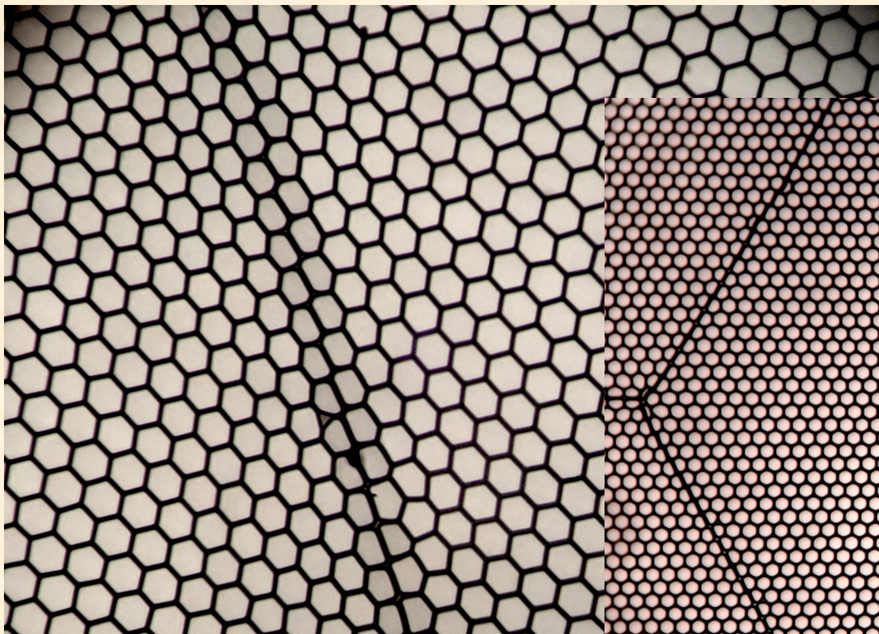
Performance Characteristics of Atomic Layer Functionalized Microchannel Plates

Oswald Siegmund, Nathan Richner, Gautam Gunjala, Jason McPhate, Anton Tremsin
Space Sciences Laboratory, U.C. Berkeley
Henry Frisch, University of Chicago
Jeff Elam, Anil Mane, Robert Wagner
Argonne National Laboratory
Michael Minot, Chris Craven, INCOM Inc.

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.



40μm pore borosilicate micro-capillary MCP with 83% open area.

Pore distortions at multifiber boundaries, otherwise very uniform.

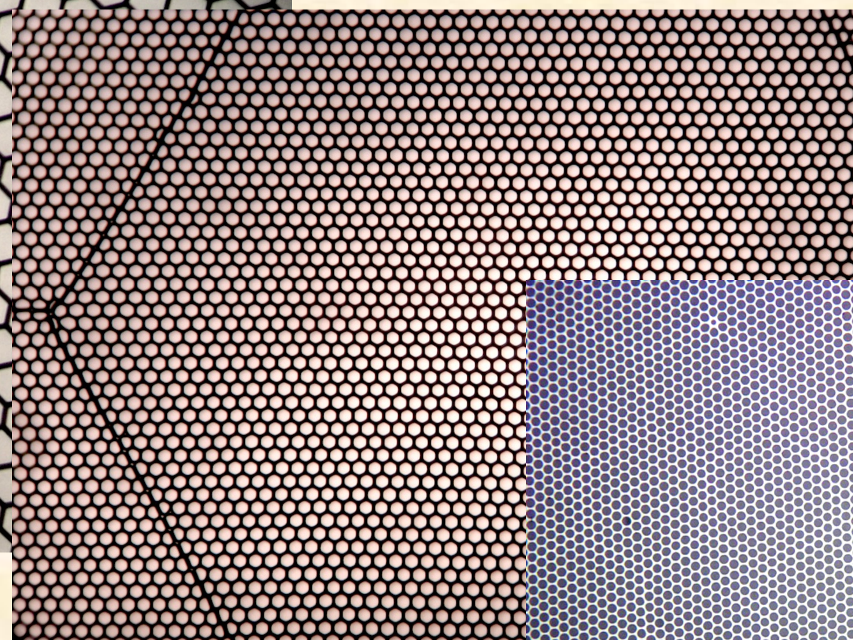


Photo of a 20 μm pore, 65% open area borosilicate micro-capillary ALD MCP (20cm).

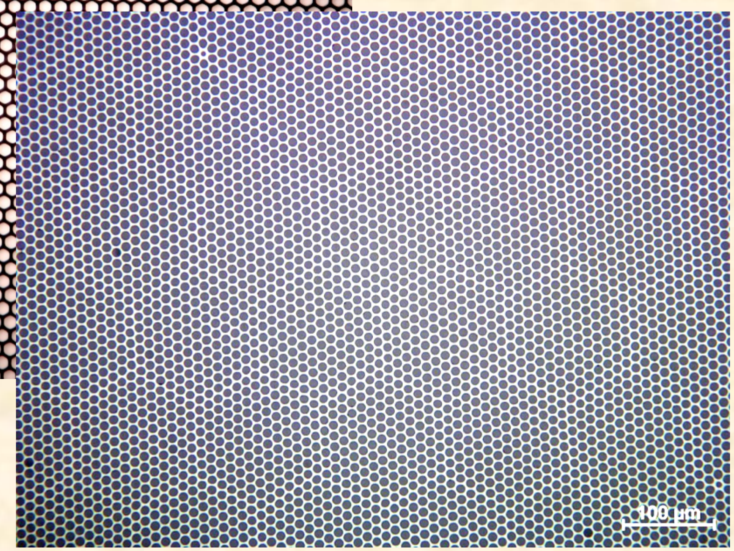


Photo of a 10 μm pore, 60% open area borosilicate micro-capillary ALD MCP.

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*

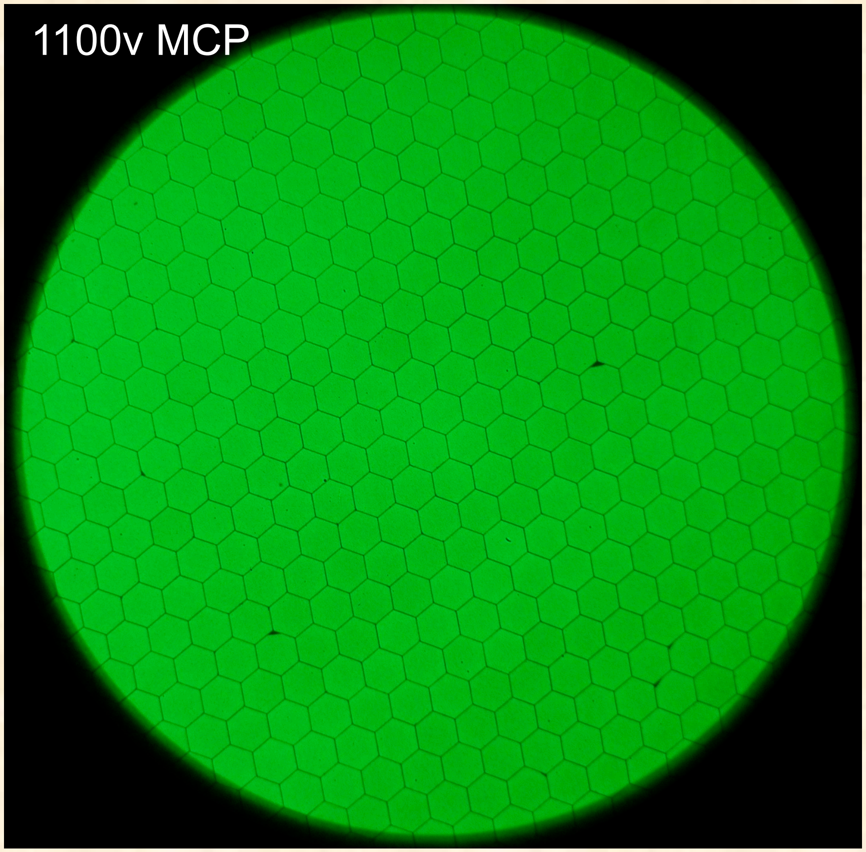
Functionalized using Atomic Layer Deposition (ALD)

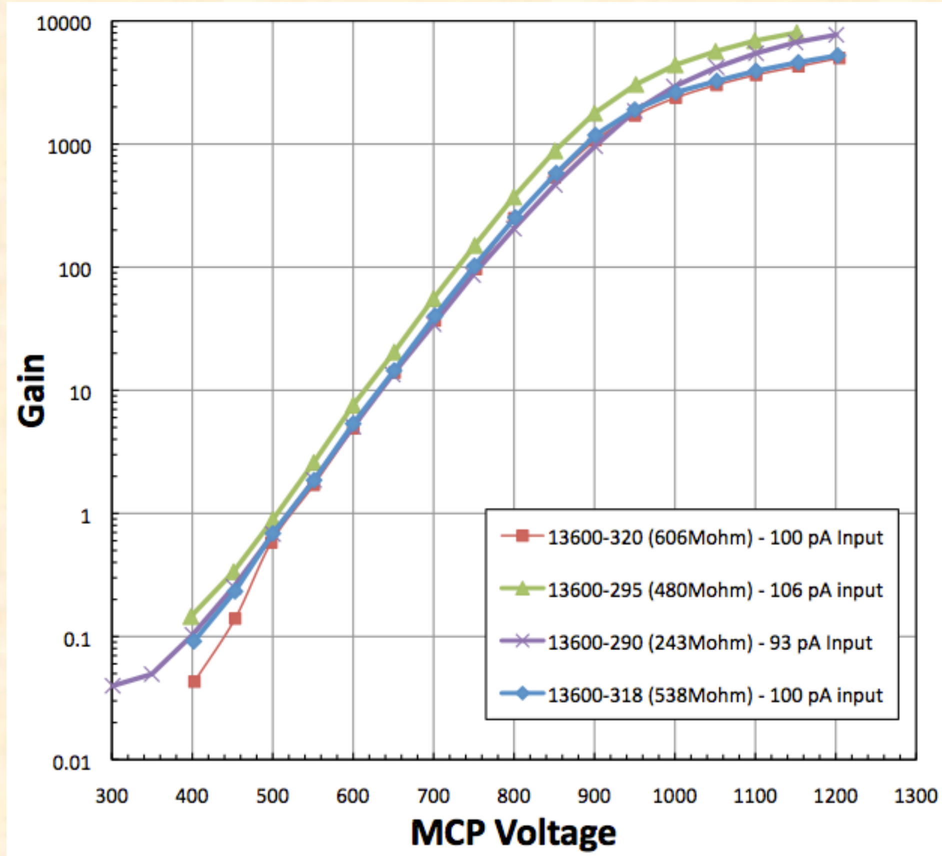
- *Semiconductor Resistive layer, tunable over wide range*
- *Amplifying layer (eg. Al_2O_3) with high secondary electron coeff.*
- *Better lattice match to GaN, also good for conventional cathodes*
- *Can be used on conventional MCPs and MCP substrates*

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.



