A novel atomic layer deposition method to fabricate economical and robust large area microchannel plates for photodetectors

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TIPP 2011 meeting

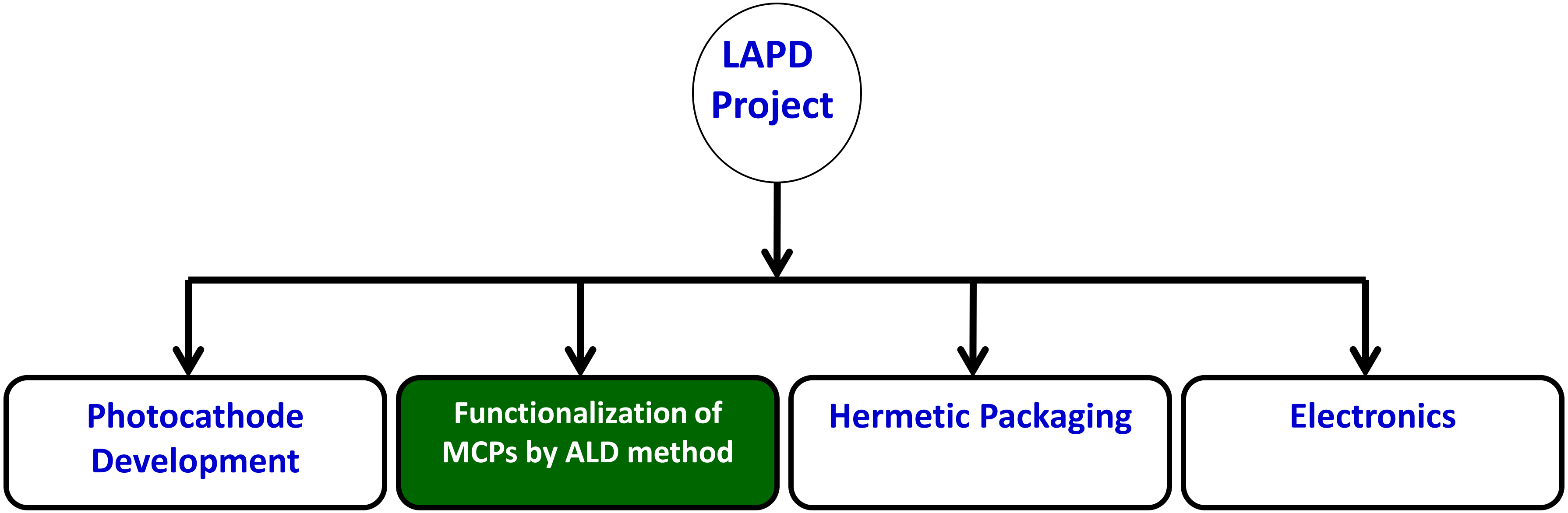
Outline

- Introduction
- ALD processes development for MCPs
- MCPs Surface functionalization by ALD method
- Characterizations of ALD grown layers and MCPs
- Summary
- Acknowledgements

Objective behind large area photodetectors 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*
  - *Time, spatial resolution and low noise*
  - *Useful in wide range of applications*
    - Particle detectors in high-energy neutrino and collider physics
    - Positron Emission Tomography cameras in medical imaging
    - Nuclear physics and Astrophysics
    - Time-of-Flight (ToF) mass spectrometry
    - Molecular and atomic collision studies, cluster physics
    - Scanners for transportation security
    - Night vision goggles and binoculars

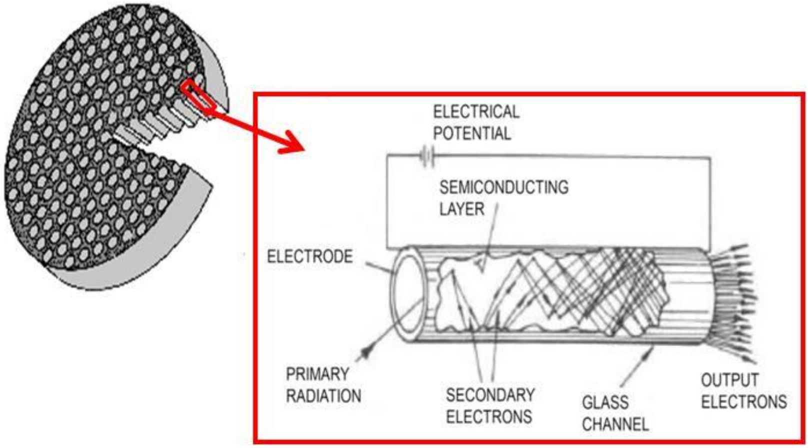
LAPD project background



LAPD Project

- Photocathode Development
- Functionalization of MCPs by ALD method
- Hermetic Packaging
- Electronics

“Microchannel plates”



Nuclear Instruments and Methods, 162, 1979, 587

Each pore of MCP act as a continuous-dynode electron multiplier in presence of a strong electric field

MCP parameters:

- Aspect ratio (L/d), bias angle, open area ratio,
- Resistance of MCPs MΩ -GΩ
- Secondary electron emission yield
- Electron amplifier (gain) ~10^3-10^6
- Time and spatial resolution
- Low noise

→COST?

MCP fabrication method

Conventional MCP Fabrication
➢**Draw lead glass fiber bundle**
➢**Slice, polish, clean**
➢**Chemical etch, clean**
➢**Heat in hydrogen (PbOx)**
➢**Top/Bottom electrode coating (NiCr)**
Drawbacks
➢**Expensive and Scalability for etch step**
➢**Resistance and secondary emission properties are linked one layer**
➢**Limited optimize MCP performance for applications where lifetime, gain, substrate size, composition and thermal runaway are important**

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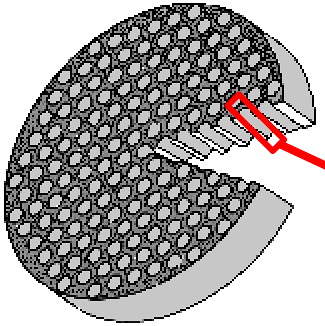
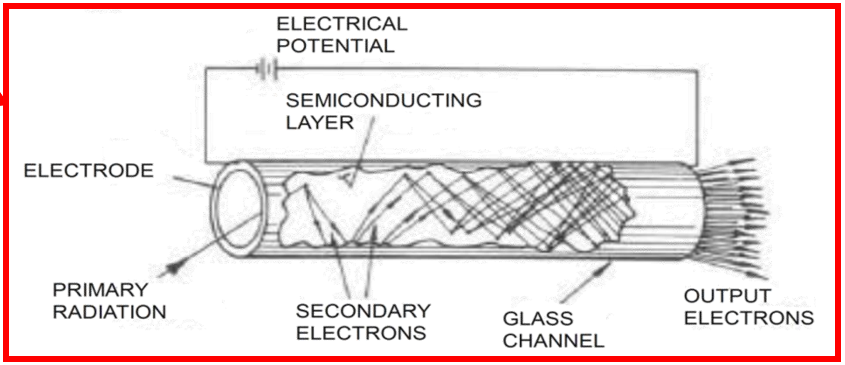
LAPD Approach
➢Start with porous, non-lead glass
➢Slice, polish, clean
➢ALD resistive layer coating
➢ALD secondary electron emission layer coating
➢Top/Bottom Electrode coating (NiCr)
Advantages
➢Independent control over composition of Resistive and SEE coatings
➢Tune the low thermal runaway
➢Applicable: Ceramics, Si/SiO_2, plastics, polymers and glass MCPs
➢Low cost (ALD offers large area batch processing)

