Results with ALD Functionalized MCPs

Oswald Siegmund, Jason McPhate, Anton Tremsin

LAPPD Program Review

18 December 2012

ALD Functionalized MCP Test Tasks

Test and evaluate MCP materials and techniques to provide feedback for MCP production, and establish performance and expectations for MCPs in the final tube configuration.

- Full evaluations of 20μm material, 33mm
  - Gain, imaging, background in singles/phosphor
  - Single MCP lifetest characteristics
  - Pairs with XDL, imaging, gain, background, PHD, uniformity
  - High temp vac bake for tube compatibility tests,
  - MCP pair lifetest characteristics – "burn-in"
  - Pair MCP spacings, spacing bias, anode bias, for charge footprint, imaging and timing tests
- 8" x 8" MCPs
  - Institute test detectors for 8" MCPs (rapid feedback, & detailed)
  - Full up evaluations of 8" MCP configurations
  - Inputs for overall detector design

MCP Basic Specifications for 33mm and 200mm

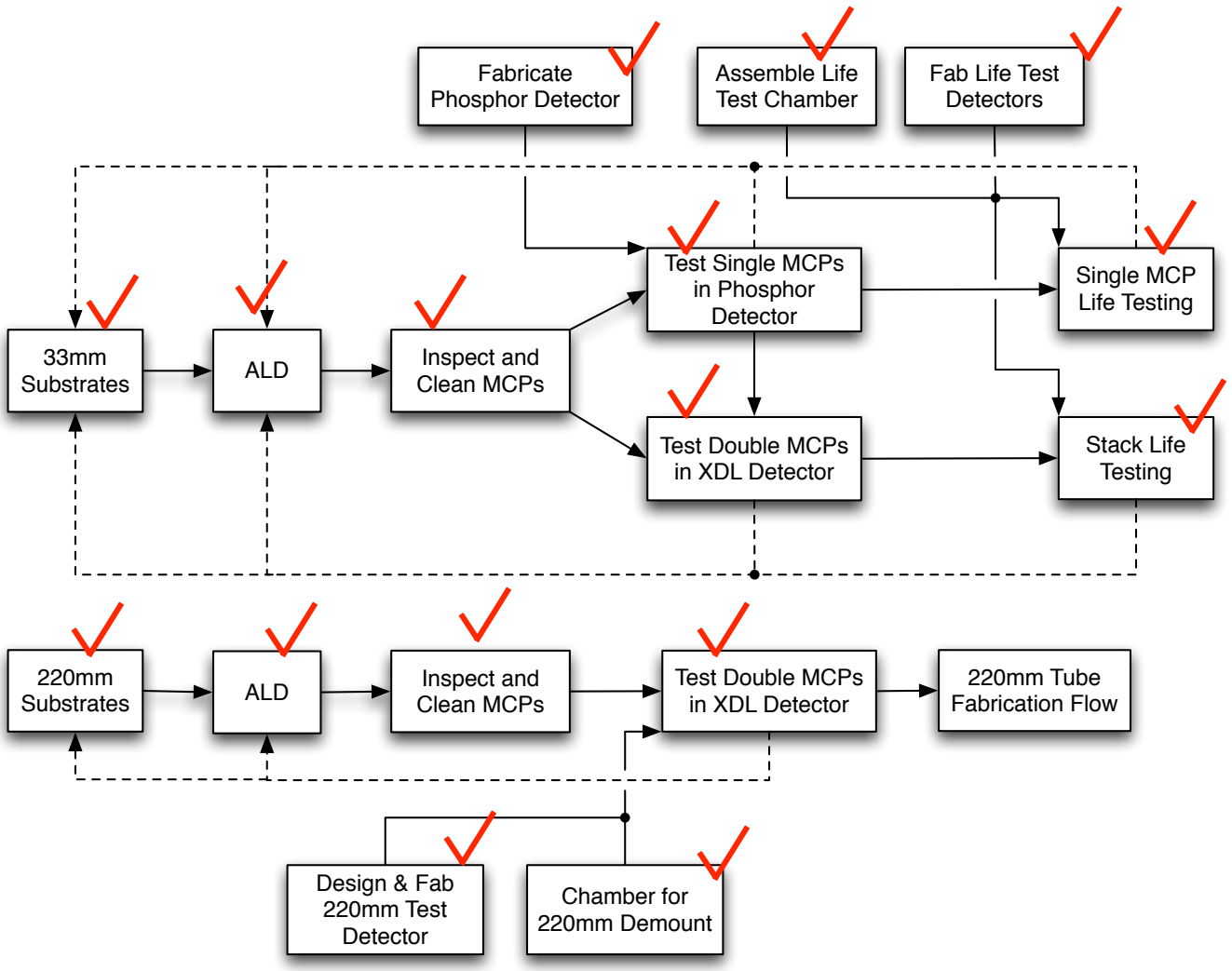
Standard 32.7mm MCP

• Plate Outside Diameter	32.7mm
• L/D, Thickness	60:1, 1.2mm
• Center-to-Center Spacing	~25μm
• Pore Size	20μm
• Bias Angle	8 Deg ±1 deg
• Open Area ratio	~60%
• Resistance	~500 Meg Ohm
• Electrode end spoiling	1 channel diameter

200mm MCP

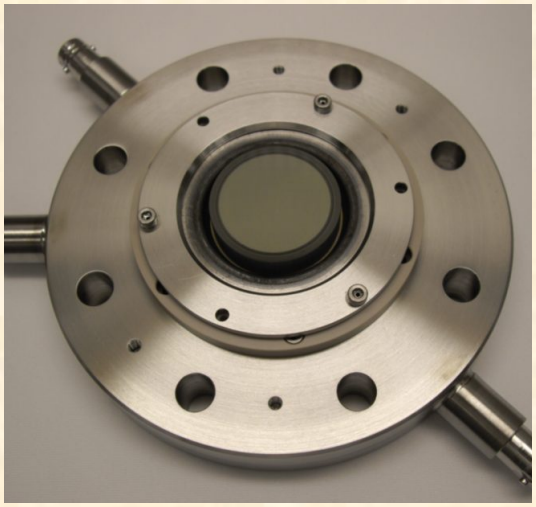
• Plate Outside Diameter	200mm
• L/D, Thickness	60:1, 1.2mm
• Center-to-Center Spacing	~25μm
• Pore Size	20μm ±0.5um
• Bias Angle	8 Deg ±1 deg
• Open Area ratio	~60%
• Resistance	~10 Meg Ohm
• Electrode end spoiling	1 channel diameter