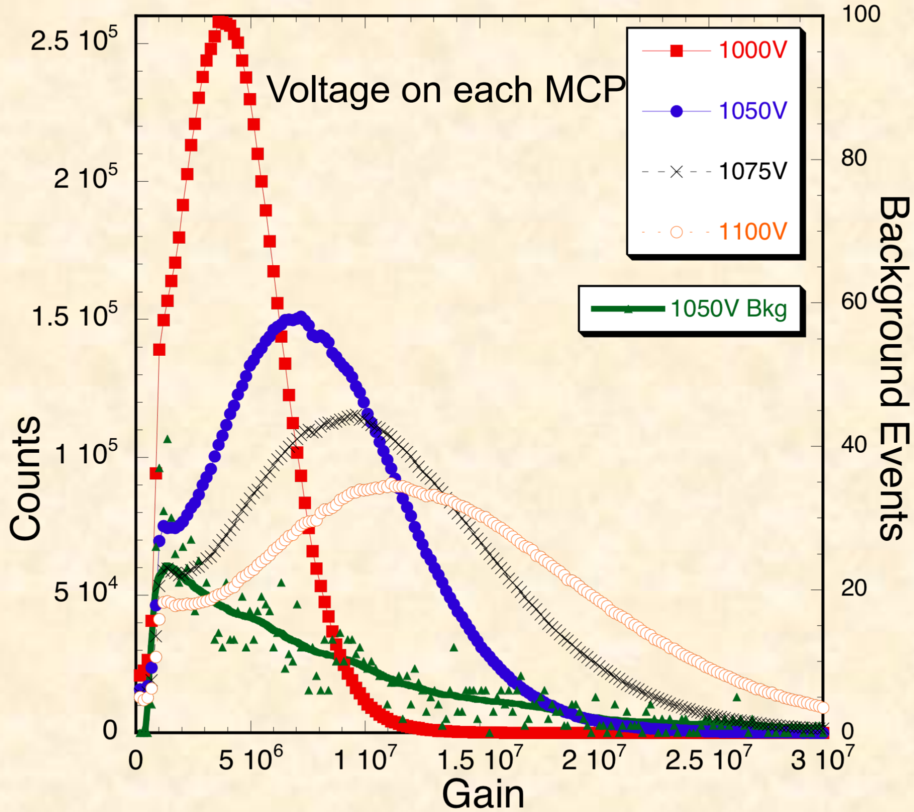


Single MCP tests in DC amplification mode show imaging and gain very similar to conventional MCPs. Sample imaging performance has improved dramatically with substrate and ALD coating process improvements.

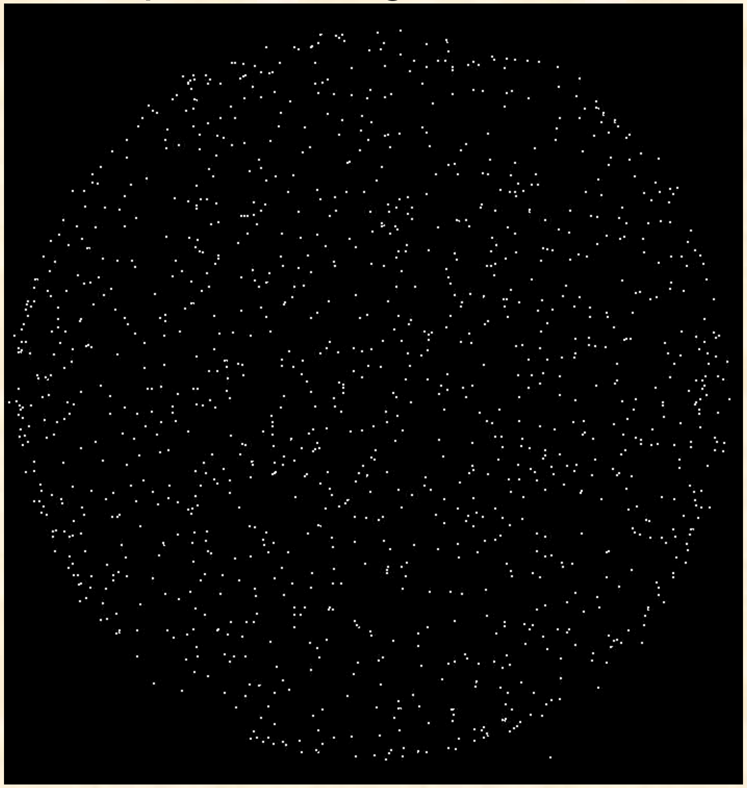
ALD-MCP Performance Tests, 33mm pairs

MCP pair, 20µm pores, 8° bias, 60:1 L/d, 0.7mm pair gap with 300V bias.

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.



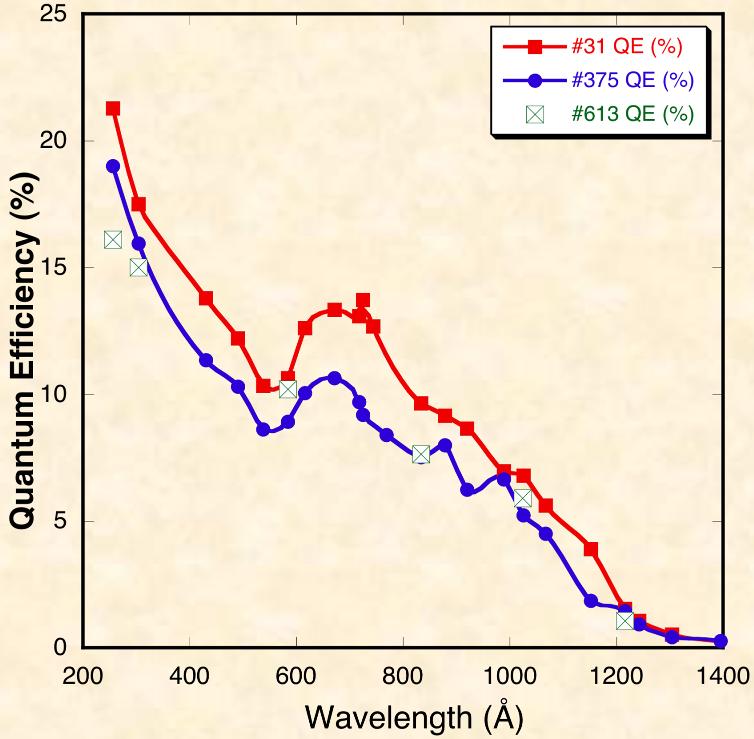
Pulse height amplitude distributions. 33mm MCP pair, 20µm pores, 8° bias, 60:1 L/d, 0.7mm pair gap with 300V bias. 3000 sec background.



3000 sec background, 0.0845 events cm^{-2} sec^{-1} at 7 x 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.

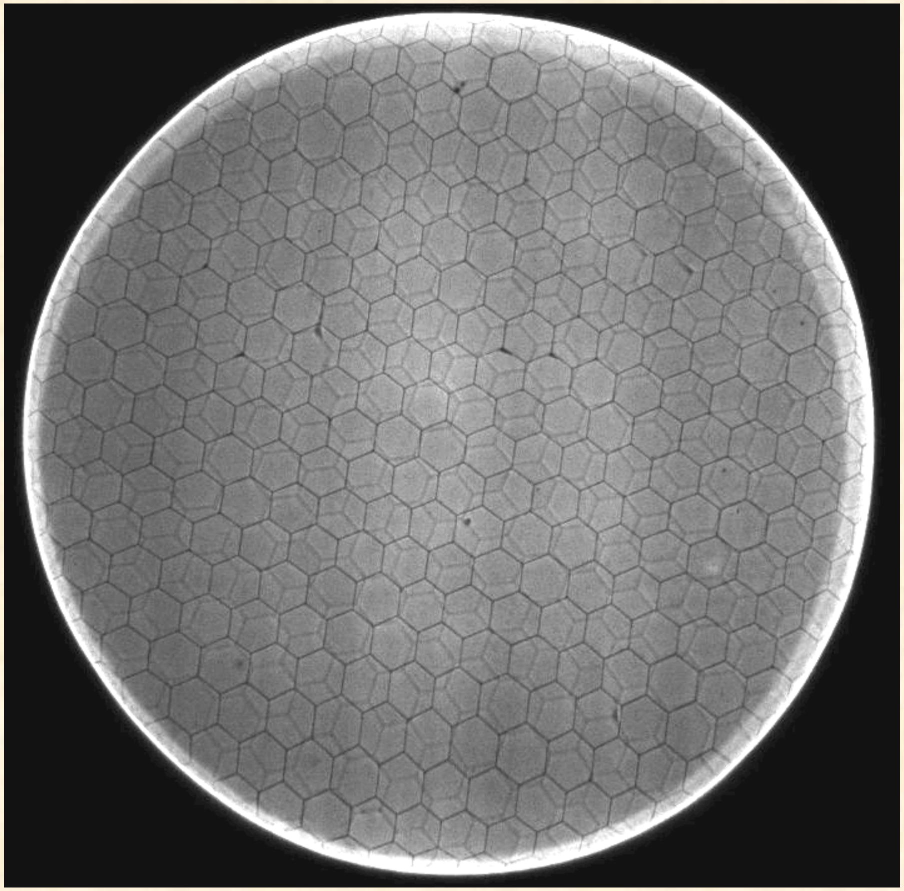
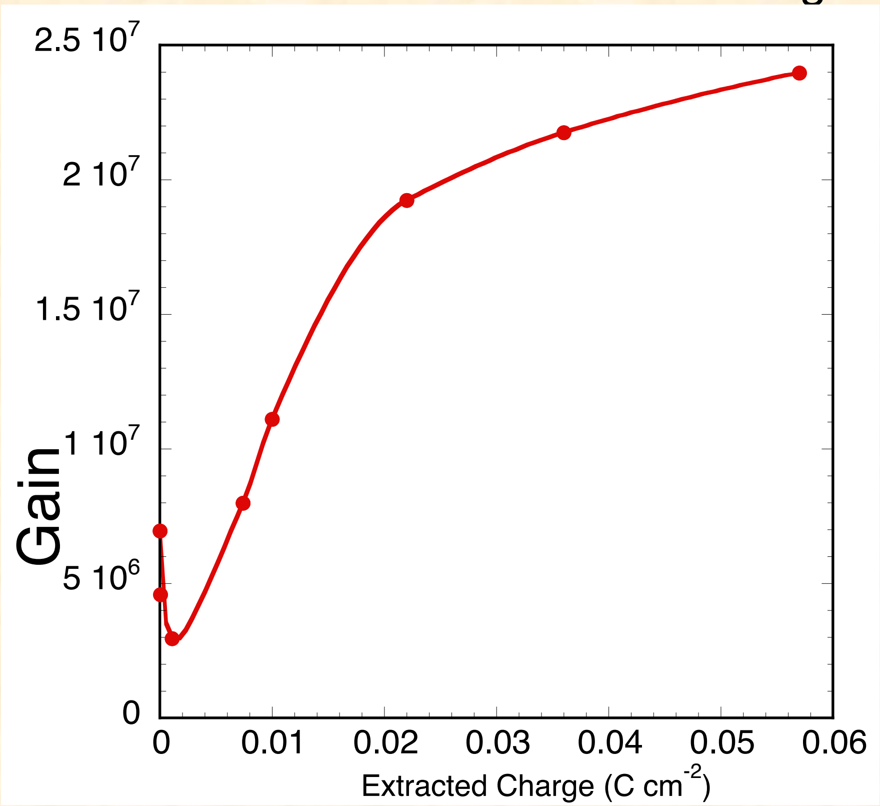


Image of 185nm UV light, **ALD MCP pair**, 20μm pores, 8° bias, 60% OAR, shows top MCP hex modulation and faint MCP hexagonal modulation from bottom MCP. 0.7mm pair gap with 300V bias.

