

R&D of Atomic Layer Deposition (ALD): Progress and near term plan for LAPD project

DOE review meeting : 05/25/2011

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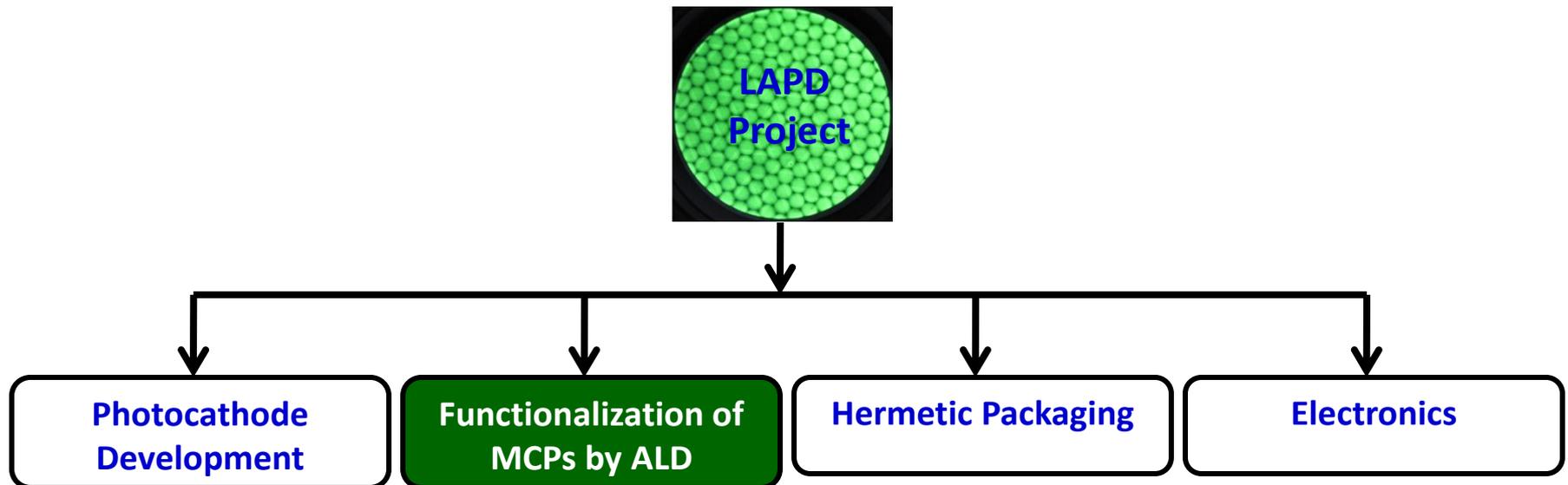
Outline

- **Background**
- **Current progress of ALD developments**
- **ALD Group achievements and delivered items for LAPD**
- **Near term plans for ALD developments**
- **Summary**
- **Acknowledgements**



LAPD project

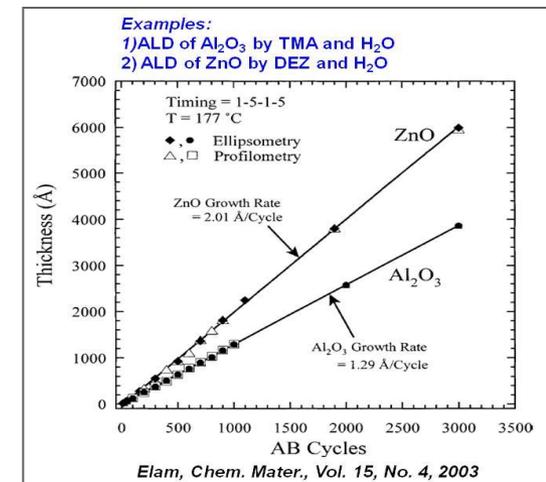
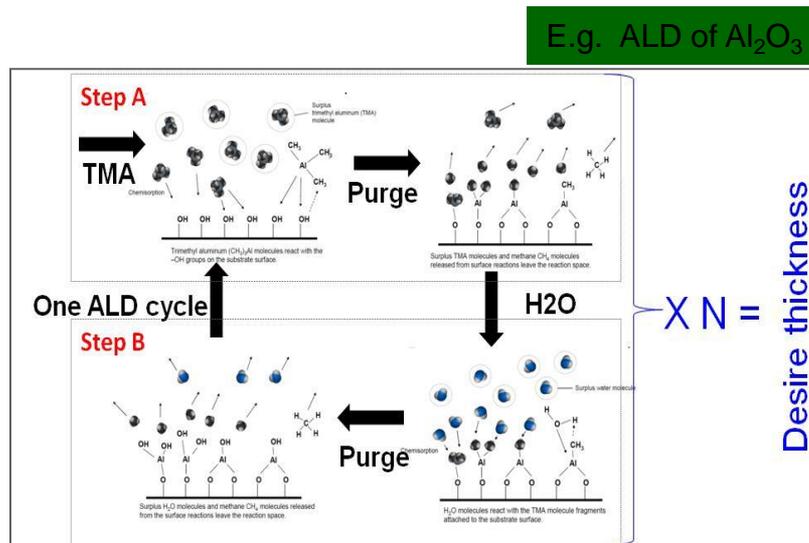
- To design and fabricate MCP(s)-based “**economical and robust large area (8”x 8”) photodetectors (LAPDs)**”
 - *Higher or similar quantum efficiencies and gains to photomultipliers*
 - *Use in wide range of applications*



Functionalization of MCPs by ALD route

Atomic layer deposition:

A chemical vapor synthesis process based on sequential, self-limiting surface reactions between precursors vapors and a solid surface to deposit films in an atomic layer-by-layer manner

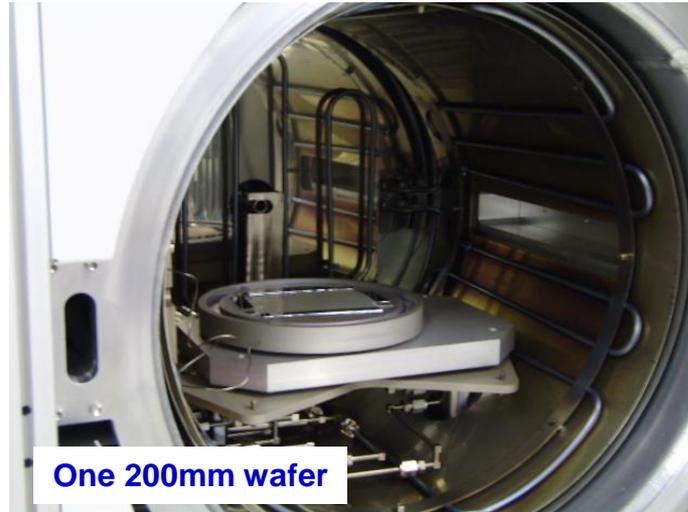


Advantages of ALD method:

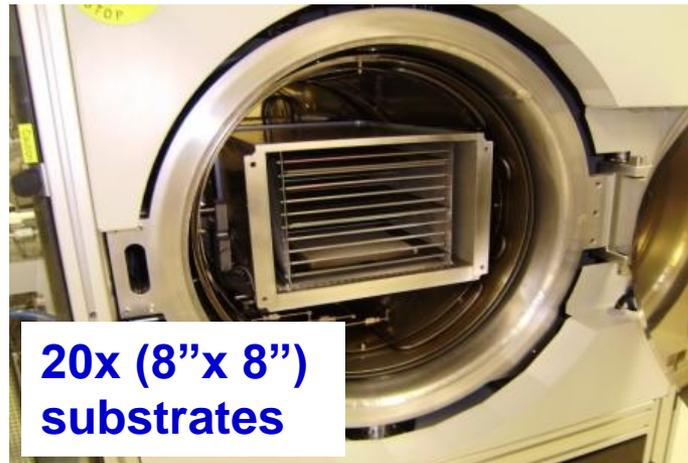
- Exquisite monolayer-level thickness and composition control
- Continuous, pinhole-free, reproducible layers on large area substrates
- Excellent conformality in very high aspect ratio structures
- Batch processing of multiple substrates for economical production



ALD method flexibility and advantages:



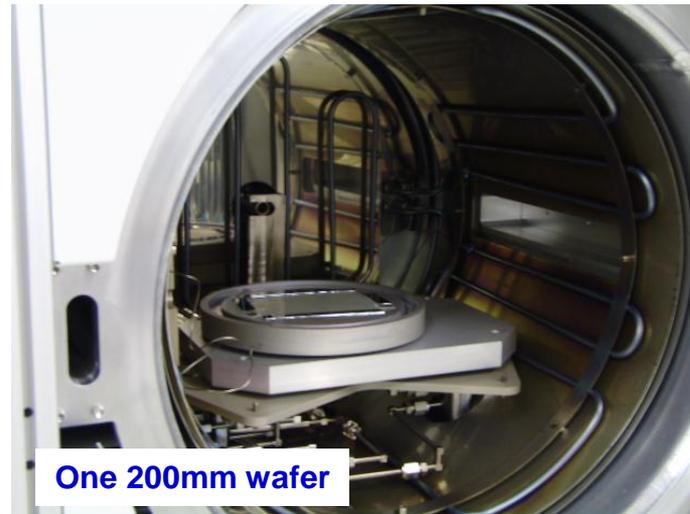
One 200mm wafer



**20x (8''x 8'')
substrates**

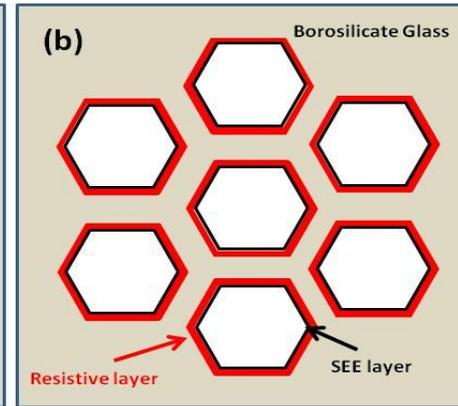
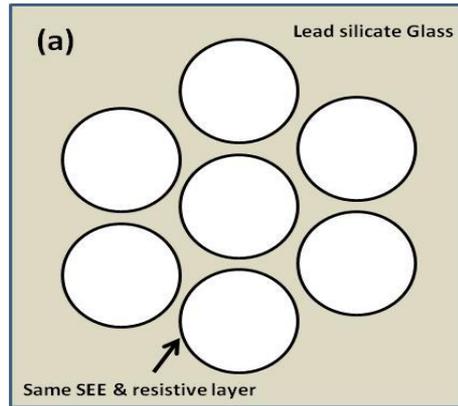


ALD method flexibility and advantages:



MCP functionalization comparisons:

Conventional
Route

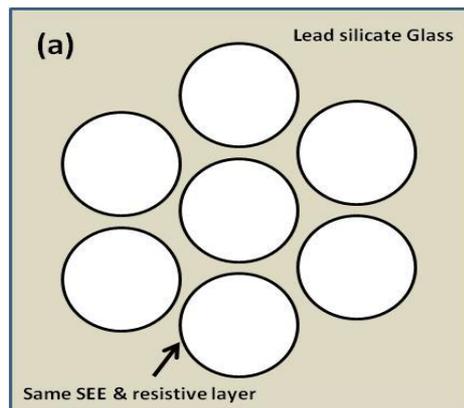


ALD Route

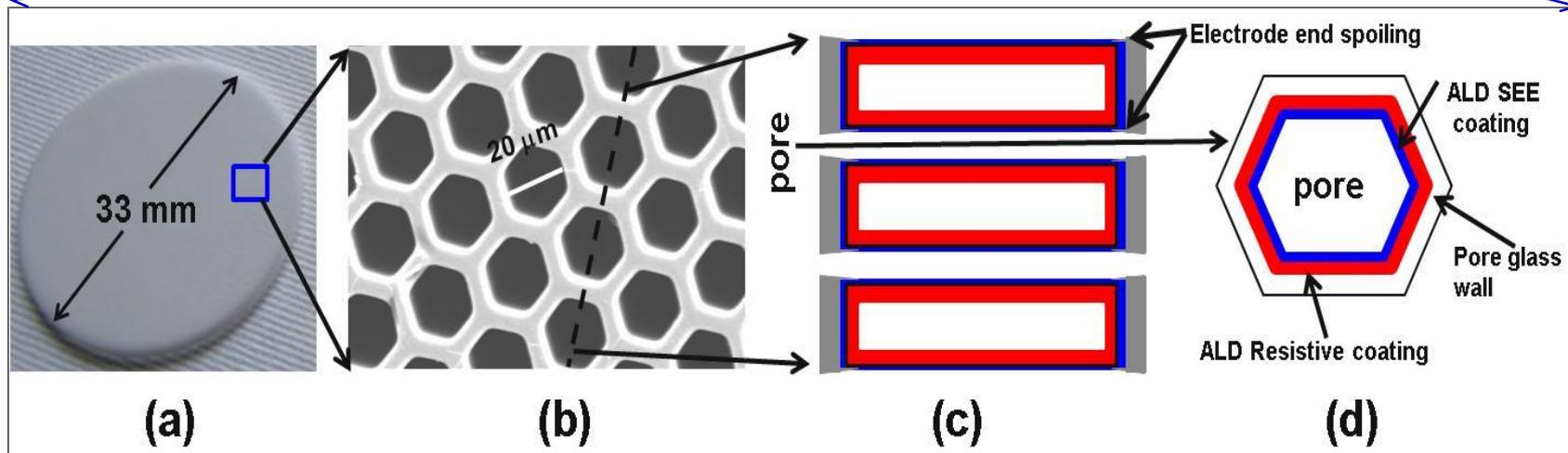
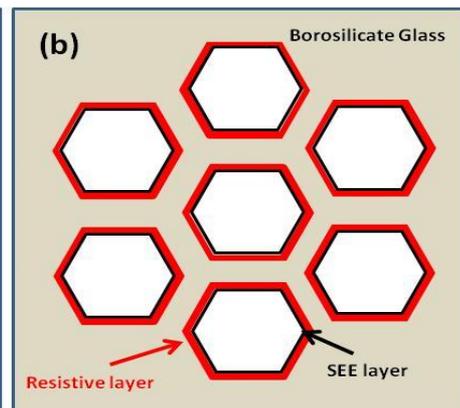