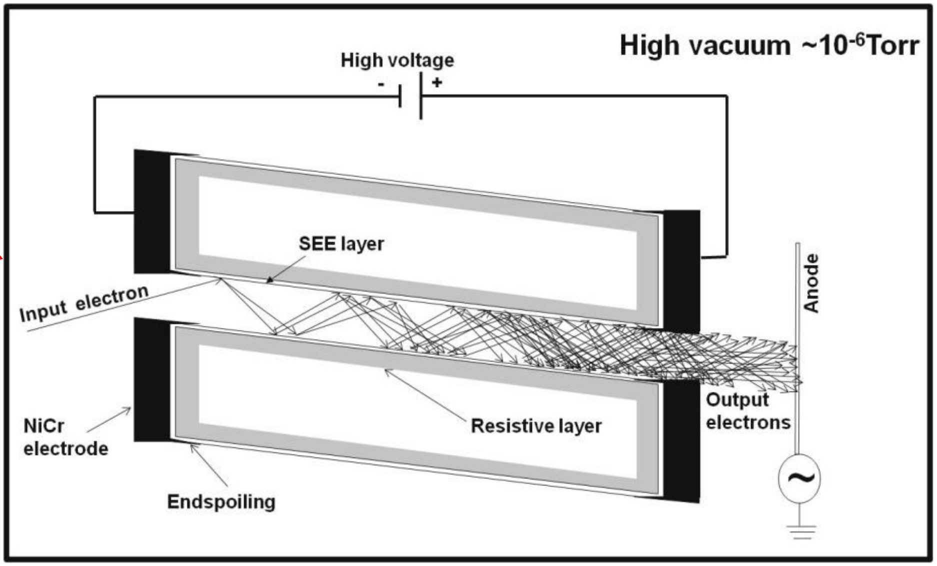
Microchannel plate for electron multiplier



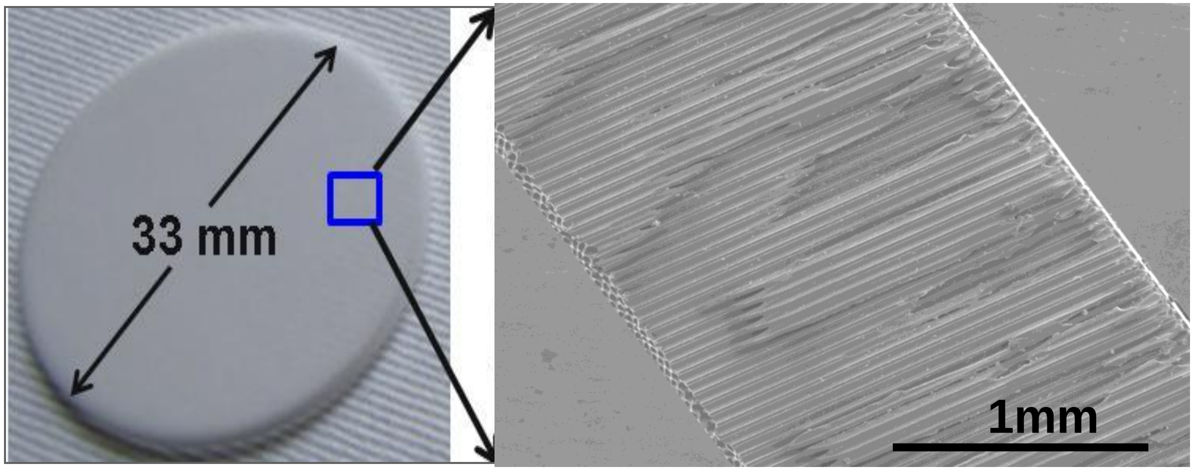
Conventional MCP pore



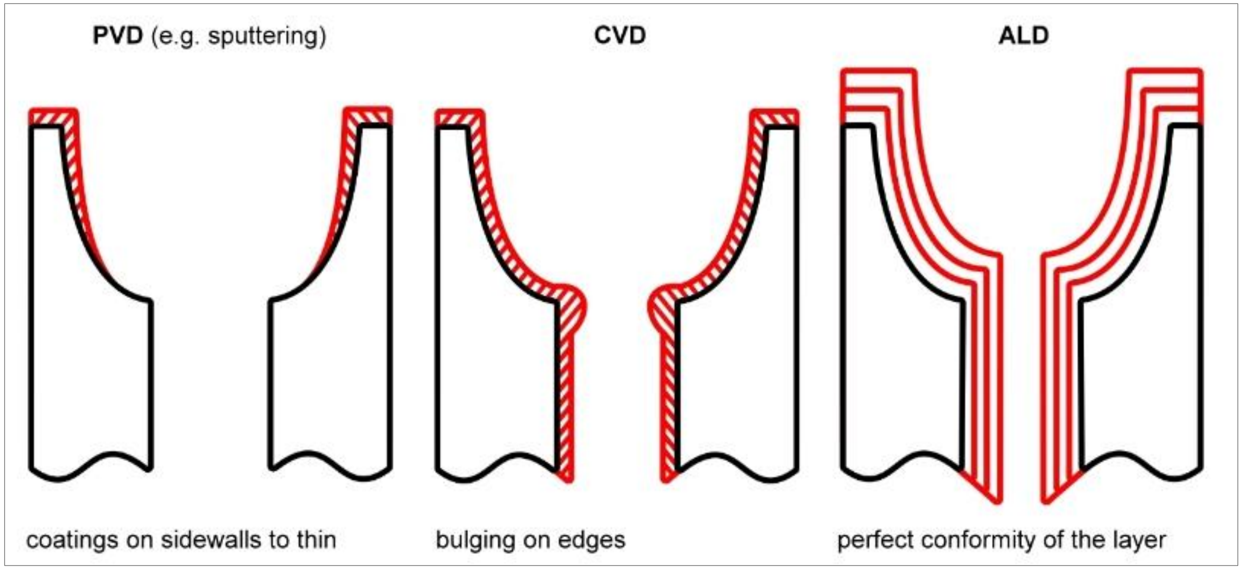
ALD functionalized MCP pore



Why ALD method?



MCP **Pores arrangement**



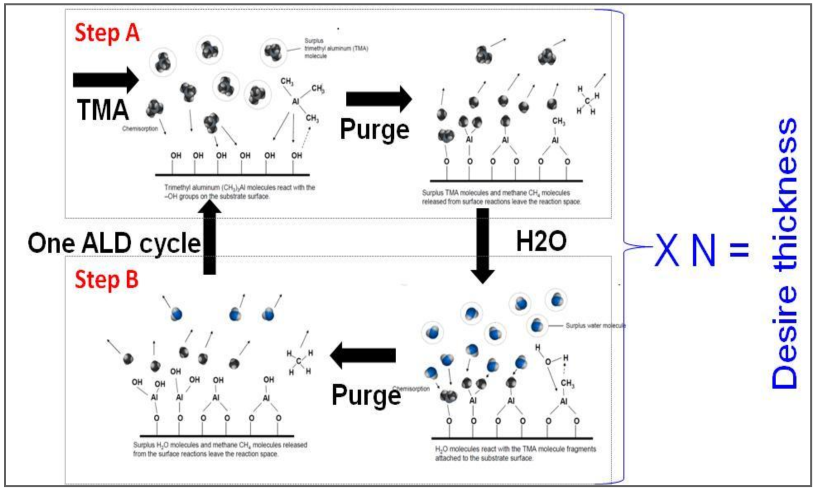
Source: http://dtf-technology.biz/explanation-4.html