Simplified MCP Testing Flow

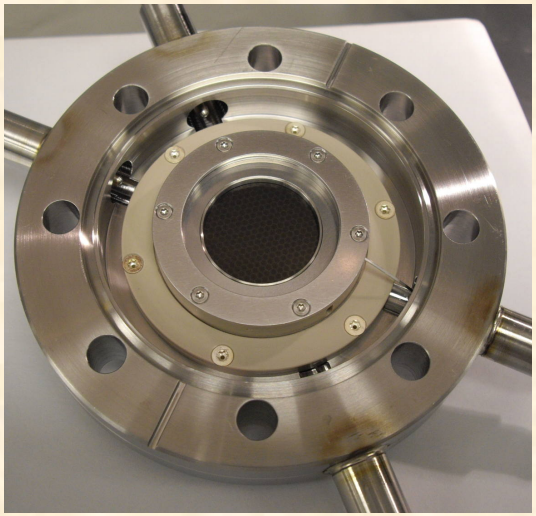


XDL & Phosphor Test Detectors
33mm MCP Pair and Single MCP Tests

Double chamber UHV test station



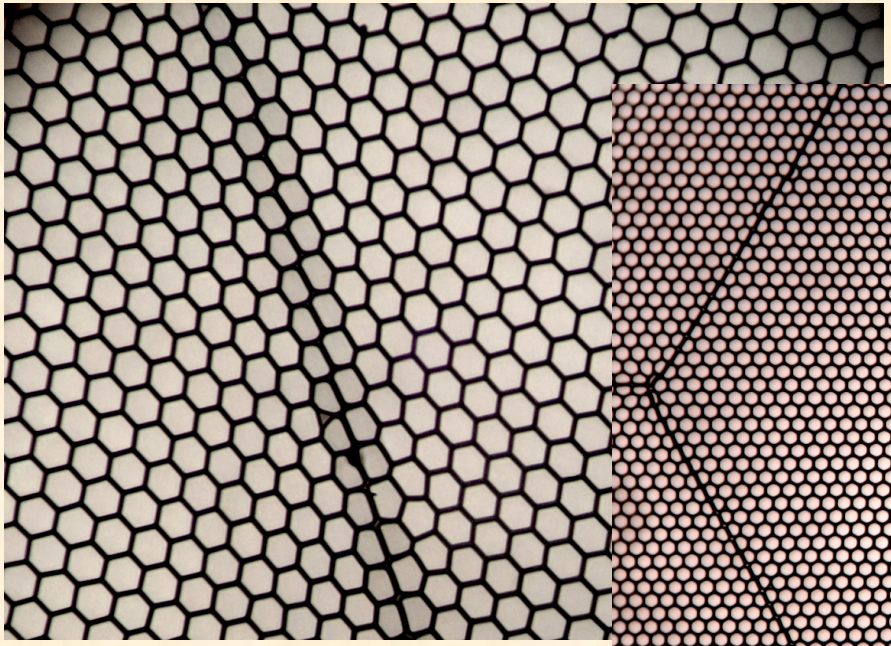
25mm phosphor screen detector with Nikon camera/electrometer



25mm XDL photon counting detector with Amp/TDC and PC Acq/display

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.

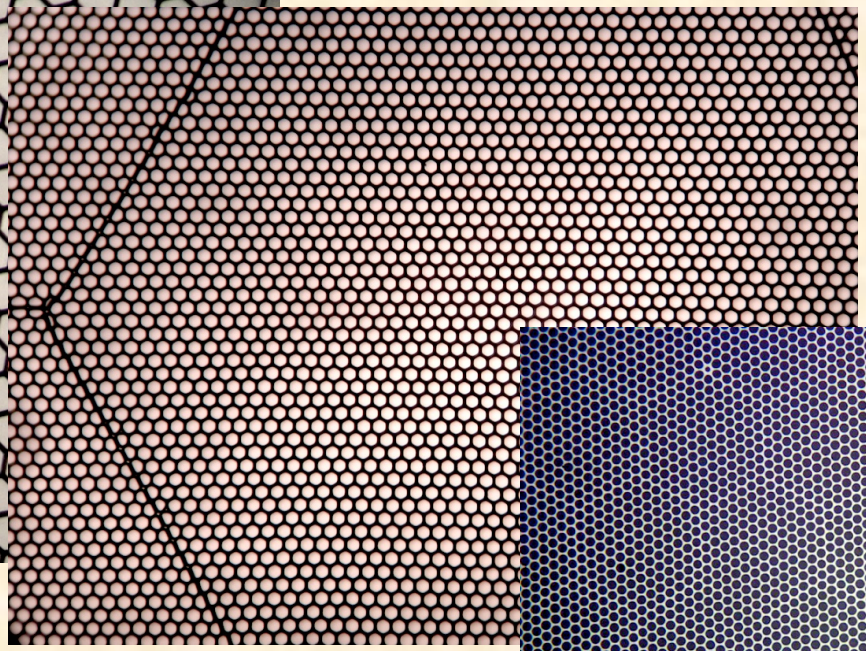


Photo of a 20 μm pore, 65% open area borosilicate micro-capillary ALD MCP (20cm).

