Large Area Photodetector Development:

Project Status

Bob Wagner, Project Physicist

for LAPD Collaboration

Visit by Alan Stone, DOE HEP

1 Feb 2010

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

John Anderson, Karen Byrum, Gary Drake, Edward May, Alexander Paramonov, Mayly Sanchez, Robert Stanek, Hendrik Weerts, Matthew Wetstein[1], Zikri Yusof
High Energy Physics Division
Argonne National Laboratory, Argonne, Illinois 60439

Bernhard Adams, Klaus Attenkofer
Advanced Photon Source Division
Argonne National Laboratory, Argonne, Illinois 60439

Zeke Insepov
Mathematics and Computer Sciences Division
Argonne National Laboratory, Argonne, Illinois 60439

Jeffrey Elam, Joseph Libera
Energy Systems Division
Argonne National Laboratory, Argonne, Illinois 60439

Michael Pellin, Igor Veryovkin, Hau Wang, Alexander Zinovev
Materials Science Division
Argonne National Laboratory, Argonne, Illinois 60439

David Beaulieu, Neal Sullivan, Ken Stenton
Arradiance Inc., Sudbury, MA 01776

Mircea Bogdan, Henry Frisch[1], Jean-Francois Genat, Mary Heintz, Richard Northrop, Fukun Tang
Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637

Erik Ramberg, Anatoly Ronzhin, Greg Sellberg
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

James Kennedy, Kurtis Nishimura, Marc Rosen, Larry Ruckman, Gary Varner
University of Hawaii, 2505 Correa Road, Honolulu, HI, 96822

Robert Abrams, Valentin Ivanov, Thomas Roberts
Muons,Inc 552 N. Batavia Avenue, Batavia, IL 60510

Jerry Va'vra
SLAC National Accelerator Laboratory, Menlo Park, CA 94025

Oswald Siegmund, Anton Tremsin
Space Sciences Laboratory, University of California, Berkeley,CA 94720

Dmitri Routkevitch
Synkera Technologies Inc., Longmont, CO 80501

David Forbush, Tianchi Zhao
Department of Physics, University of Washington, Seattle, WA 98195

[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*
    - *Dual readout calorimeters*
    - *Medical imaging?*
- Possibly novel front-end electronics, e.g. picosecond timing ASIC chip
- Design by vetted and tuned simulation

Photocathode Development

- Initial photocathode will be bialkali: Na-K-Sb
- First year milestone is upgrade of SSL facilities for large area MCP-PMT assembly
- Need to study/develop large area photocathode deposition technique
  - Largest bialkali 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

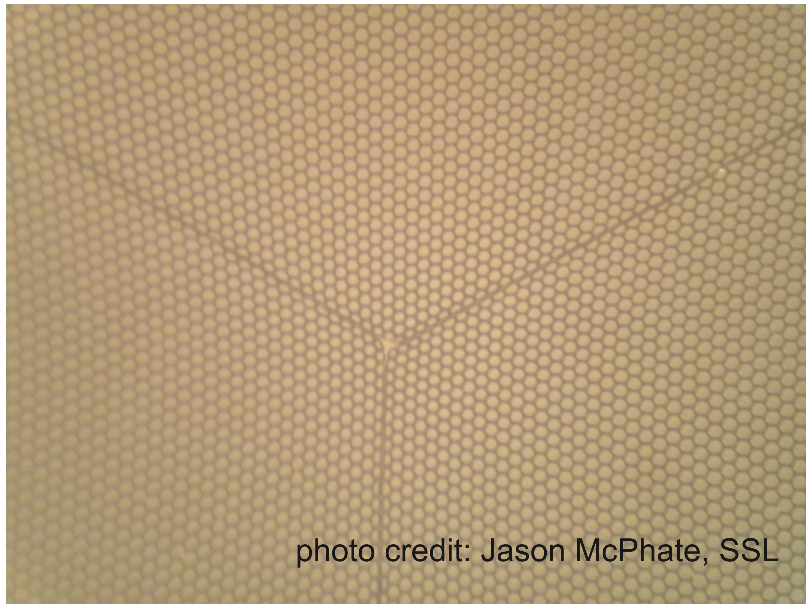
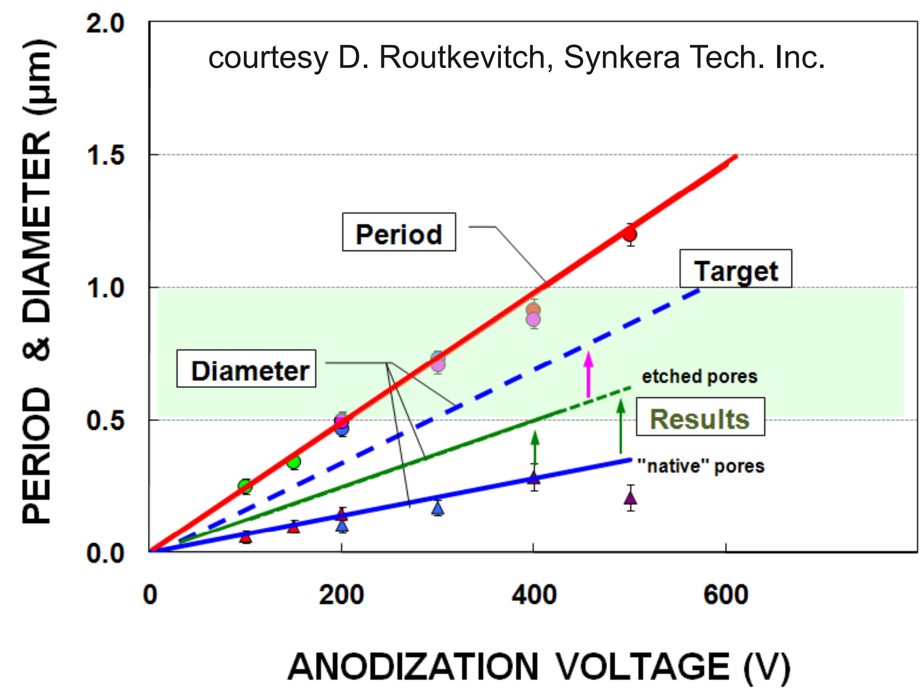