MCP functionalization comparisons:

Conventional Route



ALD Route

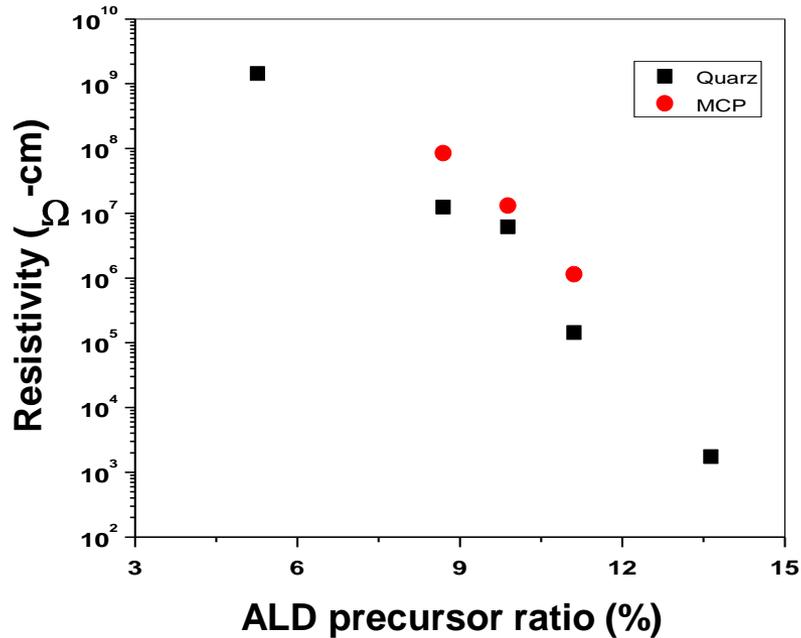


- (a) As received capillary glass array substrate,
- (b) Plan-view SEM of capillary array front surface,
- (c) Schematic cross section of fully-functionalized MCP,
- (d) Schematic cross section of individual MCP pore after ALD functionalization

Current progress of ALD developments

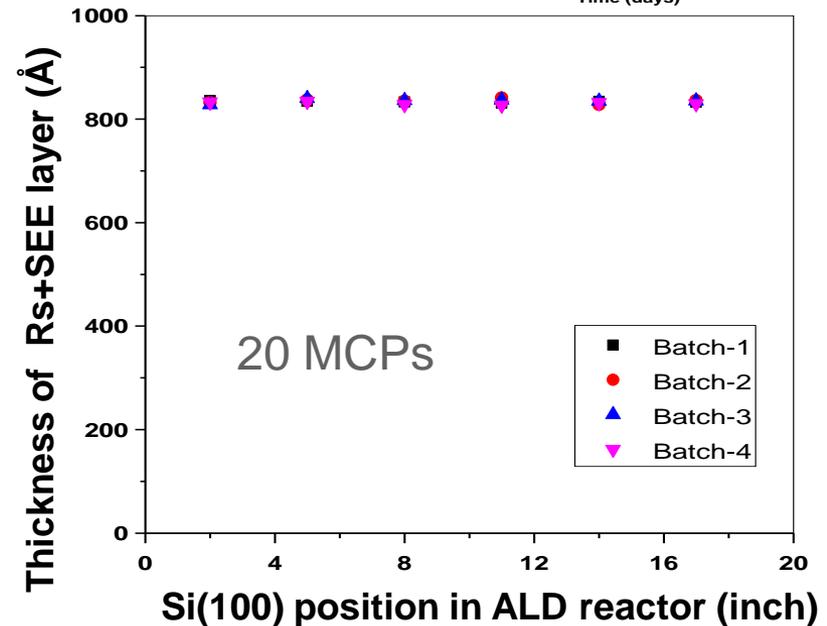
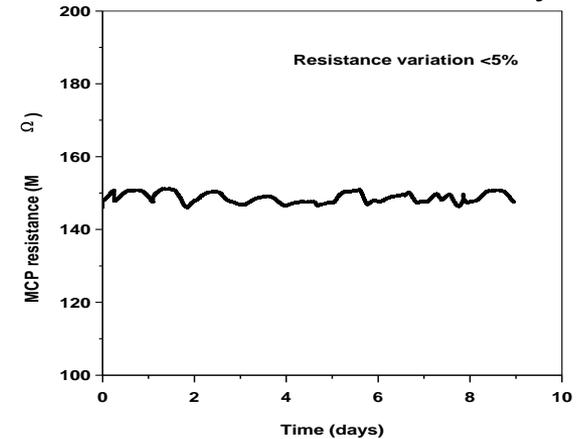


BKM ALD process (Chem-2) for MCPs:



- Control over desire resistance range

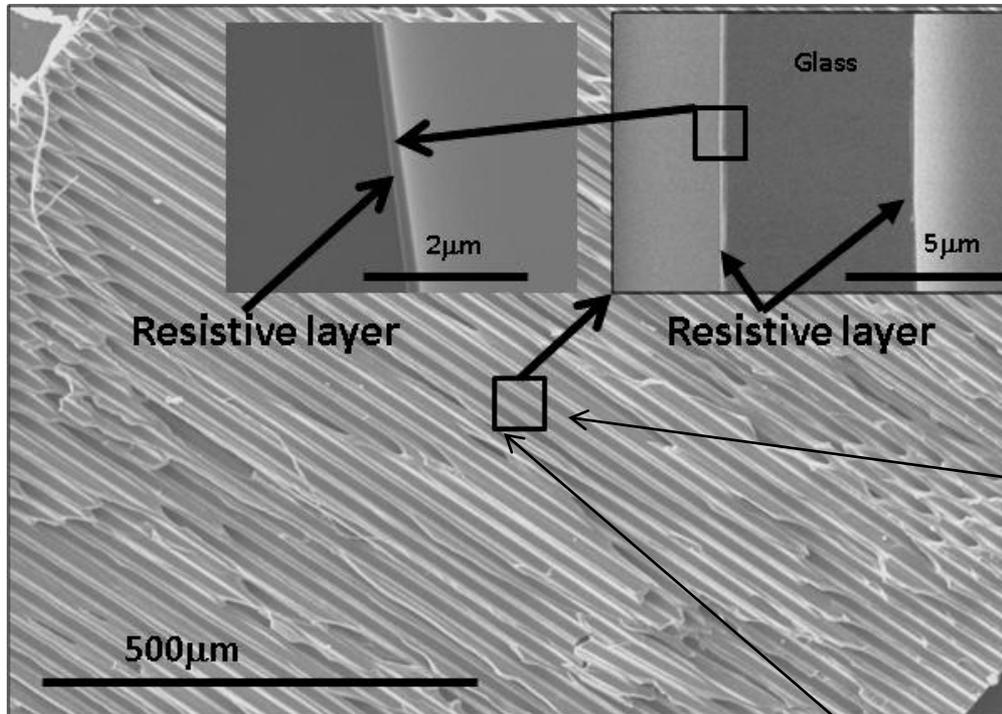
• Stability



- Within a batch and Batch-to-batch reproducibility

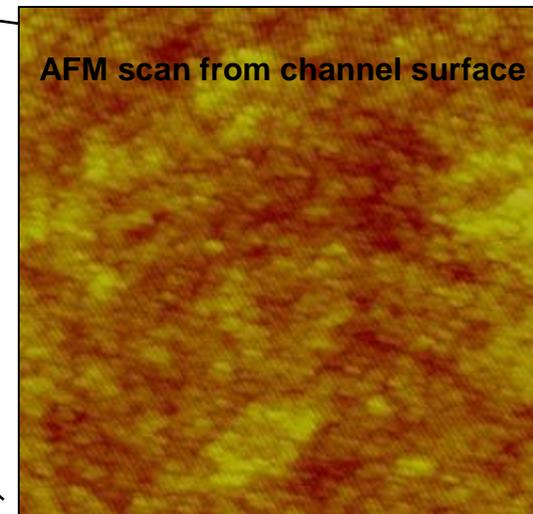


BKM ALD process for MCPs:



Courtesy: Hau Wang

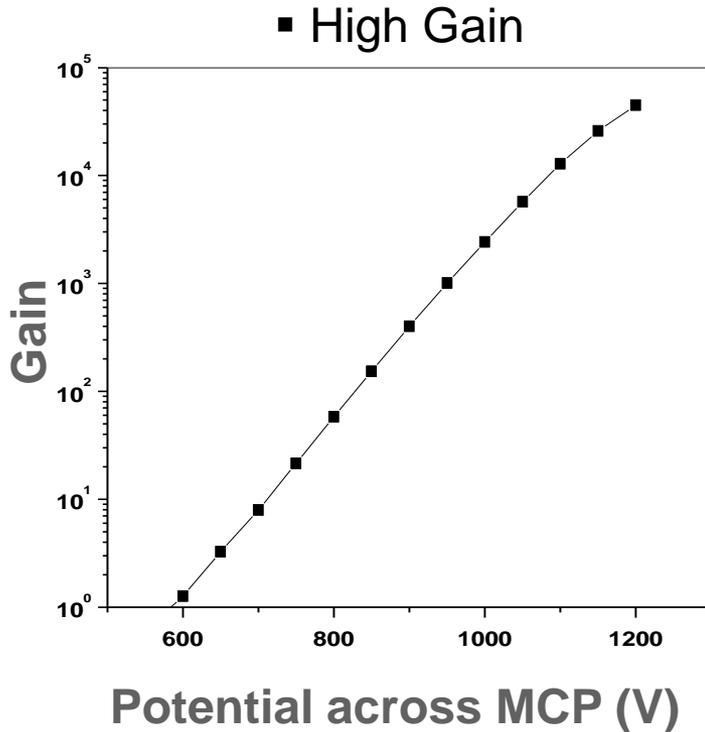
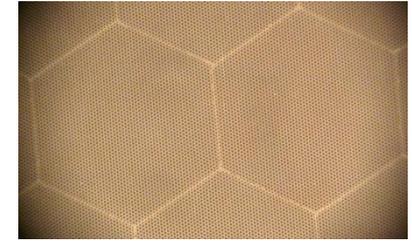
- Uniform and smooth layer



- Uniform coating across the MCP pores

- RMS roughness = 0.634 nm for 85 nm ALD layer \rightarrow $<1\%$

BKM ALD process for MCPs:



- Uniform spatial resolution



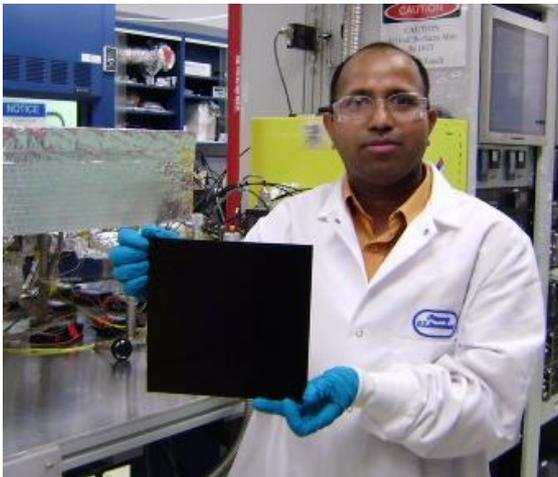
Phosphor image of MCP with ΔV across MCP = 1100V

- Demonstrated dozens of working MCPs

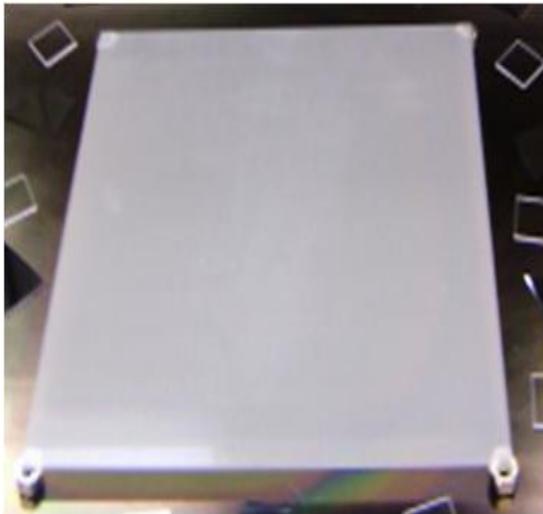
Courtesy: Ossy and Jason UCB



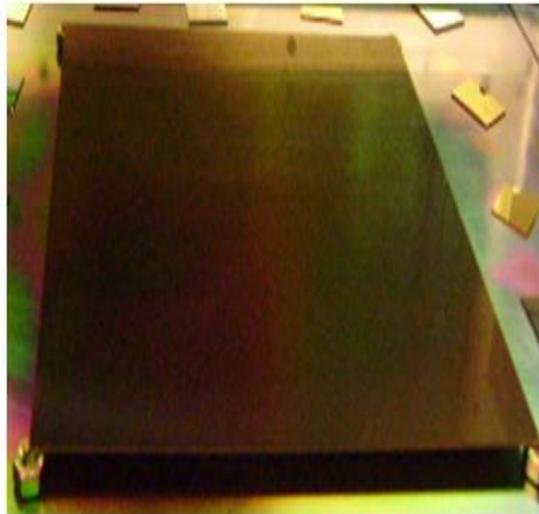
Demonstration of fully functionalization 8"x8" MCPs:



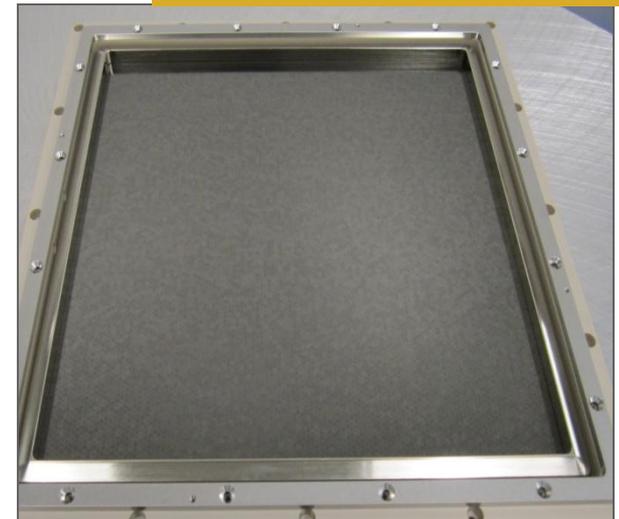
First exploration of ALD on with 8"x8" MCPs



As received 8"x8" MCP



After ALD Rs and SEE layers



Electrode deposition at UCB

After NiCr electrode

UCB group manage to measure the Gain out of this MCP

Achievements of ANL ALD Group:

→ Publications

- Patent application = 1
- Poster presentation= 1 (SPIE 2011)
- Publication = 2
- Abstract submitted = 2
- ALD group co-authors in several LAPD publications

→ Design and construction of new electrical measurement system for MCPs

→ Mock tile parts fabrication

→ Delivered Items/Efforts in “Year-2”



Photograph of gain measurement setup:



Dual MCPs testing
(Possible to load 3 MCPs)

EMWCD

Labview Vi developed

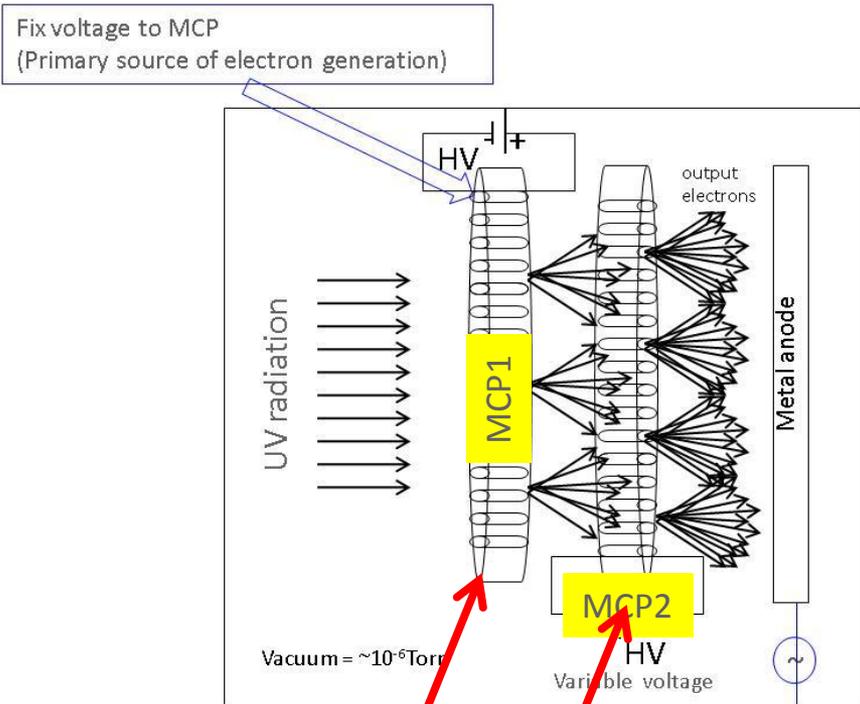
pA current meter

3 high voltage (0-5kV)
DC power supply

■ Several MCPs electrical characteristic tested

Electrical characterization of MCPs :

Gain measurement arrangement :