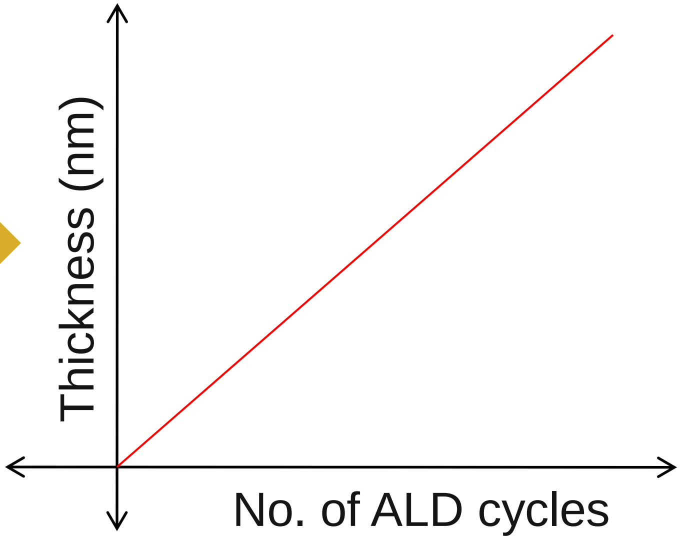
ALD thin film deposition process

- **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

E.g. ALD of Al_2O_3





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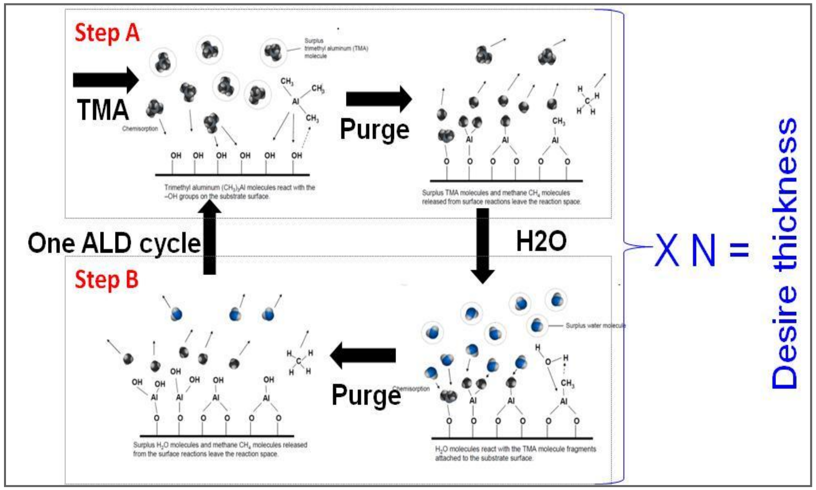
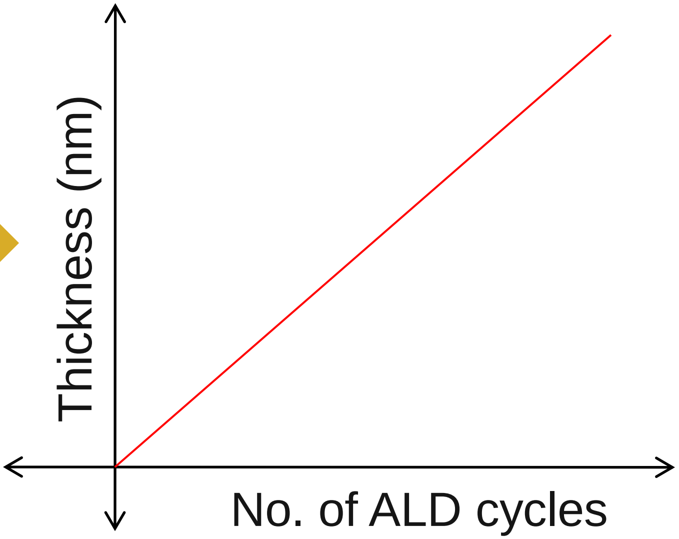


Trimethyl aluminum $(CH_3)_3Al$ molecules react with the –OH groups on the substrate surface.

Surplus TMA molecules and methane CH_4 molecules released from surface reactions leave the reaction space.

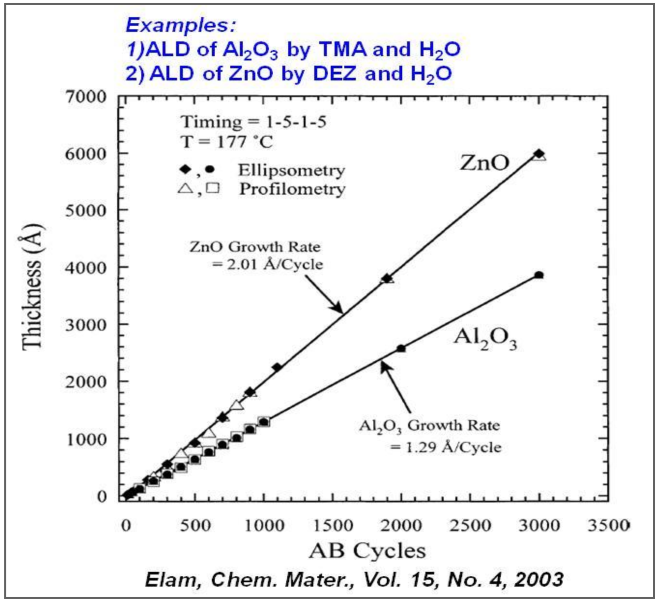
H_2O molecules react with the TMA molecule fragments attached to the substrate surface.

Surplus H_2O molecules and methane CH_4 molecules released from the surface reactions leave the reaction space.

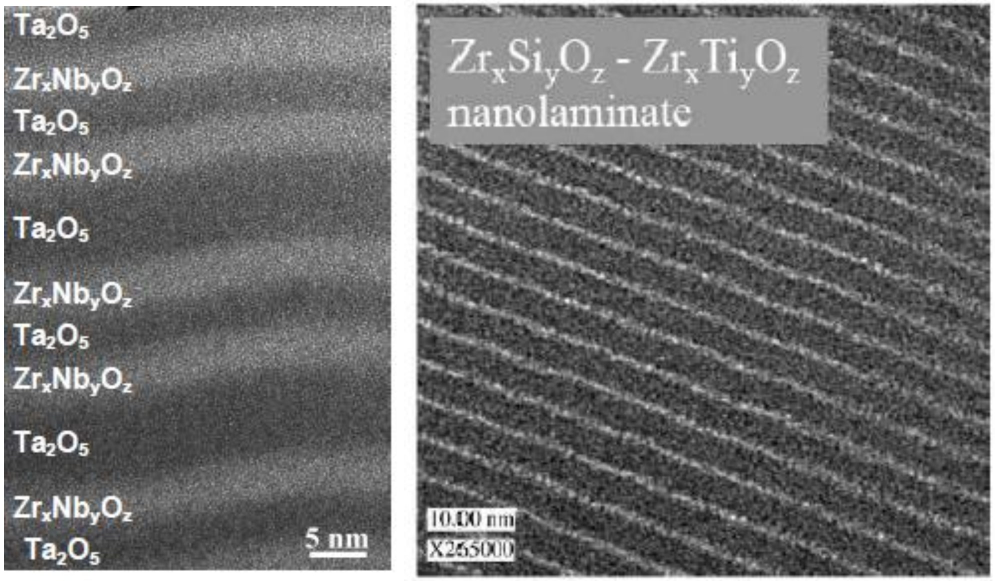


- **Advantages of ALD method:**
  - **Exquisite monolayer-level thickness and composition control**
  - **Wide range of materials growth**
  - **Continuous, pinhole-free, reproducible layers on large area substrates**
  - **Excellent conformality in very high aspect ratio structures**
  - **Batch processing of multiple substrates for economical production**

ALD thin film deposition process


Examples:
1)ALD of Al_2O_3 by TMA and H_2O
2) ALD of ZnO by DEZ and H_2O

Elam, Chem. Mater., Vol. 15, No. 4, 2003



Materials Science and Engineering C 27 (2007) 1504–1508

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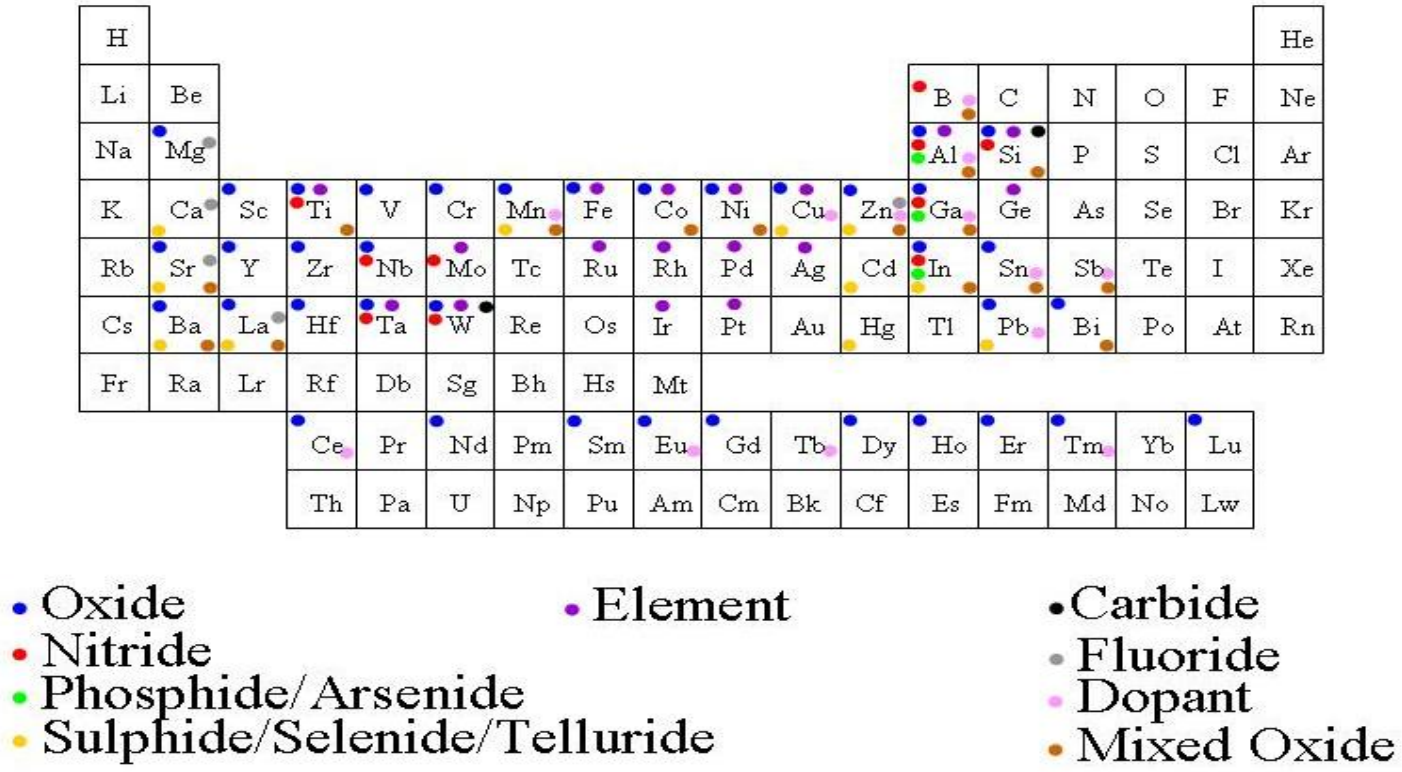