photo credit: Jason McPhate, SSL

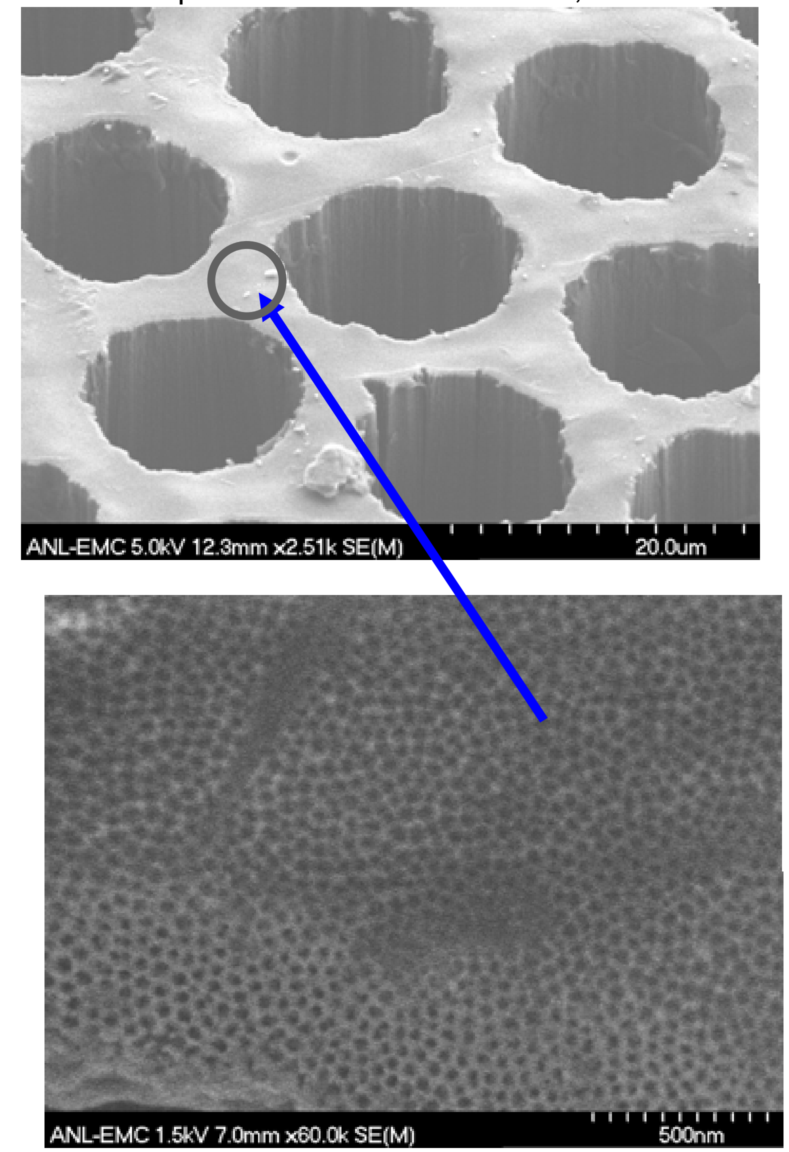
Anodic Aluminum Oxide (AAO)

