Application of Atomic Layer Deposited Microchannel Plates to Fast Timing Imaging Detectors

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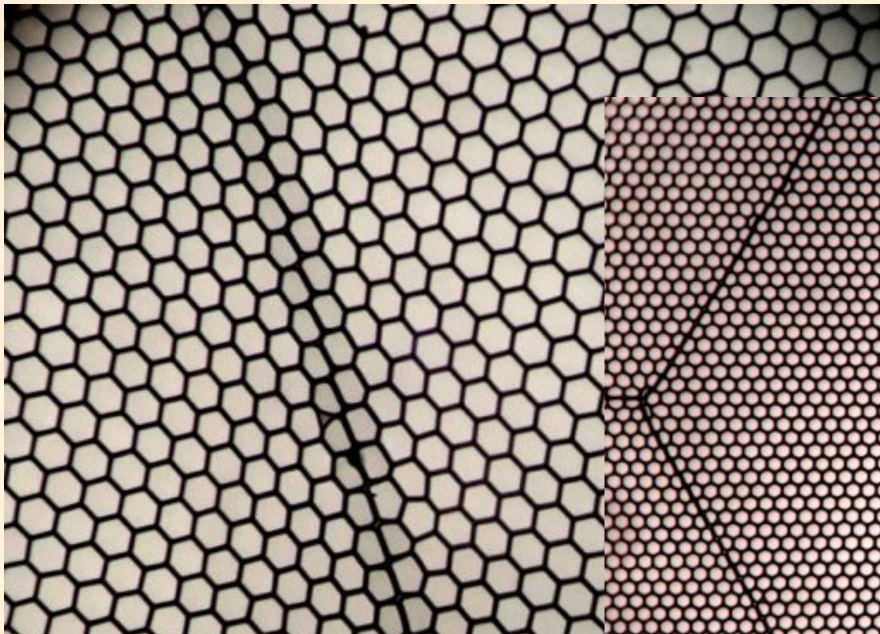
Borosilicate Substrate Atomic Layer Deposited Microchannel Plates

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.



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

Pore distortions at multifiber boundaries, otherwise very uniform.

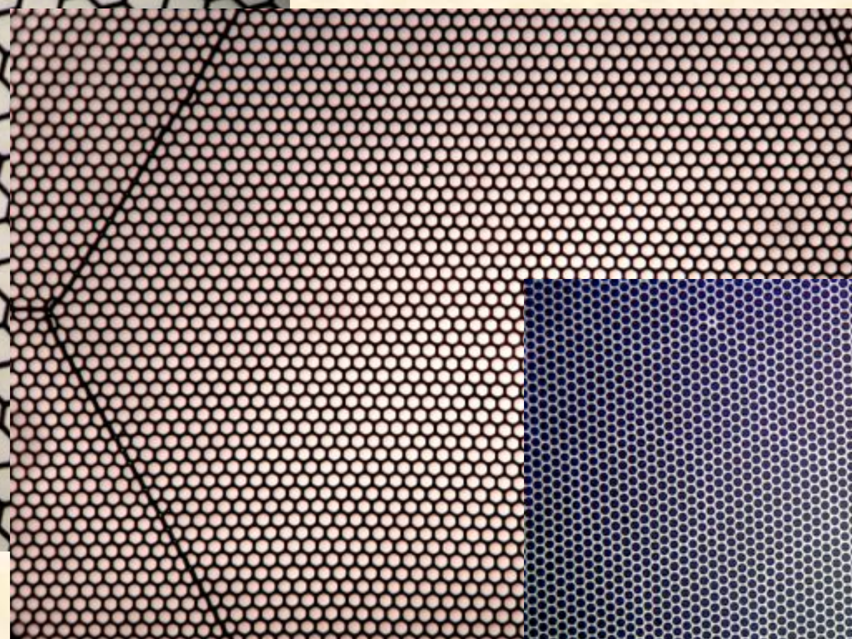


Photo of a 20 µm pore, 65% open area borosilicate micro-capillary ALD MCP (20cm).

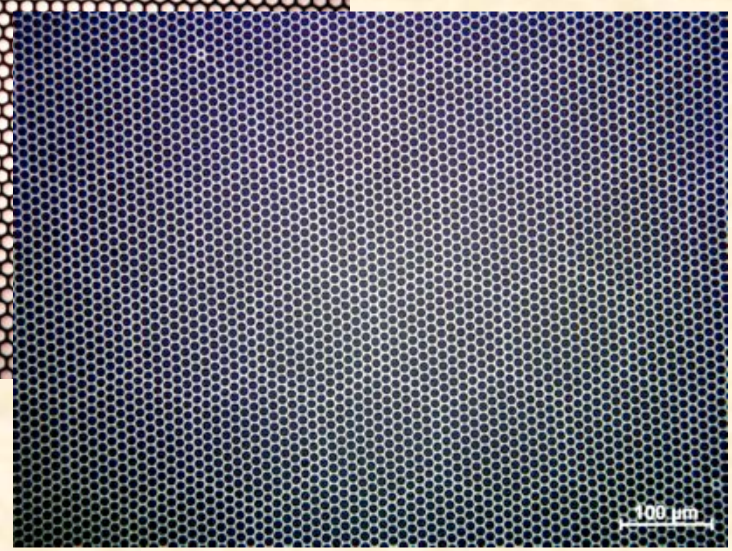


Photo of a 10 µm pore, 60% open area borosilicate micro-capillary ALD MCP.

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 background, and 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)

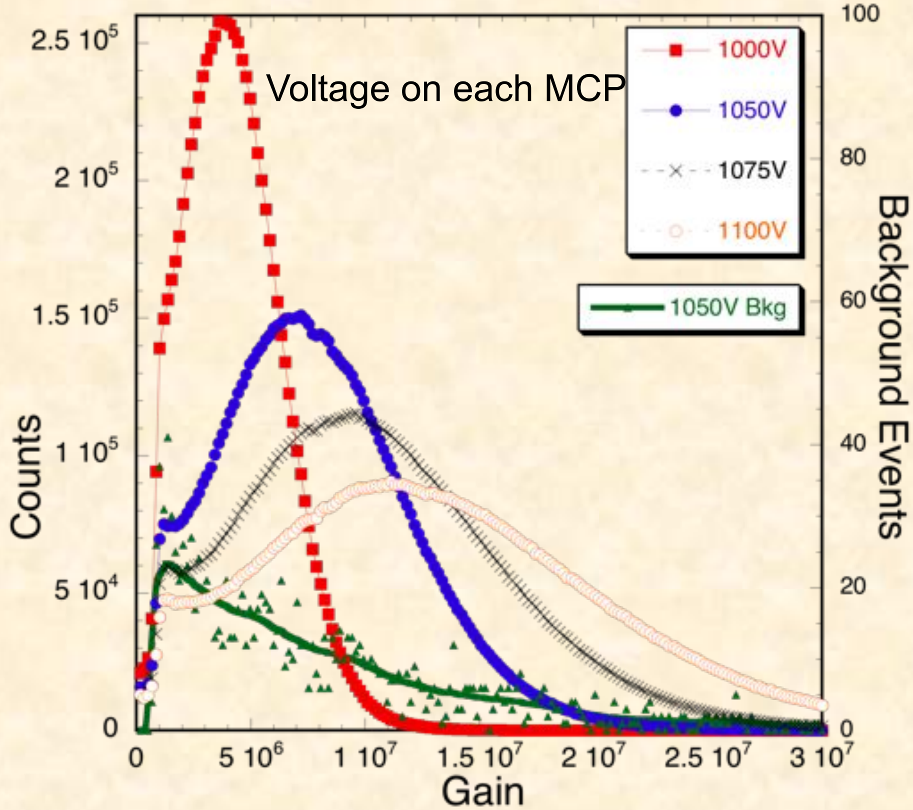
- *Semiconductor Resistive layer, tunable over wide range*
- *Amplifying layer (eg. Al_2O_3) with high secondary electron coeff.*
- *Better lattice match to GaN, also good for conventional cathodes*
- *Can be used on conventional MCPs and MCP substrates*

Separates surface optimization from substrate optimization!