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt									
			Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
			Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lw	

- Oxide
- Nitride
- Phosphide/Arsenide
- Sulphide/Selenide/Telluride
- Element
- Carbide
- Fluoride
- Dopant
- Mixed Oxide

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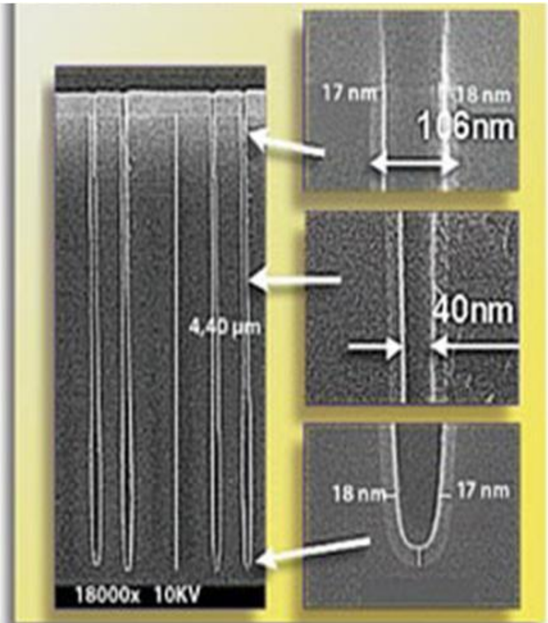
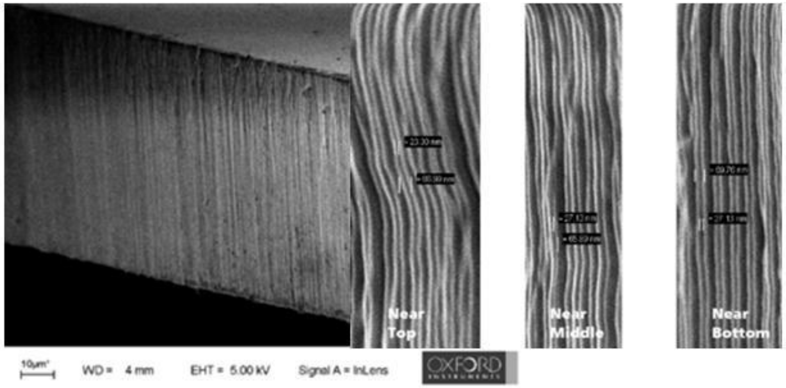
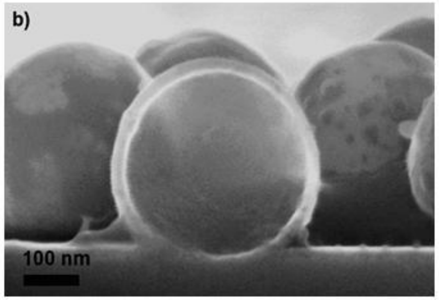
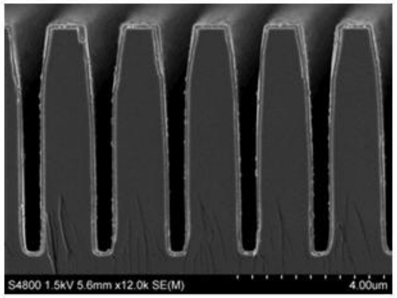


Source: ASM





ZnO on Nanoshperes



Al2O3 on trench wafer

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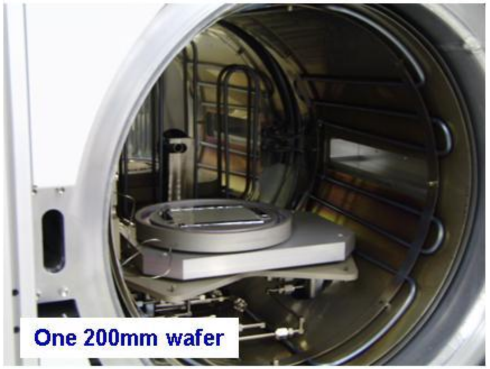
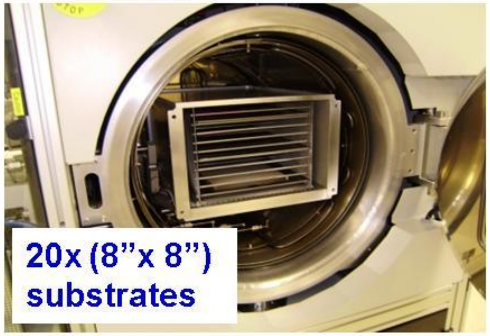
ALD thin film deposition process

Source : www.beneq.com





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→COST ↓

ALD capability at ANL

- 3 custom made ALD systems (10 precursors, up to 18x12” substrates)
- ALD powder coating system (up to 1 kg powder)
- Beneq TFS 500 ALD system (multiple 16” substrates)
- Cambridge Nanotechnology Fiji F200 ALD reactor (plasma assisted ALD)
- ALD systems equipped with in-situ FTIR, QCM, mass spec, resistivity

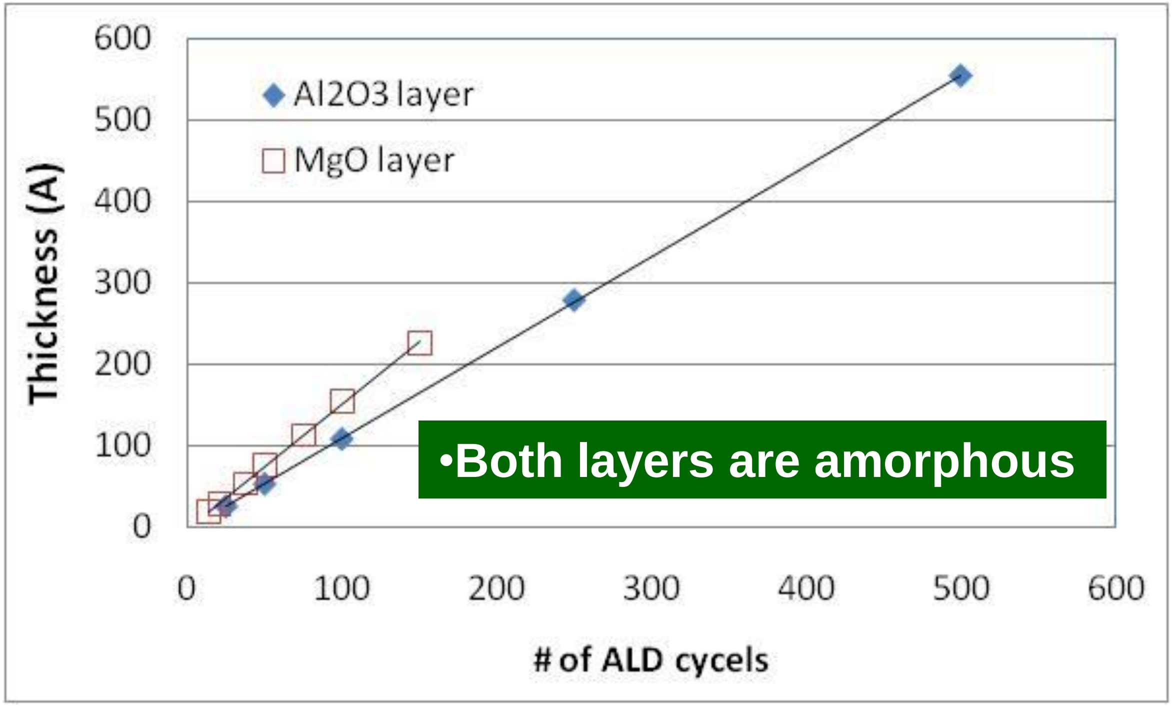
Materials selection for functionalisation of MCPs