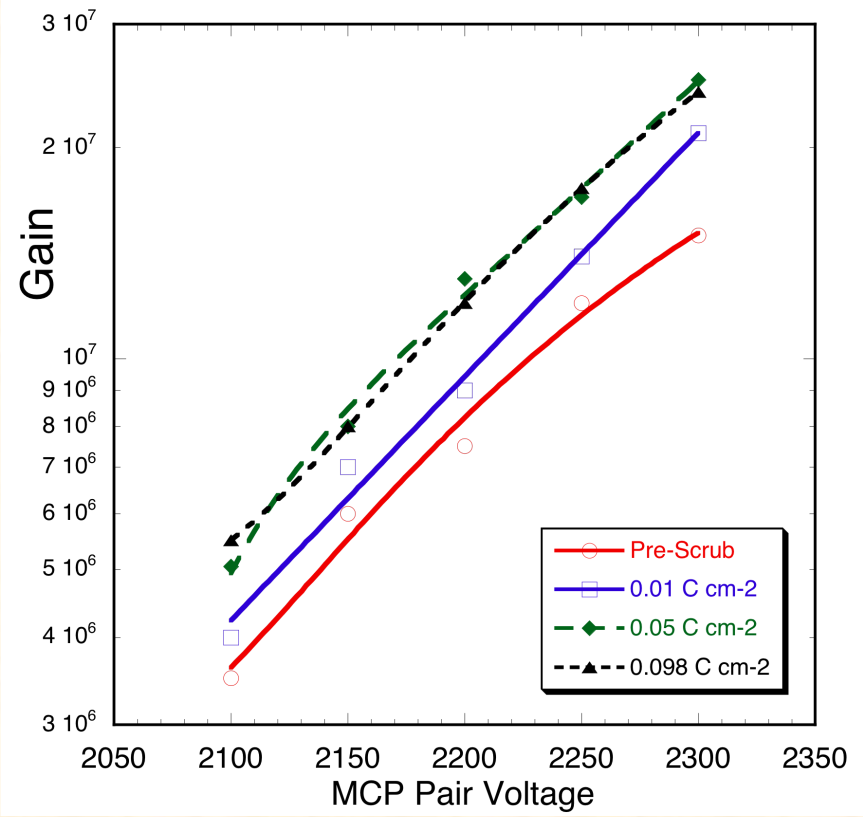
ALD-MCP Preconditioning Tests

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_2O_3 ALD 20µm, 60:1 borosilicate MCP on top, MgO ALD on bottom MCP (6µm pore, 80:1, 33mm lead glass)

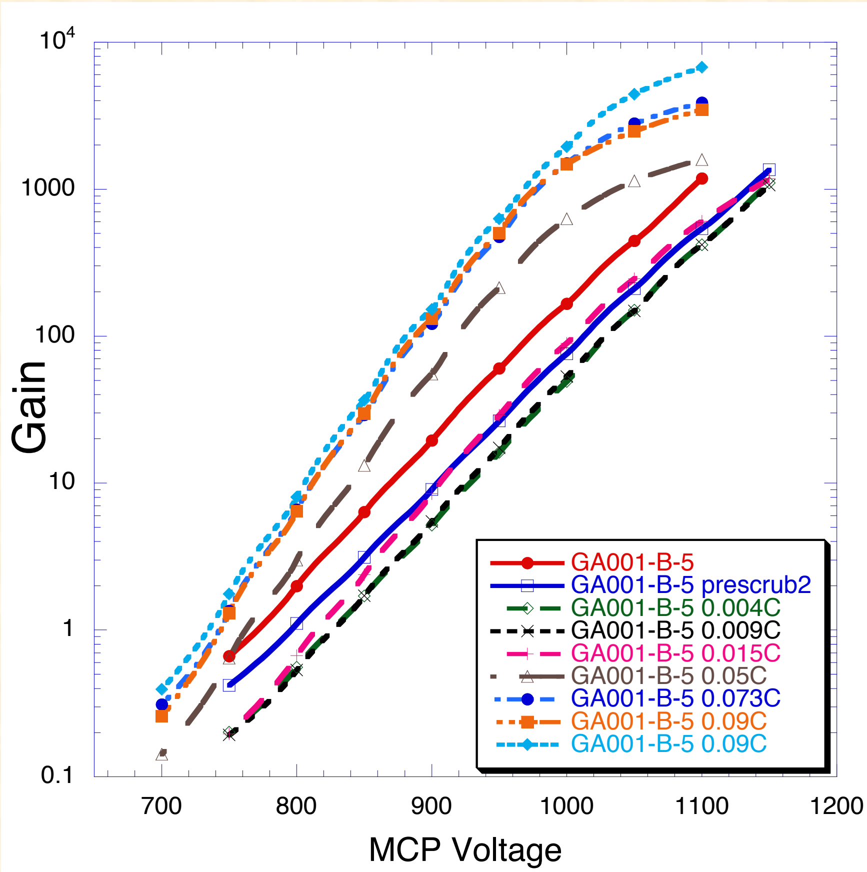
Absolute gain curves for MCP pair with NO vacuum bake. Gain rises with use.

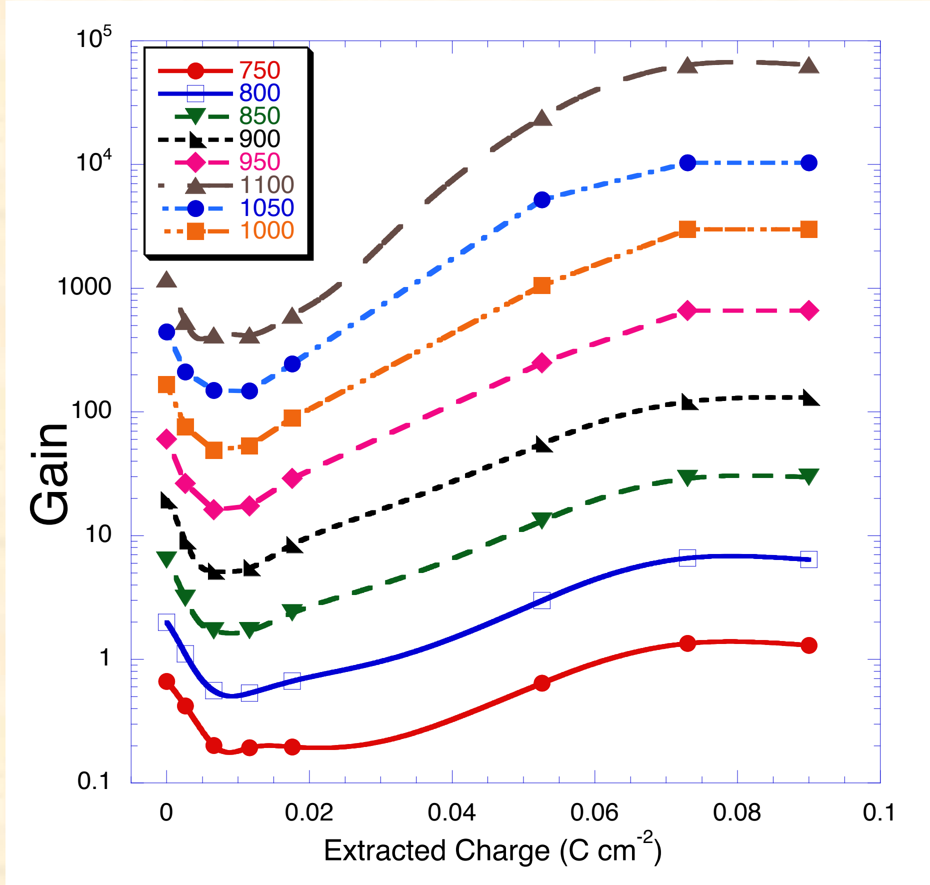


UV scrub gain curves for ALD MCP pair 180-141 each with MgO ALD (20µm pore, 60:1 L/d, 8° bias, borosilicate).

Conventional MCP – MgO ALD Coated

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



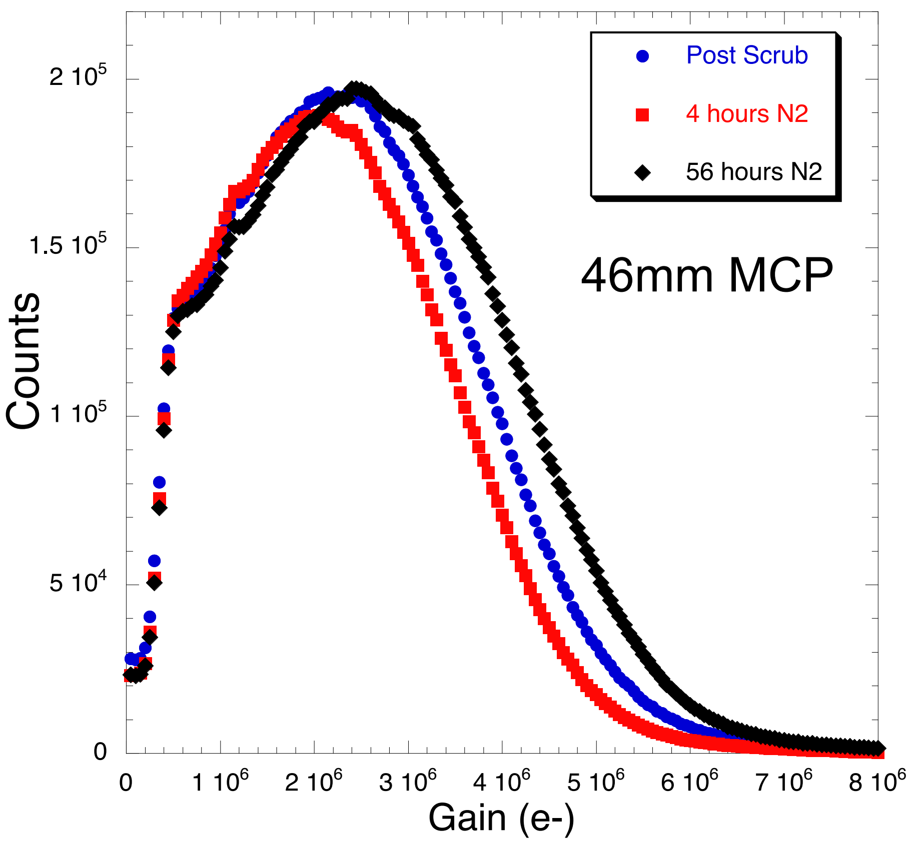


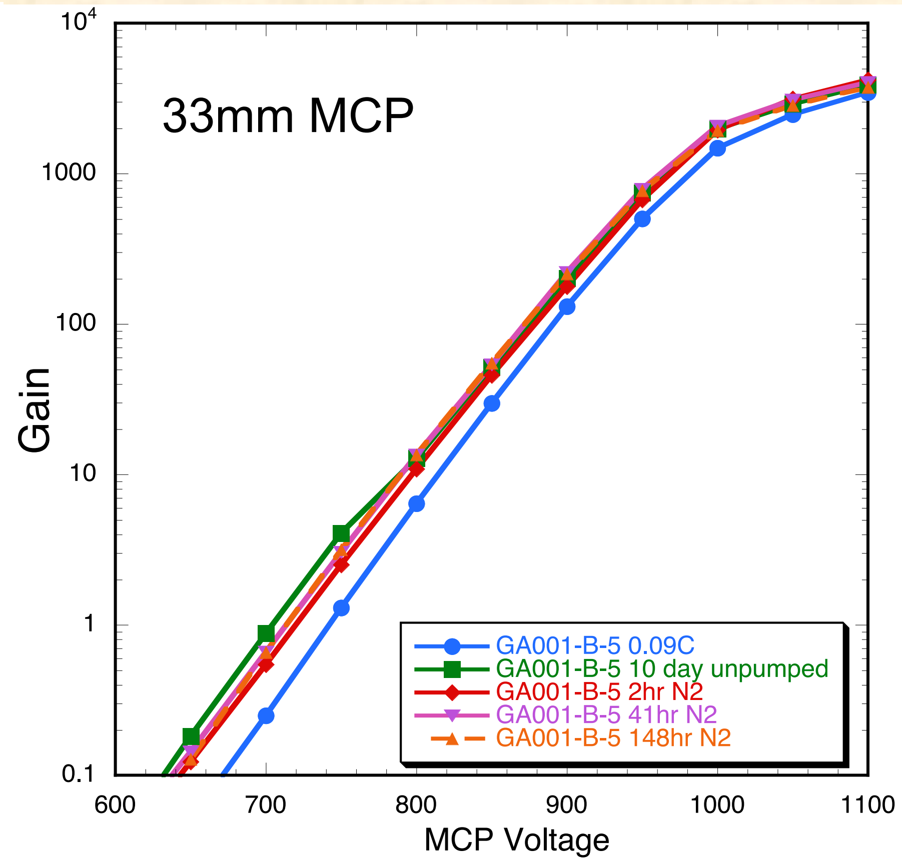
Slight gain drop (x2) at scrub initiation with significant gain increase thereafter