- 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

Pore Size/Spacing vs Anodization Voltage Synkera AAO development



SEM photo credit: Seon Woo Lee, ANL

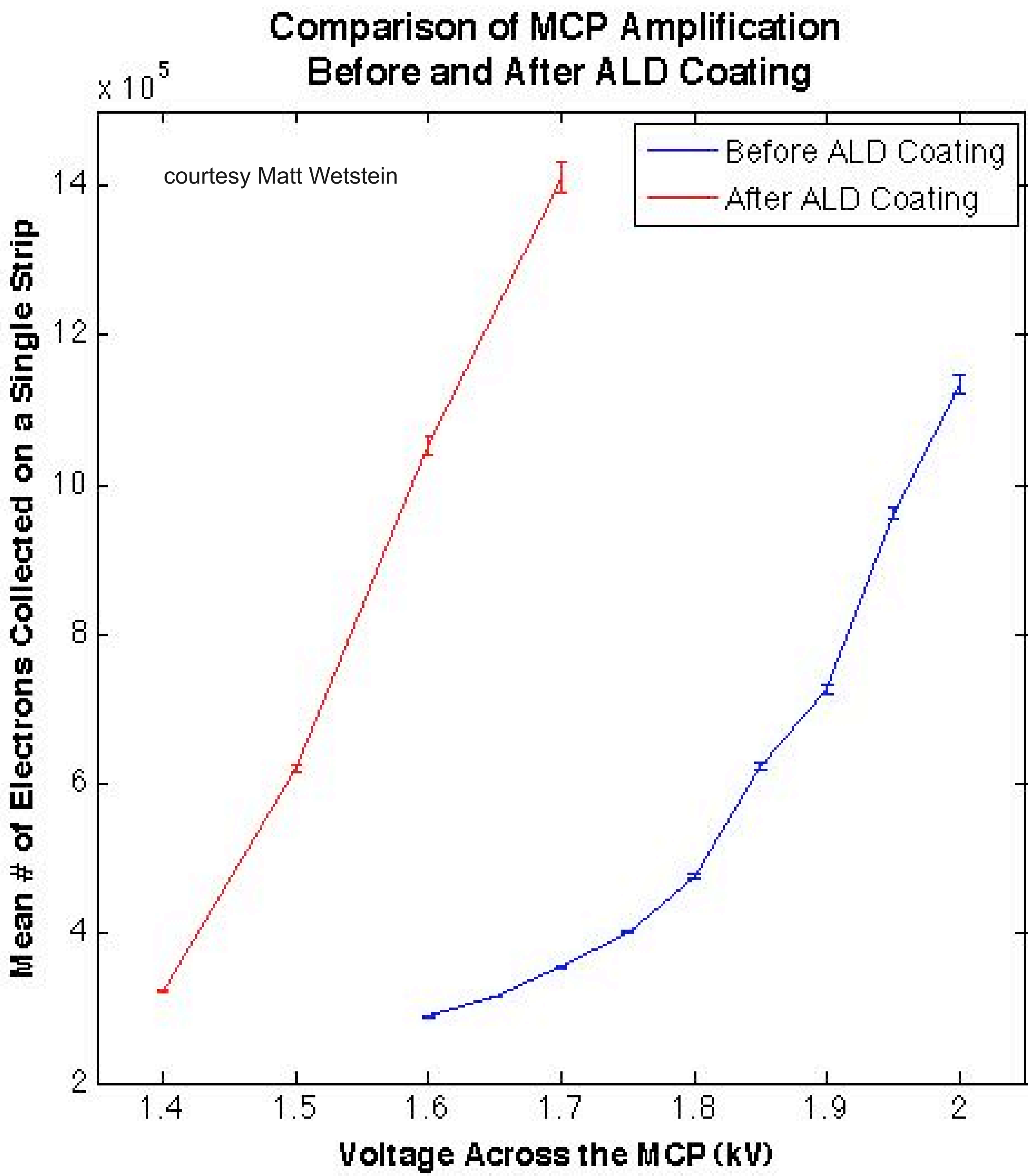


AAO development at Argonne

Observation of Gain with ALD Coating

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

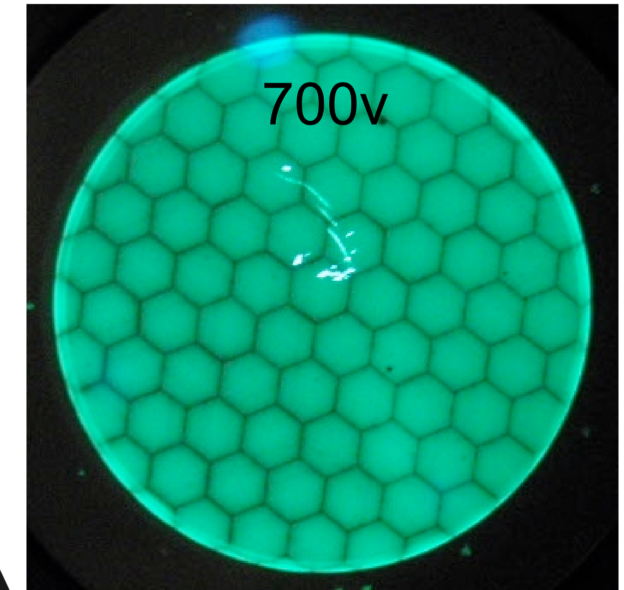
Observe increased gain
lower voltage for equivalent gain

