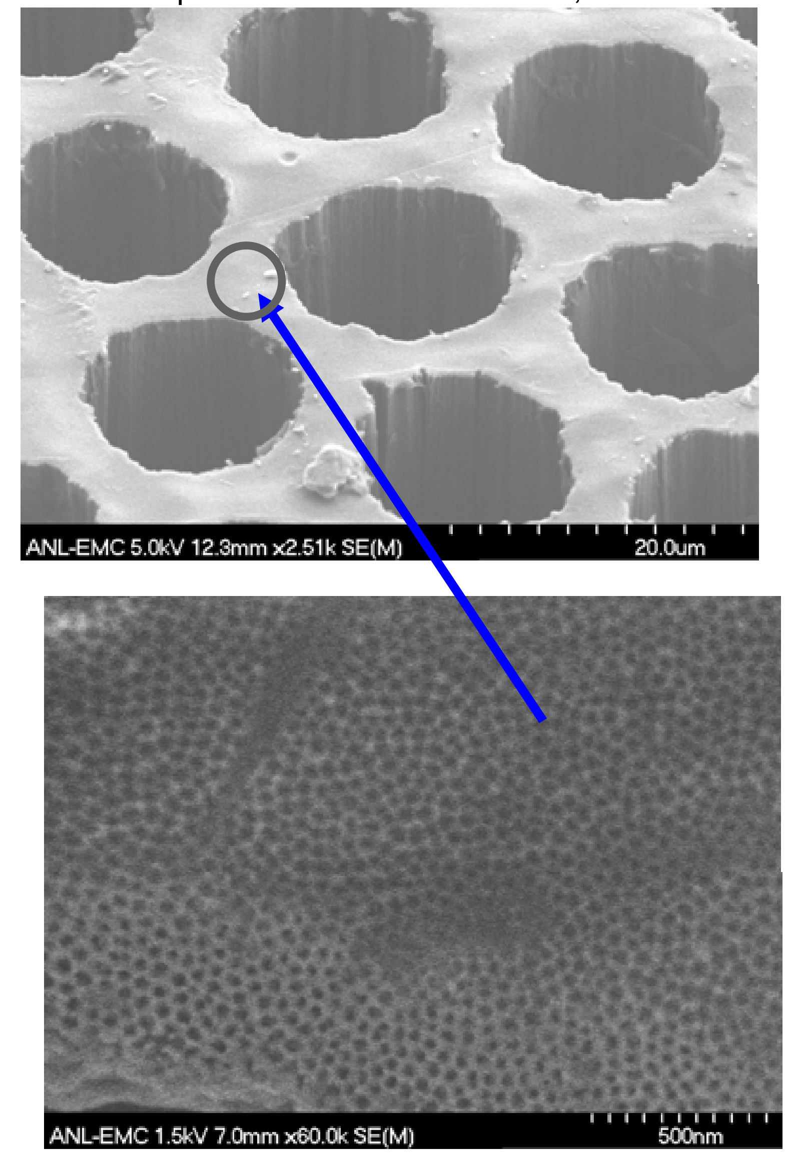
32.8mm 20µm pore L/D=60 disks



Anodic Aluminum Oxide (AAO)

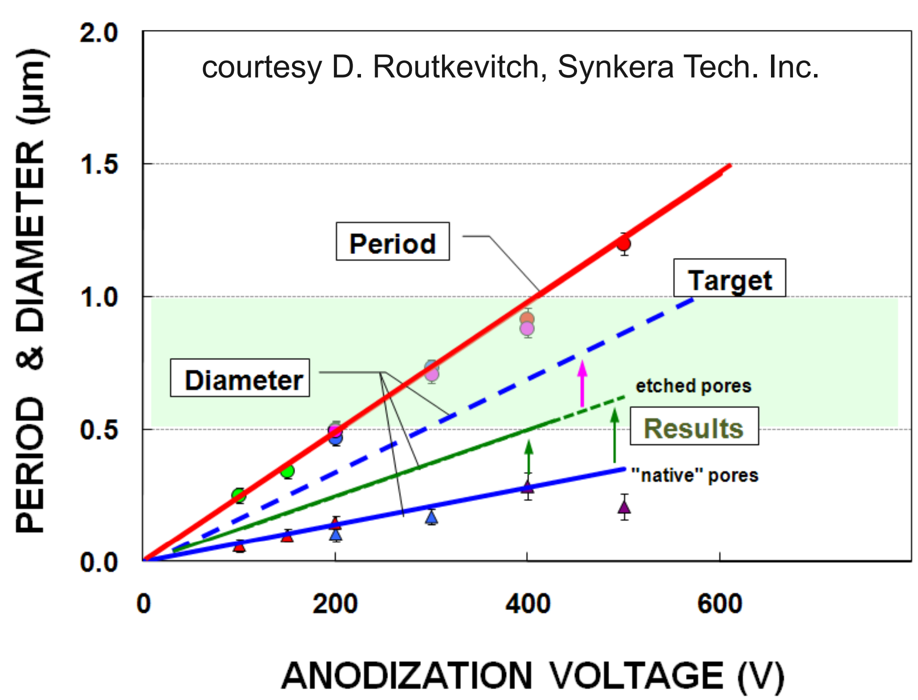
- Potential inexpensive method to produce pore structure
  - Electrochemical etching of pure Al
  - Pores form self-organizing structure
- Maximum pore size limited ≪ 1 μm. No bias angle.
- Development at Argonne (Wang/Lee)
  - Etch pore size 20-40nm
  - Use photolithography to enlarge pores to 2-10 μm
  - Small initial pores produce straight wall larger pores
- Synkera Technologies, Colorado (Routkevitch)
  - Produce larger pores directly with larger anodization voltage

SEM photo credit: Seon Woo Lee, ANL



AAO development at Argonne

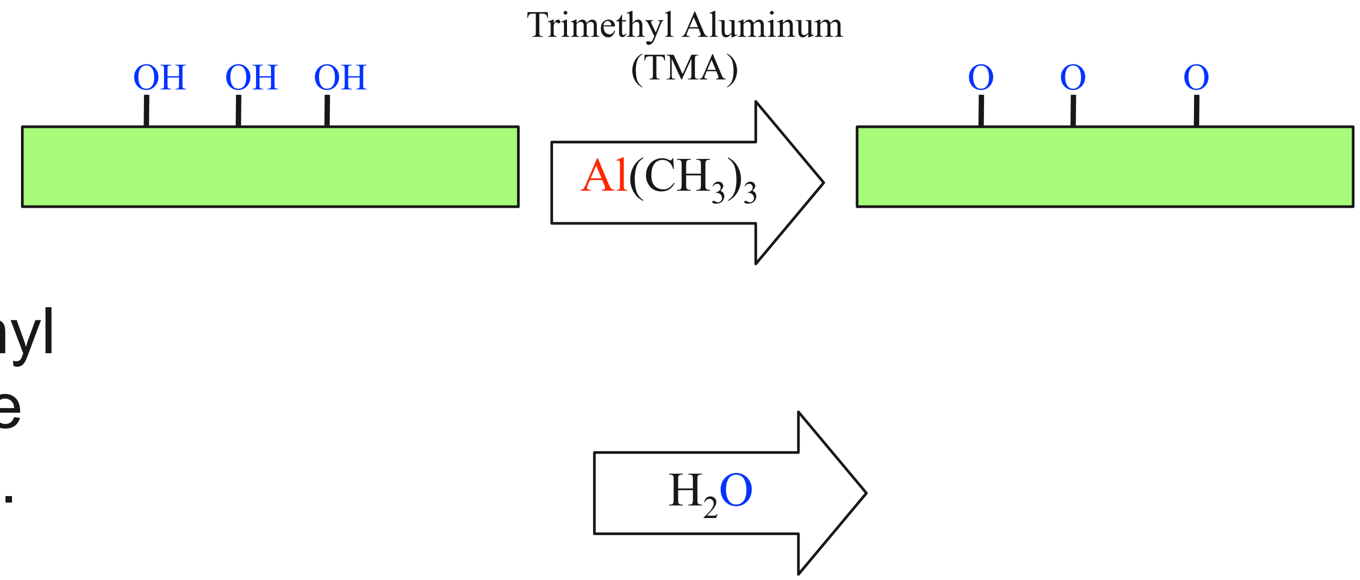
Pore Size/Spacing vs Anodization Voltage Synkera AAO development

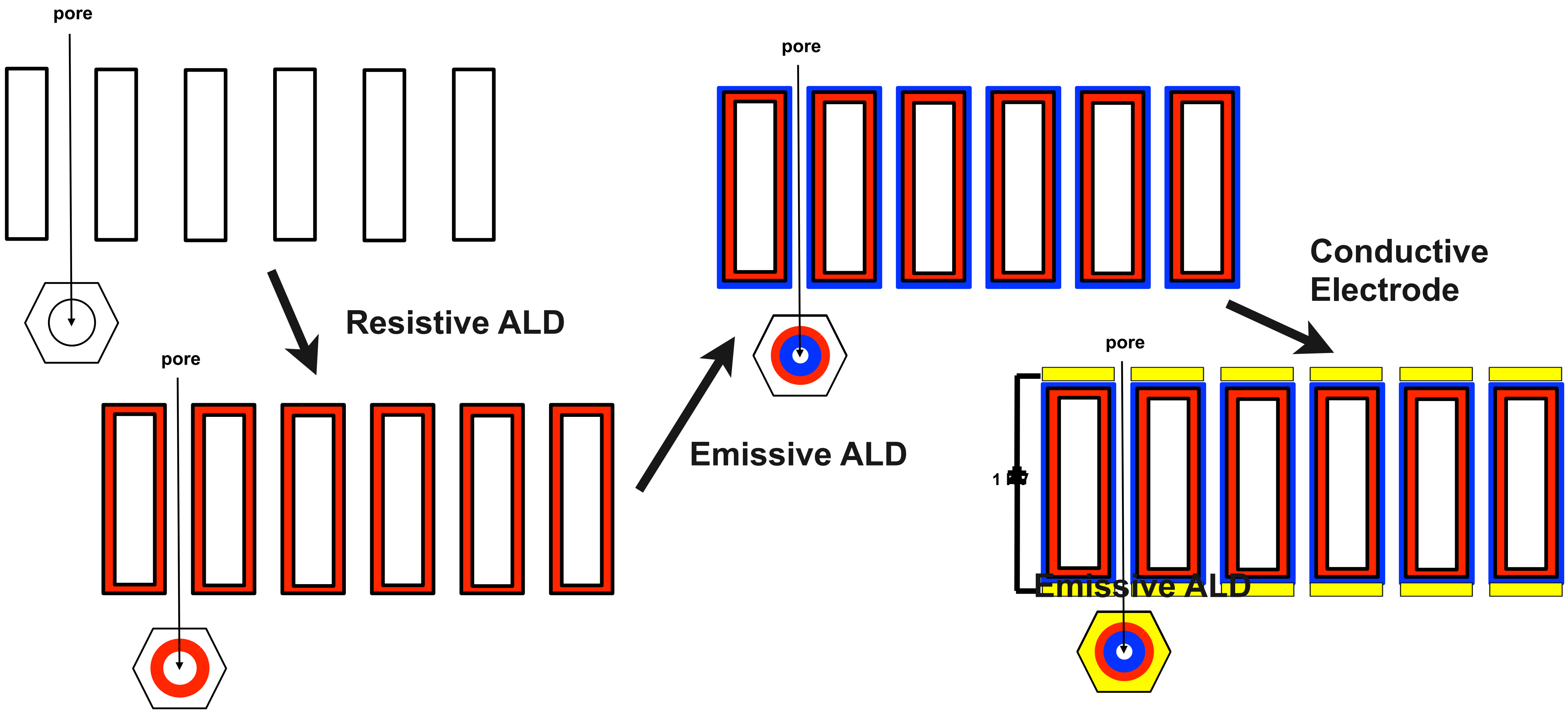


Pore Activation via Atomic Layer Deposition (ALD)