Stabilizing after ~0.07 C cm^{-2} extracted

Vacuum and N_2 Stability of ALD-MgO MCPs

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

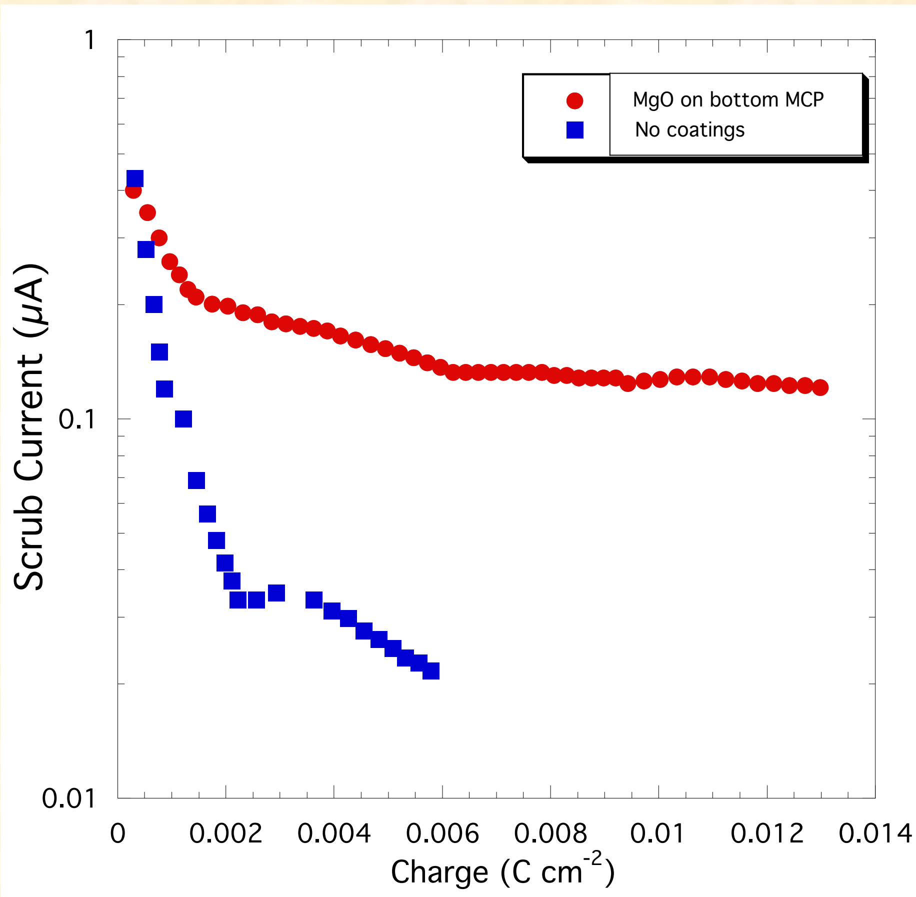




Untreated MCP on top of a MgO treated MCP. Scrub to 0.03 C cm^{-2} to reach stable gain, then dry N_2 exposures. Differences are most likely variation in room temp and length of MCP warmup time.

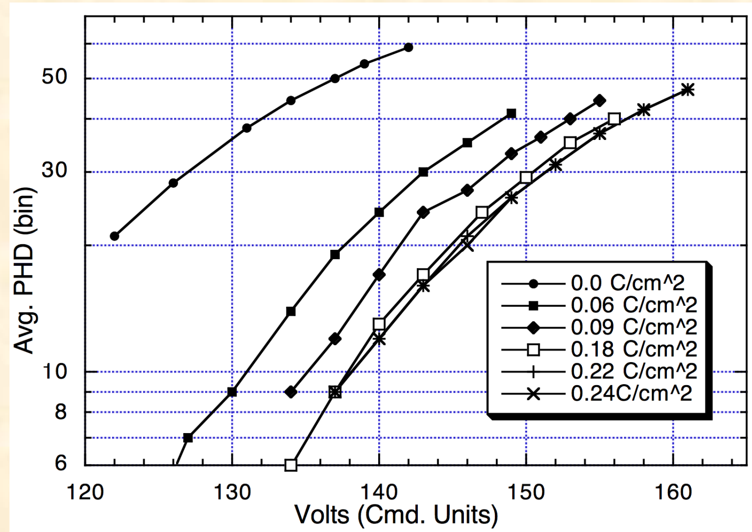
After 10 days at poor vacuum (rose to 400mTorr) the gain is slightly higher (~900v, ~ 20%). After 2hr, 41hr and 148hr dry N_2 exposures little changes.

Gain Burn-in of Conventional MCPs

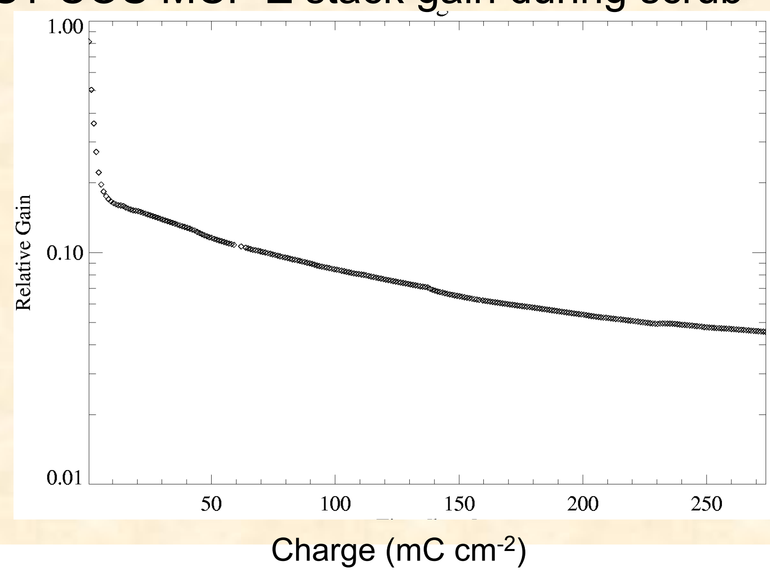


Comparison of MCP Z stacks, 10µm pore 60:1 L/D, MgO coated bottom MCP in one stack