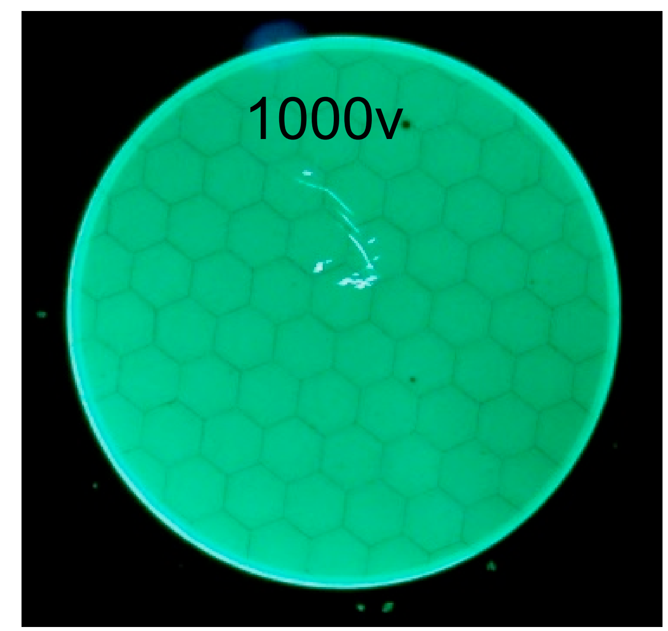


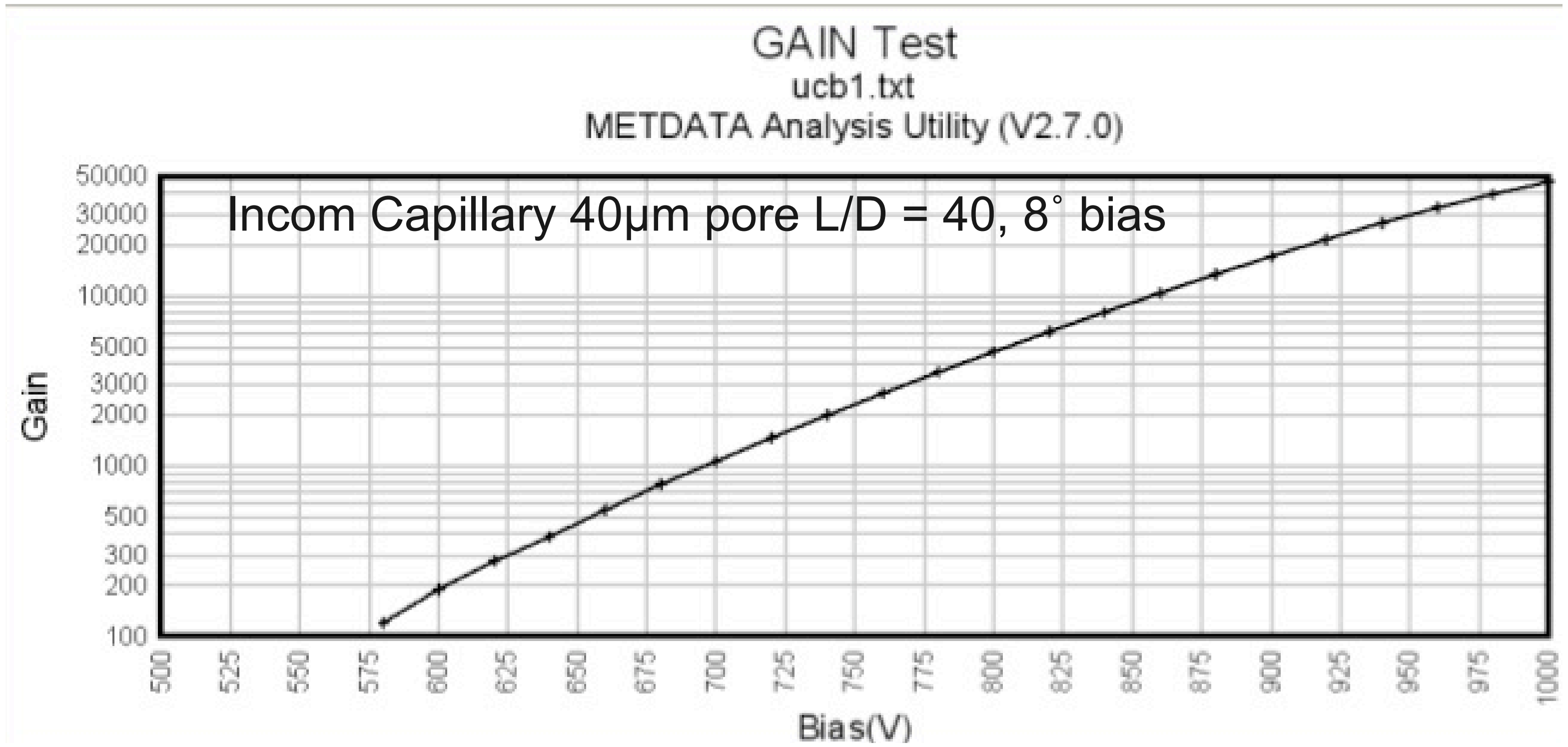
Observation of Gain with ALD Coating -- Arradiance/SSL

- 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!