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





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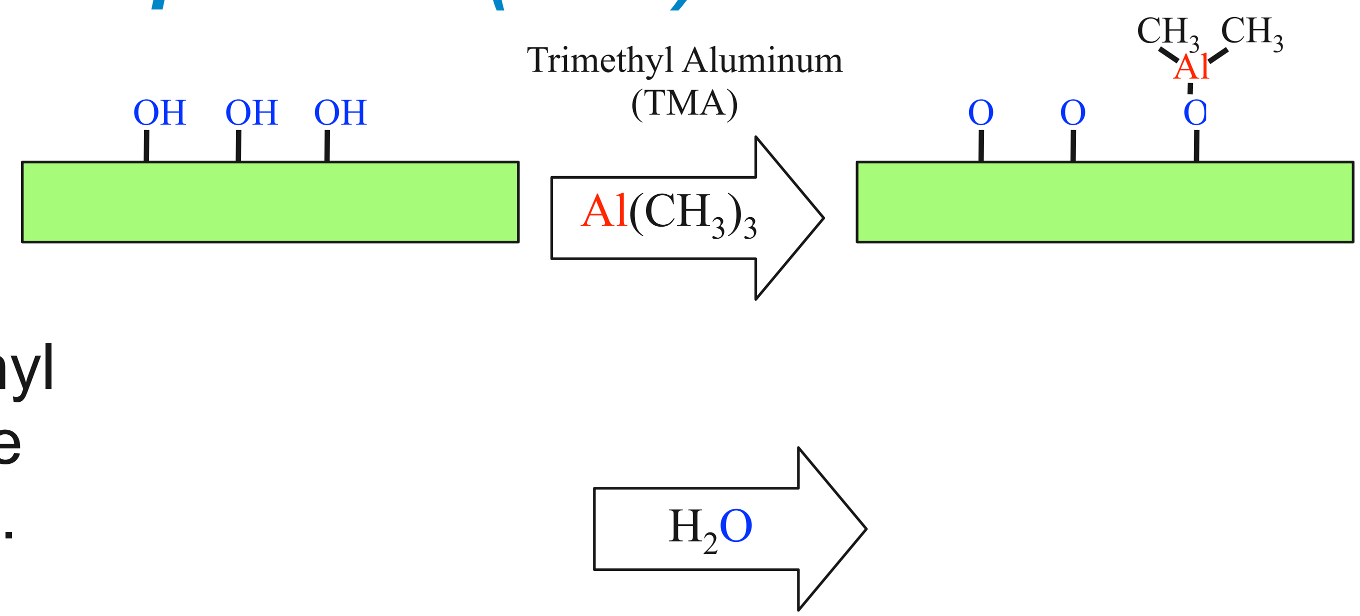

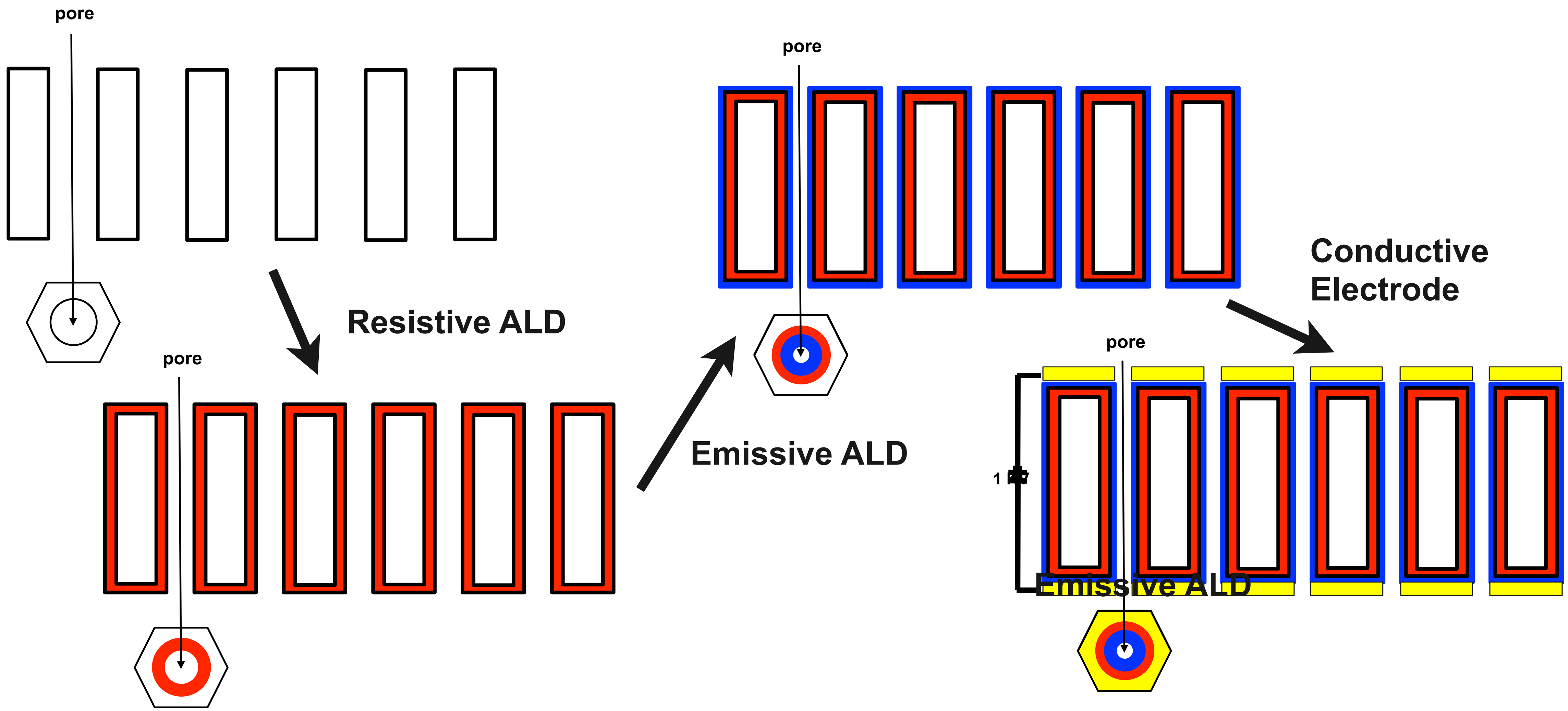

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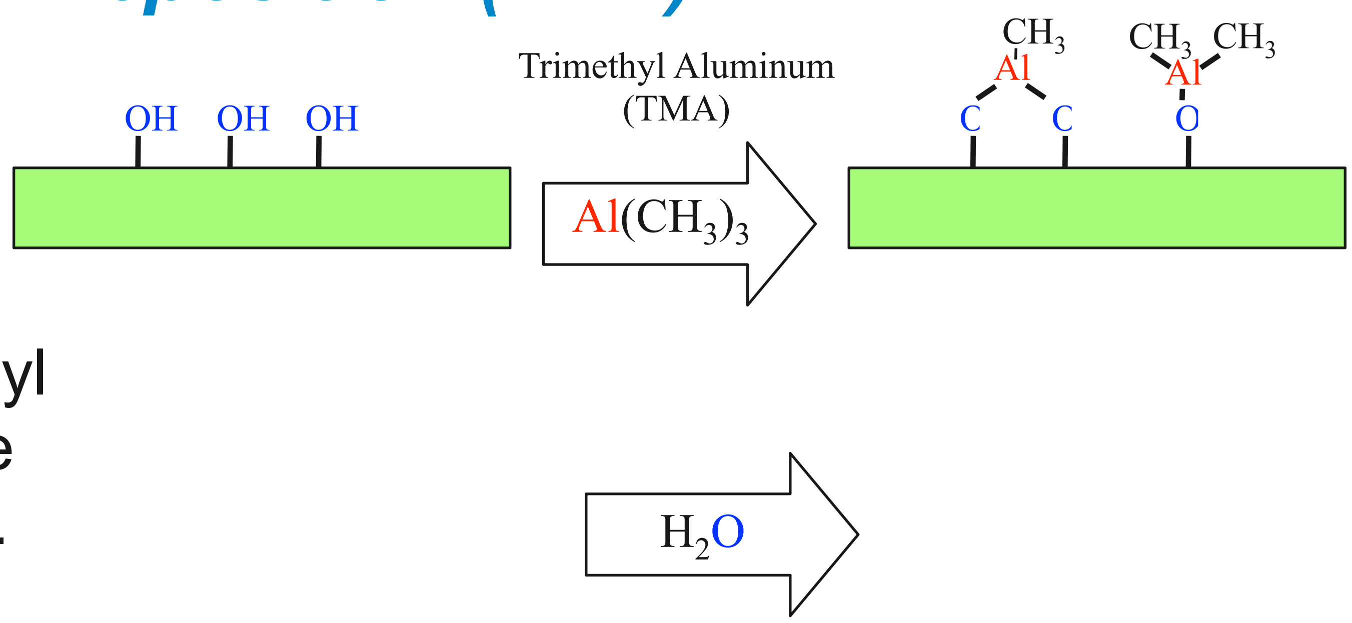