10µm conventional MCP, 80:1 L/D

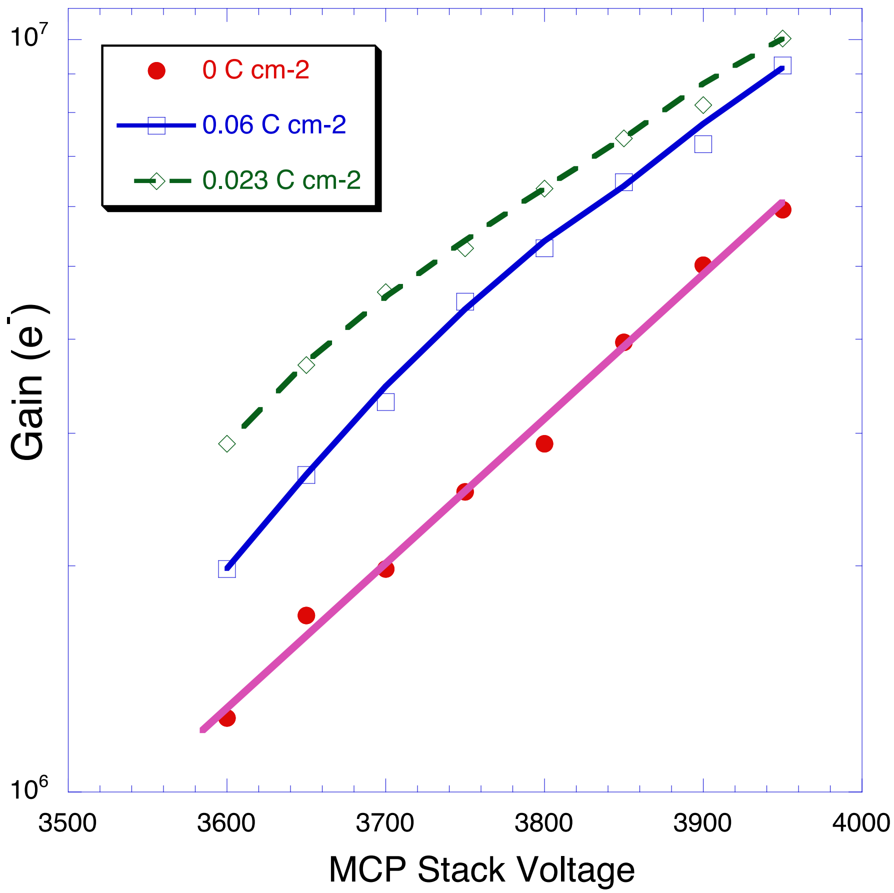


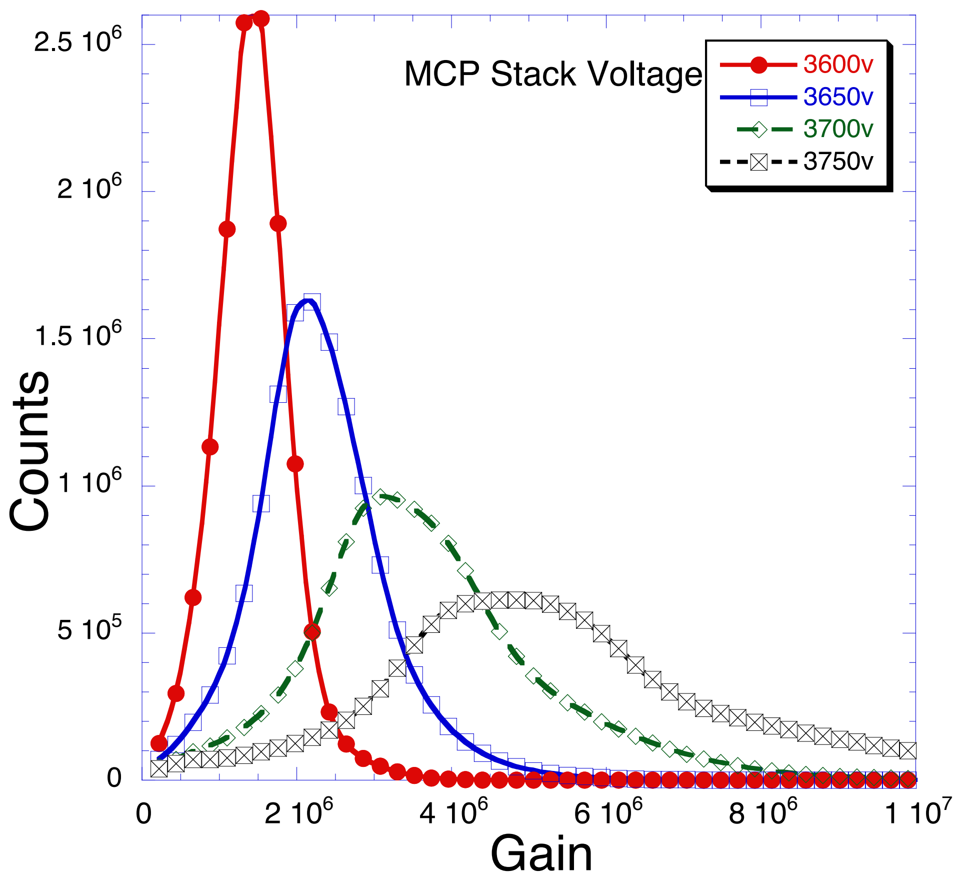
HST COS MCP Z stack gain during scrub



MgO ALD on Conventional MCP "Z" Stack

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



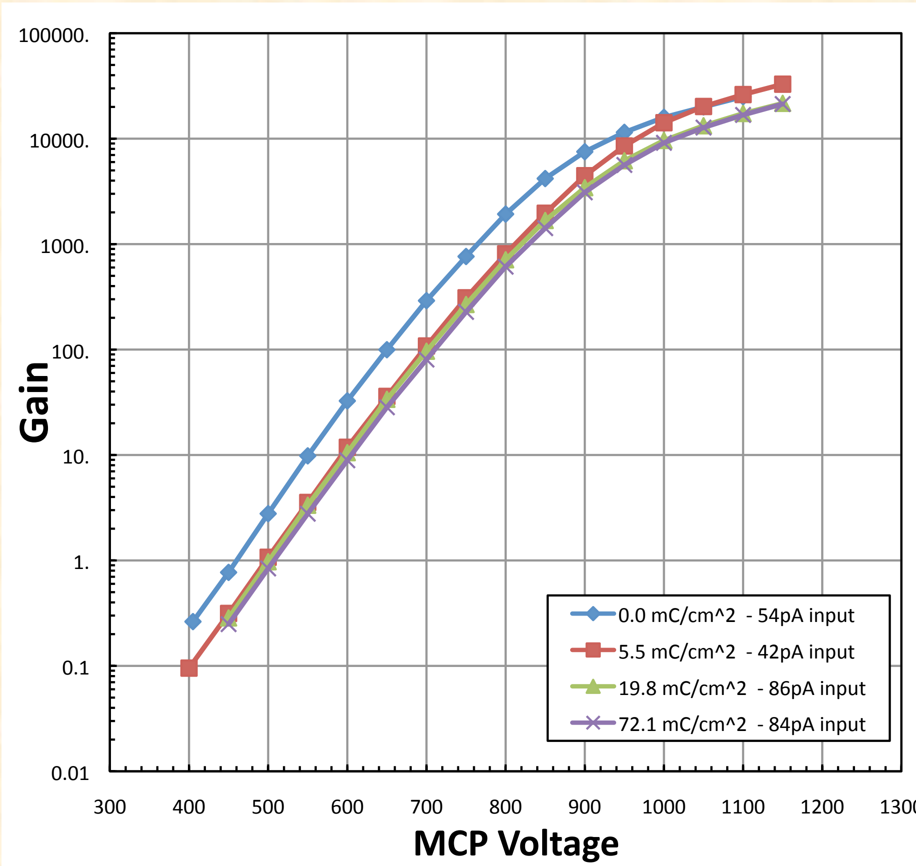


Stack scrubs up in gain as expected from earlier data. Expect stabilization at ~0.05 C cm^{-2}. General background stays at typical values (~0.4 events cm^{-2}). High secondary yield gives quite narrow PHDs even at comparatively low gain/applied voltages.

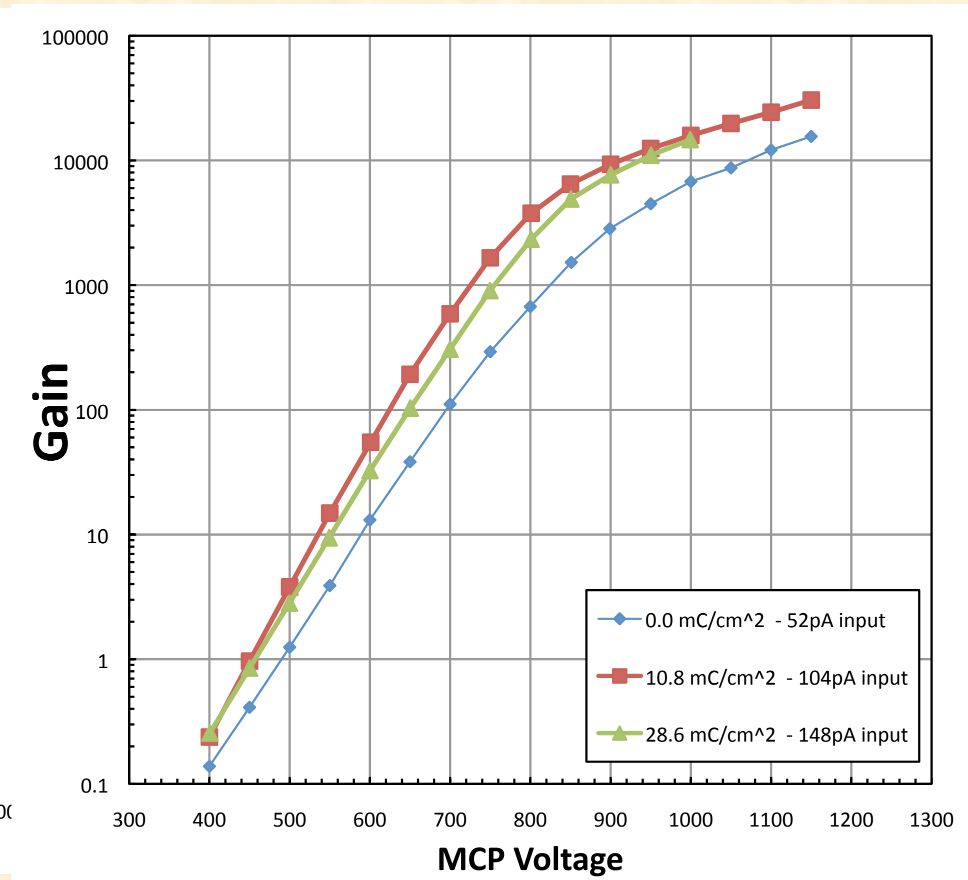
Gain vs Charge Extraction Test, MCP Pairs

