Performance Characteristics of Atomic Layer Functionalized Microchannel Plates

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Borosilicate Substrate Atomic Layer Deposited Microchannel Plates

Micro-capillary arrays (Incom) with 10µm, 20 µm or 40µm pores (8° bias) made with borosilicate glass. L/d typically 60:1 but can be much larger. Open area ratios from 60% to 83%. These are made with hollow tubes, no etching is needed. Resistive and secondary emissive layers are applied (Argonne Lab, Arradiance) to allow these to function as MCP electron multipliers.

Pore distortions at multifiber boundaries, otherwise very uniform.
ALD / Borosilicate Glass MCPs

Fabricated using hollow tube draw and stack technique

Glass is inexpensive, low Z (no lead), and has a higher softening temperature (>700°C)

- Lower gamma background, low high energy particle cross section
- Deposition of high Temp opaque photocathodes like GaN
- Very large formats (>20cm) are possible

Functionalized using Atomic Layer Deposition (ALD)

- Semiconductor Resistive layer, tunable over wide range
- Amplifying layer (e.g. Al₂O₃) with high secondary electron coeff.
- Better lattice match to GaN, also good for conventional cathodes
- Can be used on conventional MCPs and MCP substrates

Separates surface optimization from substrate optimization!
Single MCP – Imaging and Gain Tests

33mm, 20µm pore borosilicate MCP substrate, 60:1 L/d, 8 degree pore bias.

Single MCP tests in DC amplification mode show imaging and gain very similar to conventional MCPs. Sample imaging performance has improved dramatically with substrate and ALD coating process improvements.
UV illuminated test results show similar gains to conventional MCPs, exponential gain dependence for low applied voltages, then saturation effects appear above gains of $10^6$. Pulse heights are reasonably normal for 60:1 L/d pairs. Background rates are low.

Pulse height amplitude distributions. 33mm MCP pair, 20µm pores, 8° bias, 60:1 L/d, 0.7mm pair gap with 300V bias. 3000 sec background.

3000 sec background, 0.0845 events cm$^{-2}$ sec$^{-1}$ at $7 \times 10^6$ gain, 1050v bias each MCP. Get same behavior for most of the current 20µm ALD MCPs.
**ALD-MCP Quantum Efficiency and Imaging**

**BARE** ALD –borosilicate MCP, photon counting quantum detection efficiency, normal NiCr electrode coating gives normal bare MCP QE.

#375 & #613 MCP pairs, 20µm pores, 8° bias, 60:1 L/d, 60% OAR. #31 MCP pair, 40µm pores 8° bias, 40:1 L/d, 83% open area - higher QDE.

Image of 185nm UV light, **ALD MCP pair**, 20µm pores, 8° bias, 60% OAR, shows top MCP hex modulation and faint MCP hexagonal modulation from bottom MCP. 0.7mm pair gap with 300V bias.
**ALD-MCP Preconditioning Tests**

Scrub test for ALD MgO layer on standard glass MCP shows that the gain increases from a standard MCP value to >5x higher.

MCP pair gain vs scrub. Al$_2$O$_3$ ALD 20µm, 60:1 borosilicate MCP on top, MgO ALD on bottom MCP (6µm pore, 80:1, 33mm lead glass).

Absolute gain curves for MCP pair with NO vacuum bake. Gain rises with use.

UV scrub gain curves for ALD MCP pair 180-141 each with MgO ALD (20µm pore, 60:1 L/d, 8° bias, borosilicate).
Conventional MCP – MgO ALD Coated

Conventional MCP with 6µm pores, 80:1 L/D, MgO coating

Slight gain drop (x2) at scrub initiation with significant gain increase thereafter
Stabilizing after ~0.07 C cm\(^{-2}\) extracted
真空和N₂稳定性的ALD-MgO MCPs

**Conventional** MCP’s with 6µm pores, 80:1 L/D, MgO coating

- After 10 days at poor vacuum (rose to 400mTorr) the gain is slightly higher (~900v, ~20%). After 2hr, 41hr and 148hr dry N₂ exposures little changes.

**46mm MCP**

**33mm MCP**

Untreated MCP on top of a MgO treated MCP. Scrub to 0.03 C cm⁻² to reach stable gain, then dry N₂ exposures. Differences are most likely variation in room temp and length of MCP warmup time.

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Gain Burn-in of Conventional MCPs

Comparison of MCP Z stacks, 10µm pore 60:1 L/D, MgO coated bottom MCP in one stack
MgO ALD on Conventional MCP “Z” Stack

Conventional MCP “Z” stack with 10 µm pores, 80:1 L/D, MgO coating on all MCPs.