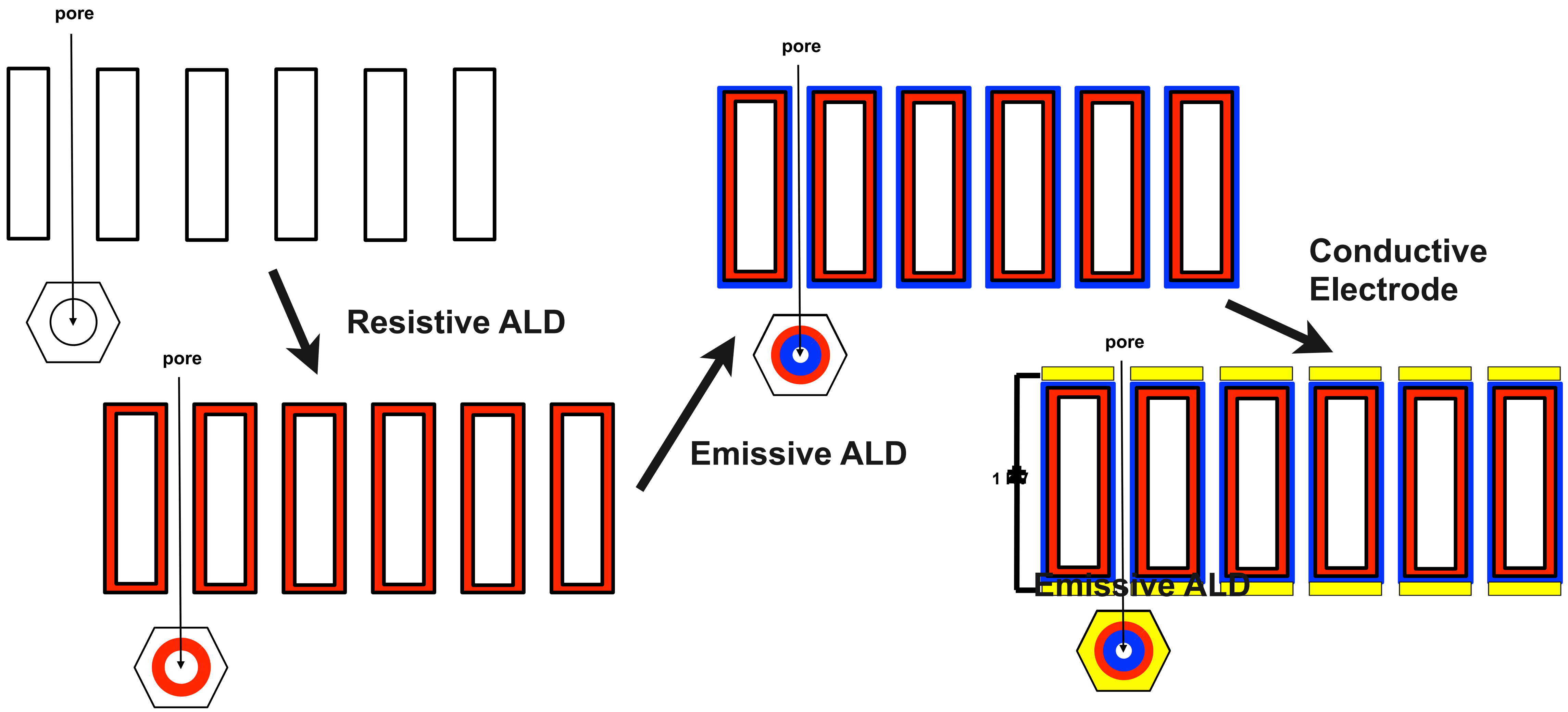

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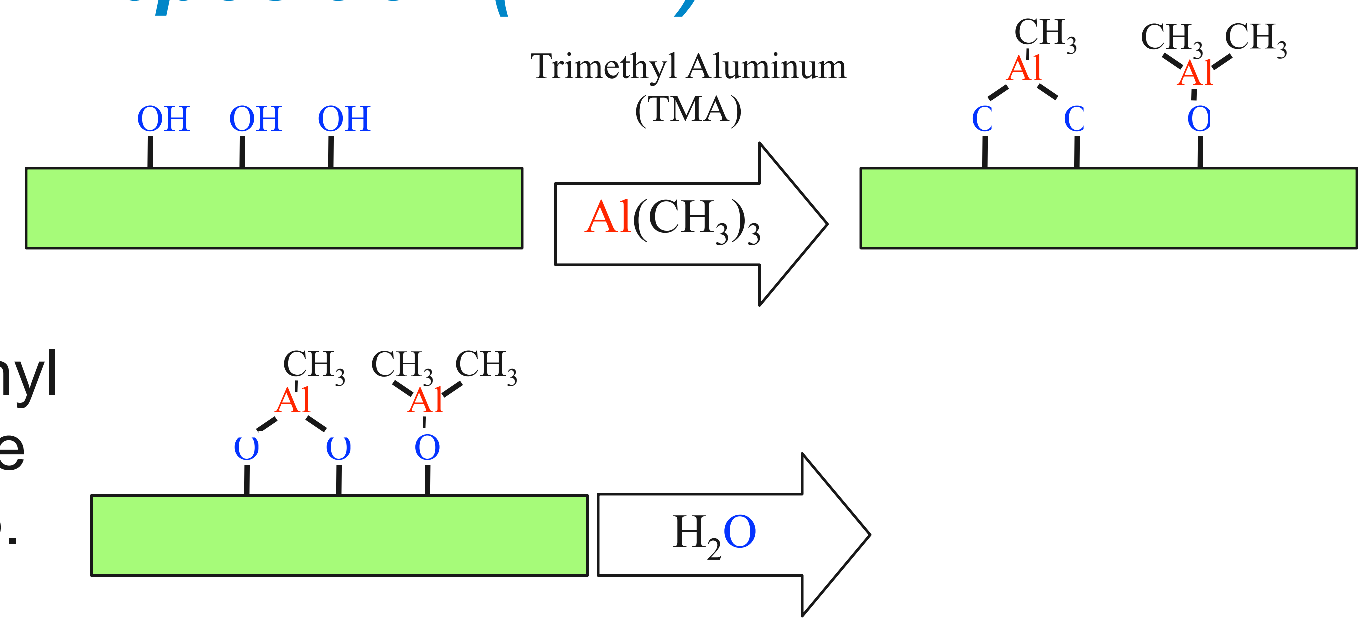

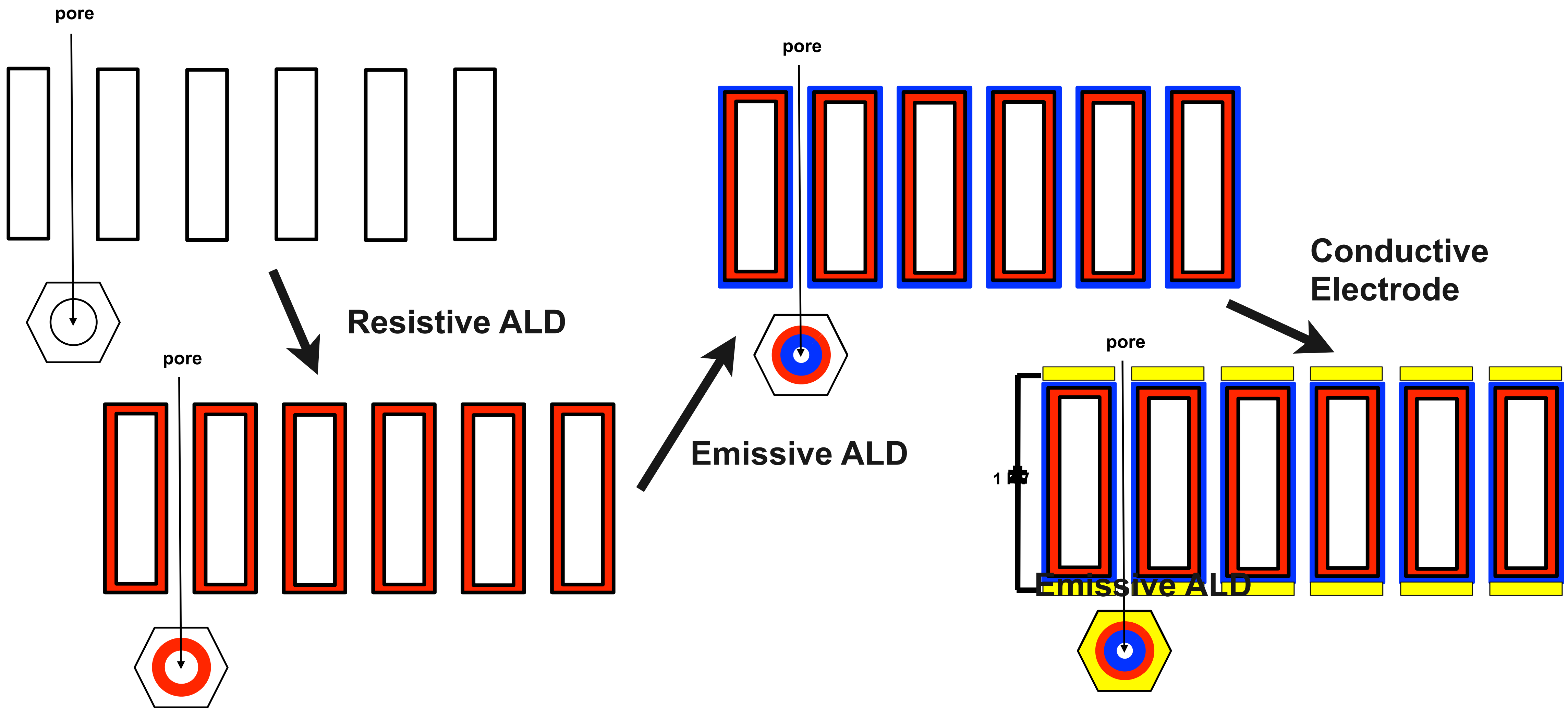

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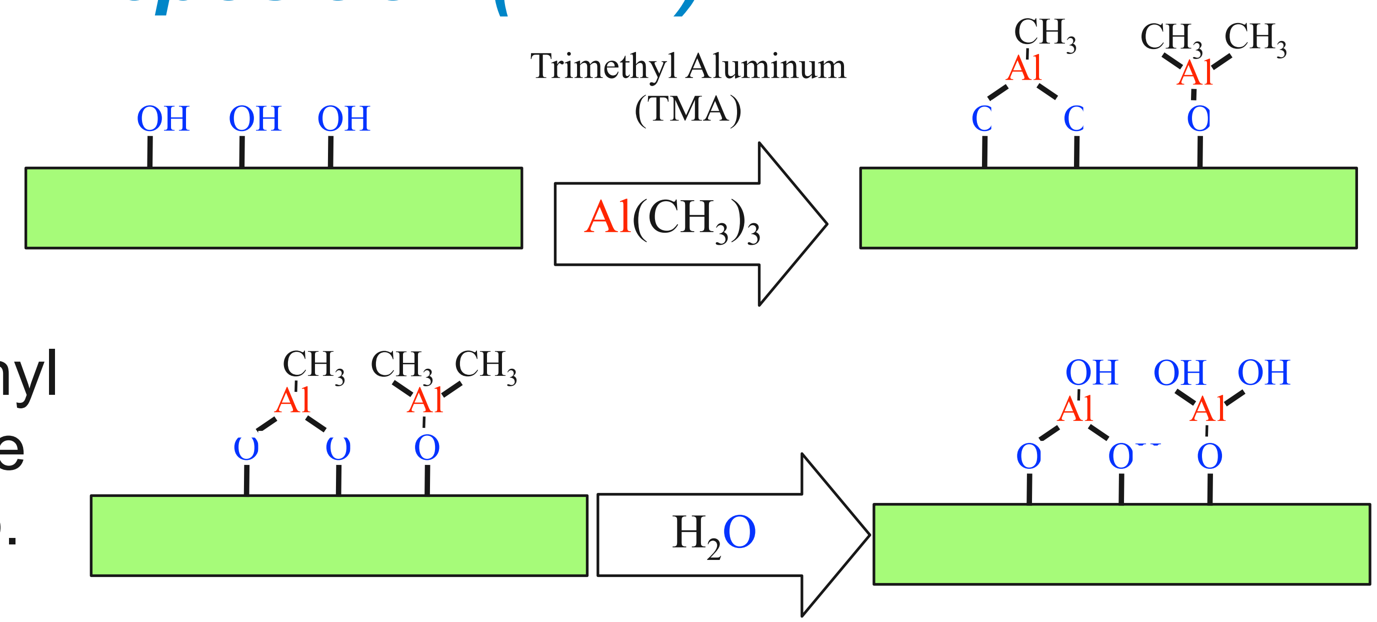
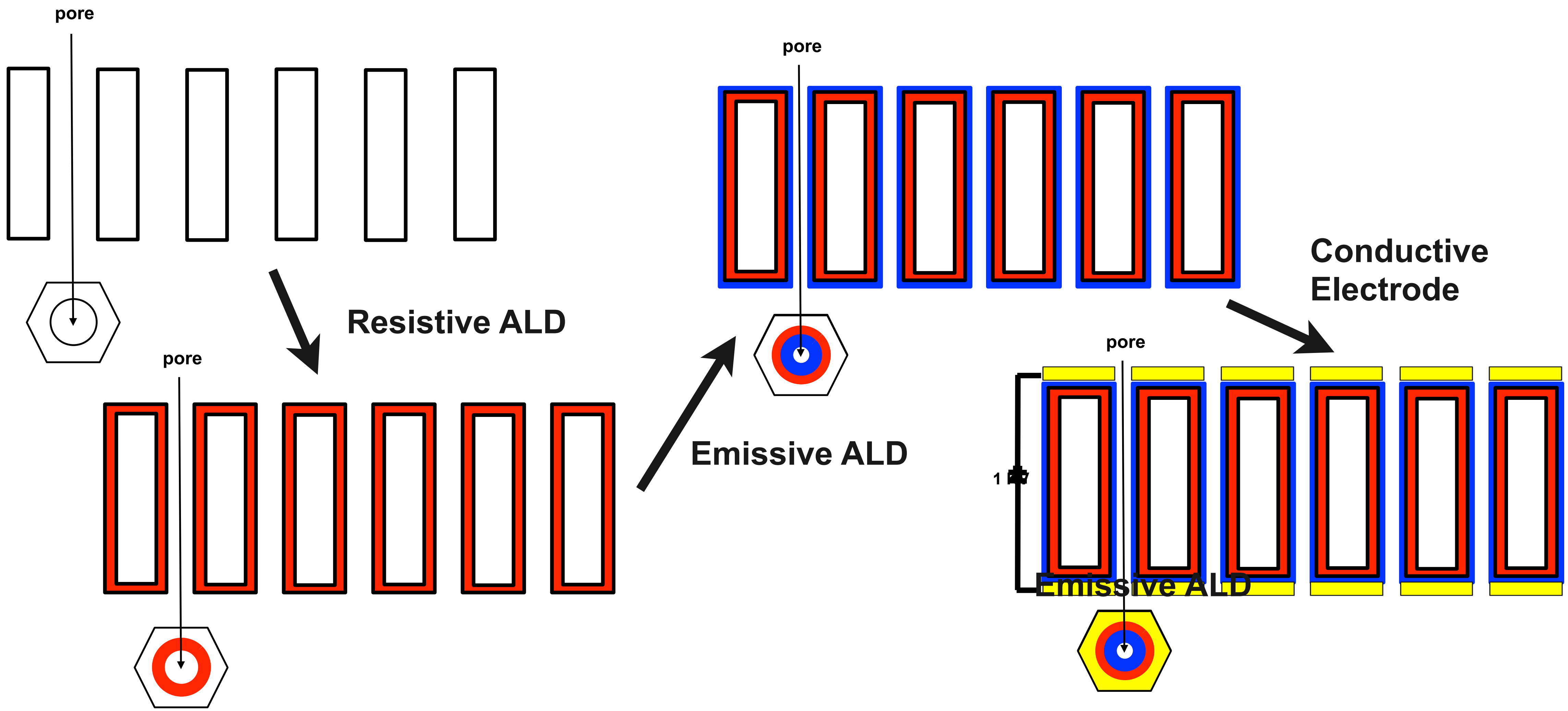
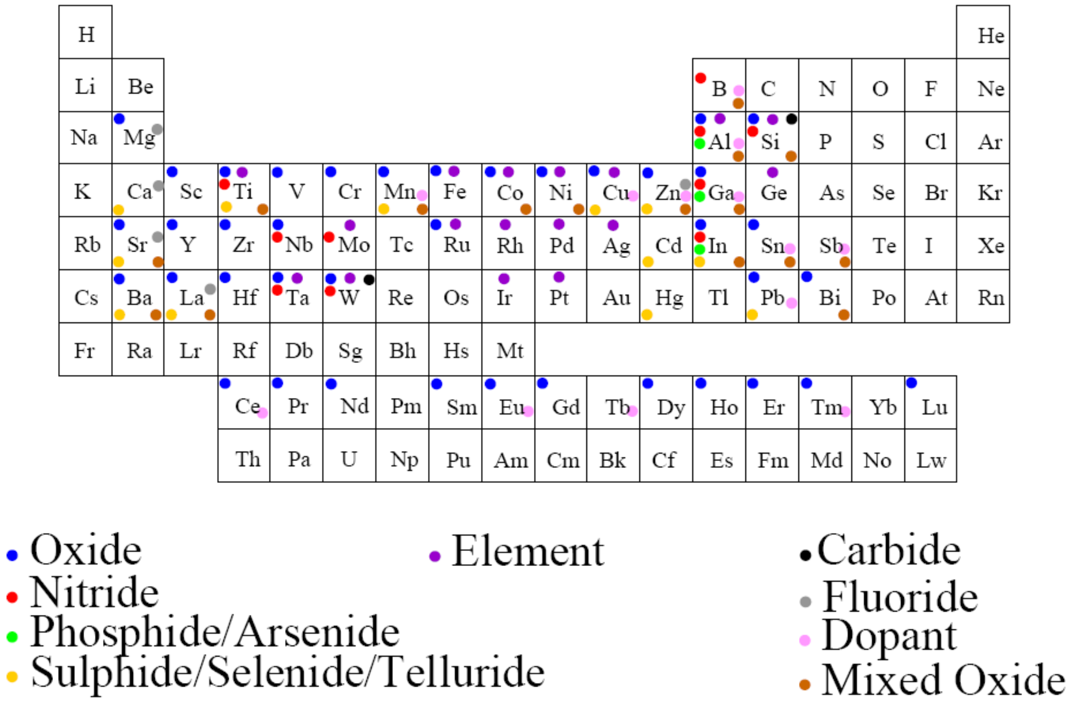