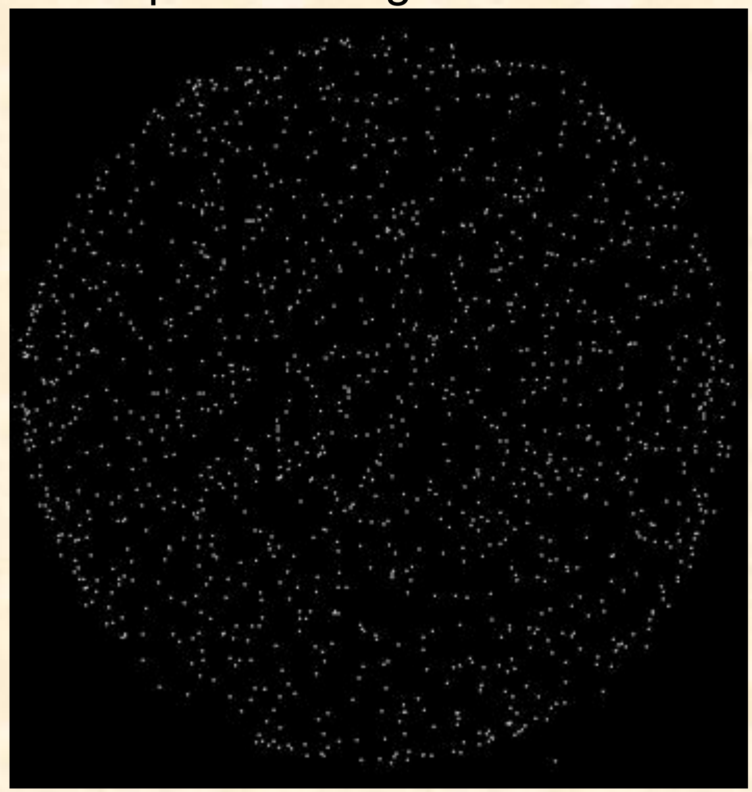
ALD-MCP Performance Tests, 33mm pairs

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.

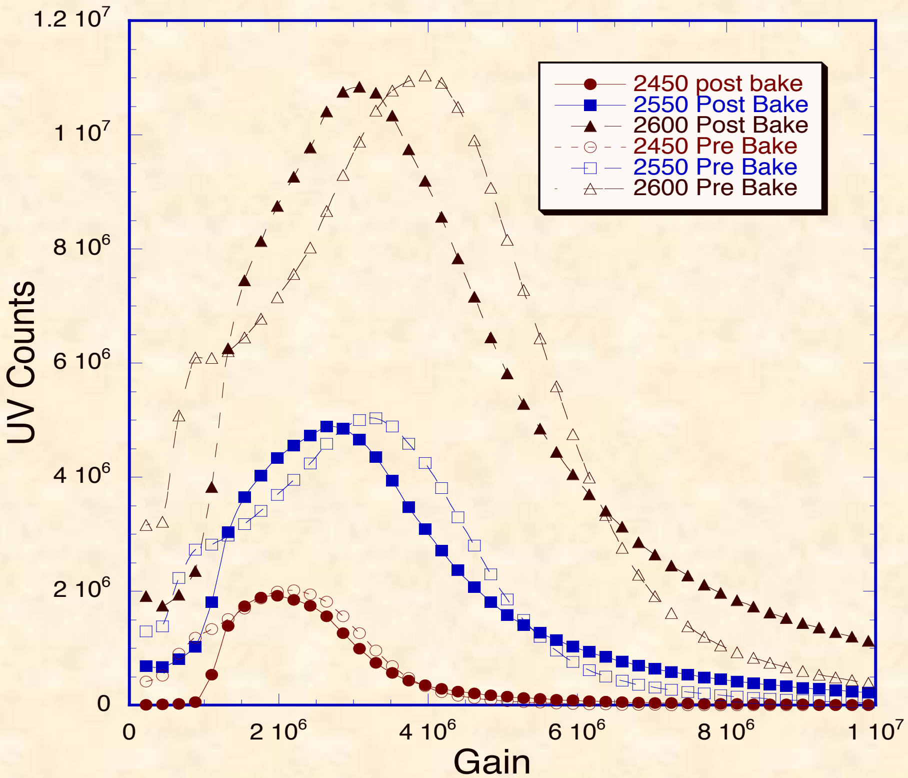


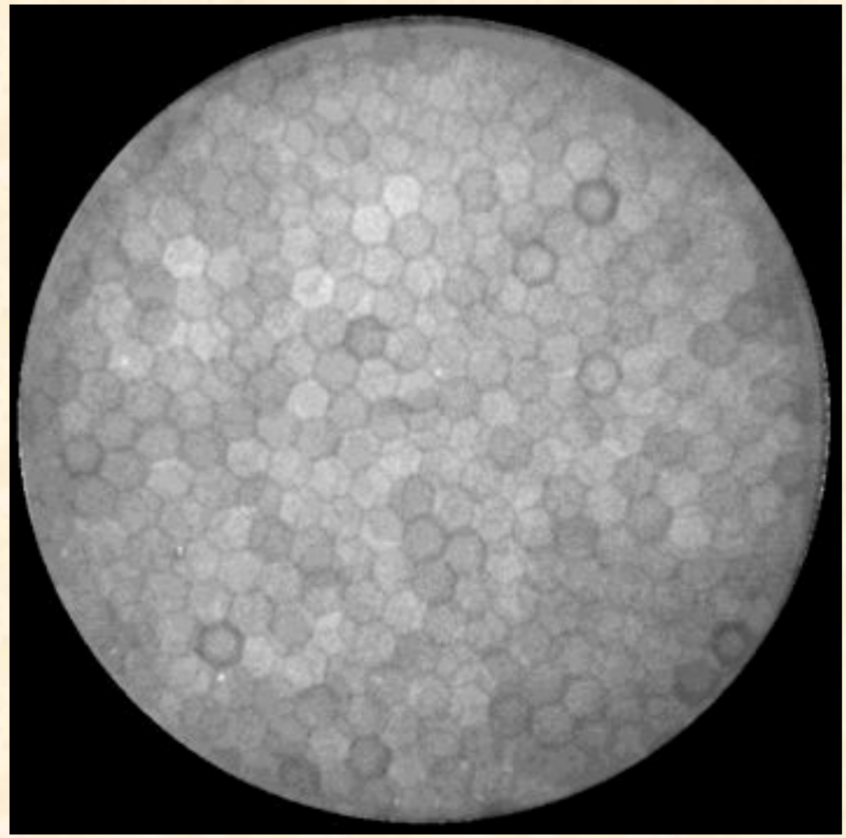
Pulse height amplitude distributions. 33mm MCP pair, 20μm pores, 8° bias, 60:1 L/d, 0.7mm pair gap with 300V bias. 3000 sec background.



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 Gain and Pulse Amplitude





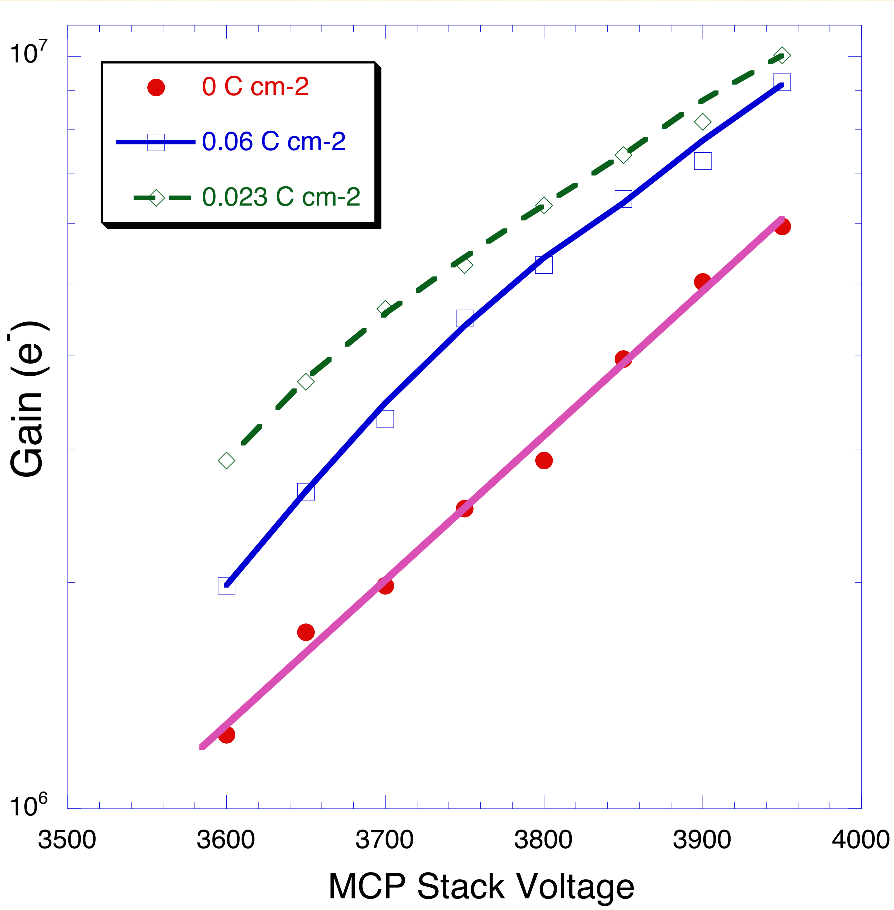
Pulse amplitude distributions for UV events