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

20µm pores, 60:1 L/D, Al_2O_3 coating



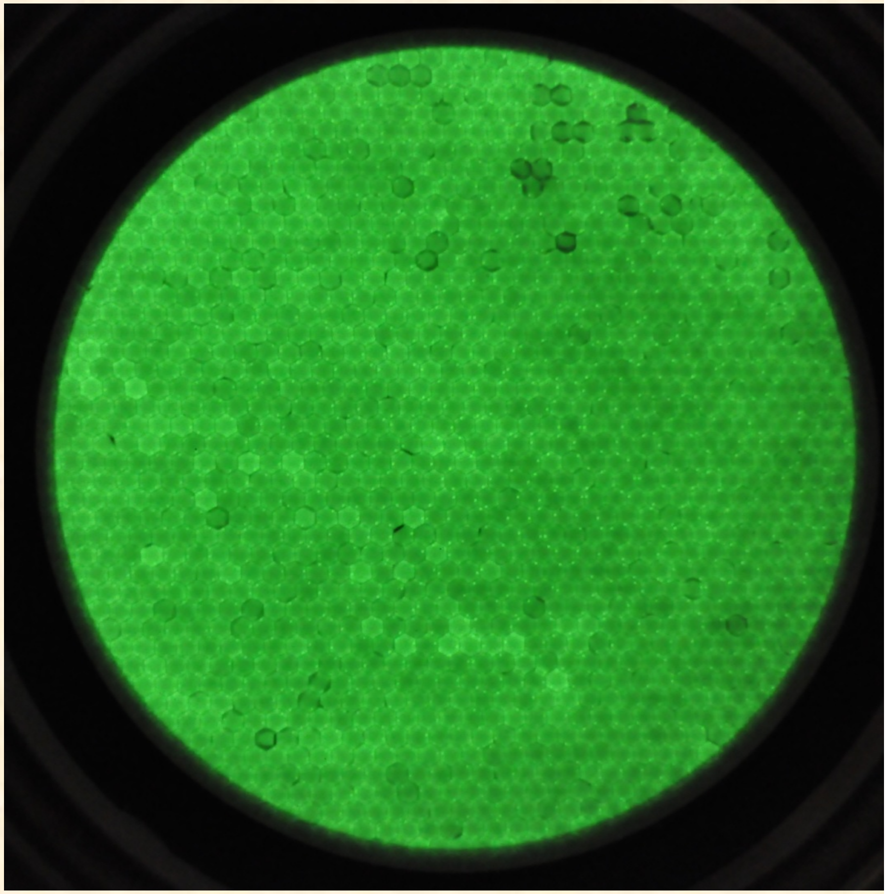
20µm pores, 60:1 L/D, MgO coating



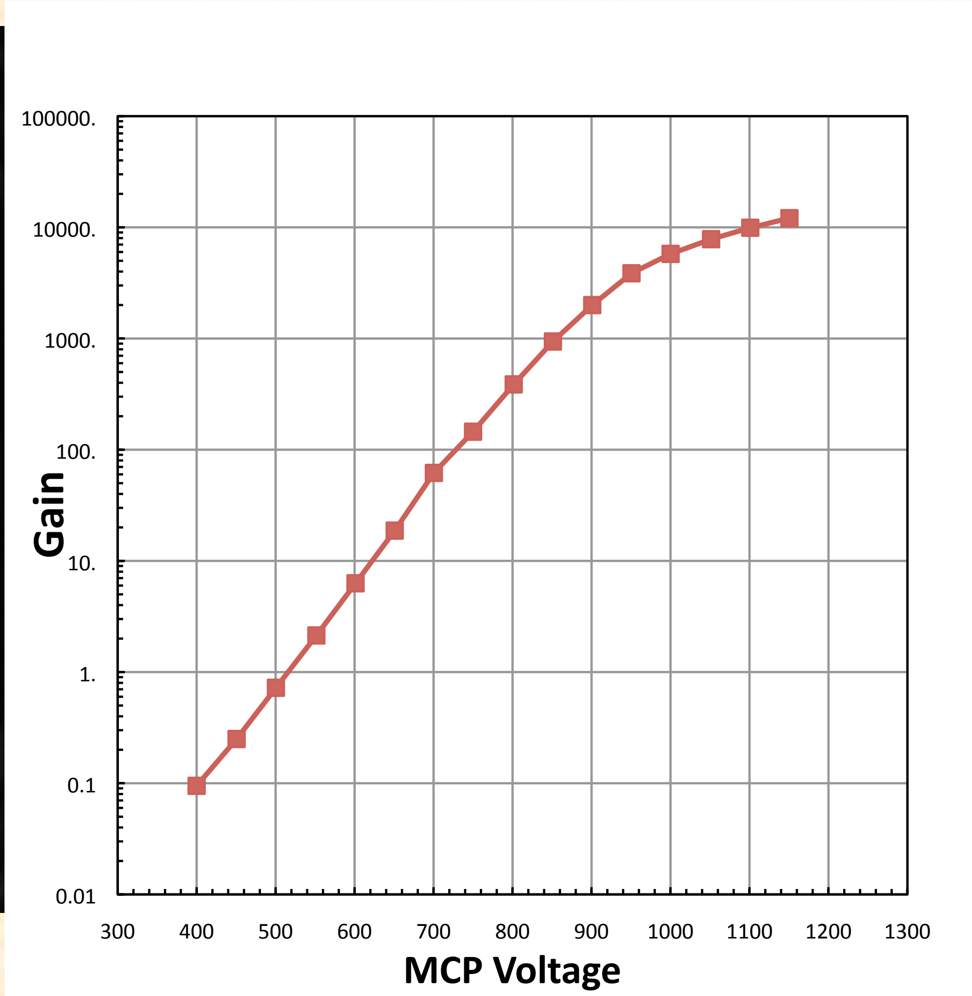
MCP gain measured for bottom MCP

10μm Borosilicate MCP Substrate with ALD

Borosilicate MCP with 10μm pores, 80:1 L/D, Al_2O_3 coating, 8° bias



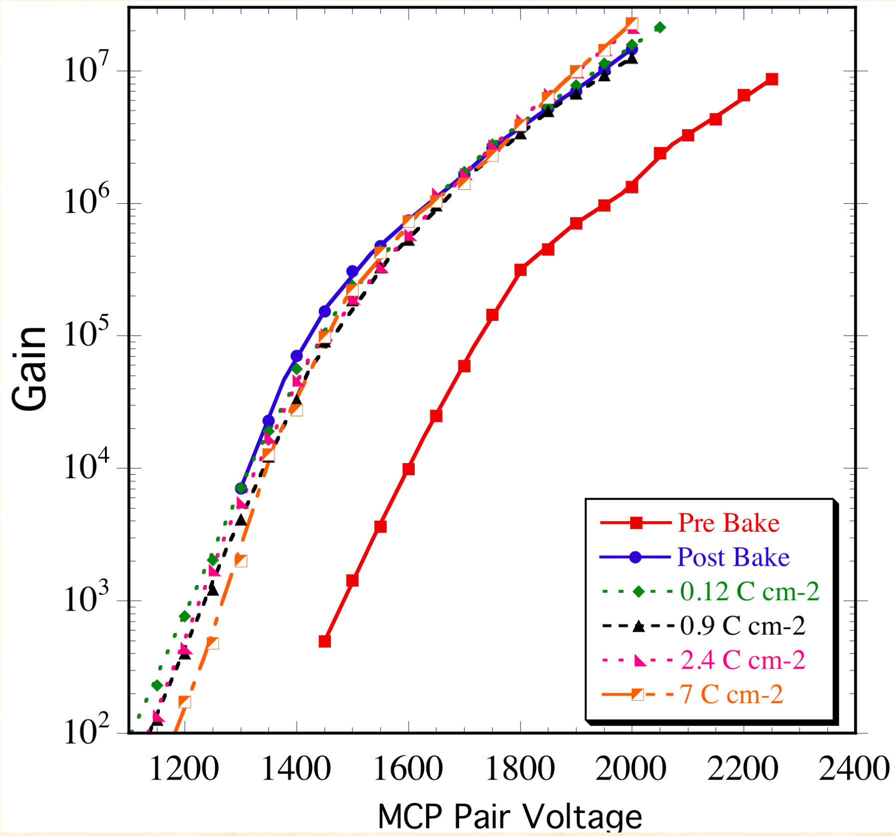
Single MCP Image (Phosphor) shows some multifiber issues, but not too bad for first attempt.



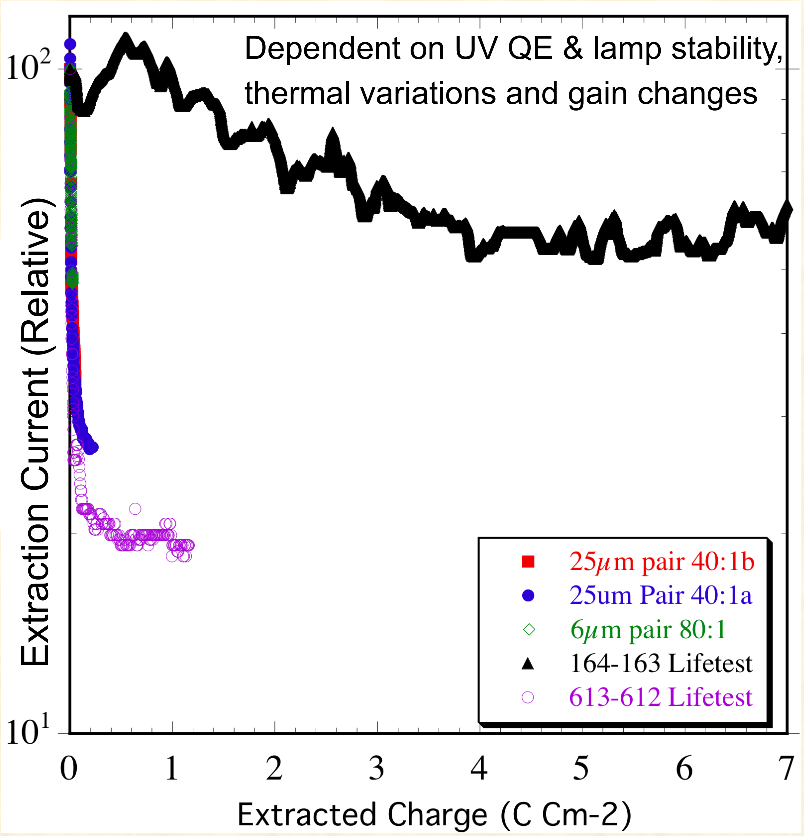
Single MCP gain is similar to conventional MCPs, gain saturation causes turnover.

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.

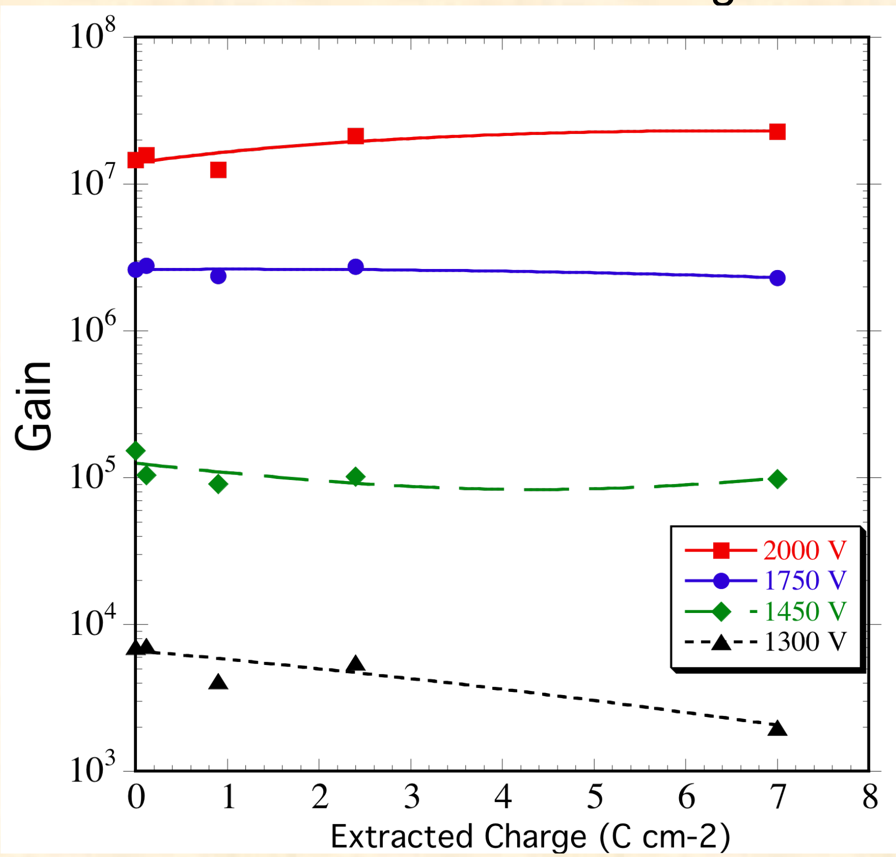


UV "burn-in" of ALD MCP pair 164-163 (20μm pore, MgO, 60:1 L/d, 8° bias) compared with conventional MCPs. Outgas during burn-in < 4 x 10^{-10} torr H_2 for the first 0.05 C cm^{-2}.

33mm ALD-MCP Preconditioning Tests

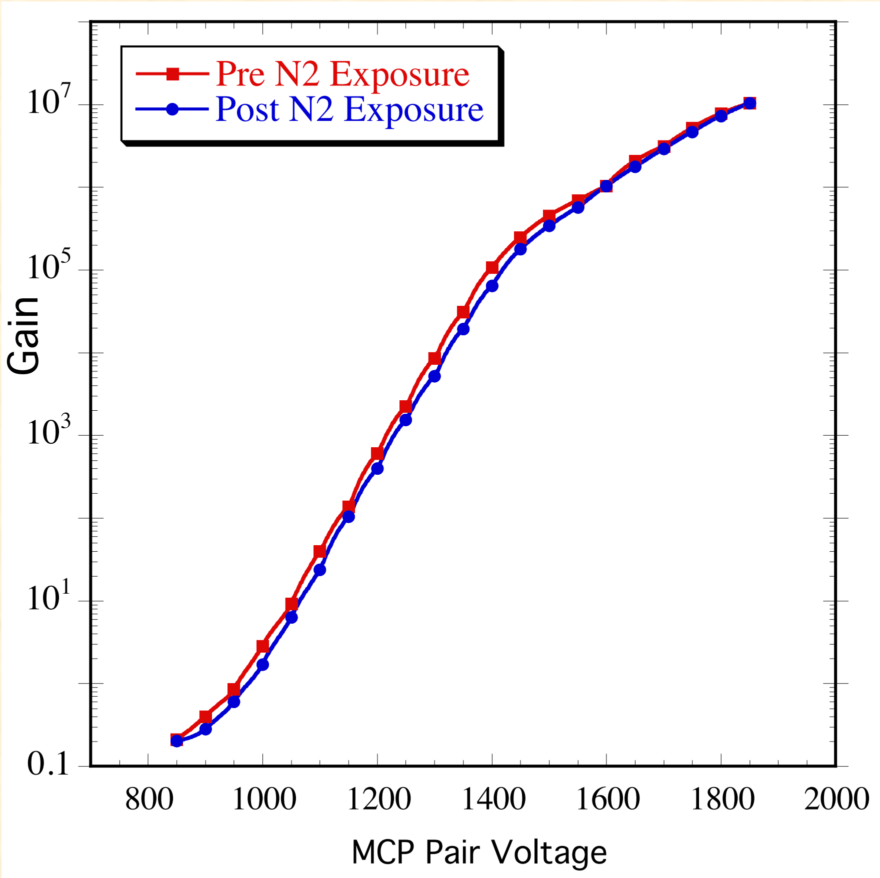
Vacuum 350°C bakeout and "burn in".

Absolute measured gain is very stable at "normal use" voltages



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

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



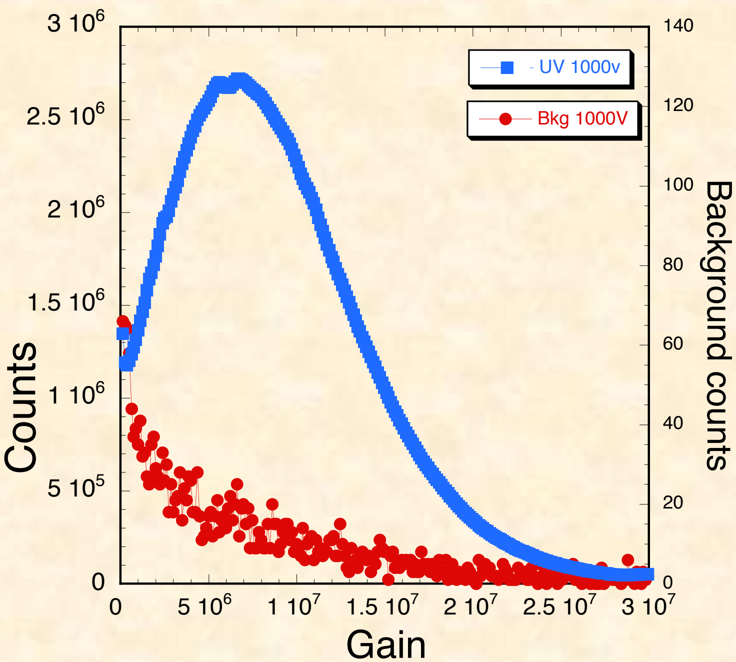
Gain curves for ALD MCP pair 164-163 (20µm pore, MgO, 60:1 L/d, 8° bias)

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 .