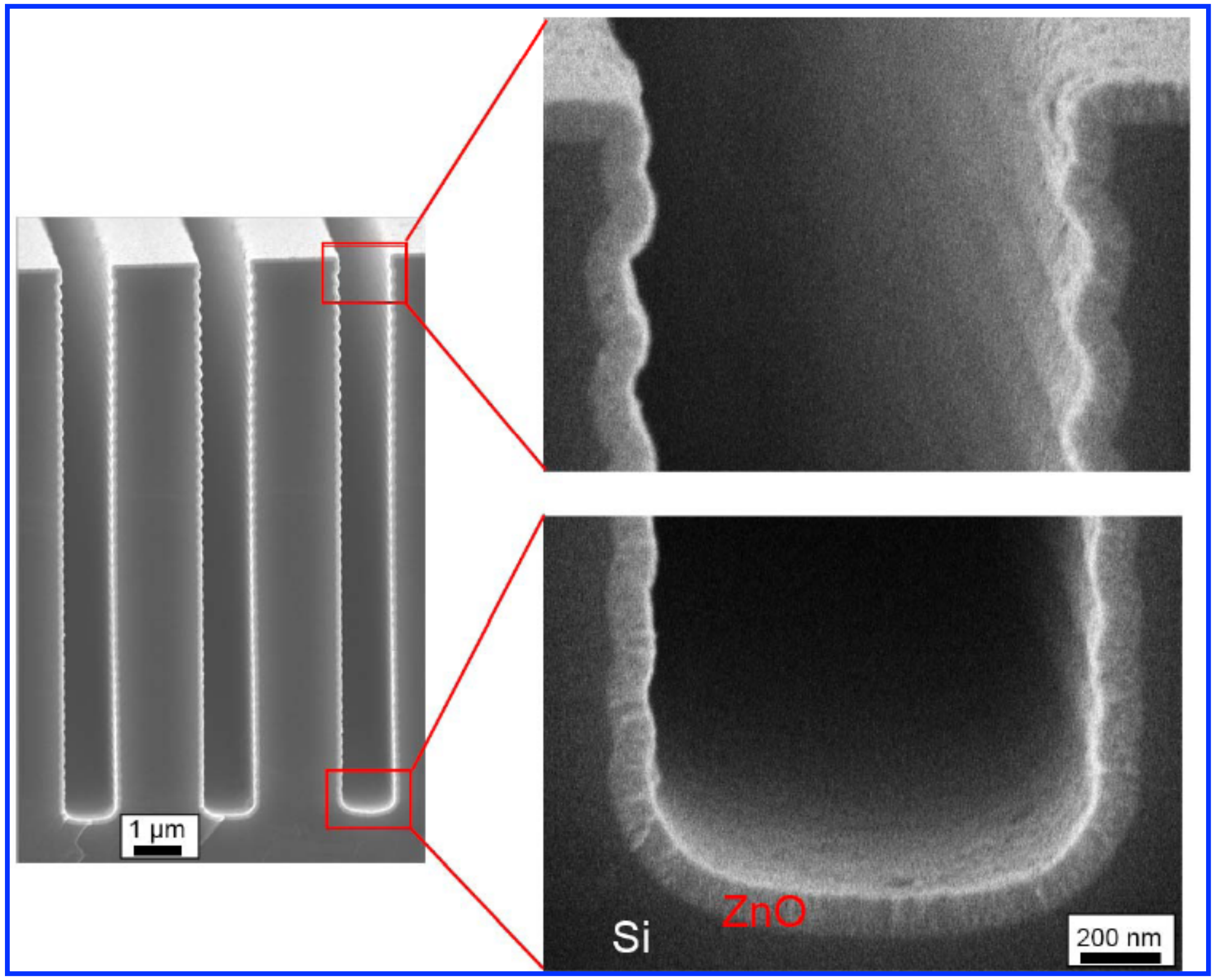
Pore Activation via ALD -- 2

ALD Thin Film Materials

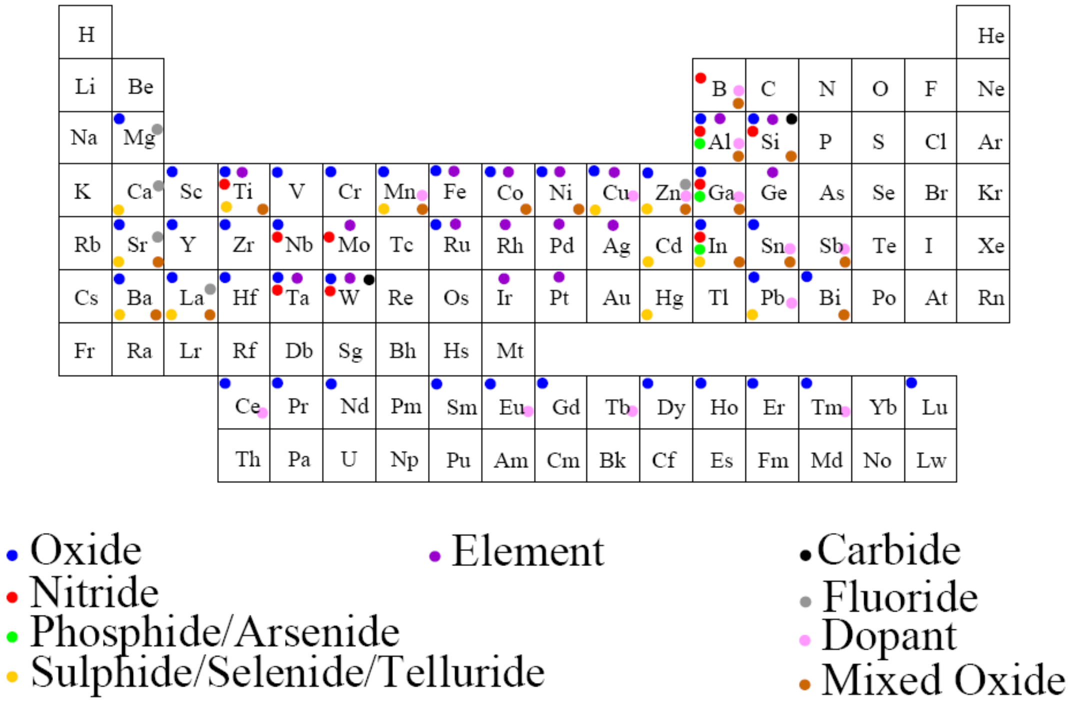


- ALD produces very uniform and continuous coating
- Footprint of apparatus is modest
- Wide variety of elements and compounds amenable to ALD

Pore Activation via ALD -- 2



ALD Thin Film Materials



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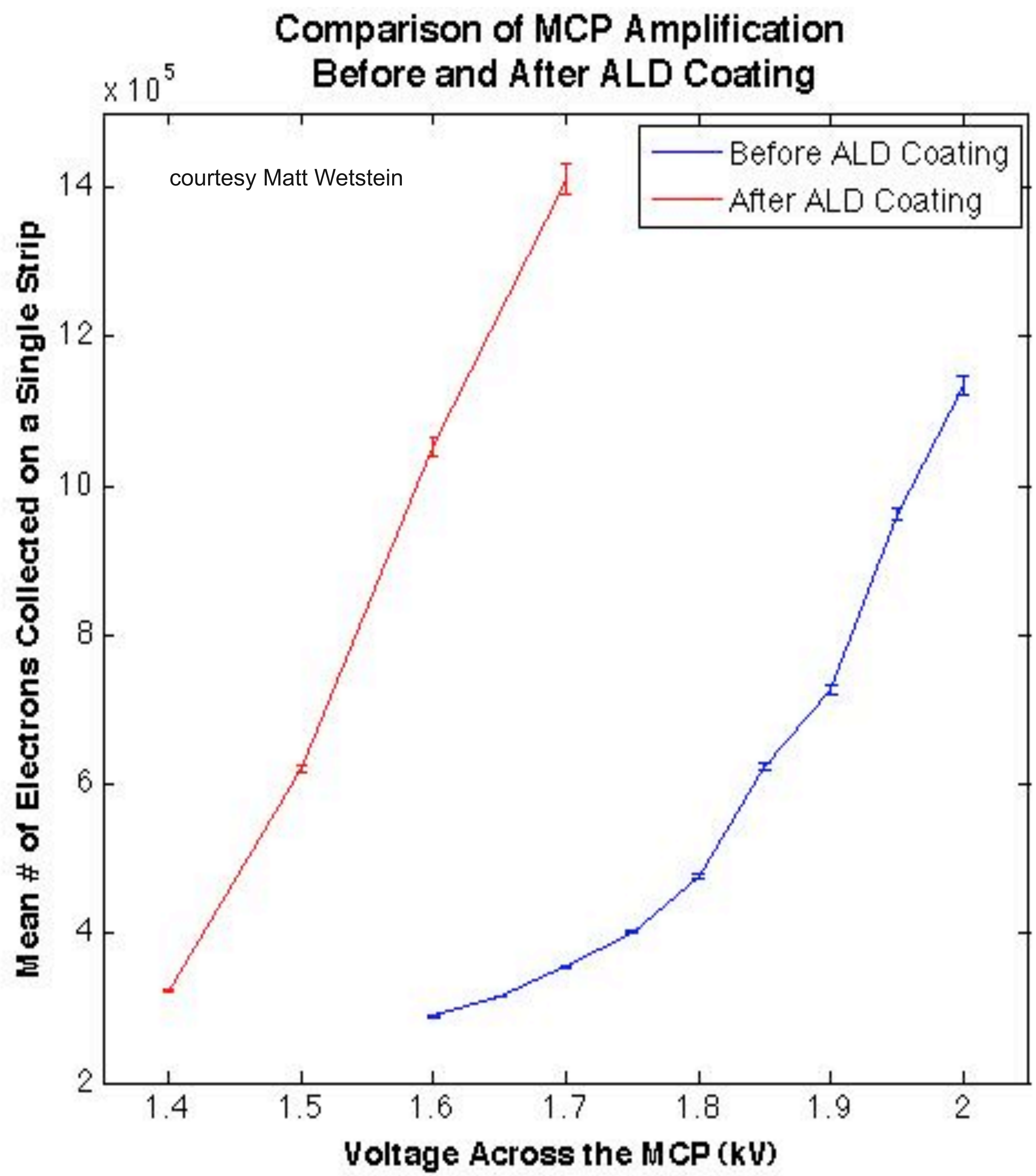
Observation of Gain with ALD Coating