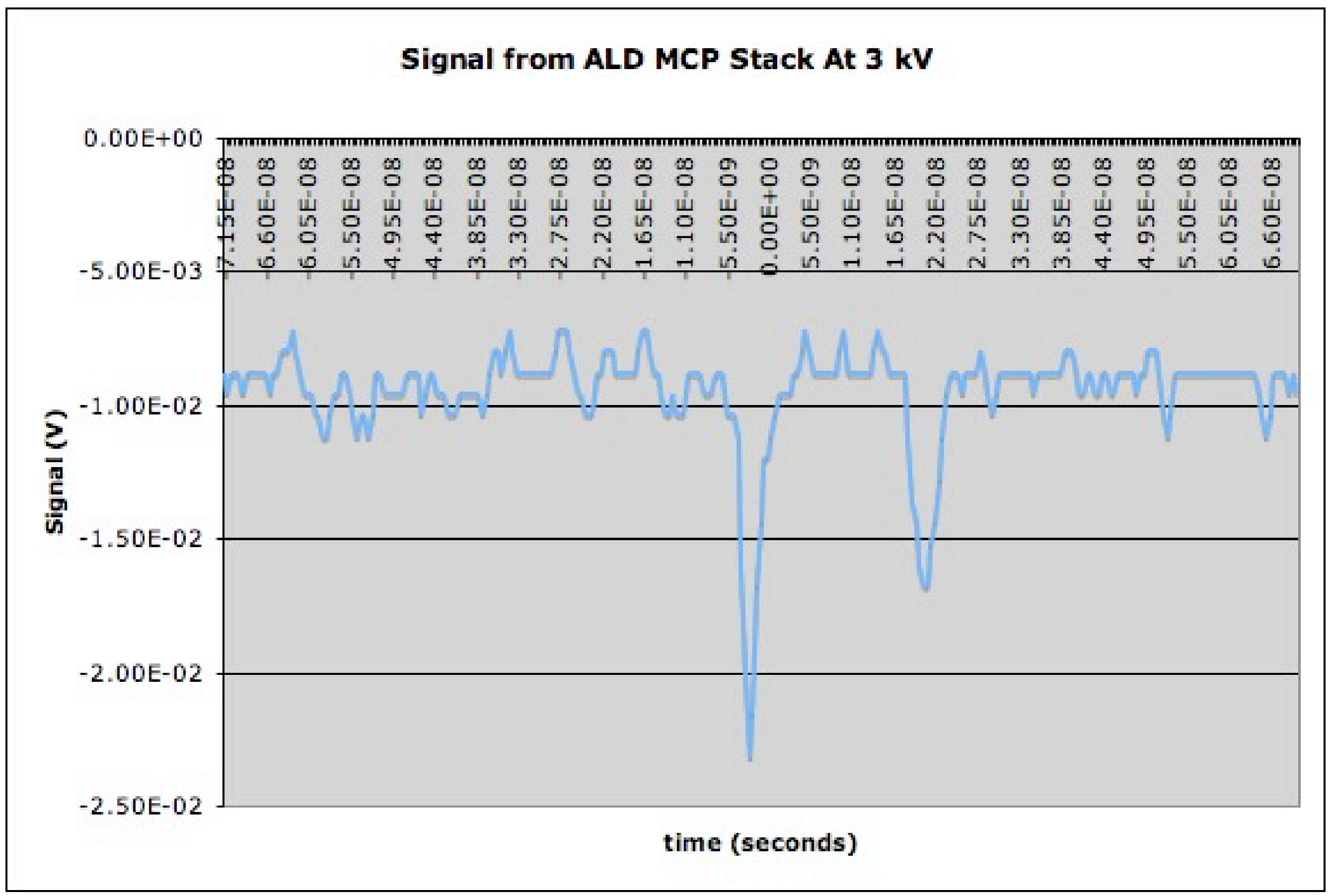


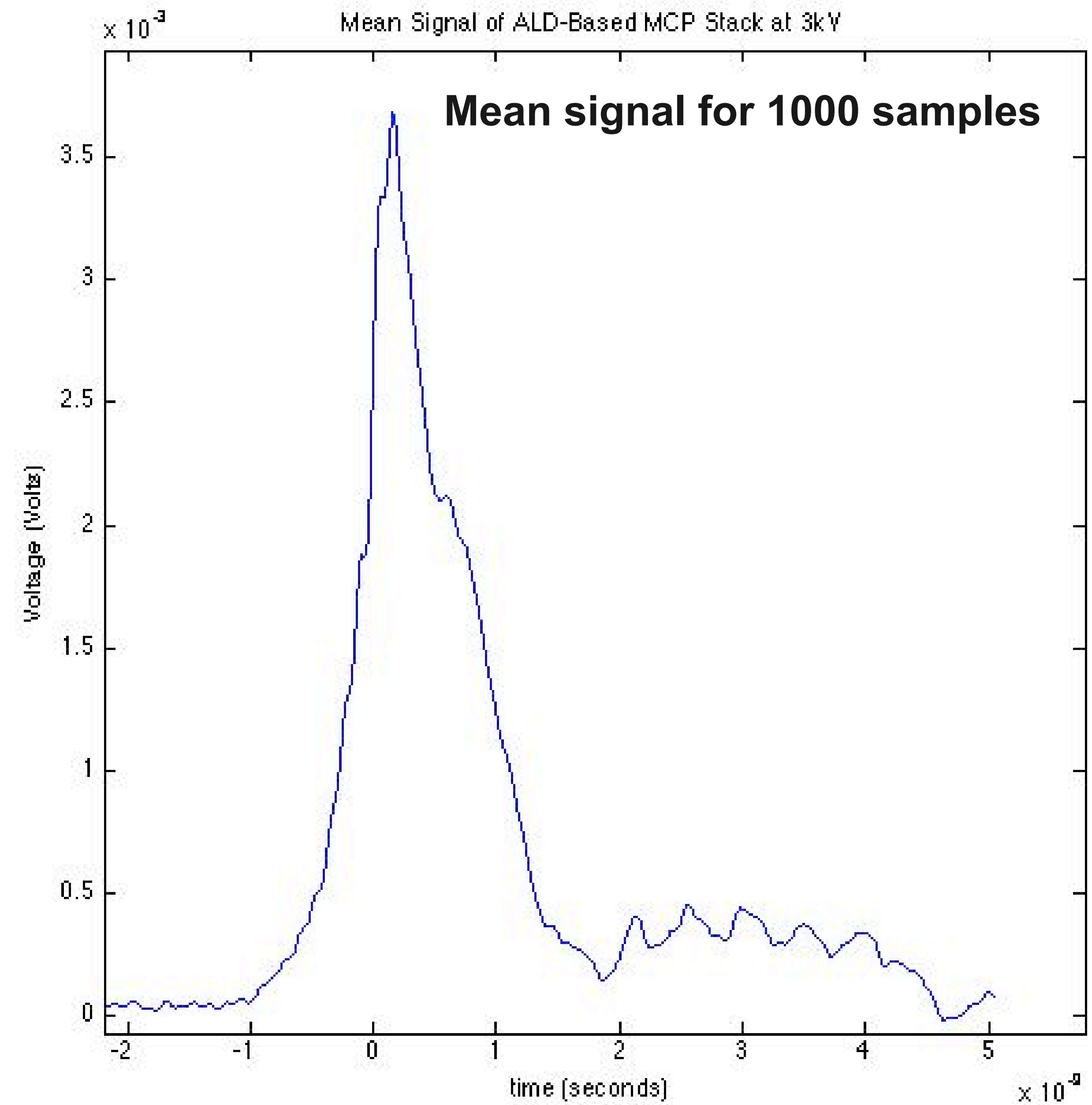


Gain measured at Arradiance, Inc.
50,000 @ 1000V

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