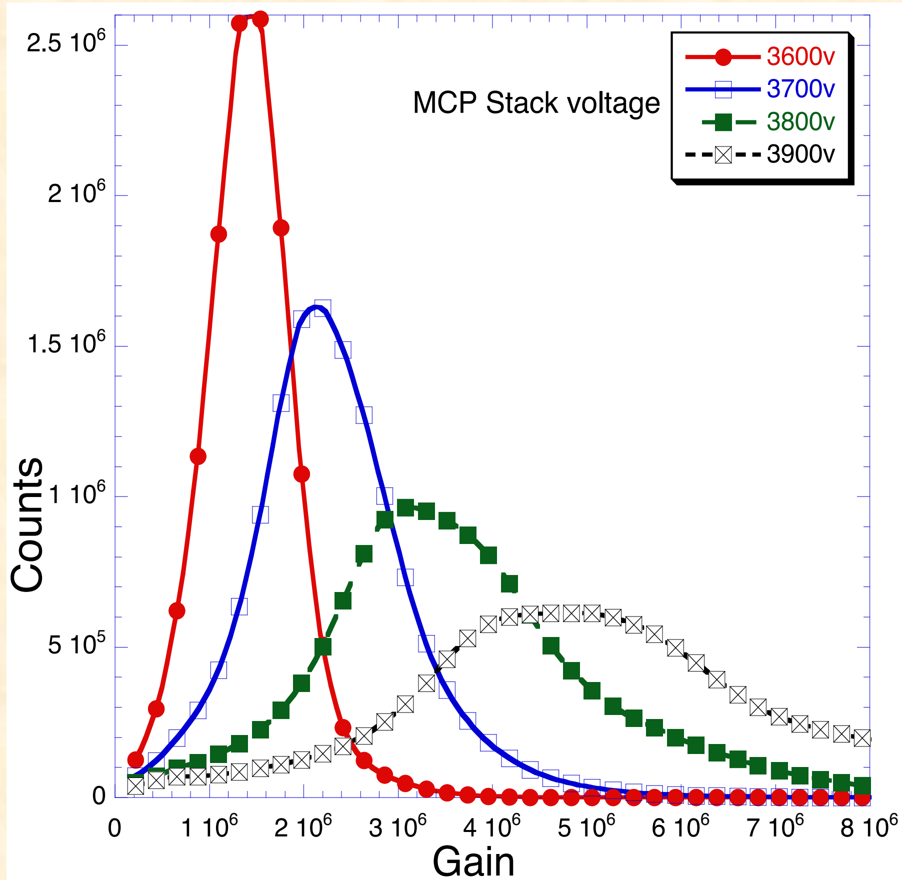
60:1 L/d, 60% OAR, MCP pair, 20µm pores
8° bias, 60:1 L/d, before and after 350°C bake.

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

MgO ALD on Conventional MCP "Z" Stack

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

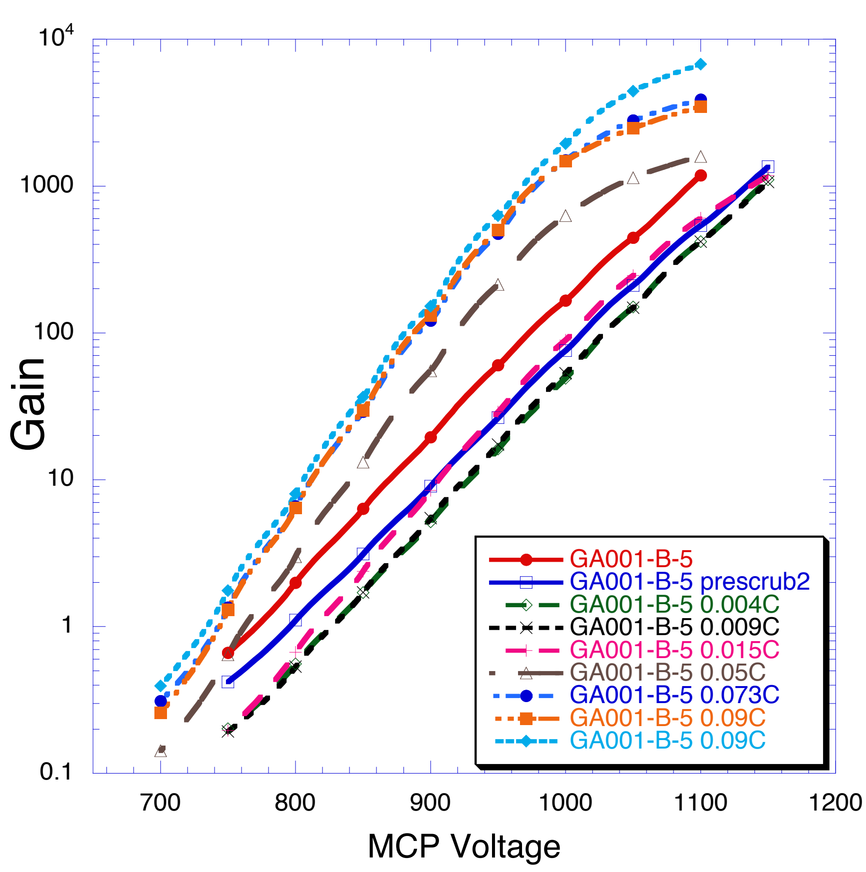


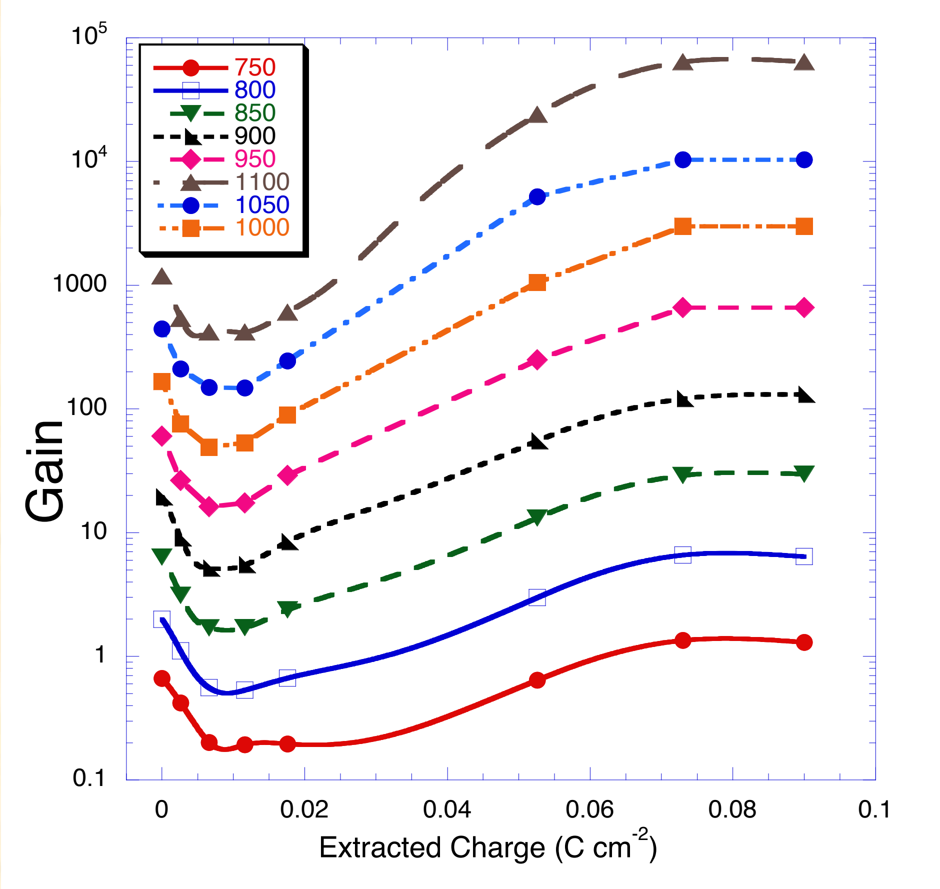


Stack scrubs up in gain as expected from earlier data. Expect stabilization at ~0.05 C cm^{-2}. General background stays at typical values (~0.4 events cm^{-2}). High secondary yield gives quite narrow PHDs even at comparatively low gain/applied voltages.