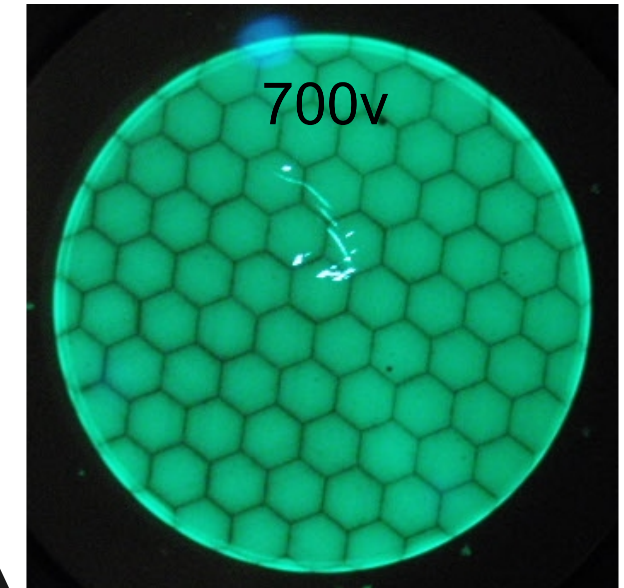
Early Test: Coat Pb-Glass Photonis MCP with Al_2O_3; emissive coating only

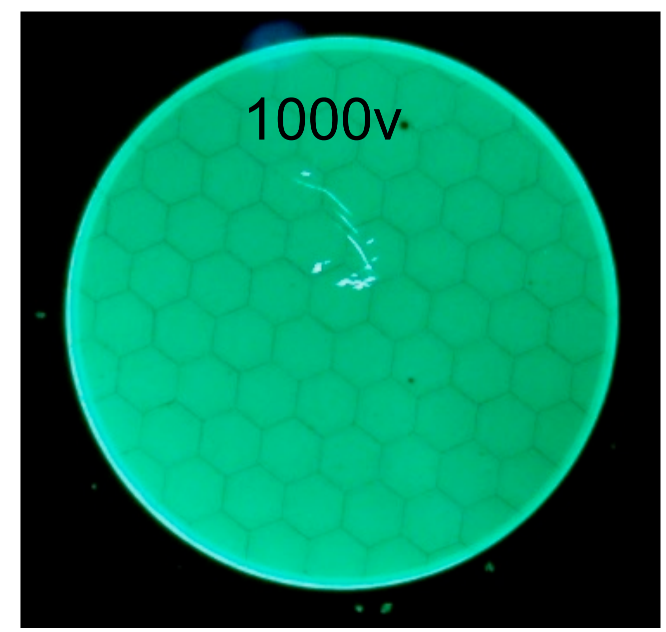
Observe increased gain
lower voltage for equivalent gain

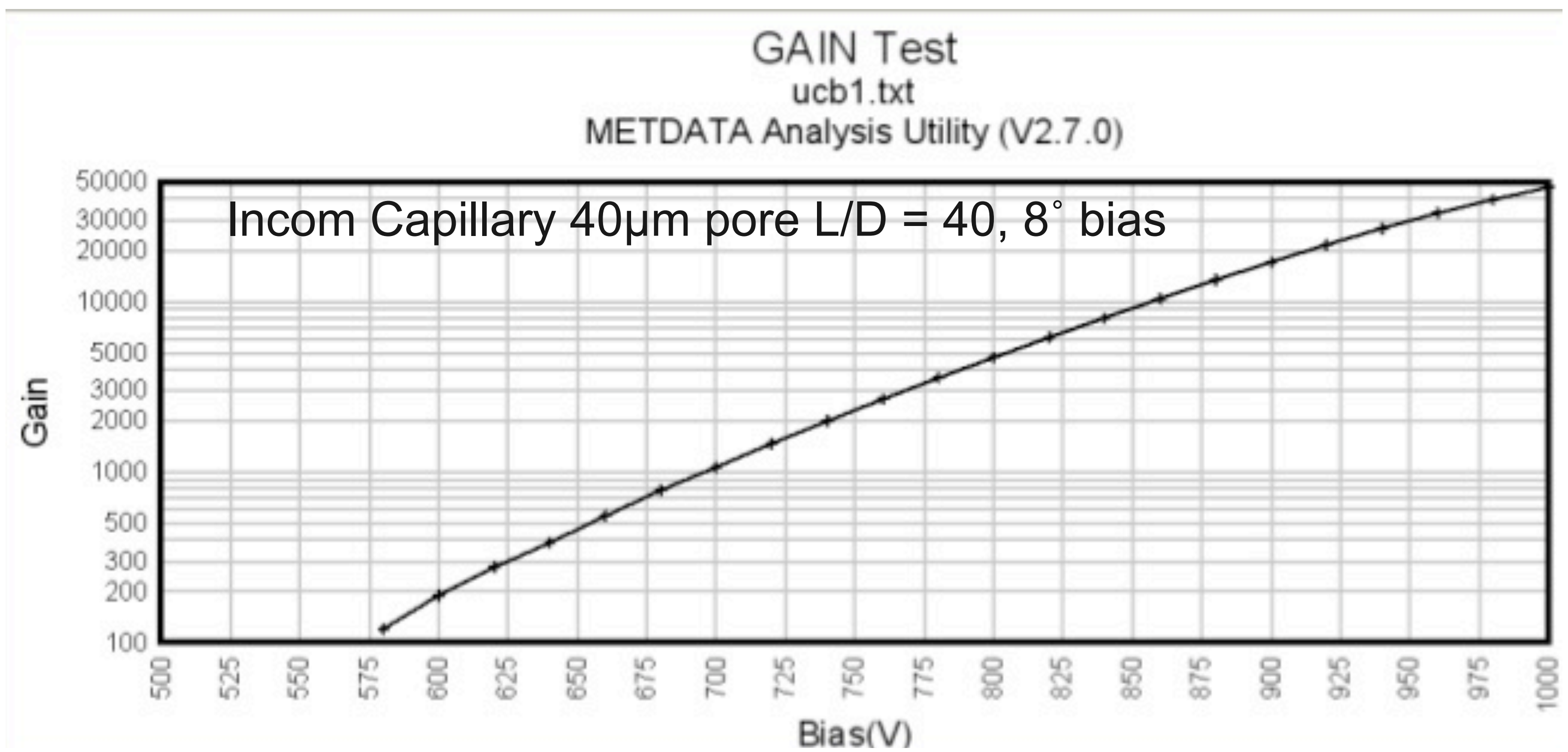
Observation of Gain with ALD Coating -- Arradiance/SSL

- Incom substrate, 40µm pore, L/D = 40, 8˚ bias
- Resistivie + Secondary Emissive + Electrode @ Arradiance
- Tested using phosphor with UV light at UC Berkeley - SSL
- No light → black, UV light → bright image
- Gain measured at Arradiance below

It Works!



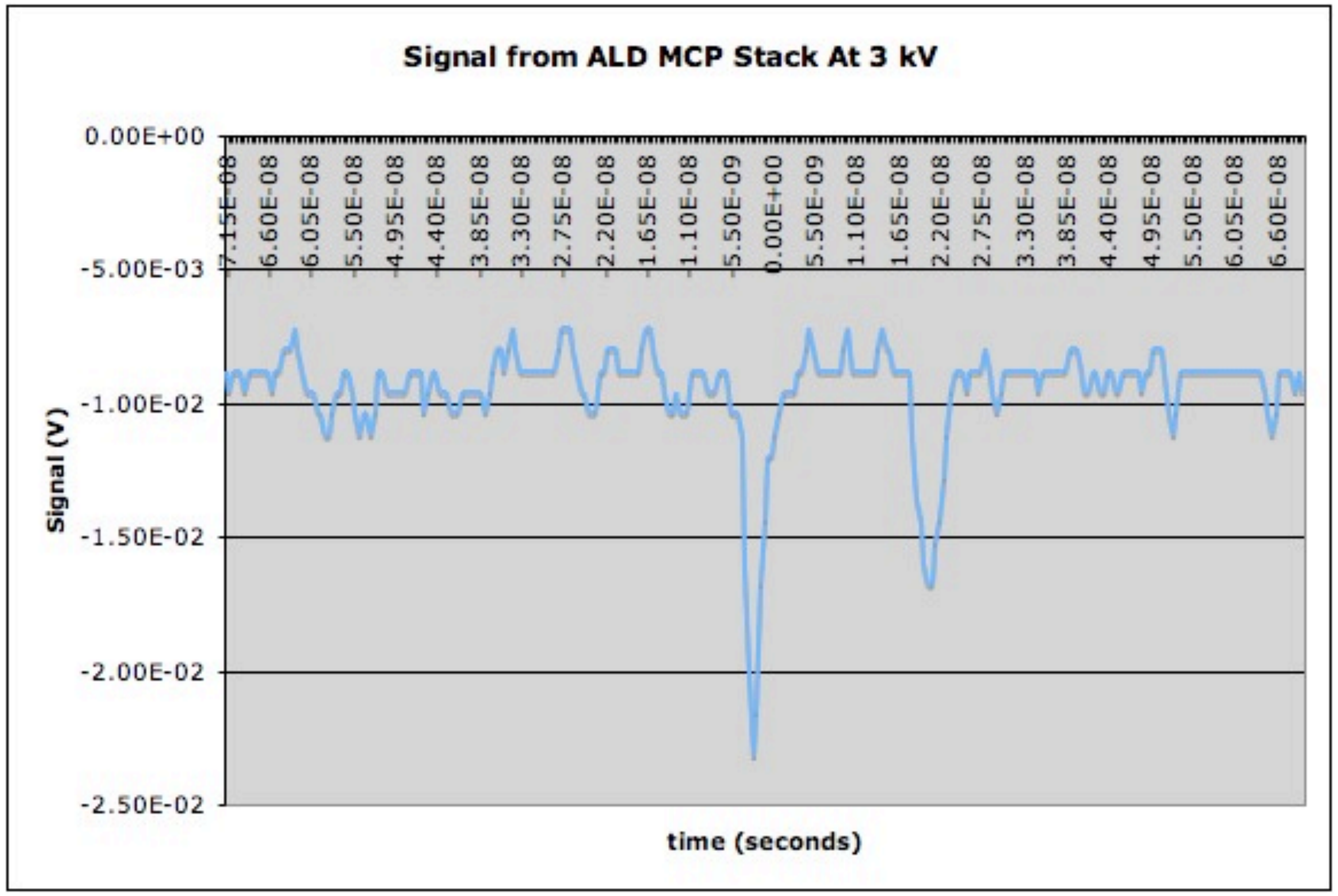


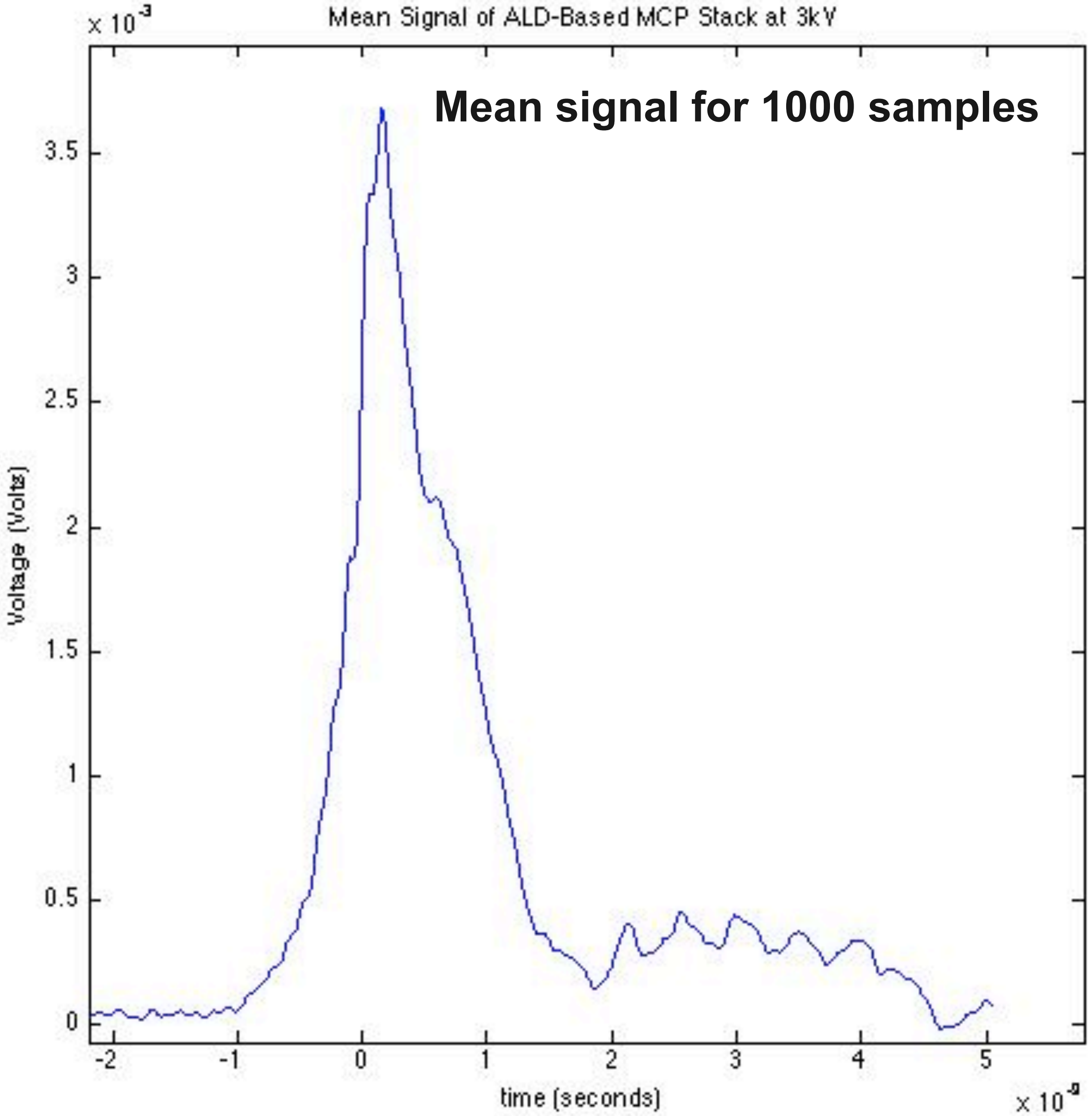


Gain measured at Arradiance, Inc.
50,000 @ 1000V

Observation of Gain with ALD Coating -- Argonne

- Incom 40μm pore, L/D = 40, 8˚ bias
- ALD resistive layer ZnO, emissive Al_2O
- Gold electrode
- Observe gain multiplication @ 3kV