Stack scrubs up in gain as expected from earlier data. Expect stabilization at ~0.05 C cm\(^{-2}\). General background stays at typical values (~0.4 events cm\(^{-2}\)). High secondary yield gives quite narrow PHDs even at comparatively low gain/applied voltages.
Gain vs Charge Extraction Test, MCP Pairs

Top MCP – conventional 10µm 80:1 L/D – is the electron source

20µm pores, 60:1 L/D, Al₂O₃ coating

20µm pores, 60:1 L/D, MgO coating

MCP gain measured for bottom MCP
Single MCP Image (Phosphor) shows some multifiber issues, but not too bad for first attempt.

Single MCP gain is similar to conventional MCPs, gain saturation causes turnover.
33mm ALD-MCP Preconditioning Tests

Vacuum 350°C bakeout with RGA monitoring first, then UV flood low gain, high current extraction “burn in” (1 – 3µA). Gain increases by x10 during bake. No rapid gain drop in scrub, gain-V curves remain very stable.

Gain curves of 164-163 ALD MgO MCP pair (20µm pore, 60:1 L/d, 8° bias) during conditioning.

UV “burn-in” of ALD MCP pair 164-163 (20µm pore, MgO, 60:1 L/d, 8° bias) compared with conventional MCPs. Outgas during burn-in < 4 x 10^{-10} torr H₂ for the first 0.05 C cm⁻².
33mm ALD-MCP Preconditioning Tests

Vacuum 350°C bakeout and “burn in”.

Absolute measured gain is very stable at “normal use” voltages.

Exposure to dry nitrogen for 15 min after the lifetest shows no appreciable change in gain after re-pumpdown.

Gain stability of #164-163 MCP pair during conditioning, for several MCP voltage settings.

Gain curves for ALD MCP pair 164-163 (20µm pore, MgO, 60:1 L/d, 8° bias)
Imaging 20cm, 20µm pore ALD-MCP Pairs

A number of 20cm MCP substrates have been functionalized by ALD at ANL, and put through detailed tests at UCB-SSL.

Image striping is due to the anode period modulation as the charge cloud sizes are too small for the anode. 20cm, 20µm pore, Al₂O₃ SEY, MCP pair image with 185nm non uniform UV illumination.
Testing of 20cm, 20µm pore ALD-MCP Gain

Mean gain ~7 x 10^6

20µm pore, 60:1 L/d ALD-MCP pair. Average gain image map shows the MCP gain variations are adequate for use in most applications.

8” MCP pair average gain map image

Histograms show the gain modest variation

Mean gain ~7 x 10^6
Background, 20cm, 20µm pore ALD-MCP Pairs

20µm pore, 60:1 L/d ALD-MCP pair, 0.7mm gap/200v.

Background very low !! 0.068 cnts sec\(^{-1}\) cm\(^{-2}\) is a factor of 4 lower than normal glass MCPs.

This is a consistent observation for all MCPs with this substrate material and relates to the low intrinsic radioactivity of the glass.

Without lead content the cross section for high energy events is also lower than standard glasses.

There are issues with hotspots on some substrates, however this can be addressed

20cm MCP pair background, 2000 sec, 0.068 cnts sec\(^{-1}\) cm\(^{-2}\). 2k x 2k pixel imaging.
100 mm square Cross Strip Anode microchannel plate photon counting detector with 128 x 128 strips/amplifiers. Developed for high spatial resolution, at lower gains, with higher count rates and longer lifetime.

< 20µm FWHM resolution @ 1.5x10^6 gain, 4 MHz @85% livetime, 6µm pixels
10cm x 10cm ALD 20µm MCP Pair in Cross Strip Detector

Image resolves pores

Gain map

10 cm x 10cm cross strip readout, MCP gain \(~10^6\), 16k x 16k pixels (6µm) at > 5 MHz.
Atomic Layer Deposited-MCP Summary

• Borosilicate Micro-capillary arrays offer a robust substrate for atomic layer deposited MCPs, and distortion/defect quality is still improving.
• Gain, imaging, and detection efficiency ~same as standard MCPs
• Background rates are low, <0.07 events cm\(^{-2}\) sec\(^{-1}\)
• High temp vac bake for tube processing has very positive effects
  • Factor of >5x gain increase with MgO ALD SEY
  • Establishes very low MCP outgassing (borosilicate, ALD, MgO)
• Excellent MCP pair lifetest characteristics – “burn-in”
  • Essentially no gain drop at the nominal gain over 7 C cm\(^{-2}\)
  • Very stable to dry N\(_2\) exposure thereafter
• ALD MgO/Al\(_2\)O\(_3\) applied to normal MCPs help lifetime & gain
• ALD functionalized MCPs provide potential improvements in detector/ sealed tube/cathode lifetime and in reduction of the tube fabrication/processing turn around time.