Conventional MCP – MgO ALD Coated

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





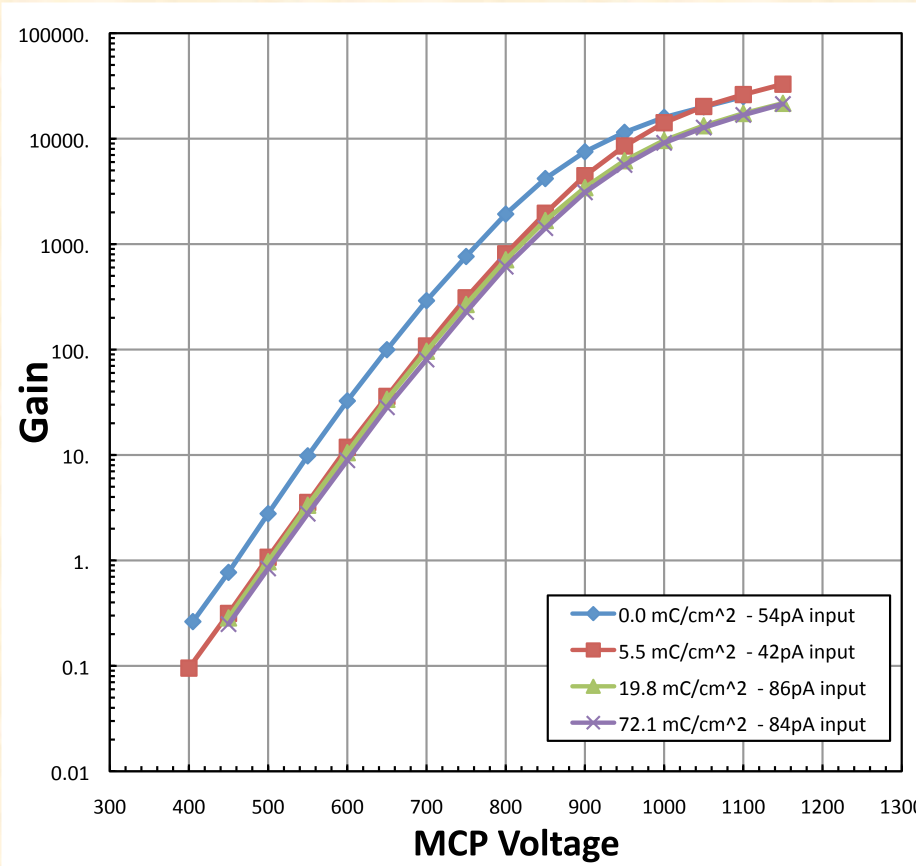
Slight gain drop (x2) at scrub initiation with significant gain increase thereafter

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

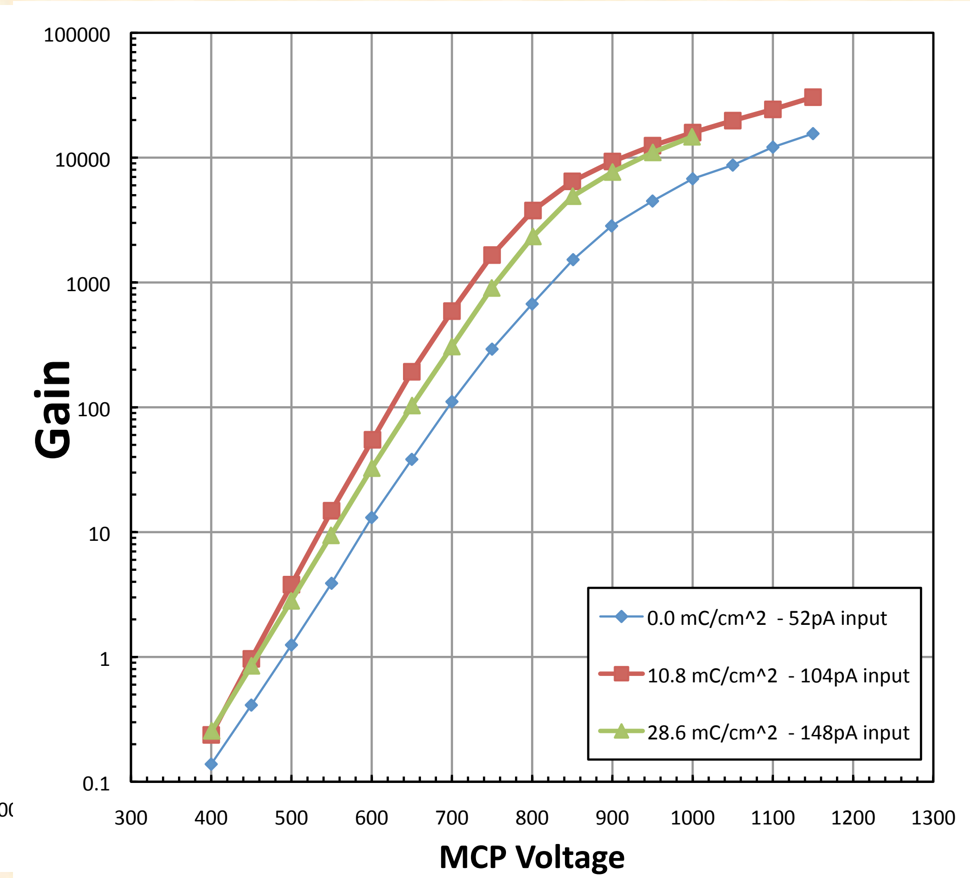
Gain vs Charge Extraction Test, MCP Pairs