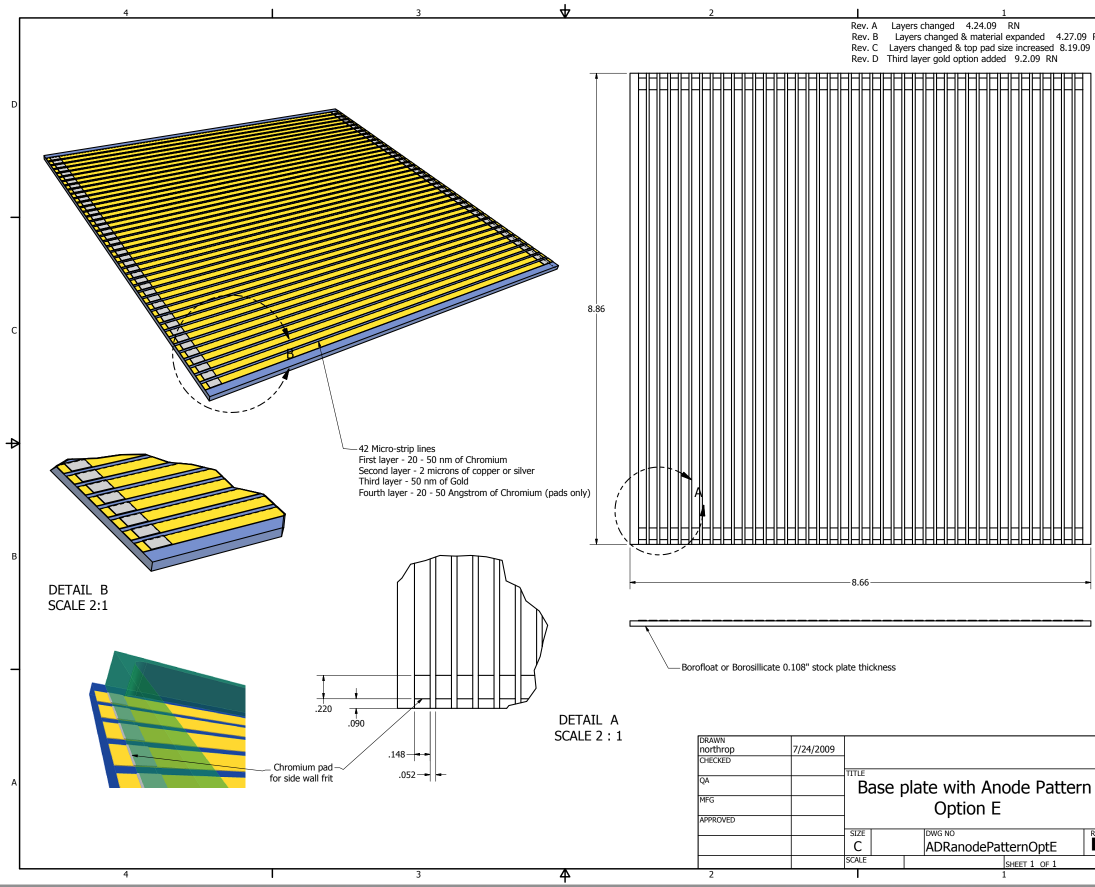


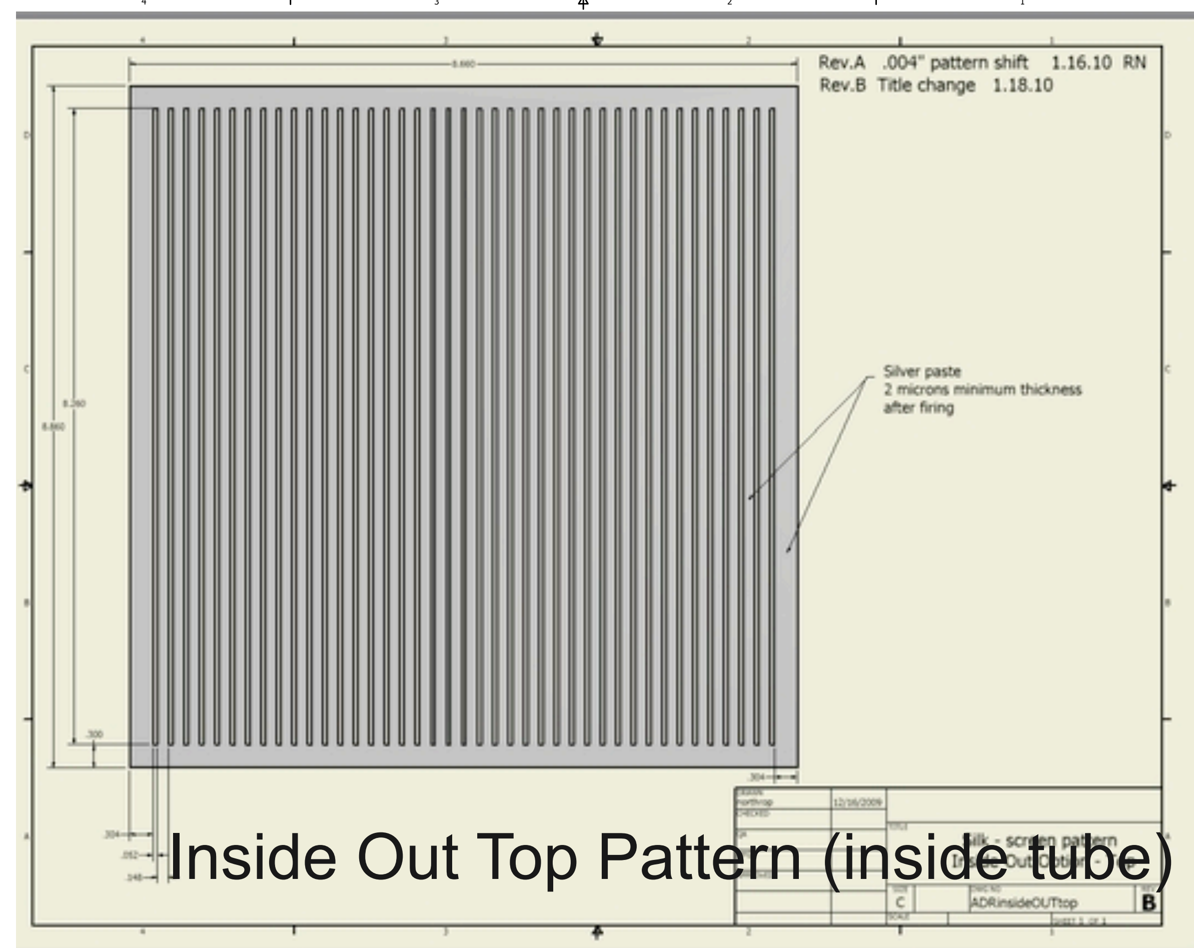
courtesy Matt Wetstein

Time (ns)

Anode Design

- Focus on anode strip line design for precision timing application
- Pursuing several alternatives for metal on glass: sputtering, evaporation, silk screening
- Anode materials
  - Chromium, Nichrome, Titanium base layer for adherence to glass
  - Copper, Silver for signal transmission
  - Gold overcoat to prevent oxidation
  - Chromium pads for sidewall-to-glass seal
- Also studying simple silk screen with silver paste. Bond sidewall to silver??
- Sidewall/bottom plate bonding alternatives
  - glass frit
  - direct metal-to-glass bond
- Studying "Inside Out" Alternative to detect image charge signal with external strip lines
- Initial solution likely to be ceramic tray with plated through vias (SSL standard)

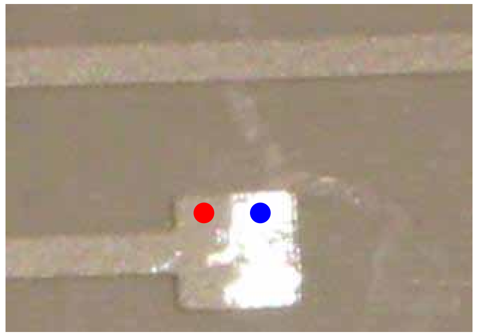


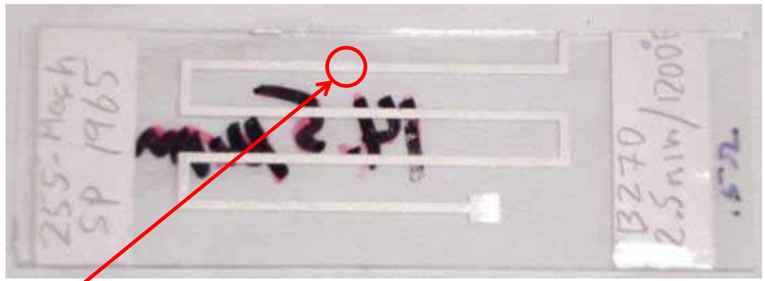


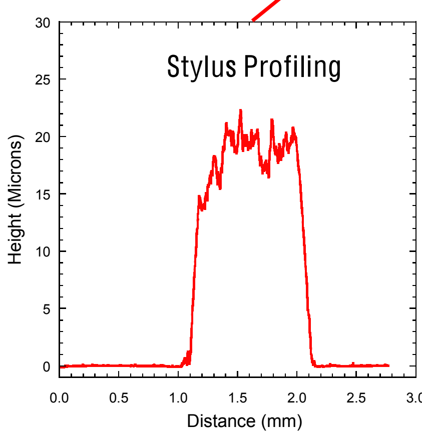
Inside Out Top Pattern (inside tube)

Silver Paste Silk Screening

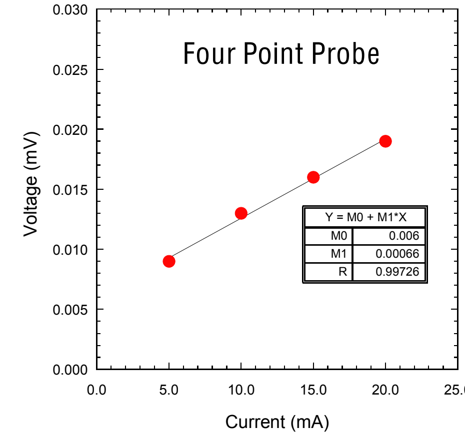
- Studying viability of silk screening anode pattern with silver paste
  - several groups involved: Ferro, Argonne glass shop, Argonne HEP
- Initial sample from Ferro characterized by Argonne ALD group (Jeff Elam)