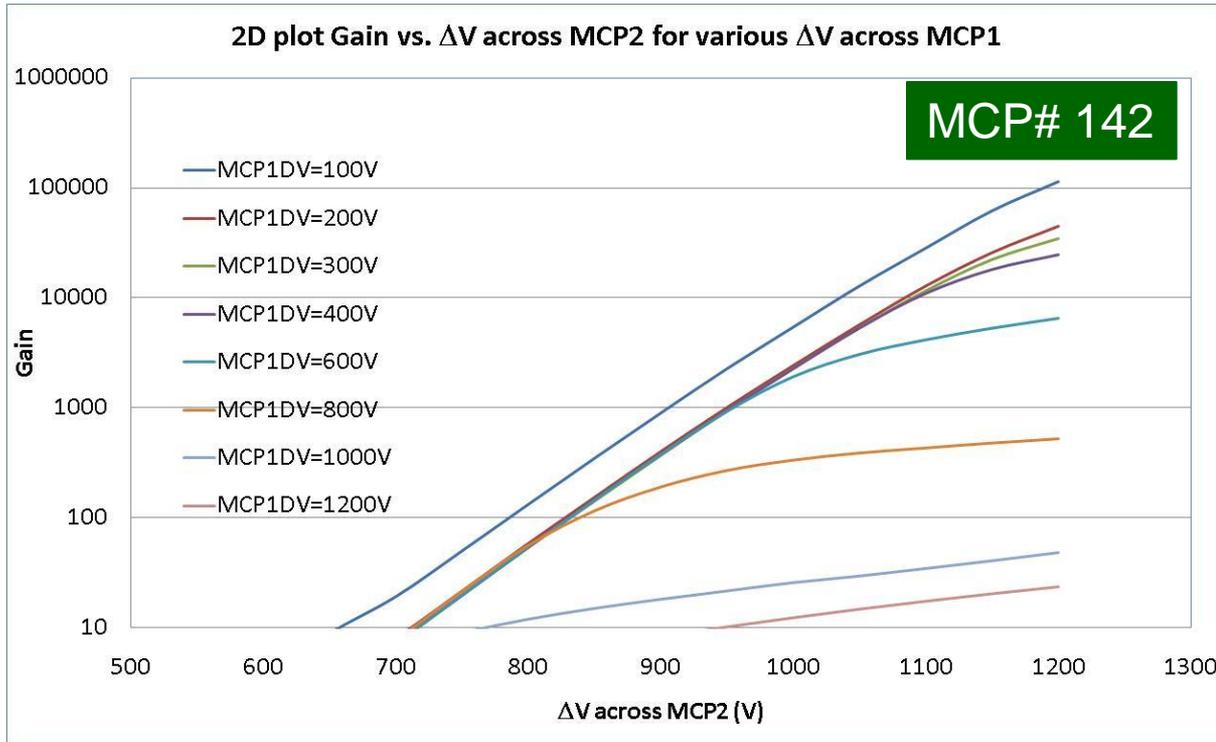
ANL MCP-1 Used as
electron source

MCP-2 "Testing MCP"

System capabilities:

- Current vs. Voltage (I-V)
- Resistance vs. Temperature (R-T)
 - (Thermal coefficient , activation energy)
- Resistance vs. Time (R-t) @ fix HV
- Gain vs. voltage
- Long term stability under scrubbing condition
- Two optical windows
 - (e.g. thermal imaging with CCD, phosphor screen)
- Easy to modify

Gain data :



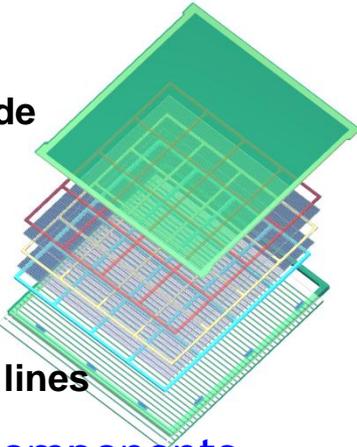
MCP gain influenced by:

- Input current
- Resistance of MCP
- Composition of Rs layer
- SEE layer



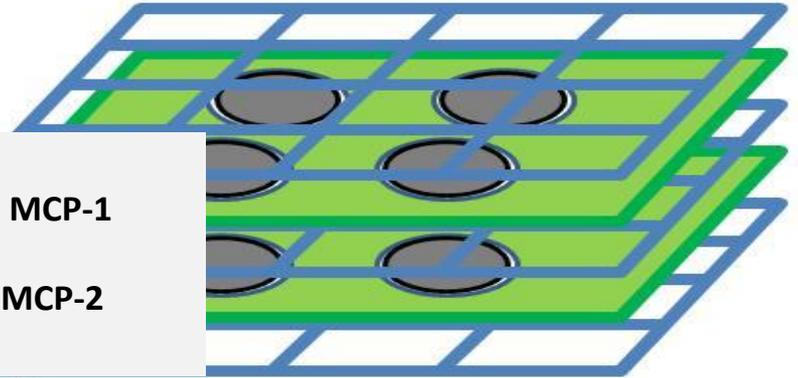
Mock tile parts fabrication by ALD

- Photocathode
- Grid spacer
- MCP
- Grid spacer
- MCP
- Grid spacer
- Anode strip lines



Real tile components

- Grid -A
- Spacer-1 + MCP-1
- Grid -A
- Spacer-2+ MCP-2
- Grid-D



$$R_{(\text{mcp support spacer})} \gg R_{\text{MCP}}$$

Mock tile components

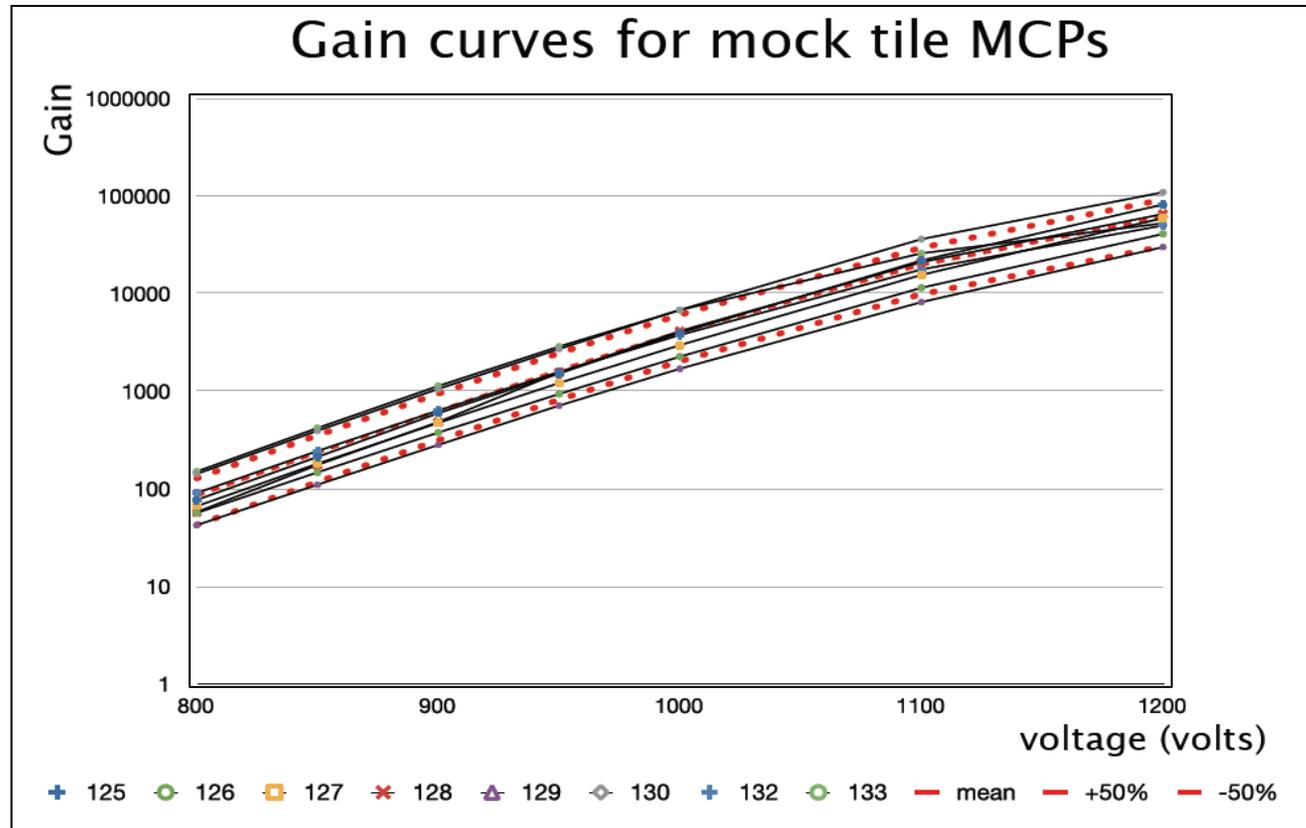
- 1) 4x pairs of 33mm MCPs
- 2) Two Type "A (1.1mm)" 8"x8" grid spacers
- 3) One Type "D (3.1mm)" 8"x8" grid spacers
- 4) Two "MCPs support spacer" [glass pate with 4 x 33 mm holes]
 - 100x higher resistance than MCP