- **Secondary electron emission (SEE) layers:**
  - **Al_2O_3, MgO, Diamond, MgF_2, CaF_2, …………**

- **Resistive layers : (Hereafter “Chemistry-2”)**
  - **Variety of material compositions**
  - **Stability**
  - **Reliability**
  - **Scaling**
  - **Cost**

Secondary electron emission layers by ALD method

- **ALD of Al_2O_3 = $Al(CH_3)_3$ and H_2O at 200^oC ➔ Growth rate =1.1 A/ALD cycle**
- **ALD of MgO = $Mg(Cp)_2$ and H_2O at 200^oC ➔ Growth rate =1.5 A/ALD cycle**

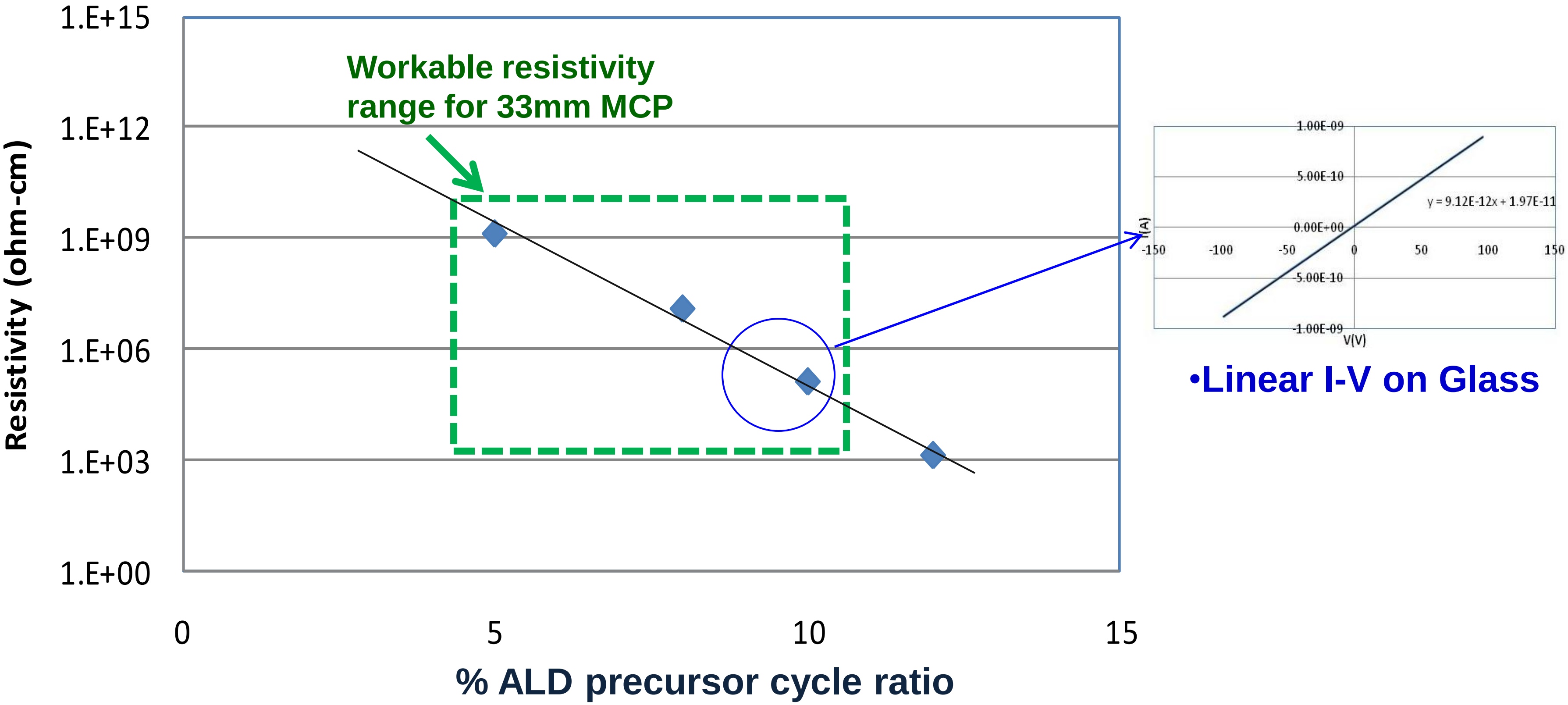


- **Both layers are amorphous**

ALD grown Material	SEE yield	Electron energy (eV)	Thickness [A]
Al_2O_3	1.5-3	100-600	20-210
MgO	2-7	100-600	20-200

For details : Slade J. Jokela, (TIPP abstract # 256)

Resistivity of Chemistry #2 ALD coating on Glass



Workable resistivity range for 33mm MCP

•Linear I-V on Glass

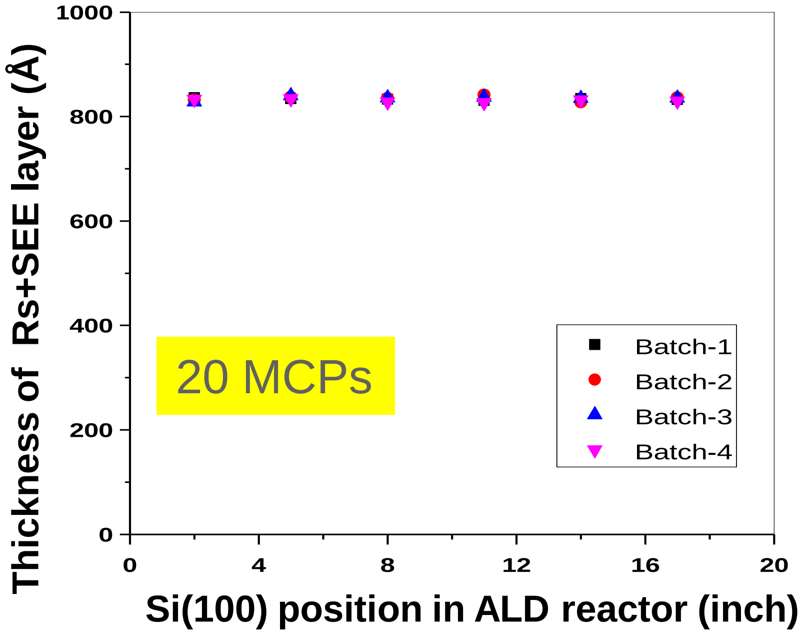
- **Control over desire resistance range**