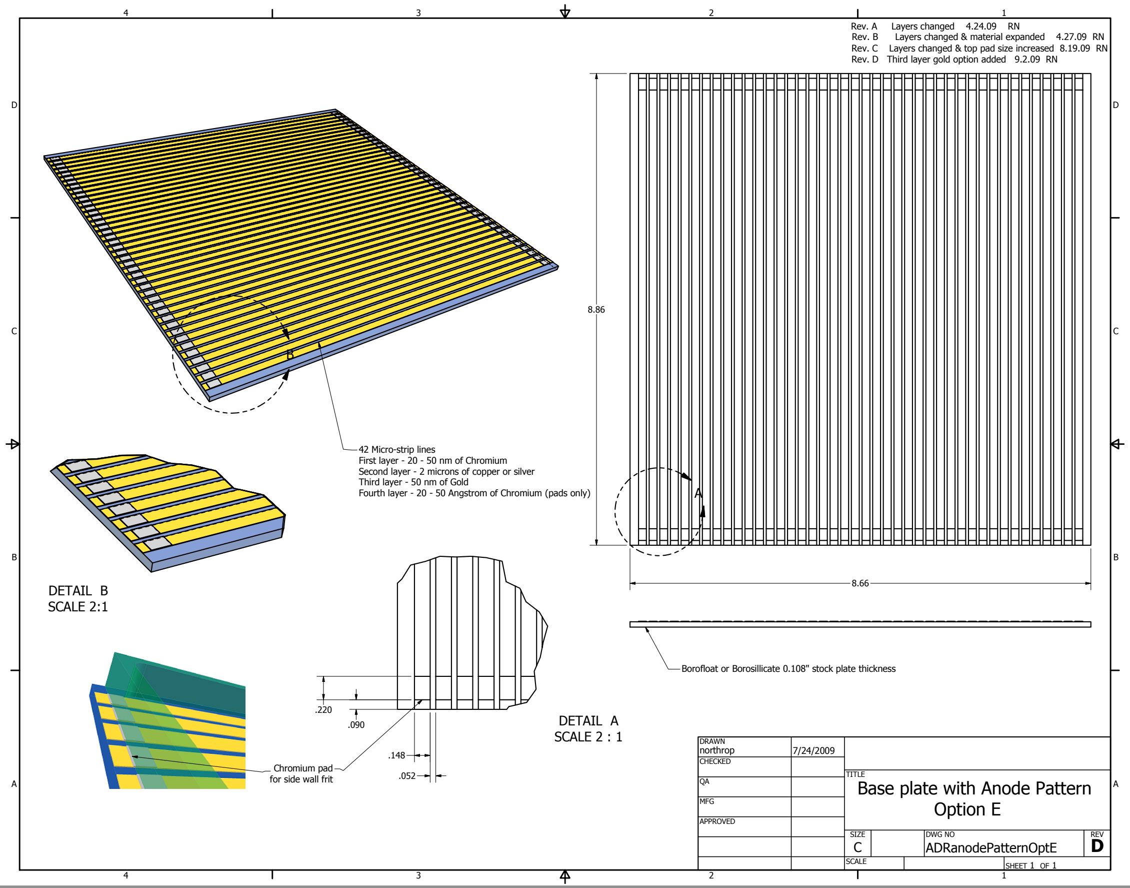


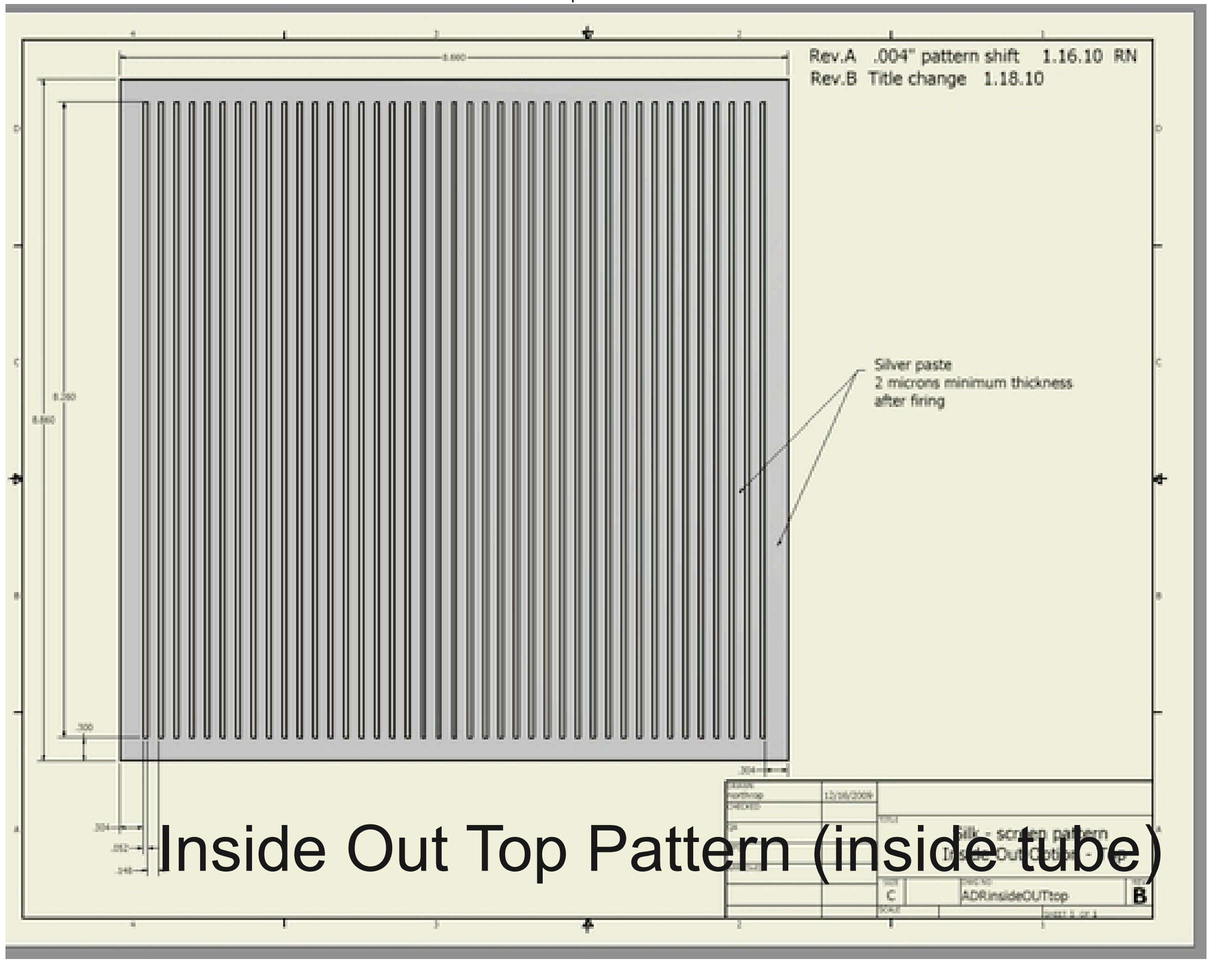
courtesy Matt Wetstein

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)