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

20µm pores, 60:1 L/D, Al_2O_3 coating



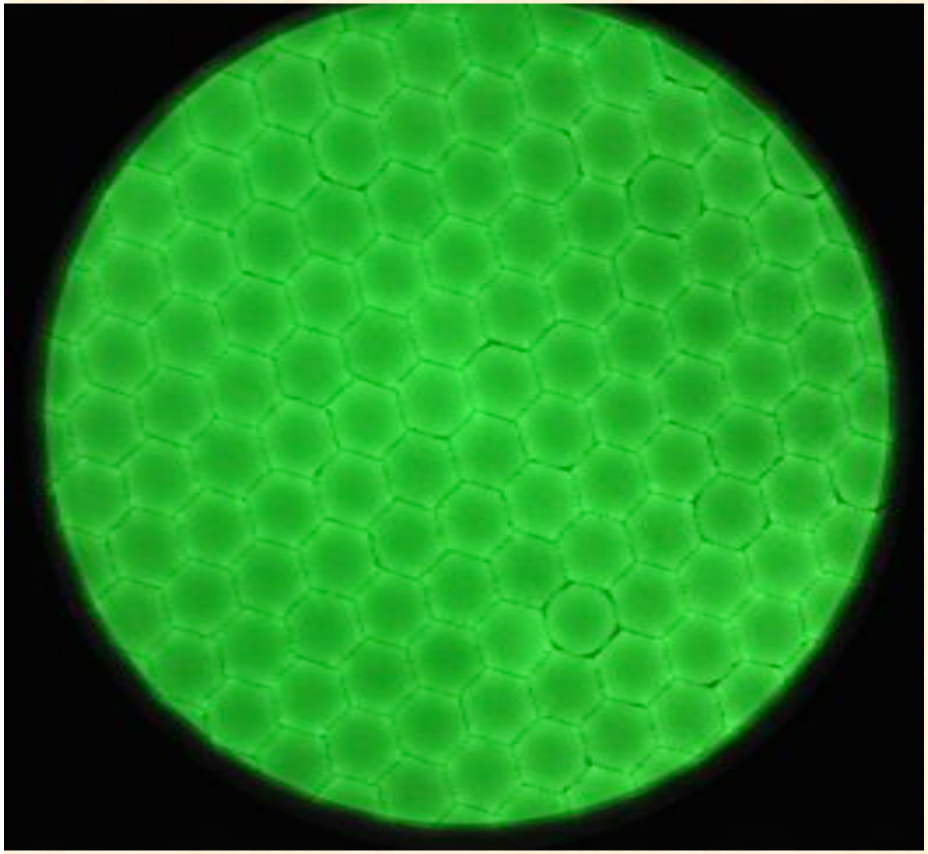
20µm pores, 60:1 L/D, MgO coating



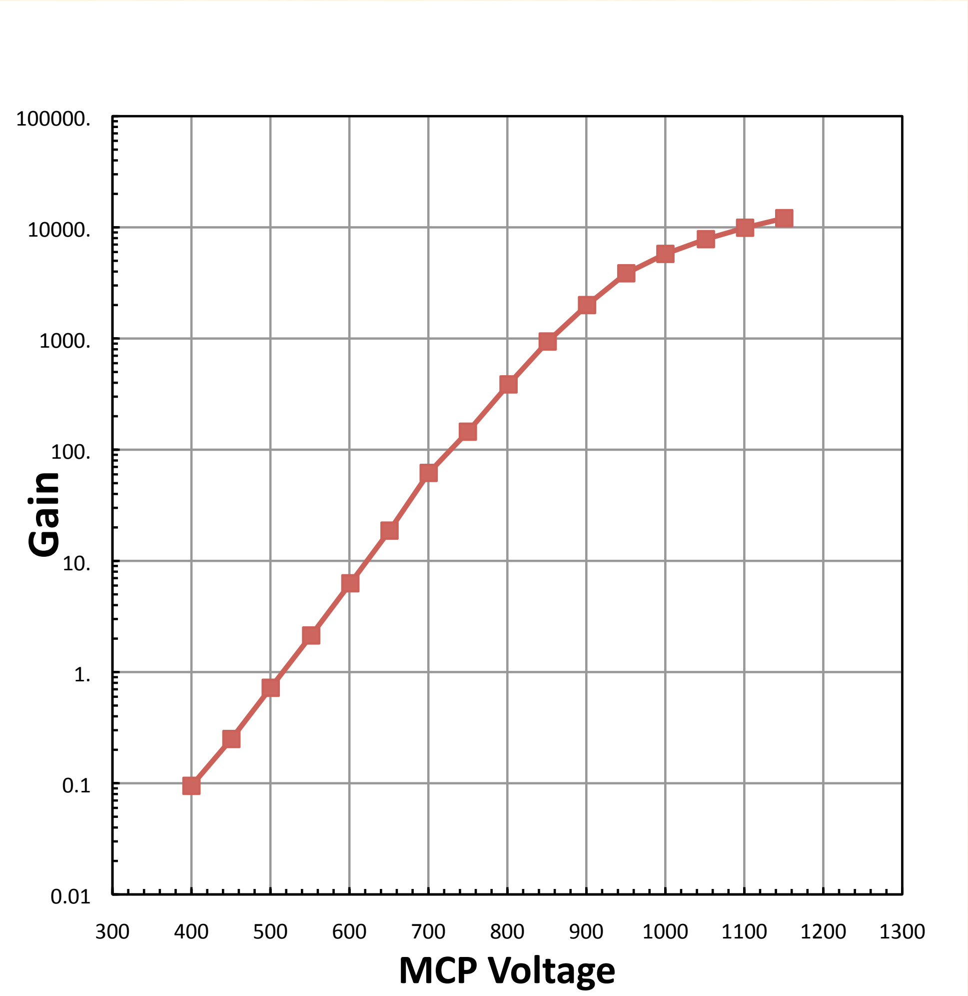
MCP gain measured for bottom MCP

10μm Borosilicate MCP Substrate with ALD

33mm Borosilicate MCP with 10μm pores, 80:1 L/D, 8° bias



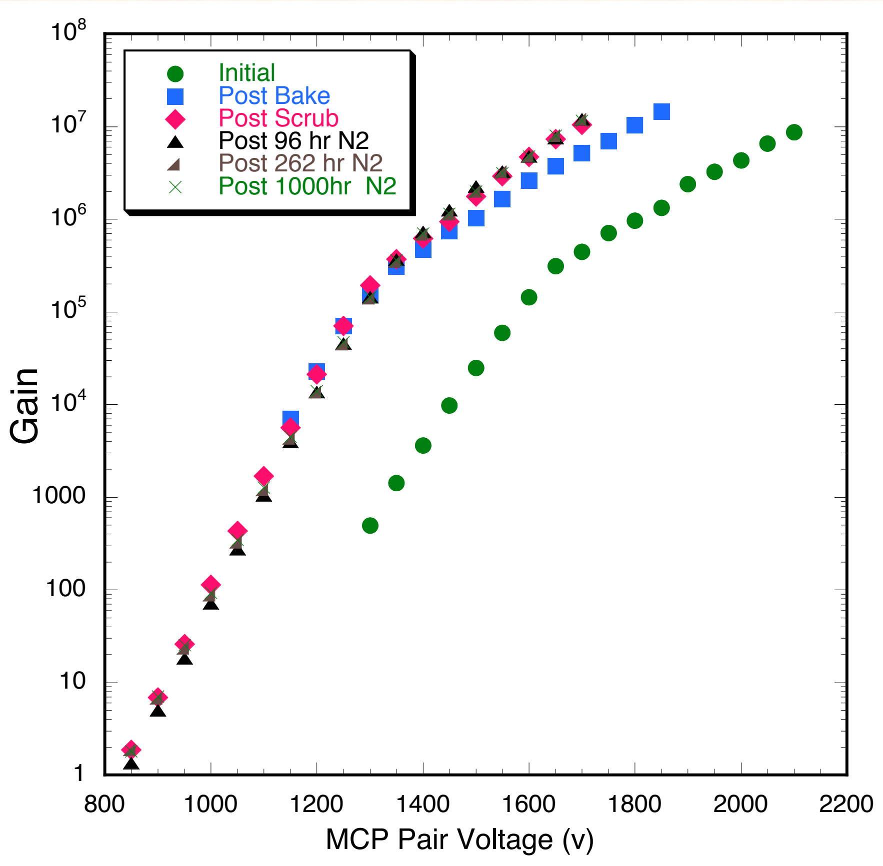
Single MCP Image (Phosphor) shows multifiber modulation (1100v MCP)



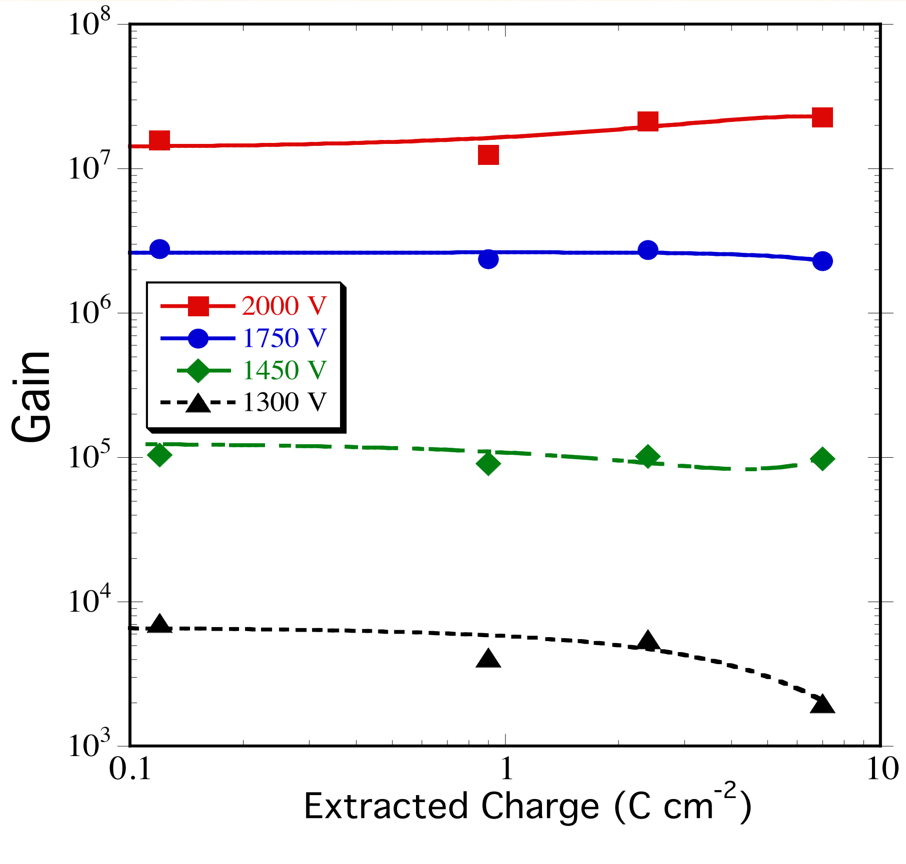
Single MCP gain is similar to conventional MCPs, gain saturation causes turnover.

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 even after 1000 hours of N_2 exposure.