Appearance of MCPs

a) Bare 33mm MCP **b) After ALD Rs+SEE** **c) After ALD + NiCr electrode**

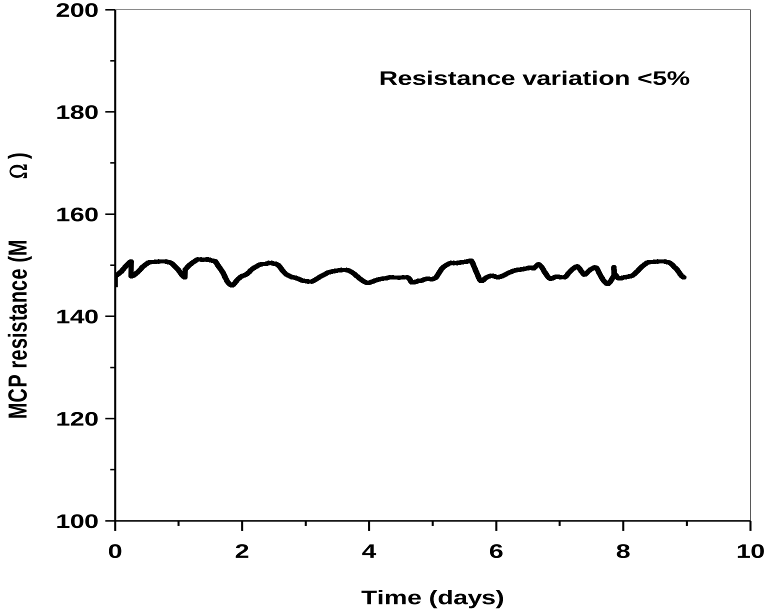
- Uniform coating on MCP pores

BKM ALD process (Chem-2) reproducibility



20 MCPs

Average resistance 150MΩ



Stability

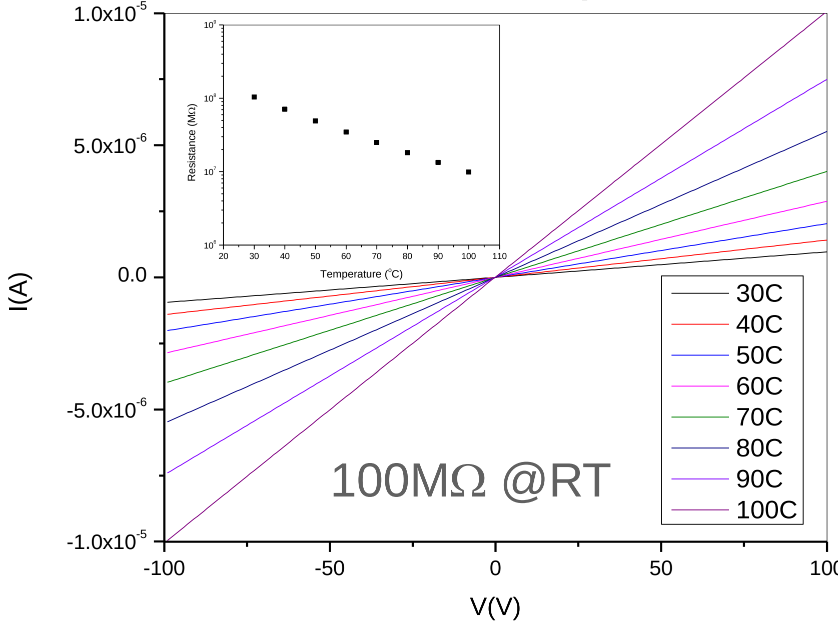
- Within a batch and Batch-to-batch reproducibility

•Life testing for 7 months at UCB

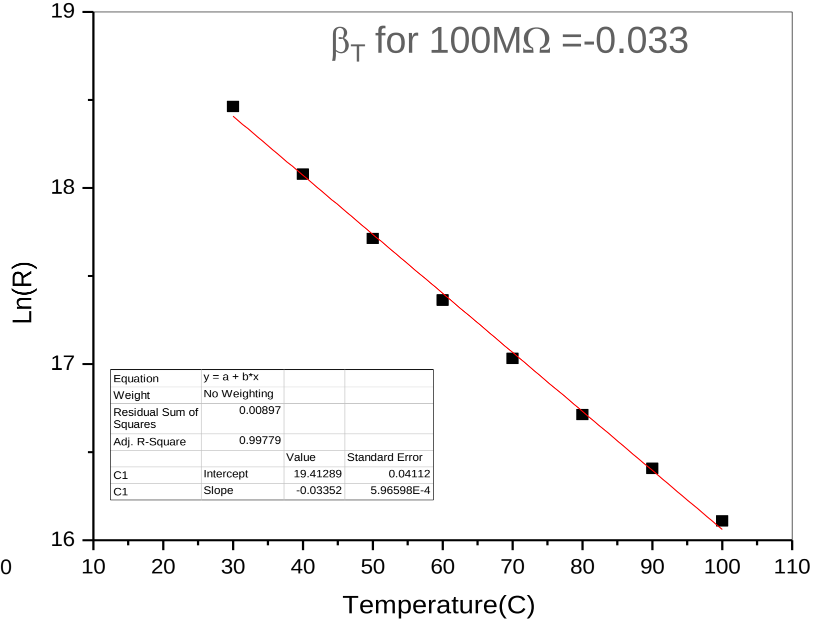
Thermal characteristics: ALD of Chemistry #2 on MCP

Thermal coefficient of resistance = $R_{mcp}=R_0\exp(-\beta_T(T_{mcp}-T_0))$

I-V data at different temperature



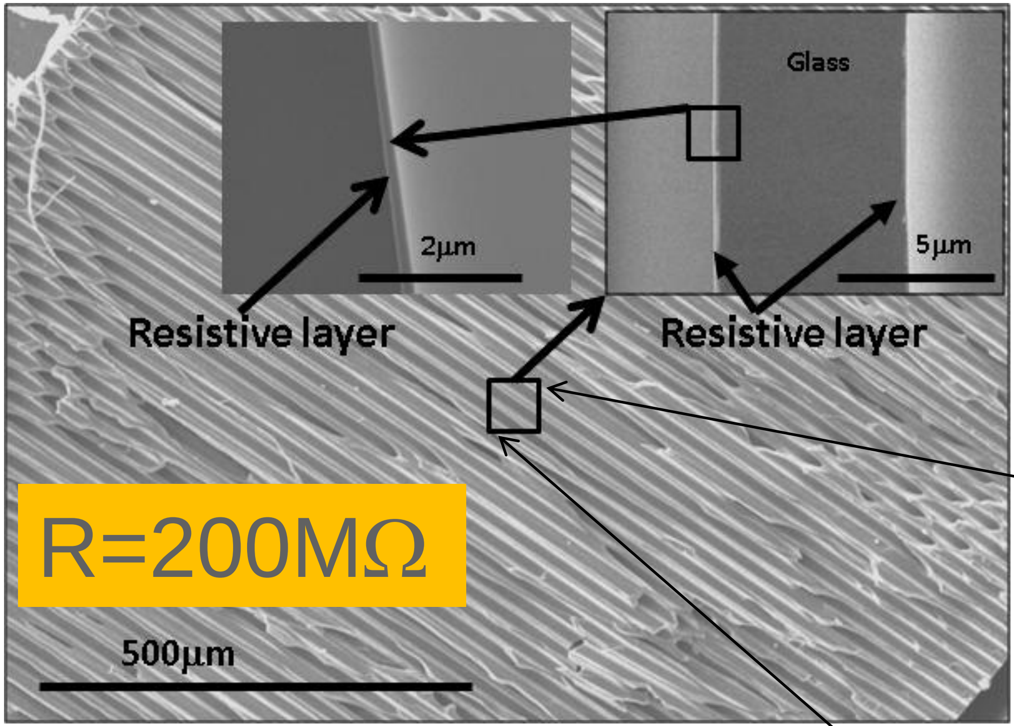
Thermal coefficient



Equation	y = a + b*x		
Weight	No Weighting		
Residual Sum of Squares	0.00897		
Adj. R-Square	0.99779		
		Value	Standard Error
C1	Intercept	19.41289	0.04112
C1	Slope	-0.03352	5.96598E-4

- **Linear I-V characteristic for all temperature**
- **ALD coated MCPs shows lower β_T**
  - **➔ Low thermal runaway**

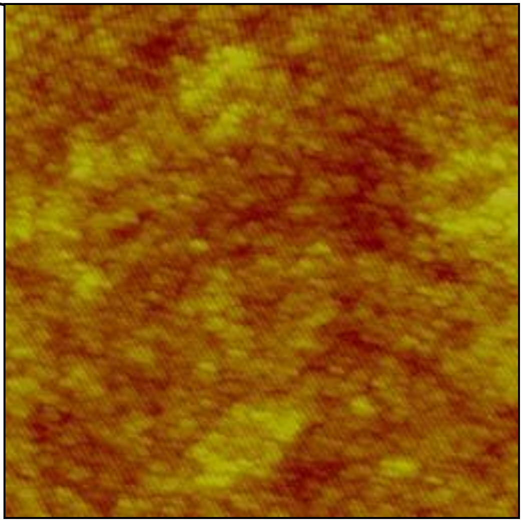
Conformal, uniform and smooth coating on MCP pores