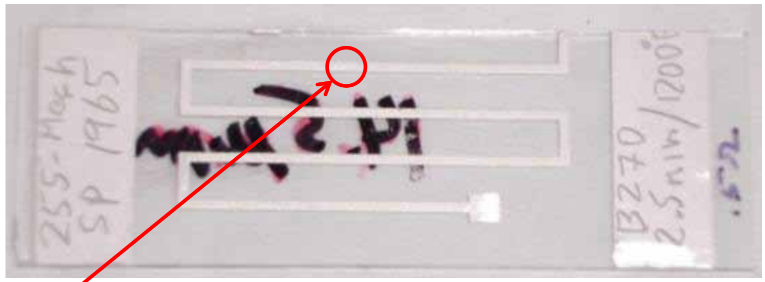


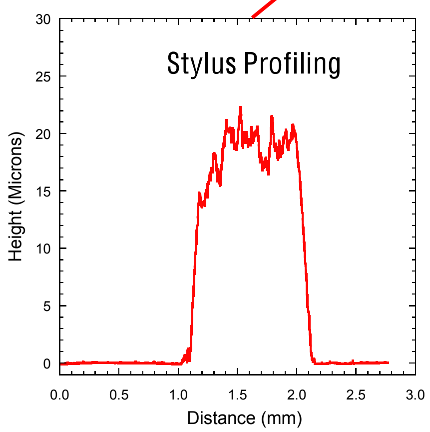


Inside Out Top Pattern (inside tube)

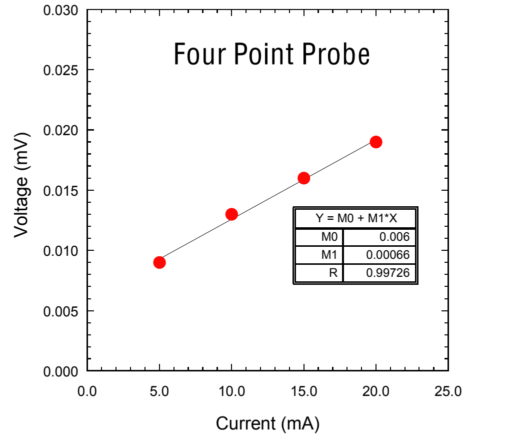
Silver Paste Silk Screening

- 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)





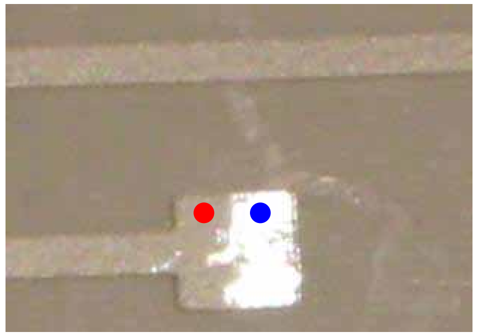
Ag thickness, t=18.5 µm
Ag roughness : RMS=2 µm