Mock tile parts fabrication by ALD

Courtesy: M. Wetstein

8 MCPs



Average R of MCP's = 115 MOhms

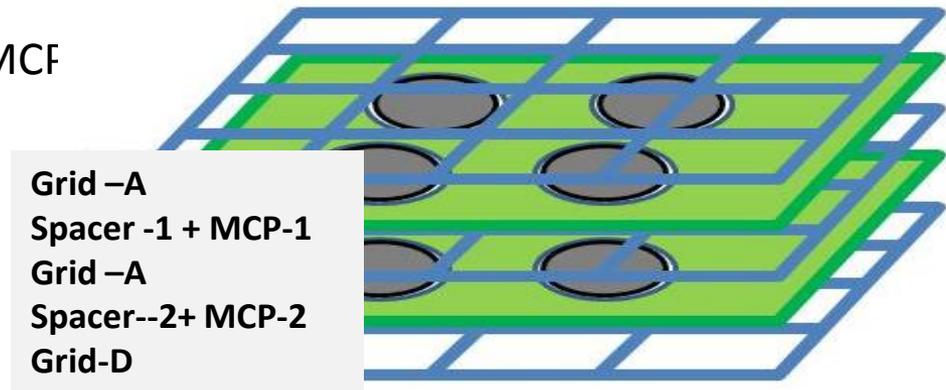
* MCPs processed with ALD chemistry-2 + ALO SEE layer



Mock tile parameters and fabrication:

Hypothesis:

- 1) Average R of MCP's = 115 MOhms
- 2) V across grid spacer A (After photocathode) = 300-800V acceptable range
- 3) E field for spacing = 200 V/mm
- 4) R for MCPs support spacer=100* R of MCF



$$R_{(\text{mcp support spacer})} \gg R_{\text{MCP}}$$

Layer	Thickness (mm)	# of items	R Item(M Ω)	R Layer(M Ω)	ΔV across item (V)	I(μA)
grid A	1.1	1		7.5	300	42
MCP-1	1.2	4	115	29.0	1200	42
grid A	1.1	1		7.5	300	42
MCP-2	1.2	4	115	29.0	1200	42
grid D	3.1	1		16.0	650	42
Total	7.7	11		89.0	3650	42

$$R \text{ of Grid spacer D} \cong 2 * R \text{ of Grid spacer A}$$



Coating of grid spacers by ALD:



**MCP support spacer
(2-10GΩ)**

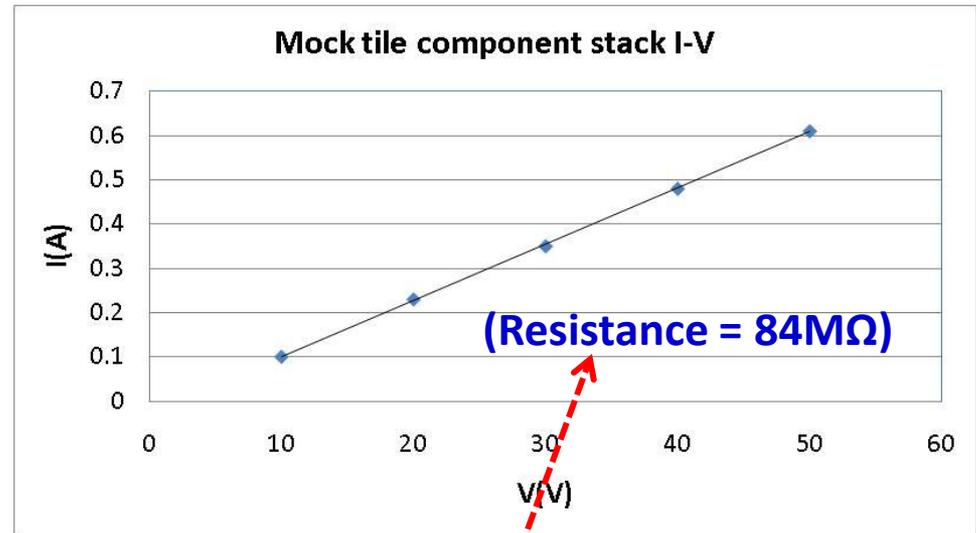
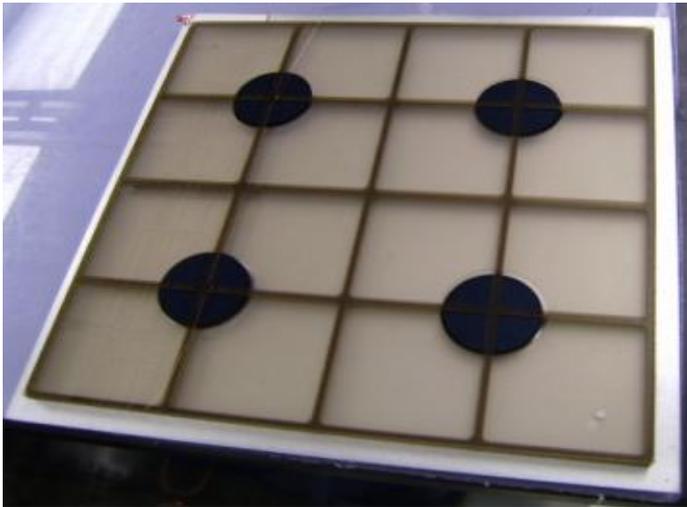
Type A grid spacer

Type D grid spacer

Resistance of Grid Spacer (MΩ)	
Type-A	Type-D
0.13	--
0.13	--
--	0.4
--	0.4
530	--
400	--
10	16
17	--
38	--
64	--
380	700
135	1000
400	--
500	--
0.2	--
0.2	--
0.5	--
4	--
4	--
1	--
3	--
3	--
3	--
38	--
10	17
10	--
10	--
10	--
--	8
2	6
8	--
9	--

Mock tile component stack resistance:

Before placing components into mock tile

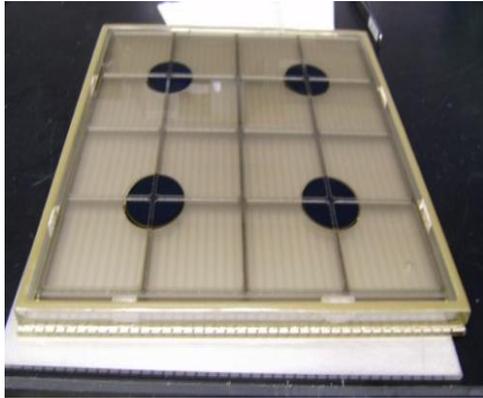


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grid A	1.1	1		7.5	300	42
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grid D	3.1	1		16.0	650	42
Total	7.7	11		89.0	3650	42

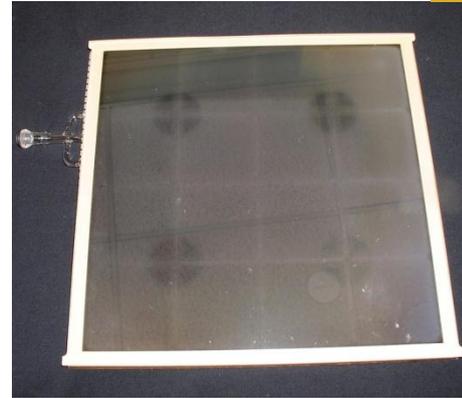


Construction of first mock tile:

Courtesy: Joe & Dean



a) Full stack ALD coated items in mock tile



b) Mock tile after sealing & evacuation



Demonstrated First mock tile prototype

Achievements of ANL ALD Group:

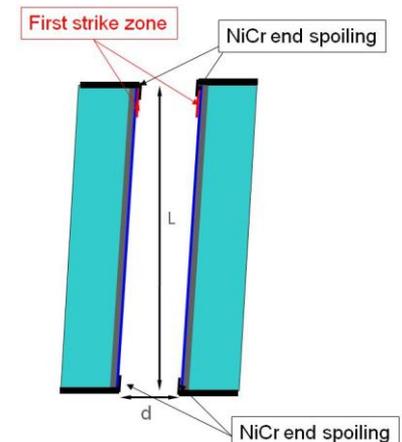
→ Delivered Items/Efforts in Year 2

Items	APS group	ALD Group	UCB group	Surface analysis Group	Comments
33mm MCPs	38	30	14		MCPs from old + new batch
8"x8" MCPs			3		MCP quality??
Coupons			24	>30	SEE with and without Rs
Grid Space A 8"x8"		20			For Mock tile
Grid Spacer D 8"x8"		6			For Mock tile
MCP support spacer 8"x8"		6			For Mock tile
Mock tile 33mm MCPs	10				For Mock tile
Circular spacers		40			New design, plan dropped
Bad 33mm MCPs		~20			Big triple pints, bad depositions
AAO 33mm MCPs		>12			(decided not to continue)



Near term plan for ALD Process development:

- **Further improvement in current BKM process**
 - **Amorphous** vs. Crystalline?
 - Thin vs. Thick layer at low /high temperature processing conditions
- **Introduce new SEE layers**
 - MgF₂ and CaF₂
 - Amorphous vs. Crystalline?
- **High temperature annealing**
 - RTA for few sec?
 - 500C or 550C annealing for 1 hrs? (Incom glass MCPs survived)
 - Crystalline microstructure?
 - Gain /uniformity?
- **New concept by ALD/PVD:**
 - Develop multi-dynode structure on MCP pores



Plan for ALD on 8"x8" MCPs/Grid spacers:



2D Chamber



→ One 200mm diameter substrate

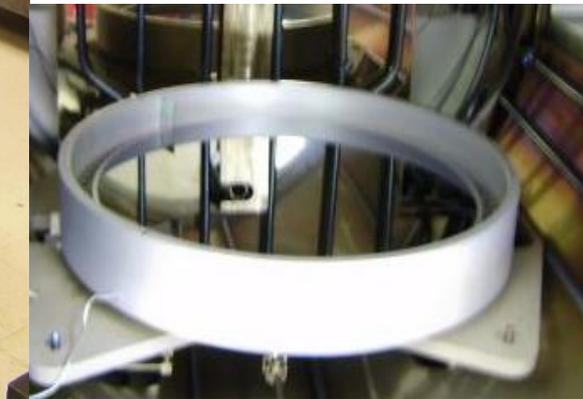
3D Chamber



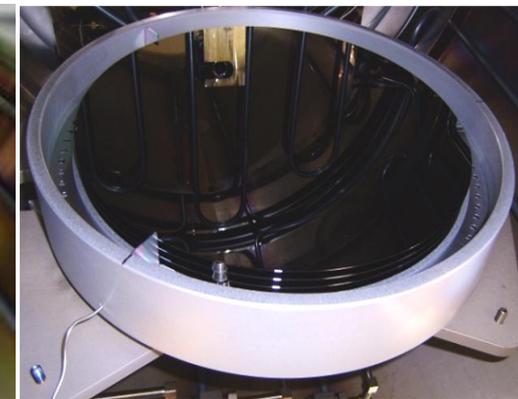
→ 20x (8"x8") substrates

Plan for ALD on 8"x8" MCPs/Grid spacers:

2D Chamber for multiple 300mm substrate



With one 200mm diameter substrate



4x 300mm diameter substrate

Timeline ALD development for large area substrate on Beneq:

Nos.	Items	June 11	July 11	Aug. 11	Sept. 11	Oct. 11
1	New 2D chamber HW testing	x				
2	Rs process testing and optimization on 33mm MCPs	x	x			
3	Batch processing test for 33mm MCPs (uniformity Thickens & Rs)		x			
4	Process testing on 8"x8" MCP		x	x	x	x
5	Batch (2-4 MCPs) processing			x	x	x
6	Grid spacer depositions	x	x	x	x	

Requirements:

- Supply of 8"x8" MCPs
- Handling, cleaning and storage items
- Need to find electrode deposition facility/vender
- Electrical measurement set-up for 8"x8" MCPs
- MCP transfer set-up



Summary

- Results from ALD BKM process for MCPs
- Demonstration of ALD functionalization of 8"x8" MCPs
- First mock tile fabrication
- Gain test setup and testing results
- Delivered items by ALD ANL group
- Near term plan for ALD development and functionalization of 8"x8" various items for LAPD project

Acknowledgements:

- Fermi lab (Dr. Eileen Hahn) for Electrode deposition
- UCB (Prof. Ossy and Dr. Jason) for MCP testing
- Prof. Henry and Dr. Bob for constant support

Thank you !!