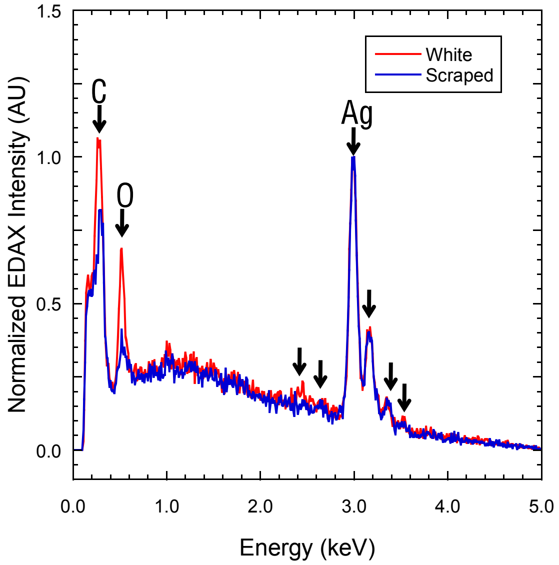
Ag thickness, t=18.5 µm
Ag roughness : RMS=2 µm



Sheet resistance Rs=4.532(V/I)=3.00e^{-3} Ω/□

- Resistivity ρ=Rs t=5.5 µΩcm
- pure Ag, ρ=1.6 µΩcm (higher for thin films), pure AgO=60 Ωcm
- Resistivity consistent with Ag thin film

courtesy of Jeff Elam



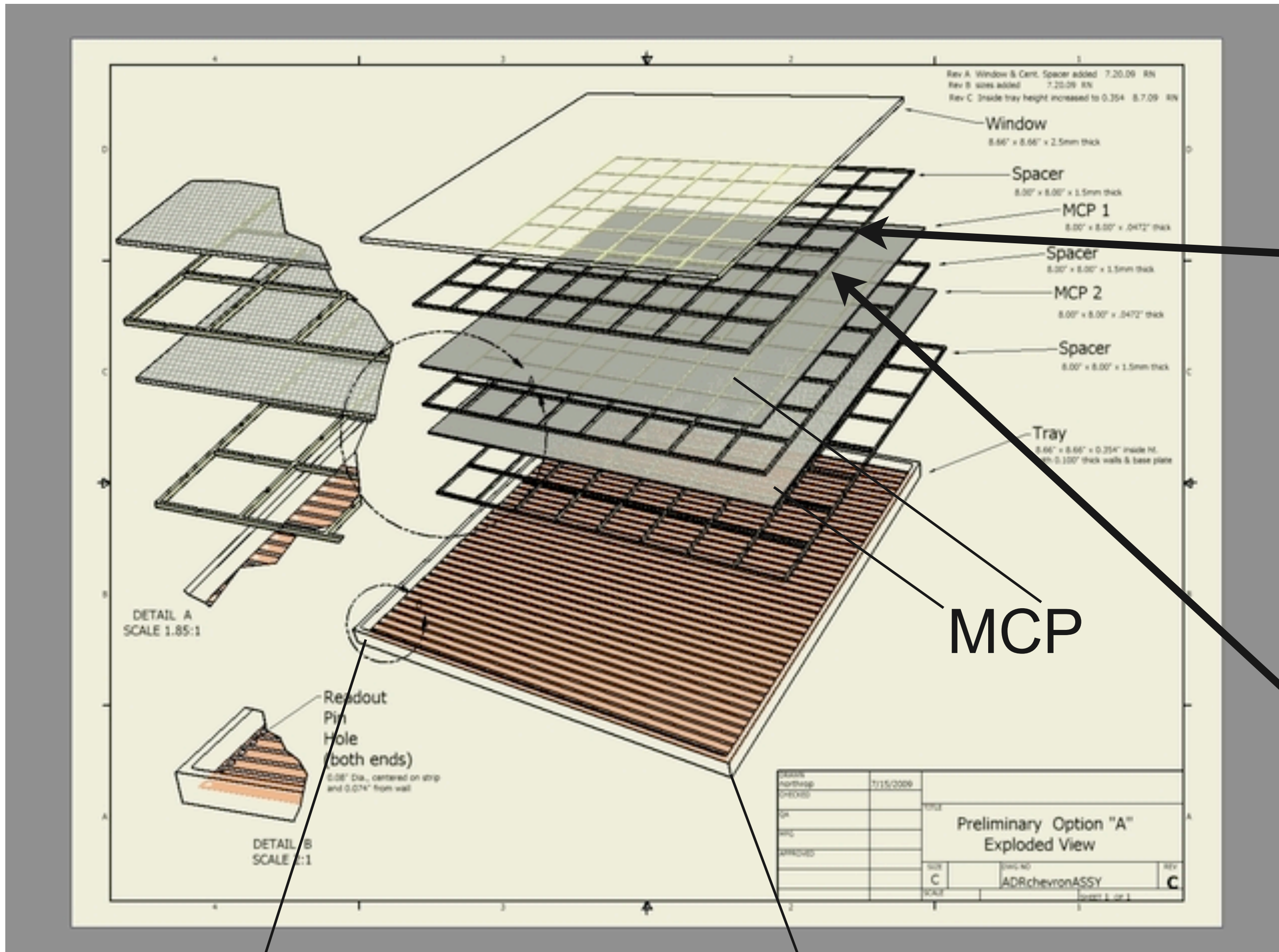
Atomic %

	C	O	Ag	O/Ag
White	60	34	6	5.7
Scraped	64	25	10	2.5

- both regions show significant C, O
- white area shows higher O/Ag
- EDAX signals might represent only near-surface region
- Ag_2O is soluble in acid – tried phosphoric, sulfuric, and acetic acid on white region – it didn't dissolve.

3

Mechanical Assembly -- 1



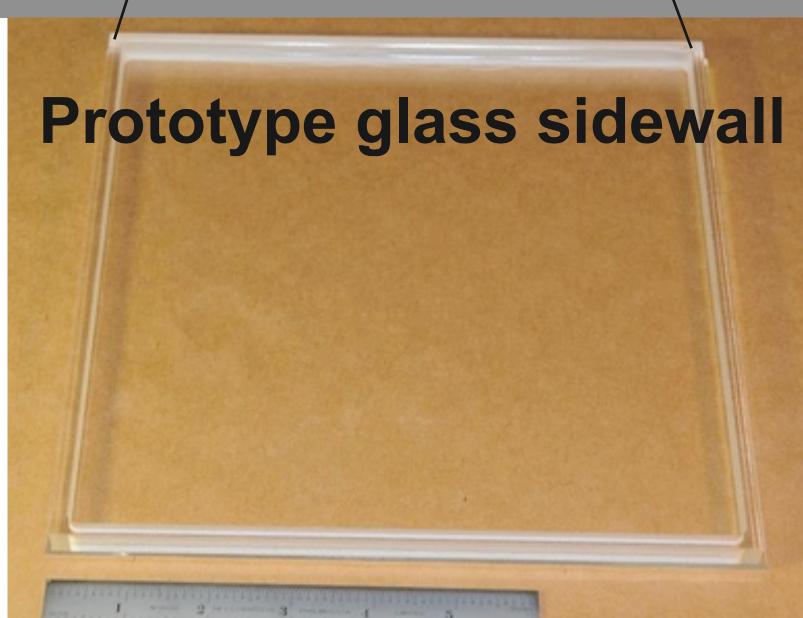


photo credit: Rich Northrop, UC

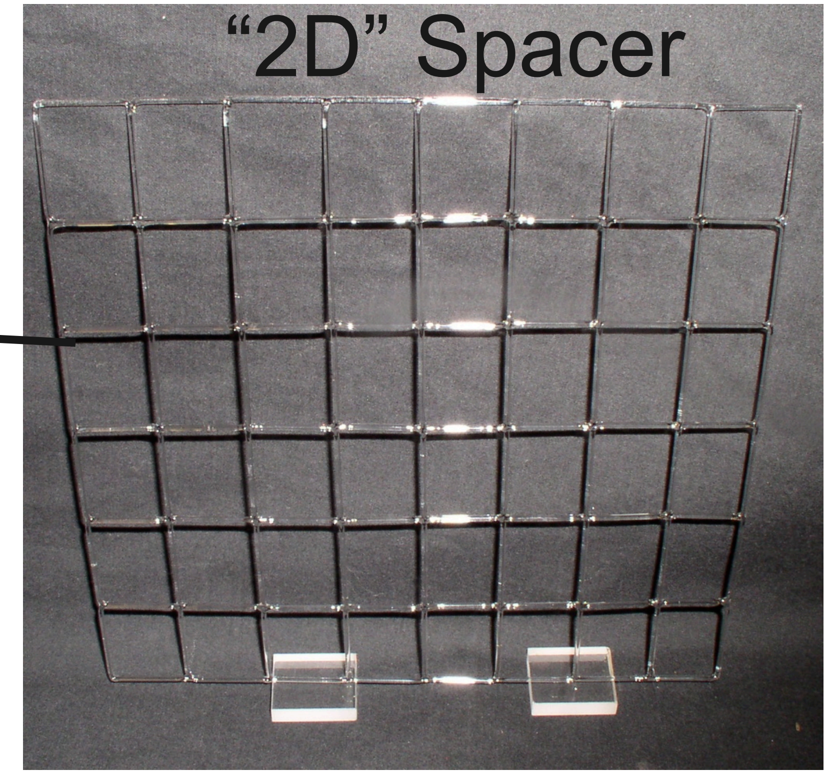
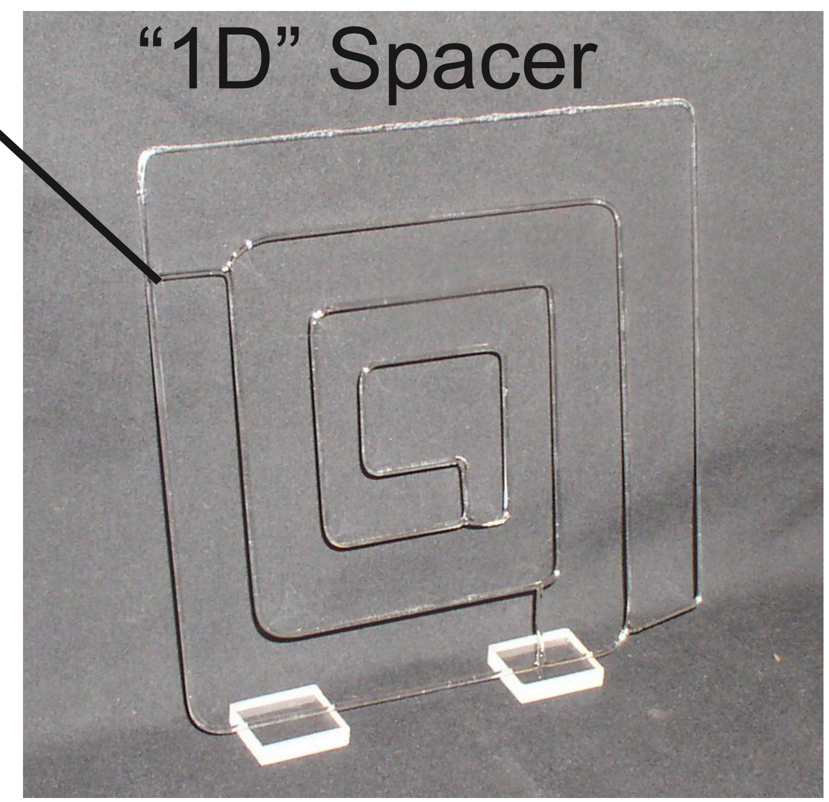
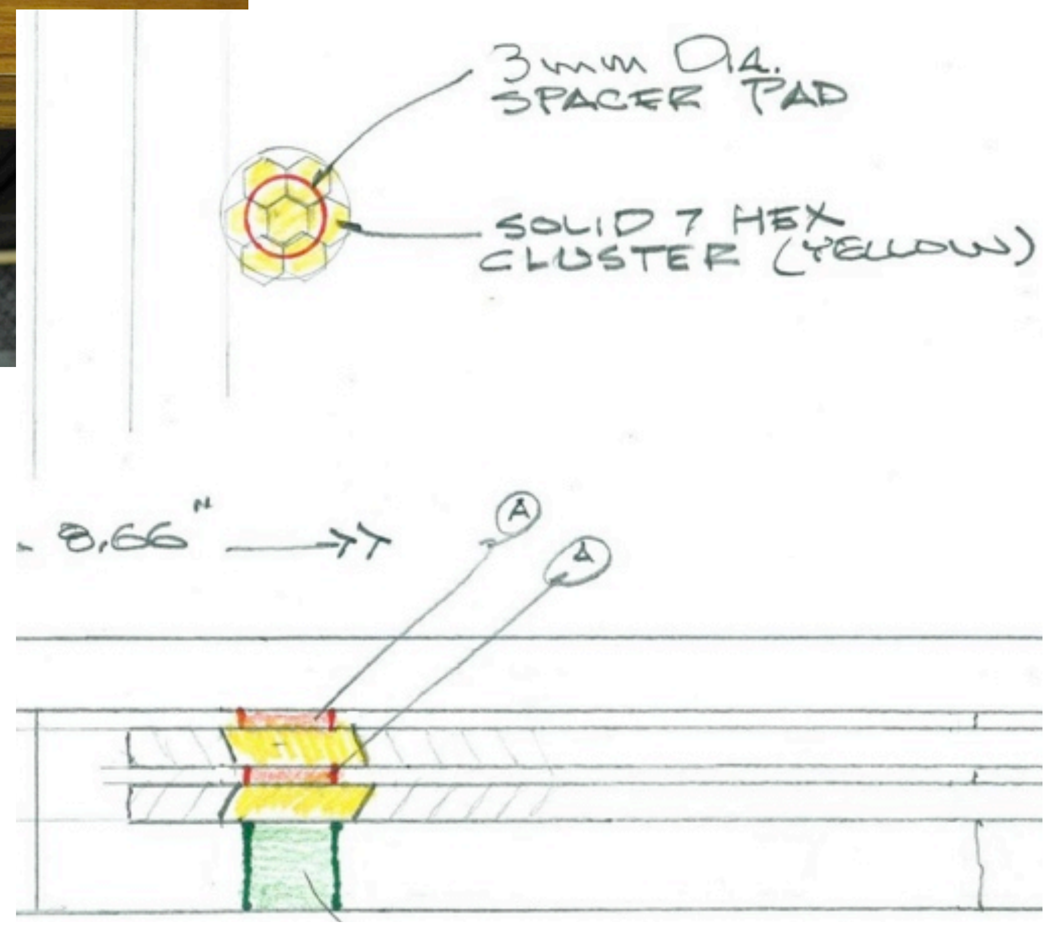