Expanded area view showing the mutifiber edge effects.

Pulse height distributions for UV and background.



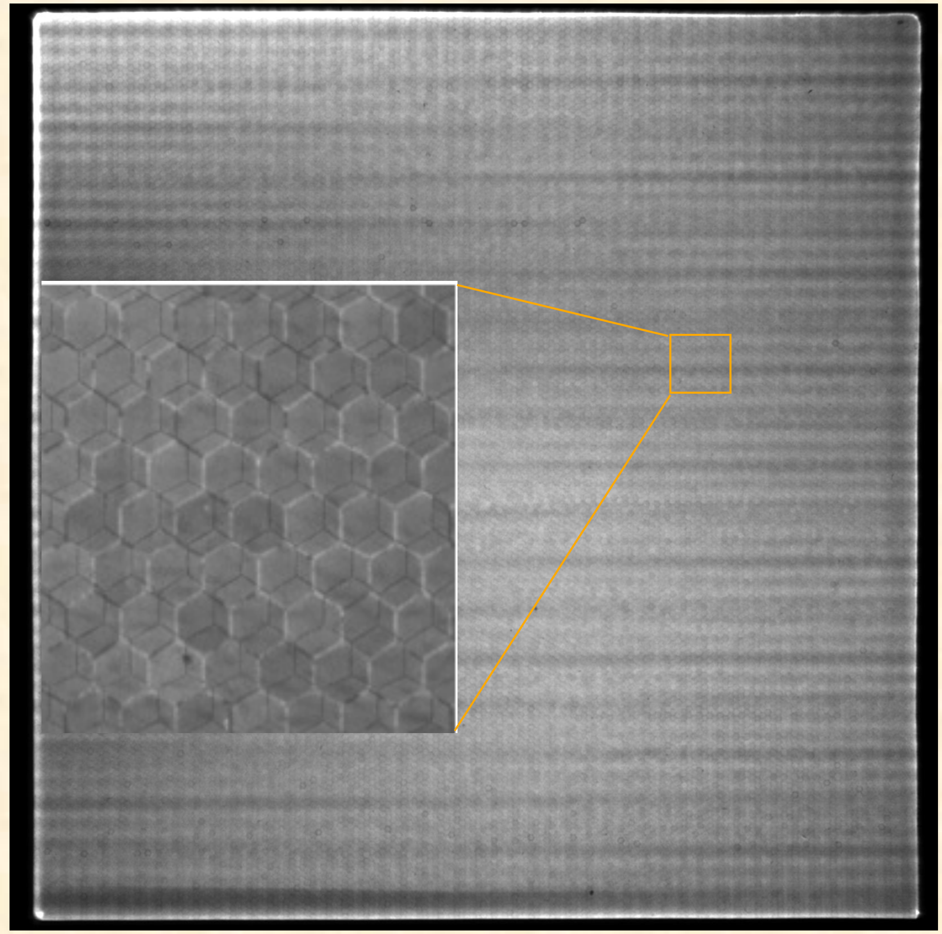
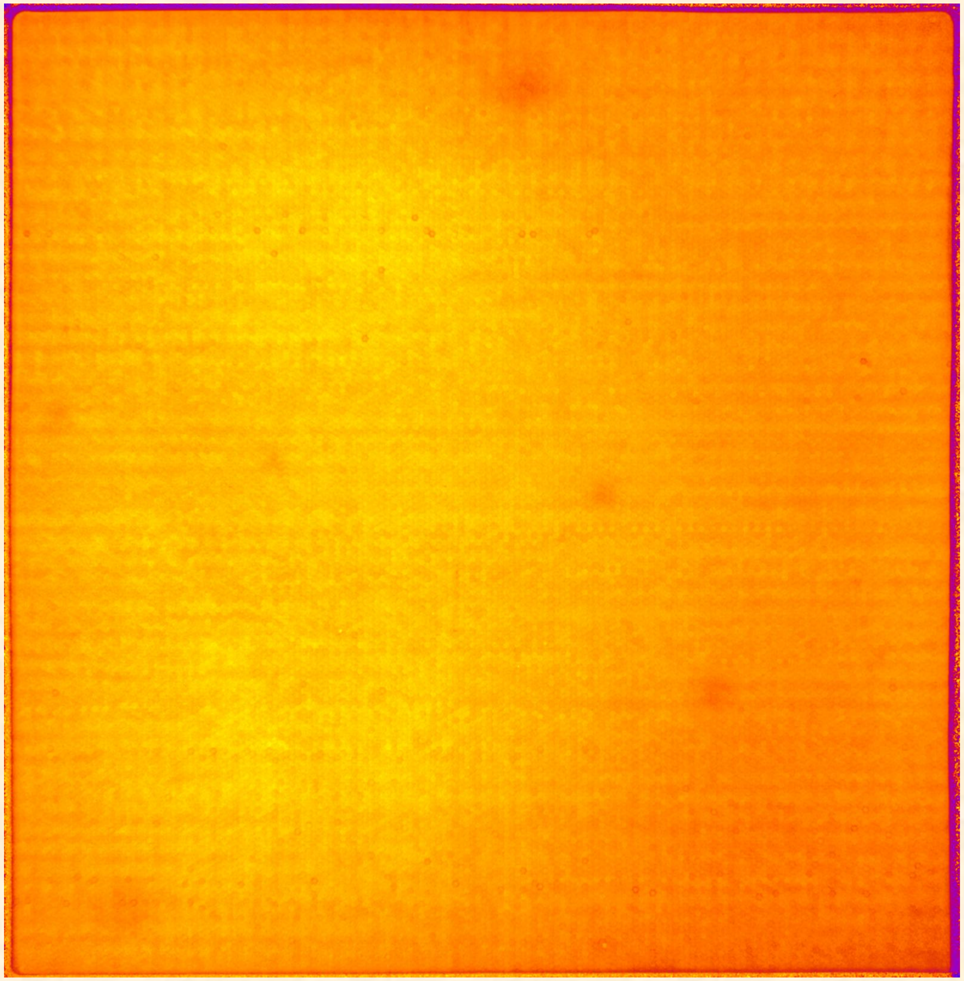


Image striping is due to the anode period modulation as the charge cloud sizes are too small for the anode. 20cm, 20µm pore, Al_2O_3 SEY, MCP pair image with 185nm non uniform UV illumination.

Testing of 20cm, 20μm pore ALD-MCP Gain

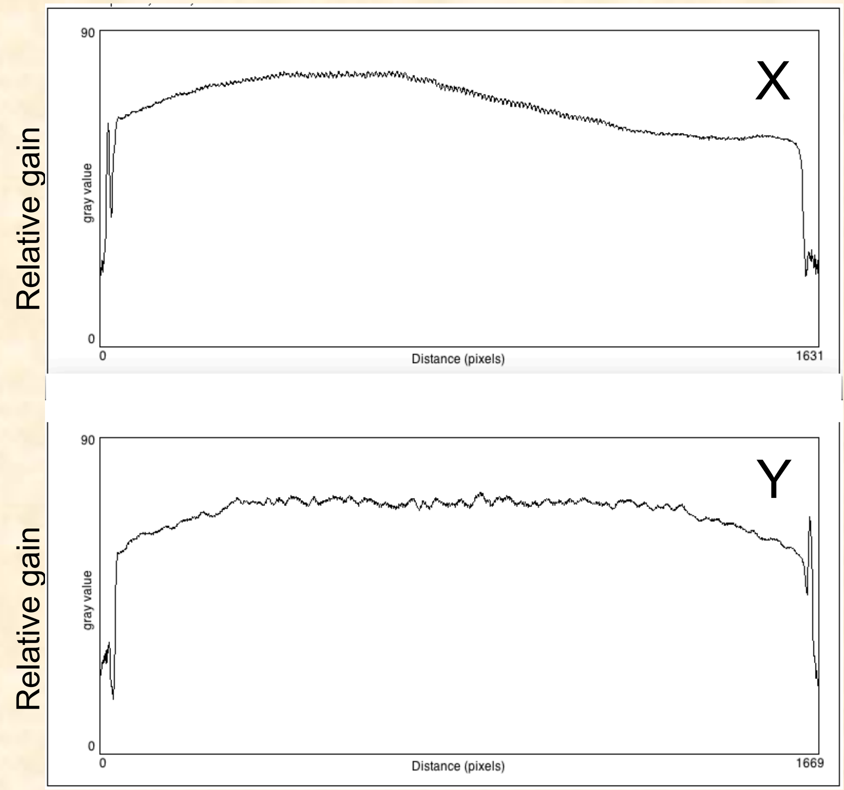
Mean gain ~7 x 10^6



8" MCP pair average gain map image

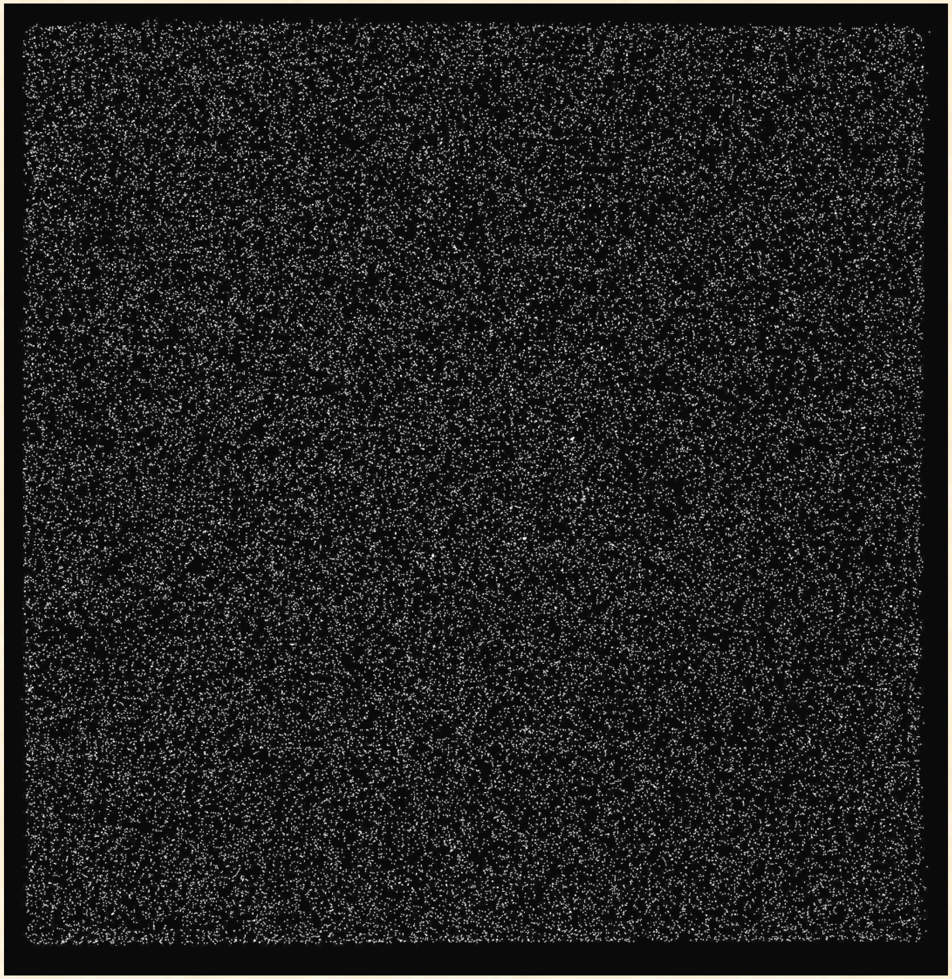
20µm pore, 60:1 L/d ALD-MCP pair.