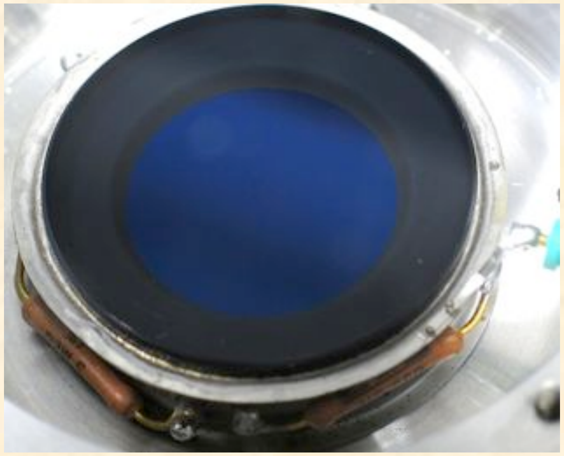


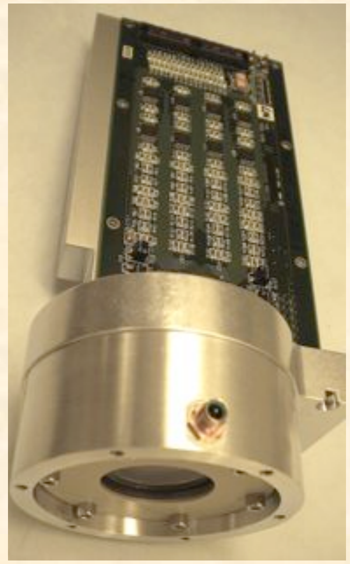
Gain curves of MCP pair (20μm pore, 60:1 L/d, 8° bias) at stages during preconditioning and nitrogen exposure (now up to 1000hr N_2 exposure, Jan 2014).

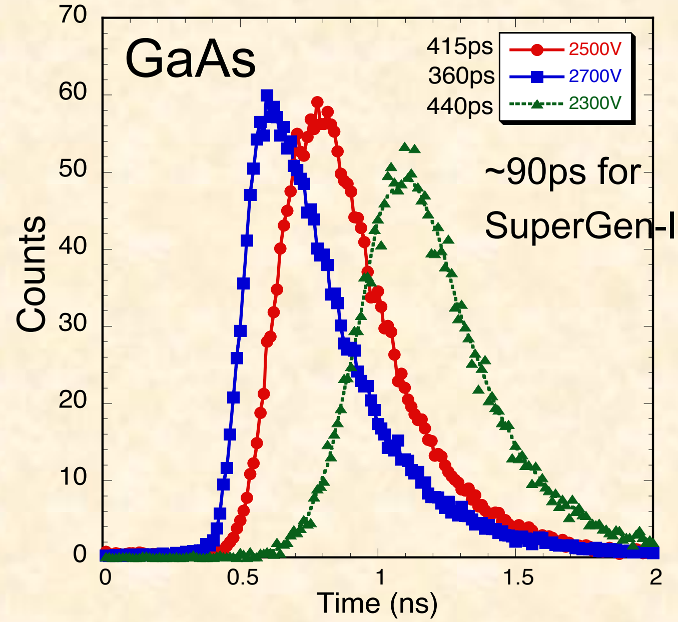


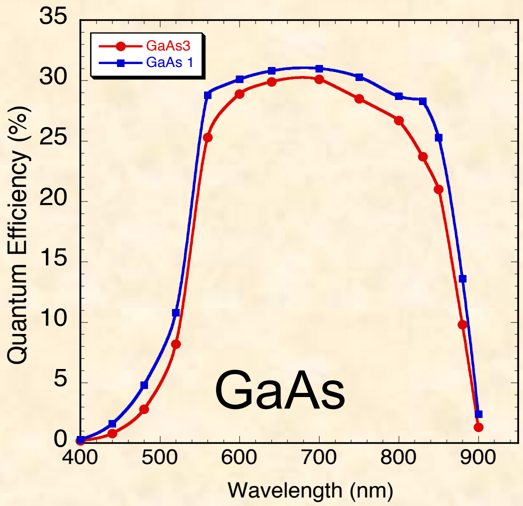
UV scrub of ALD MCP pair 164-163, (20μm pore, 60:1 L/d, 8° bias).