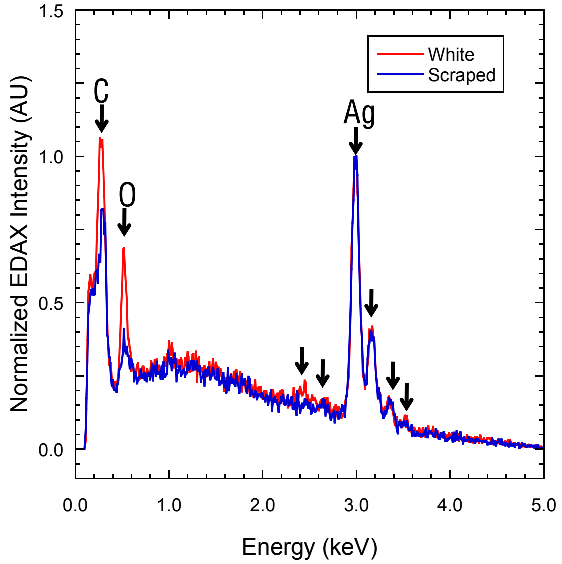


Sheet resistance Rs=4.532(V/I)=3.00e^{-3} Ω/□

- 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





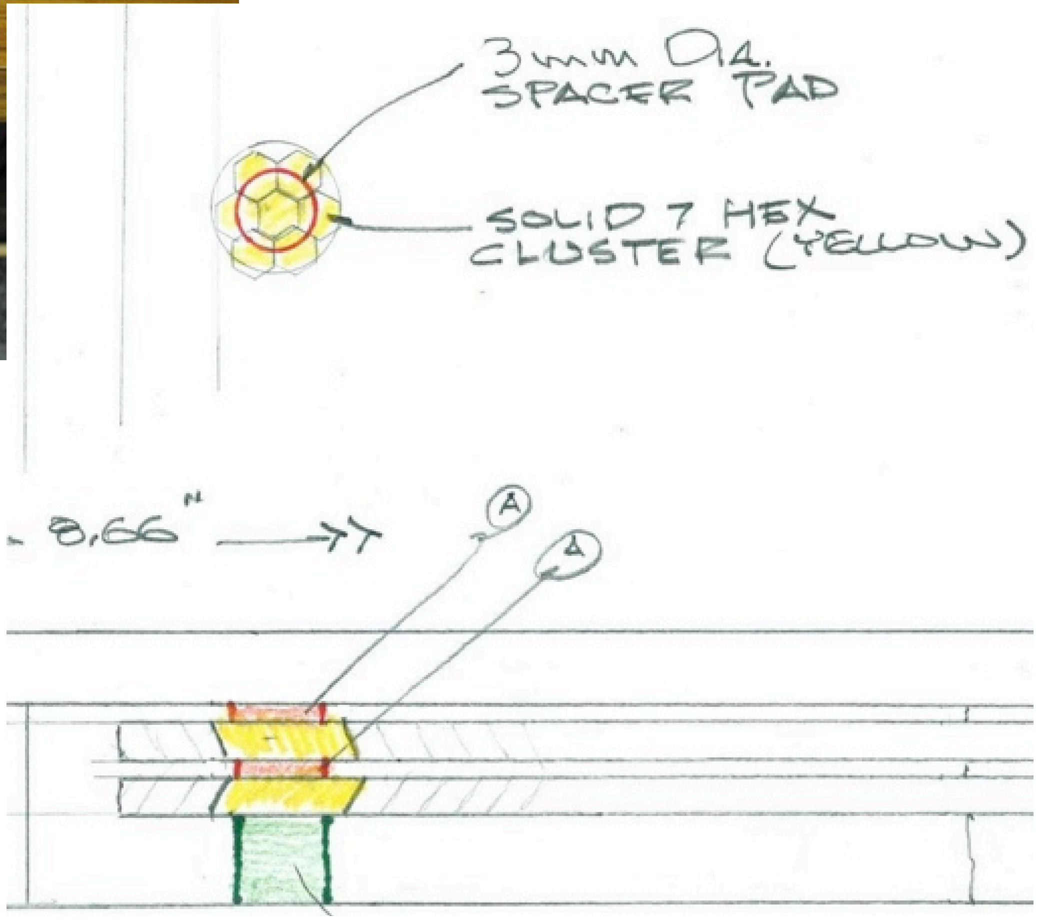
Atomic %

	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 -- 2

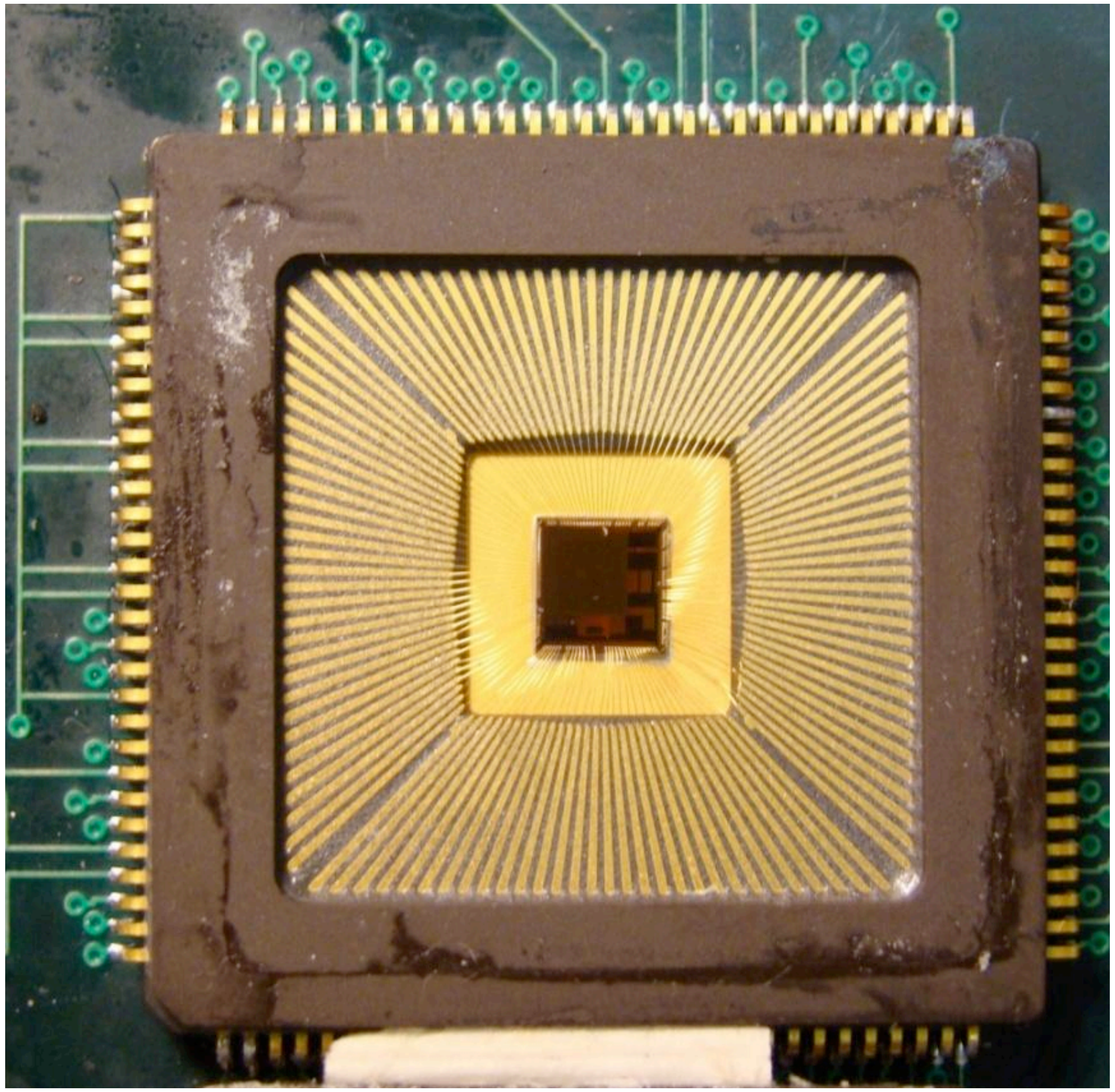


Alternative spacer design:

- 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
- 1^{st} 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



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