R=200MΩ

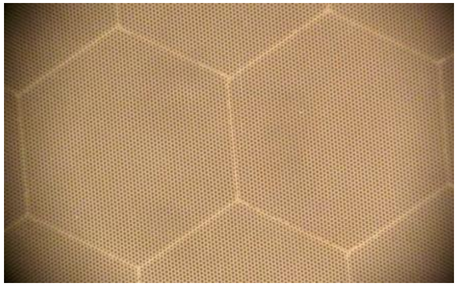
- Uniform coating across the MCP pores

AFM scan from channel surface

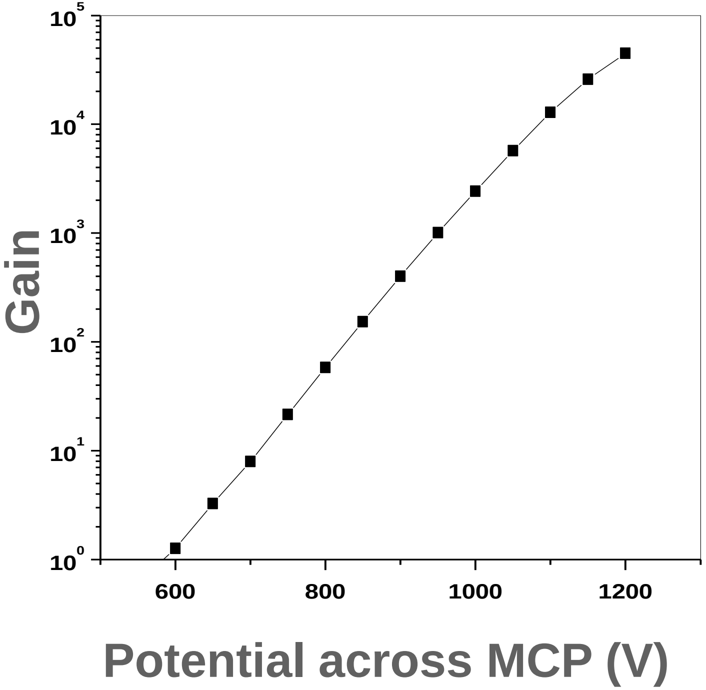


- RMS roughness = 0.634 nm for 90nm ALD layer ➔ <1%

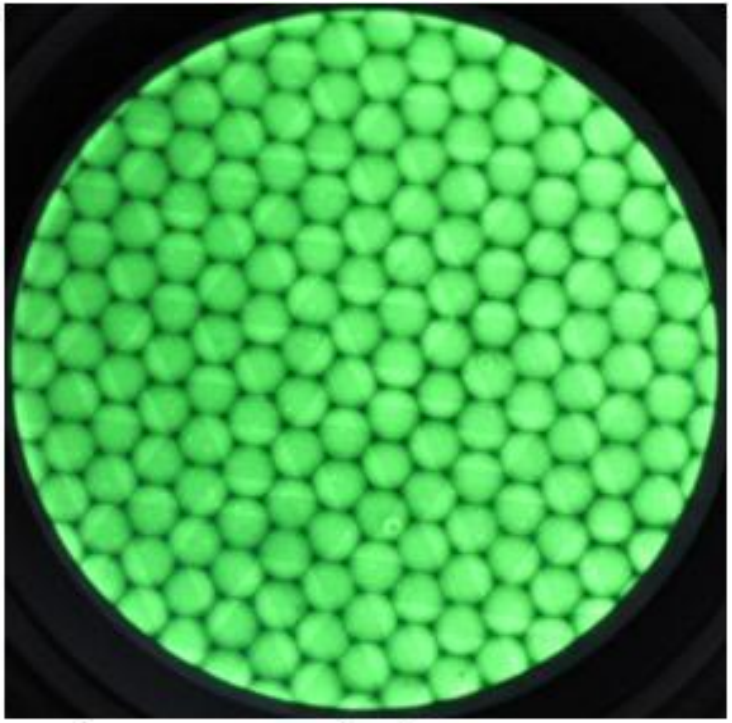
BKM ALD process for MCPs



- High Gain for single MCP



- Uniform spatial resolution



Phosphor image of MCP with
ΔV across MCP = 1100V

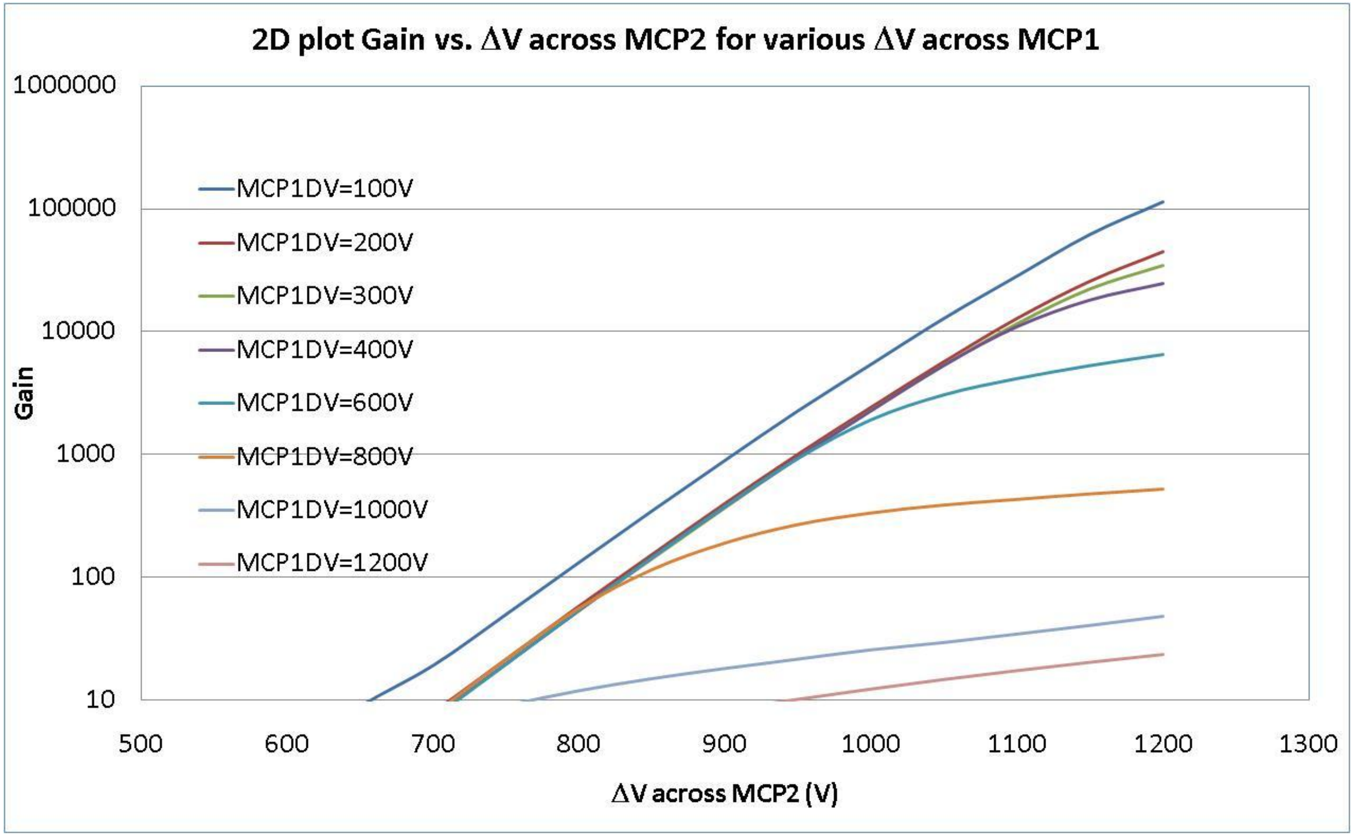
- Demonstrated dozens of working MCPs

•Uniform gain across MCP

Mane etal, SPIE 2011

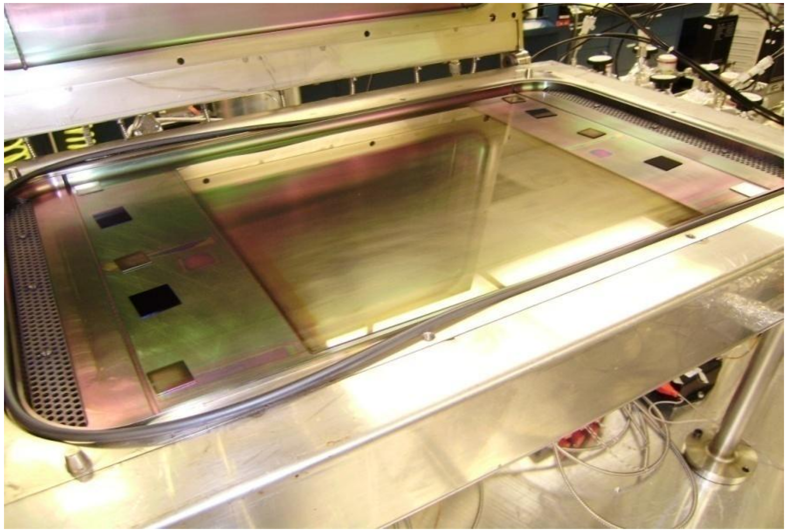
Courtesy: Ossy and Jason UCB

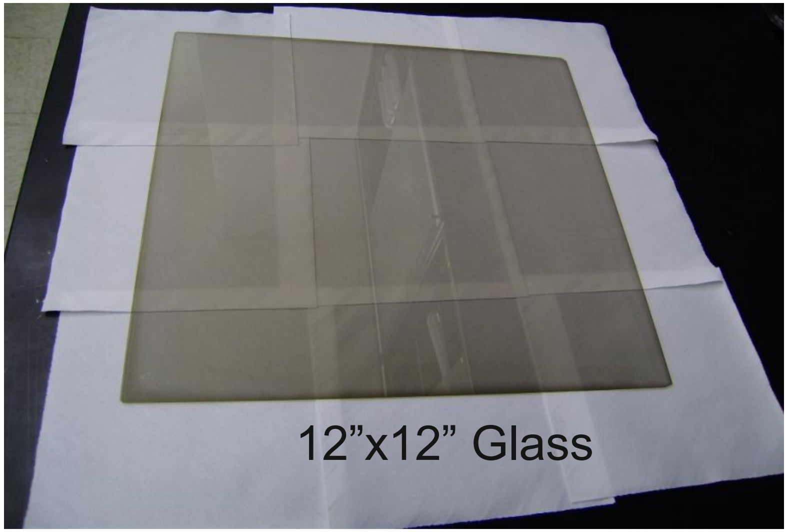
Gain study for MCPs coated with BKM ALD process



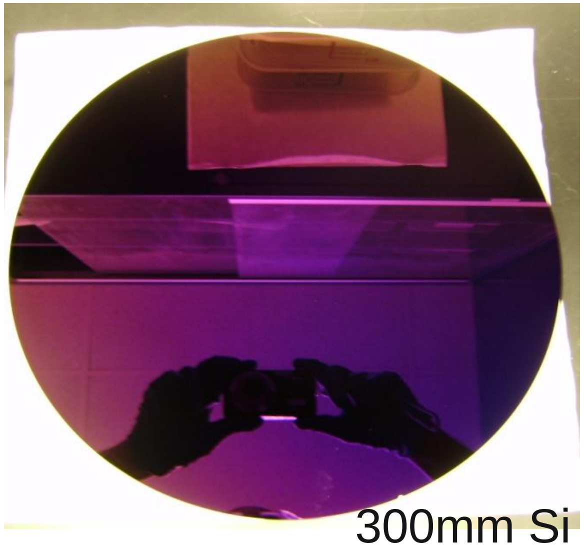
- Achieved x10^5 -10^7 gain by tuning ALD process parameters

Process scale-up: ALD chemistry #2