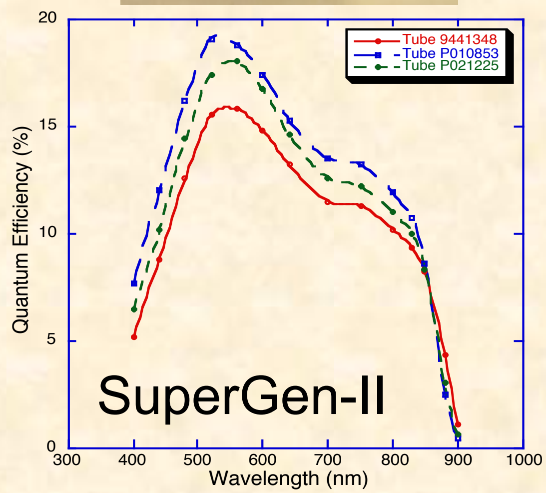
High Resolution Cross Strip Detector

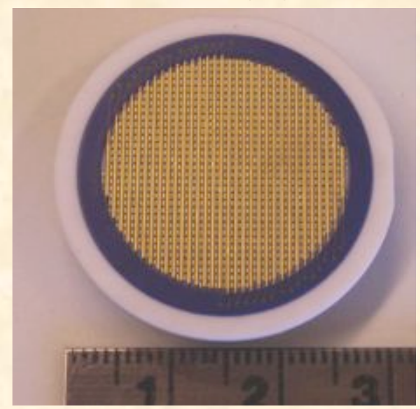








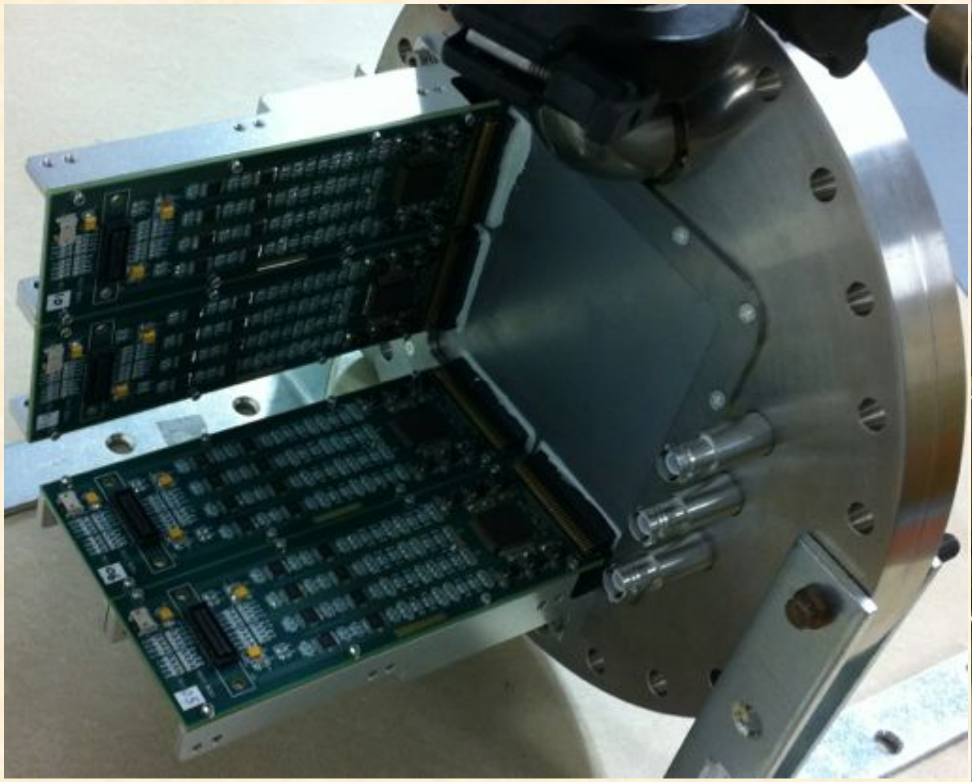


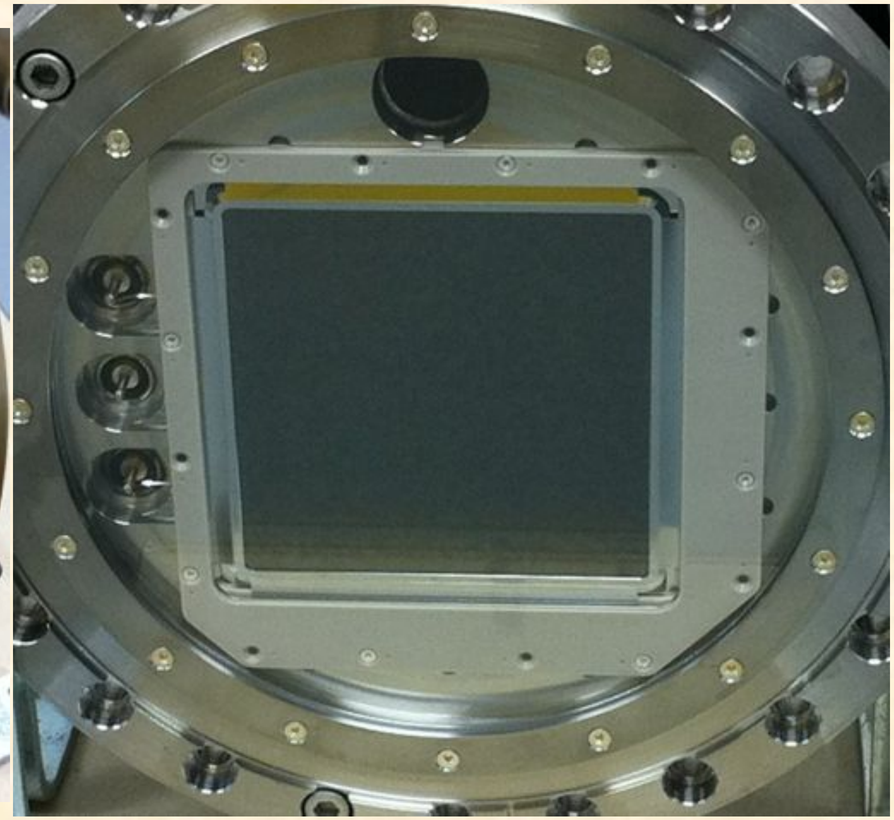


Cross Strip Anode MCP photon counting detector with 32 x 32 strips/amplifiers.

~30µm FWHM resolution @ 1.5x10^{6} gain, 4 MHz @85% livetime, conventional *MCPs*. *Siegmund et al, Amos Conf. Proceedings 2011/2012, tubes built at PHOTONIS.*

High Resolution Cross Strip Detector ALD MCP Test Scheme



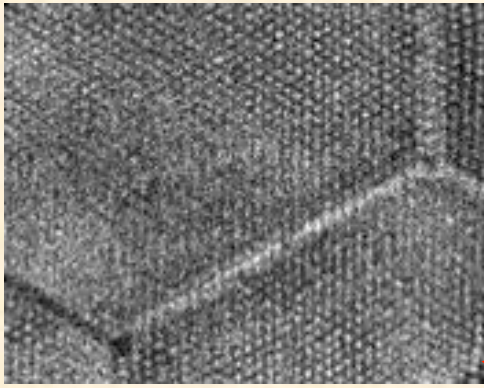


100 mm square Cross Strip Anode microchannel plate photon counting detector with 128 x 128 strips/amplifiers. Developed for high spatial resolution, at lower gains, with higher count rates and longer lifetime, ~100ps time tagging.

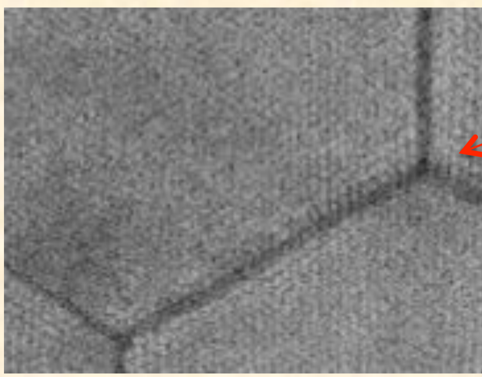
< 20μm FWHM resolution @ 1.5×10^6 gain, 4 MHz @85% livetime, 6μm pixels

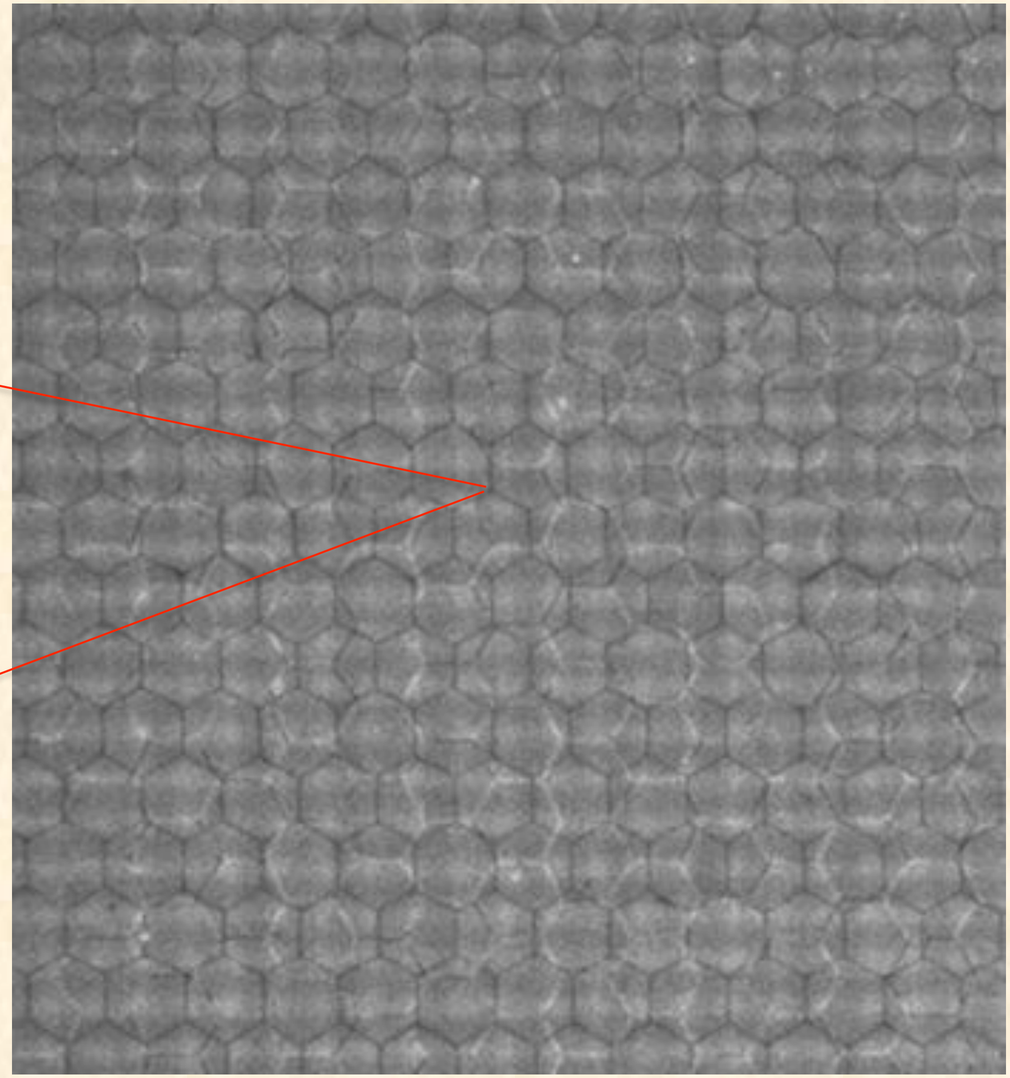
10cm x 10cm ALD 20µm MCP Pair in Cross Strip Detector