photo credit: Joe Gregar, Argonne



Mechanical Assembly -- 2

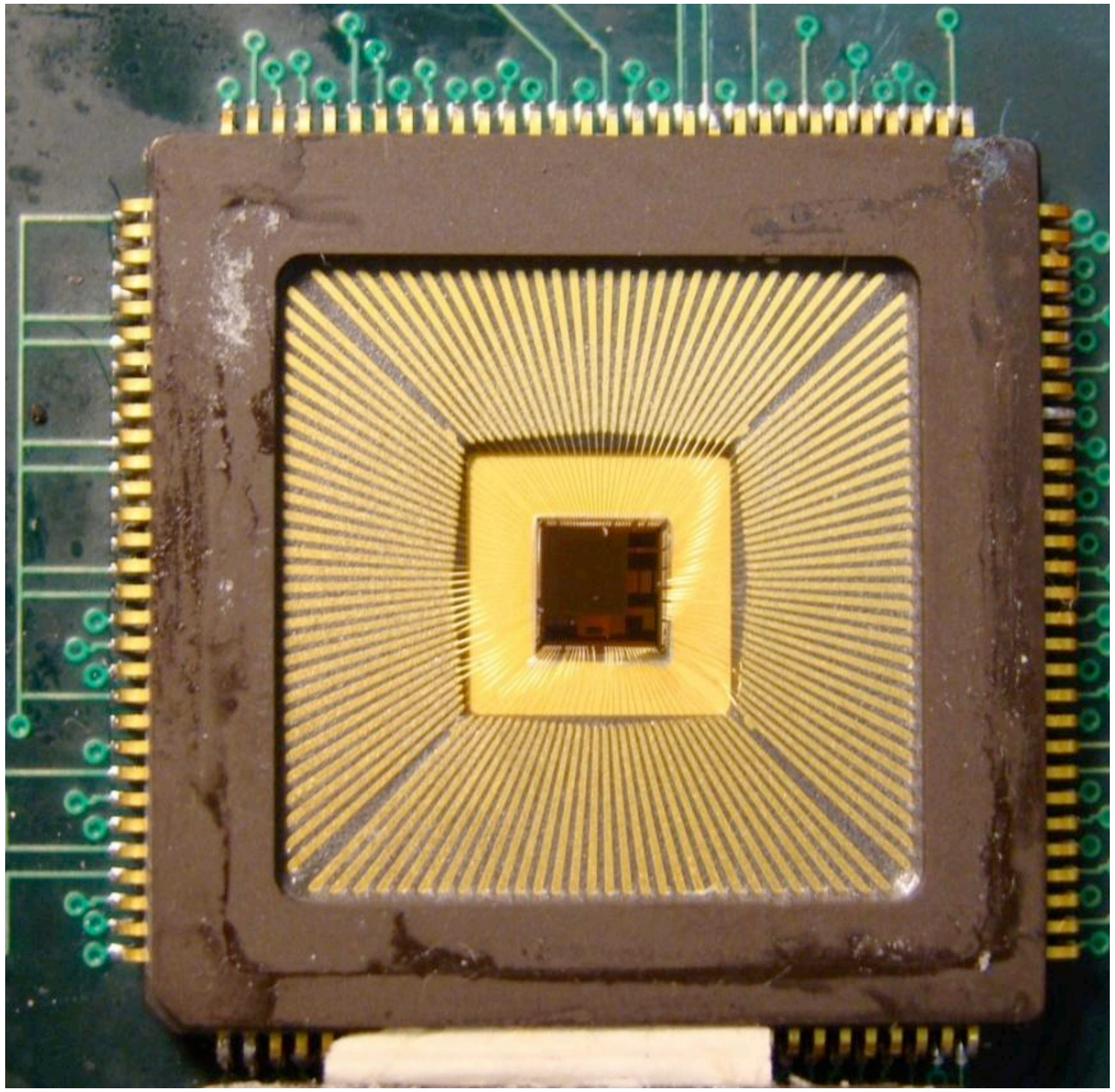


Alternative spacer design:

- Use button spacers arranged in grid
- Glass substrate has solid "multis" inserted as "lily pads"
- Buttons for each layer form columns to provide continuous solid support

Picosecond Timing Readout ASIC

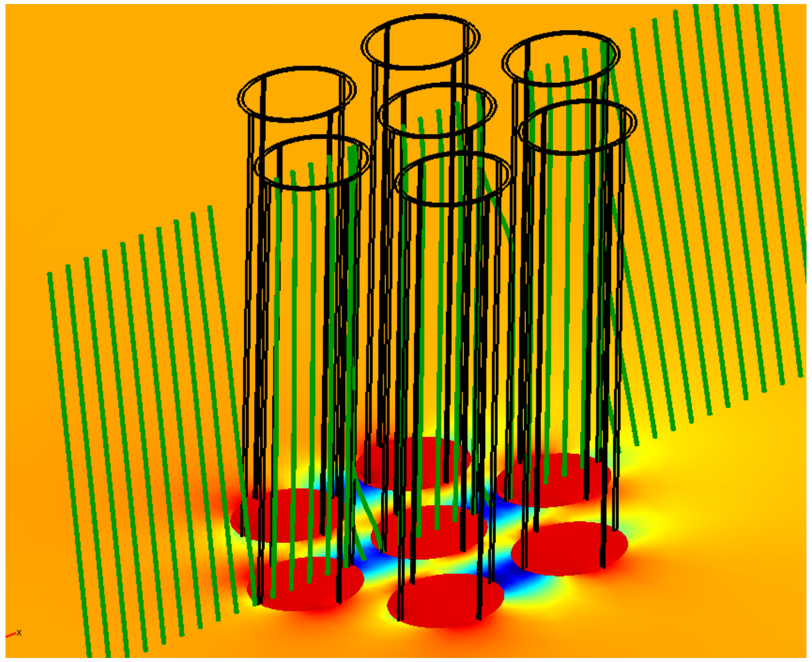
- Univs. Chicago/Hawaii ASIC design for readout using switched capacitor array in 130nm CMOS
- 1st round chips delivered in Oct, 2009
  - 4 channels of full sampling
  - 10-15 Gsamples/s
  - 256 cells @ < 100ps/cell
  - 1-2 GHz bandwidth, 50Ω
- Have tested:
  - DC power vs. bias
  - Sampling cell response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



Simulation Work

- Simulation studies being performed at Argonne, Muons, Inc., Arradiance
- Example: E-Field direction in pore done by Sergey Antipov, Argonne
- Many other simulations completed or underway
  - Saturation effects
  - Secondary electron emission
  - End spoiling effect on E-field
  - Noise factor
  - Charge relaxation time

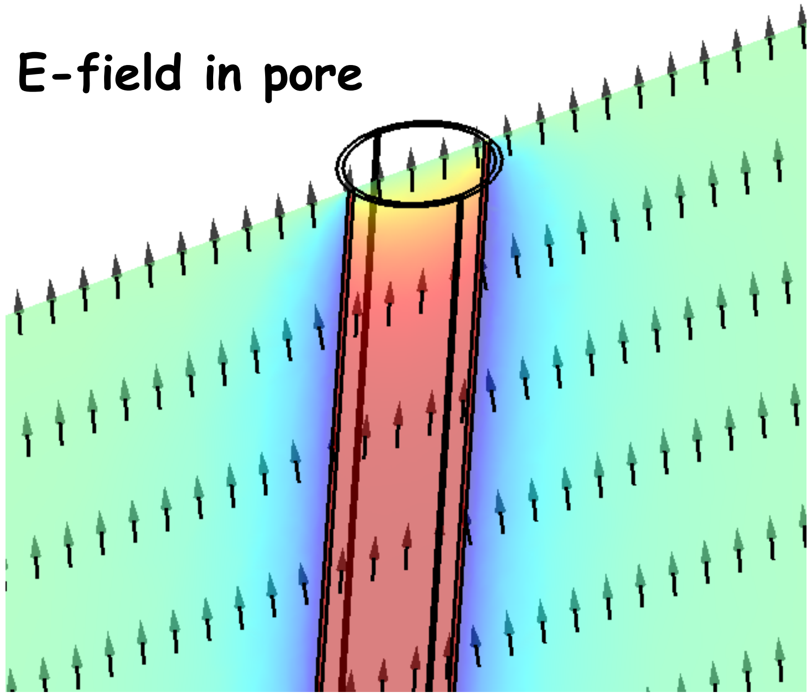
E-field Angle ~ 8°, field aligns along the pore



Color: Angle=Atan(Ex/Ez)
Streamlines in cross section - electric field

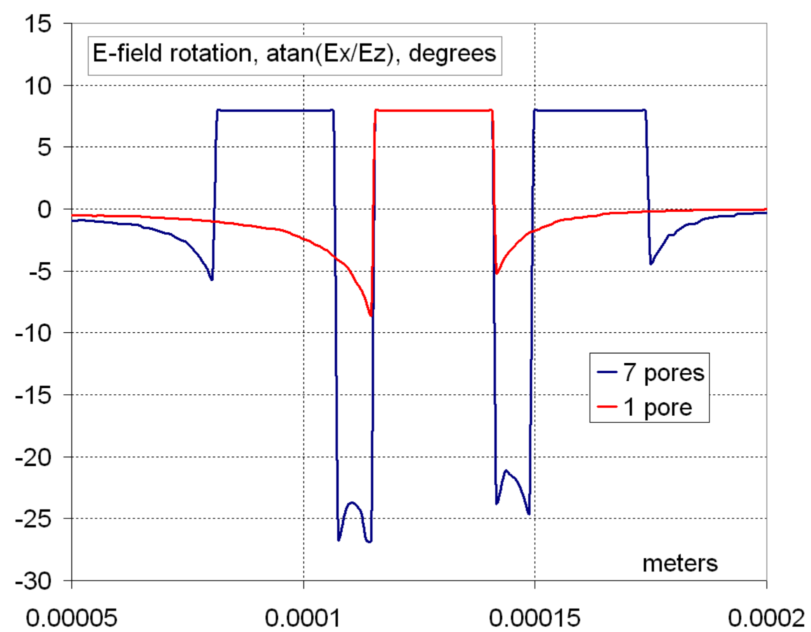
courtesy of Sergey Antipov

E-field in pore



Color: Angle=Atan(Ex/Ez)
Arrows: Electric field

E-field inside 7 pores



Summary

- Large Area Photodetector Development project has been active for 6 months; preceded by 2+ years work with Photonis Planacon and commercial amp-disc-TAC for picosecond timing development
- A lot of progress in 6 months; many studies & developments running in parallel
  - Demonstrated gain with ALD coated glass substrate MCP
  - Characterization facilities in place and producing results
  - Design of anode and mechanical assembly is maturing;
    some definite results in near future
- Expertise working on project encompasses many scientific disciplines: Material Science, Chemistry, Surface Physics, HEP, Forefront electronics, Vacuum Technology
  - Seems to be working amazingly well
  - Have a number of talented, enthusiastic young scientists producing good results
- Challenges exist in the present and future; work to date is basis for expecting success

Many topics, results neglected to keep within time.
You are invited to browse a wealth of information on our web site:
psec.uchicago.edu