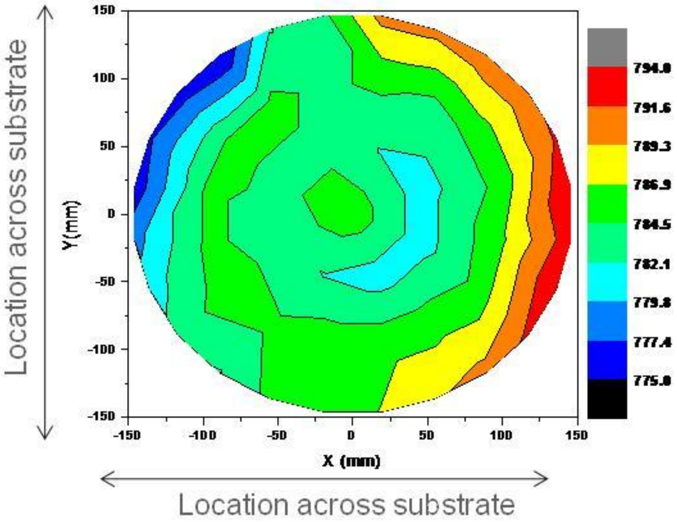




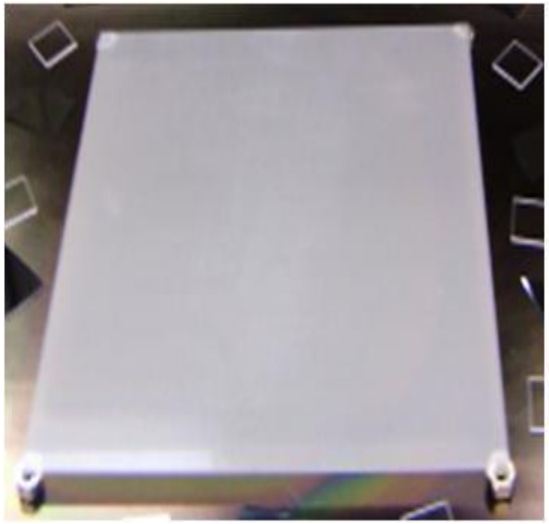
12”x12” Glass



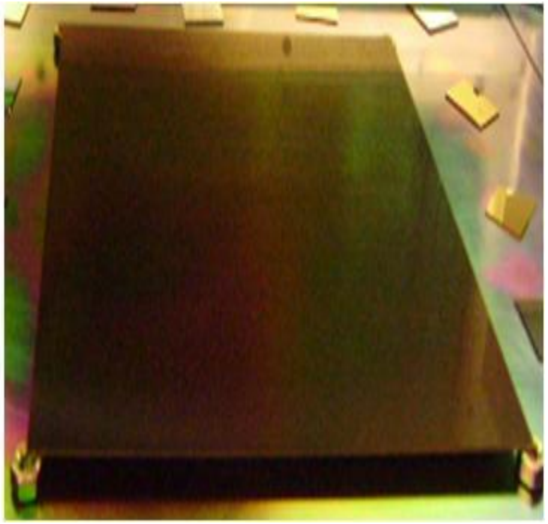
300mm Si wafer



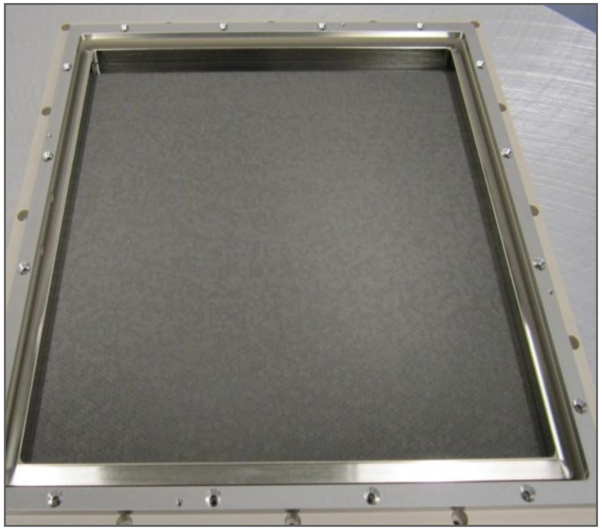
First exploration of ALD on with 8”x8” MCPs



As received 8”x8” MCP



After ALD Rs and SEE layers



After NiCr electrode

- We able to measured the gain out of this MCP further testing is in progress

- Demonstration of working 8”x8” MCP based devices opens new directions in photodetectors technology

Summary

- LAPD project background
- Quick overview of ALD process
- Resistive and SEE layers coatings by ALD
- Demonstration of working MCPs coated by ALD
- First demonstration of fully functionalization of 8”x8” MCPs by ALD method

Acknowledgements

-Fermi lab (Eileen Hahn) for Electrode deposition
-ANL EMC for SEM
-US DOE for funding

Thank you!!

Questions?