Image resolves pores



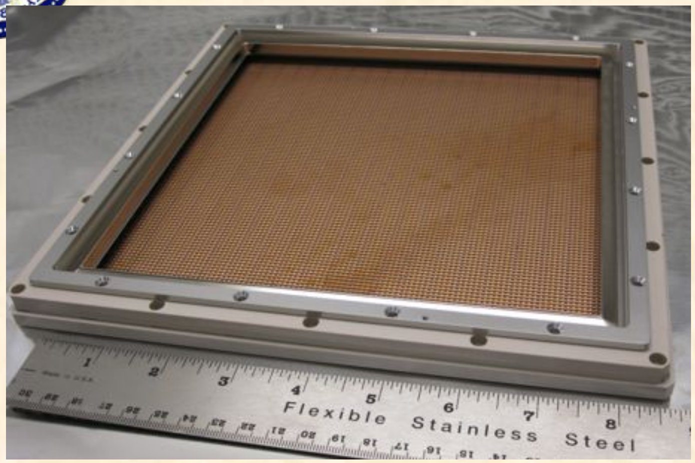
Gain map



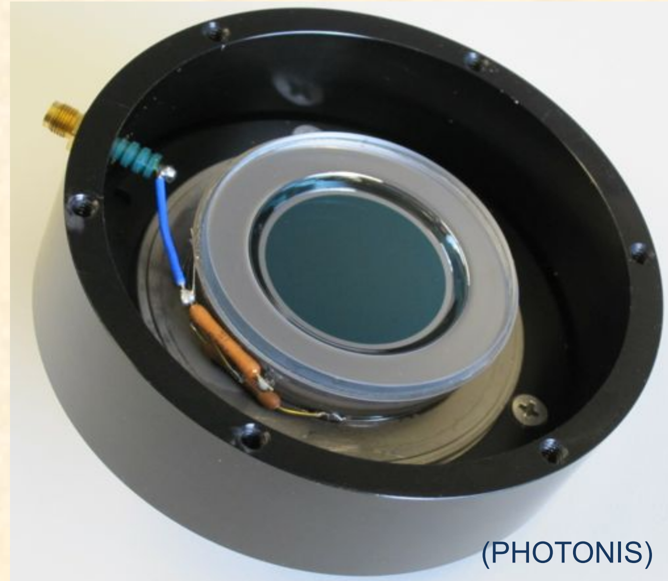


10 cm x 10cm cross strip readout, MCP gain ~10^6, 16k x 16k pixels (6µm) at > 5 MHz.
15 x 15mm section.

Cross Delay Line Detectors

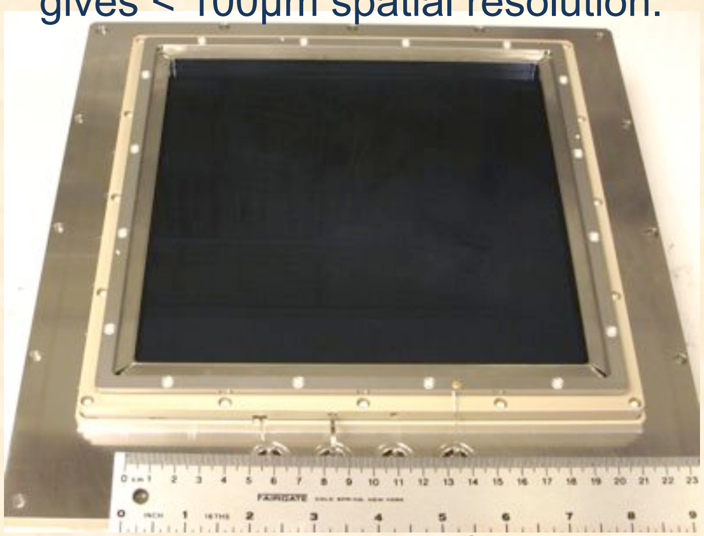


20cm MCP detector showing the cross delay line anode readout. 100ns end to end delay gives < 100μm spatial resolution.



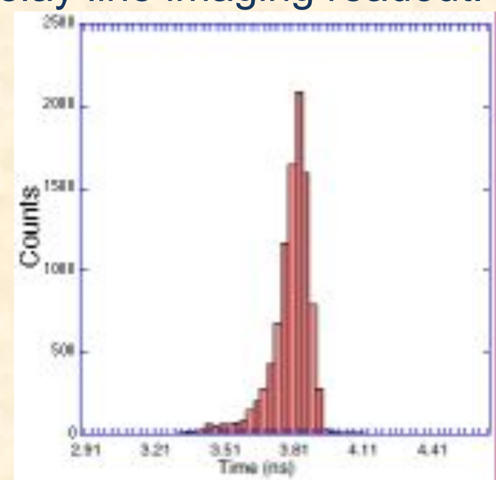
(PHOTONIS)

2.5cm 10μm MCP Z detector with SuperGen-II cathode and a cross delay line imaging readout.



20cm ALD 20μm pore MCP pair in detector assembly with a cross delay line imaging readout.

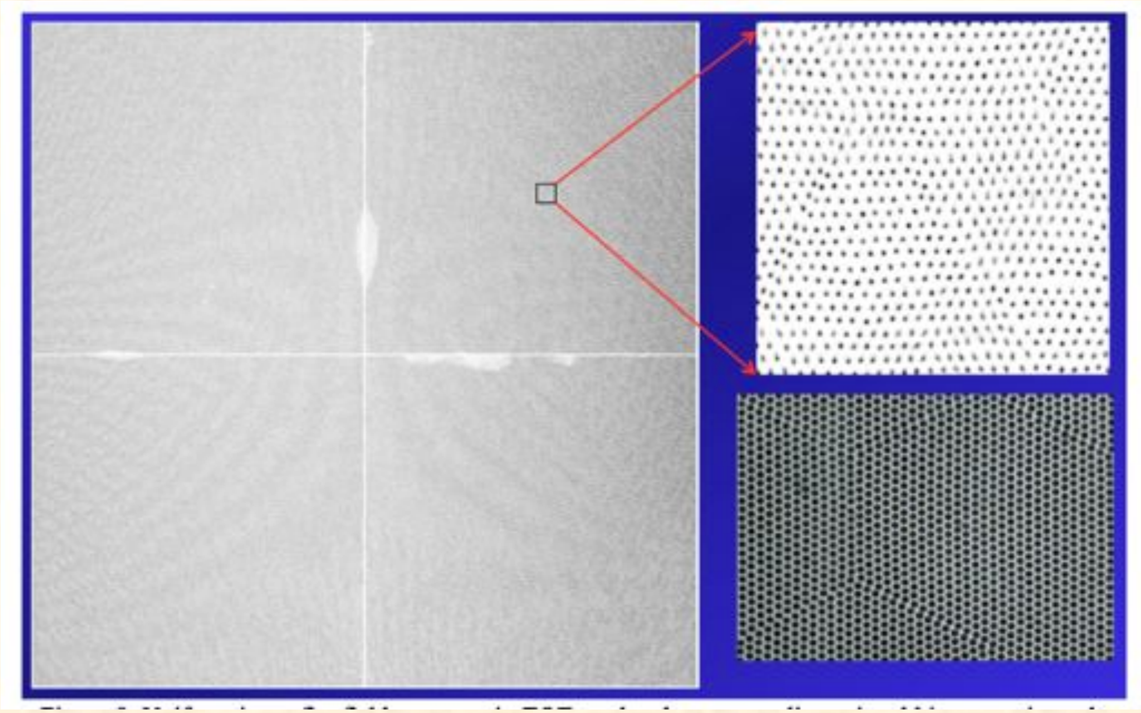
25mm cross delay line

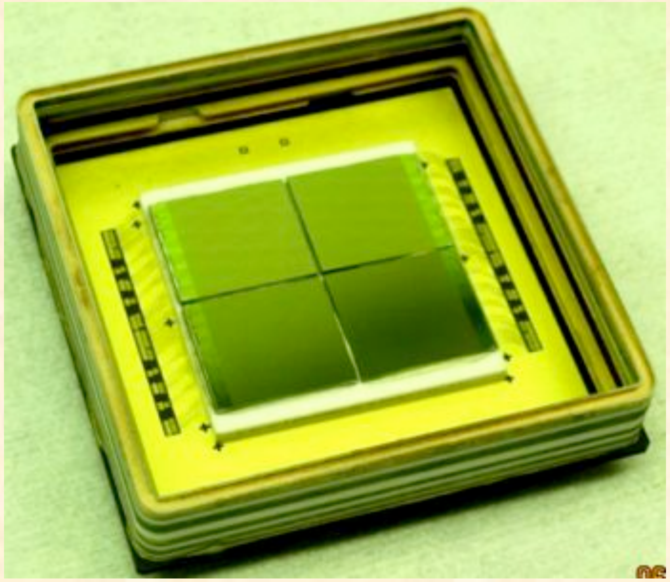


MCP timing jitter ~100 ps FWHM

Siegmund et al. Amos conference 2009

Quad-Timepix Detector in Planacon





Sealed tube "Planacon" with Quad-timepix readout, 55μm pixels, 25μm pore MCP pair, bialkali photocathode.

Readout < 20μm FWHM resolution in centroid mode @ $5x10^4$ gain,

200MHz rates, and ~20ns event time tagging in 55μm pixel mode.

Vallerga et al, iworid 2013, in collaboration with CERN and Photonis-USA

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, <0.06 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.