Average gain image map shows the MCP gain variations are adequate for use in most applications.



Histograms show the gain modest variation

Background, 20cm, 20μm pore ALD-MCP Pairs



20cm MCP pair background, 2000 sec, 0.068 cnts sec^{-1} cm^{-2}. 2k x 2k pixel imaging.

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

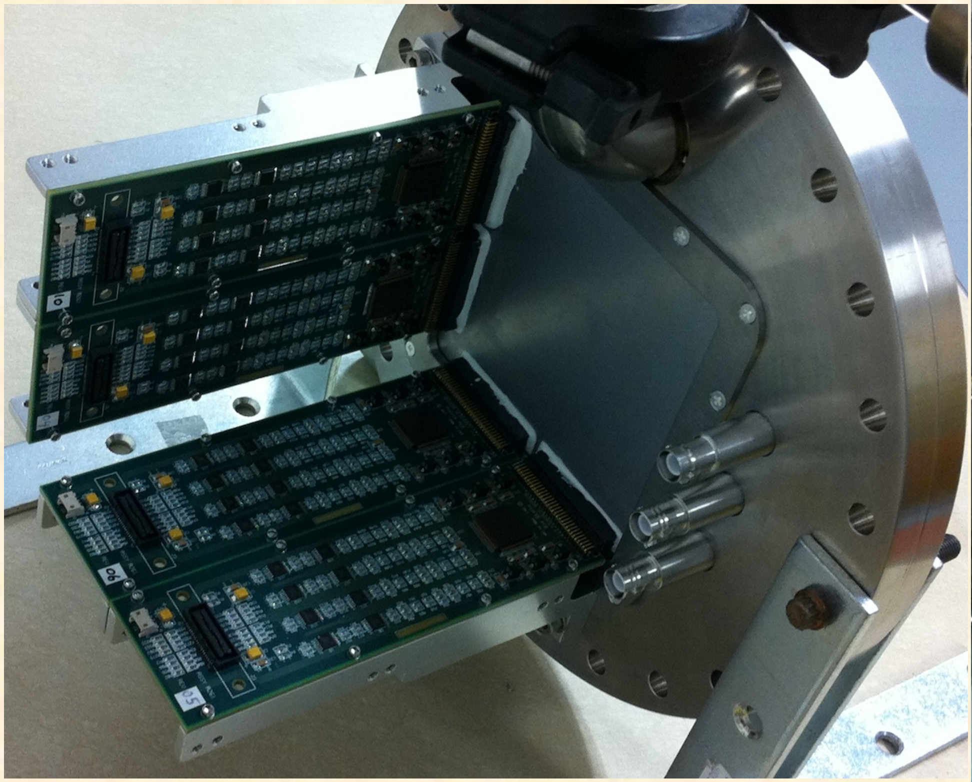
Background very low !! 0.068 cnts sec^{-1} cm^{-2} is a factor of 4 lower than normal glass MCPs.

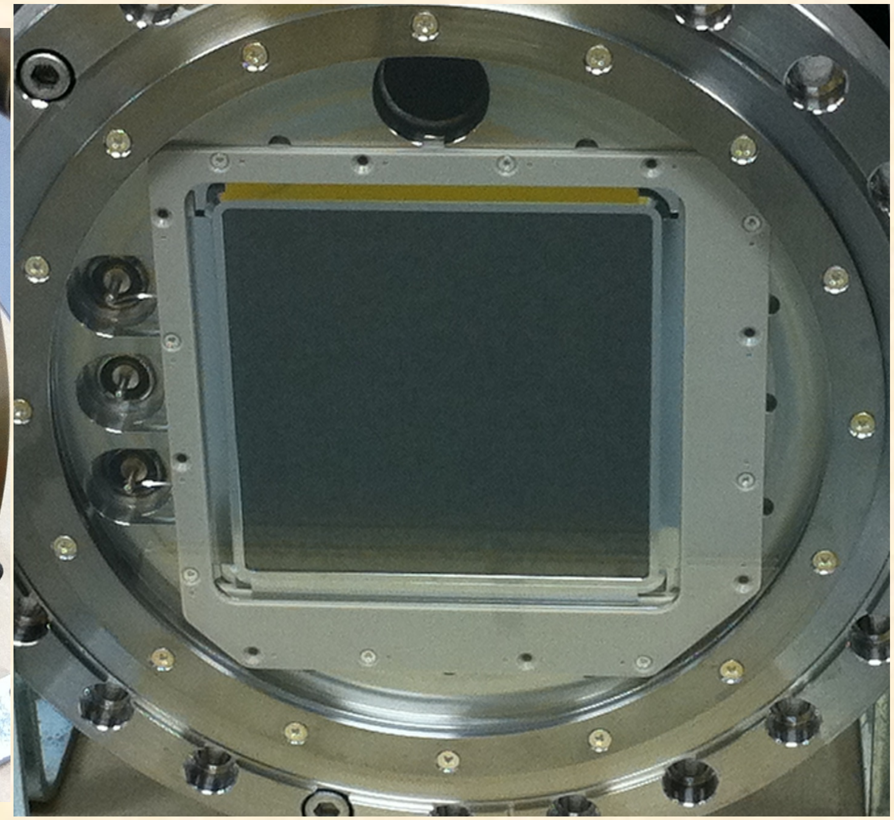
This is a consistent observation for all MCPs with this substrate material and relates to the low intrinsic radioactivity of the glass.

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

High Resolution Cross Strip Detector ALD MCP Test Scheme



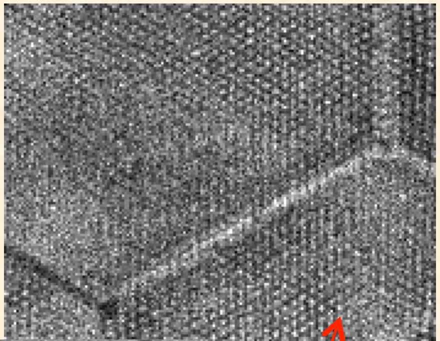


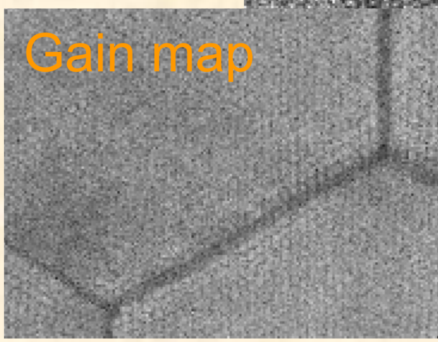
100 mm square Cross Strip Anode microchannel plate photon counting detector with 128 x 128 strips/amplifiers. Developed for high spatial resolution, at lower gains, with higher count rates and longer lifetime.

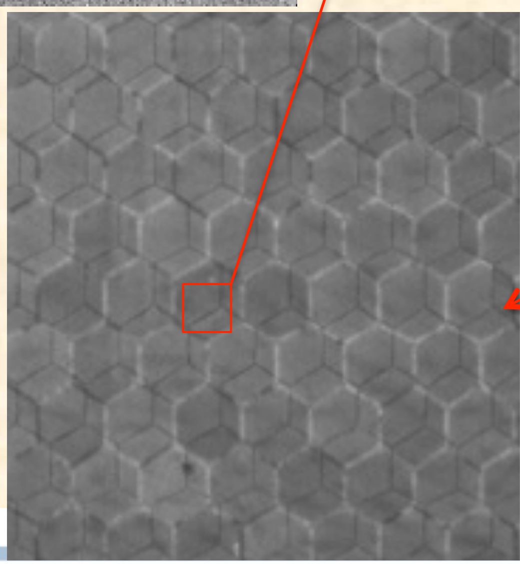
< 20μm FWHM resolution @ 1.5x10^{6} gain, 4 MHz @85% livetime, 6μm pixels

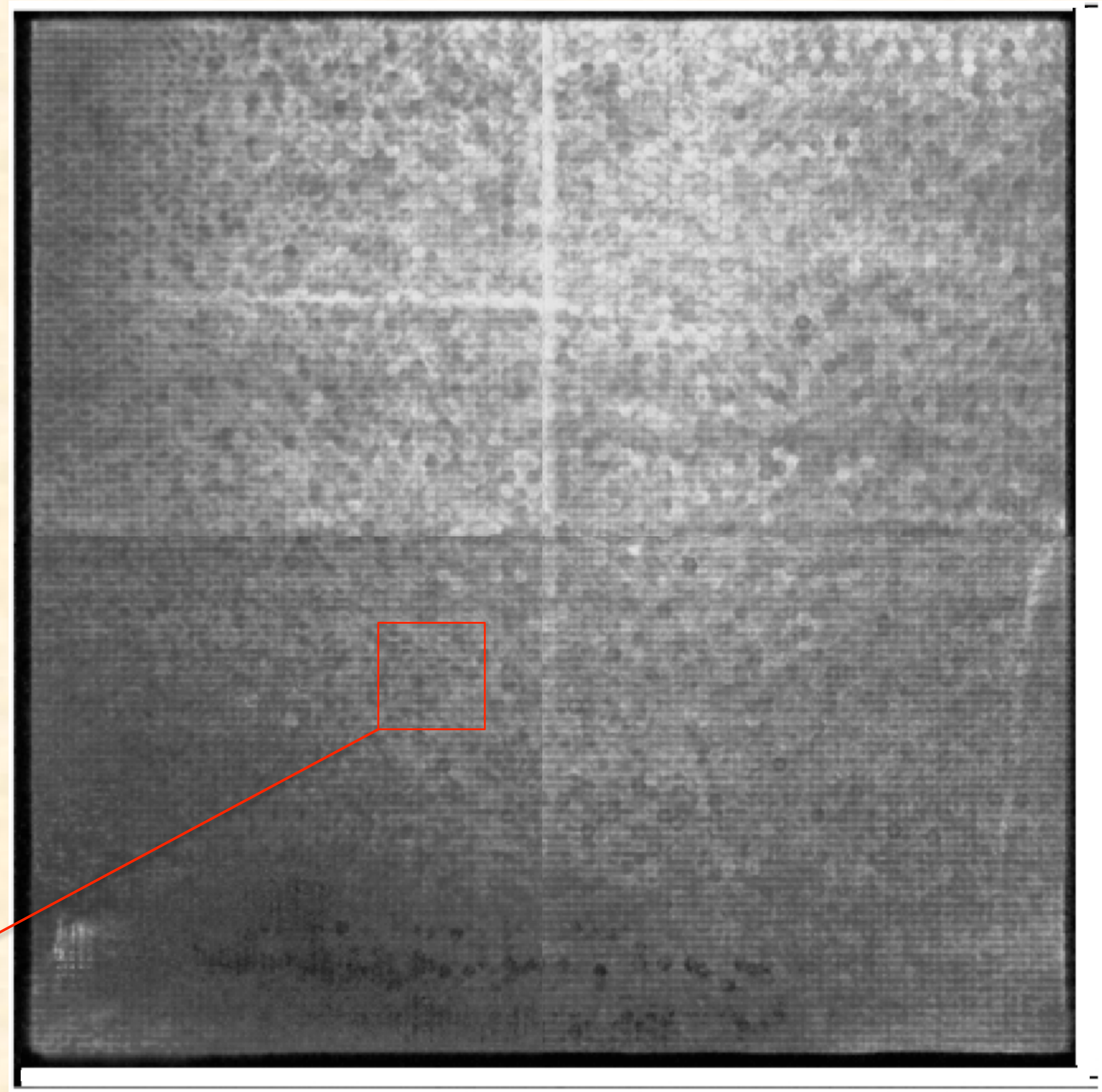
10cm x 10cm ALD 20μm MCP Pair in Cross Strip Detector

Image resolves pores









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_2O_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.