Pore distortions at multifiber boundaries, otherwise very uniform.

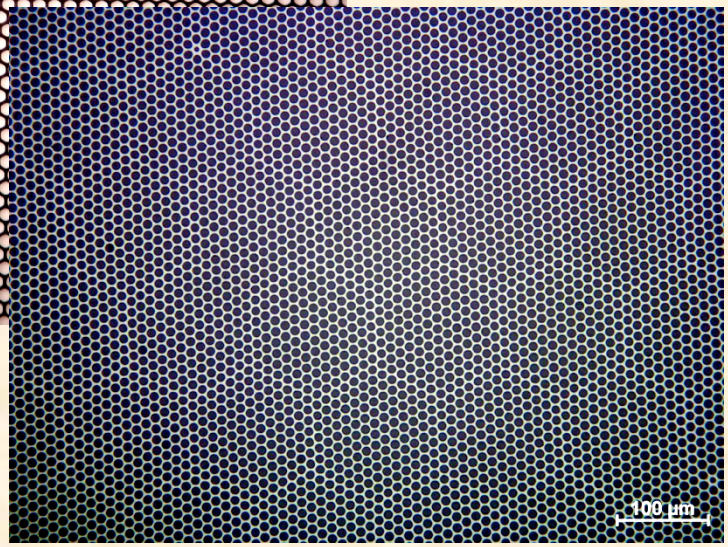
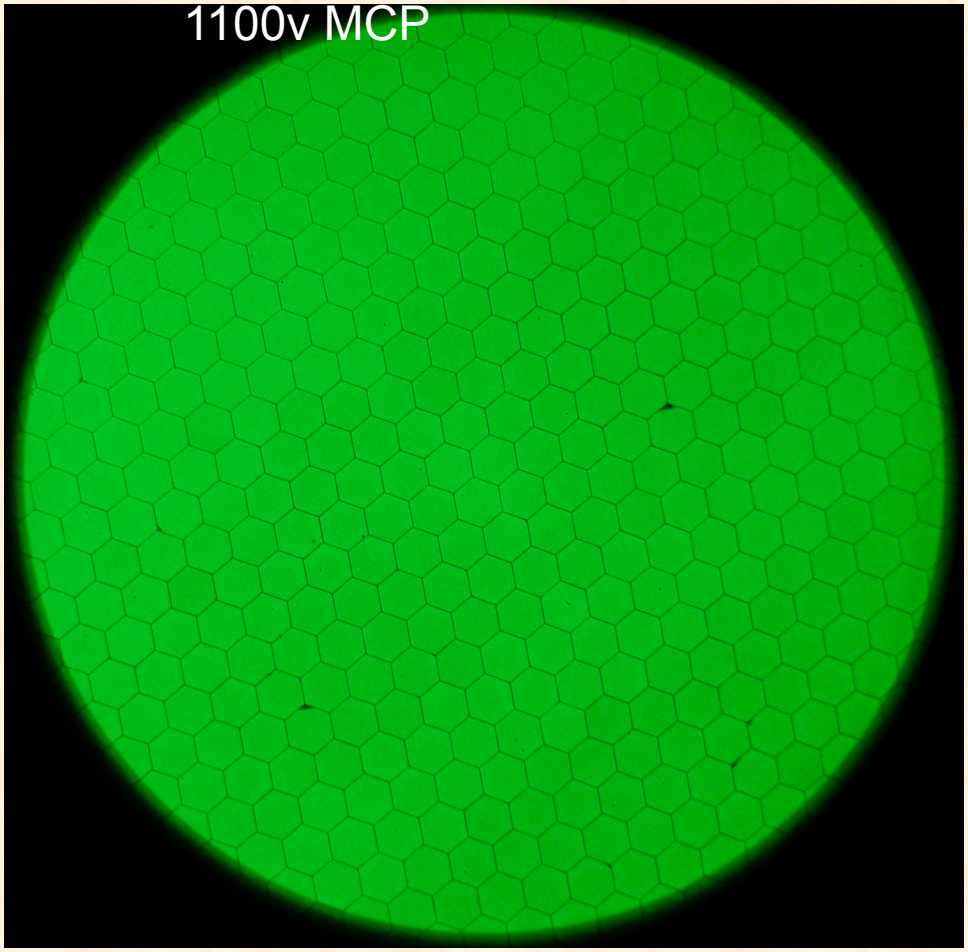
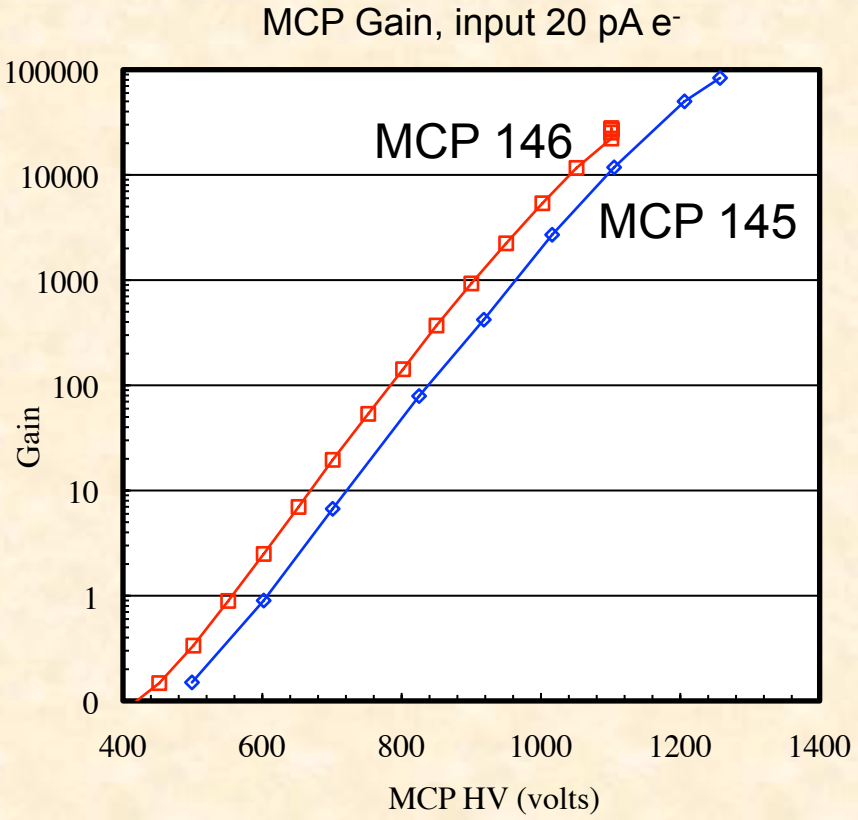


Photo of a 10 μm pore, 60% open area borosilicate micro-capillary ALD MCP.

Single MCP – Phosphor Screen Tests

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



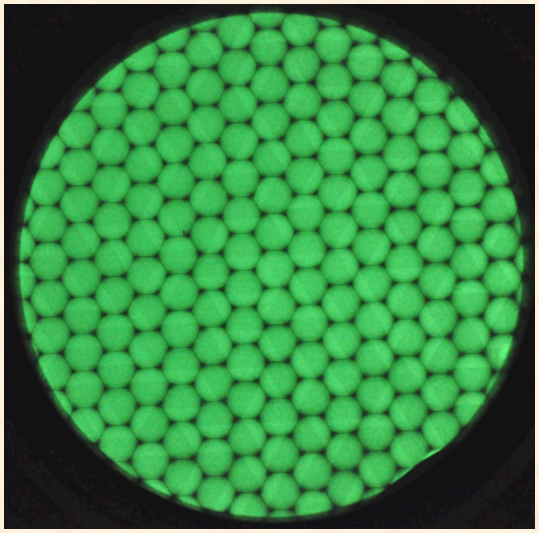


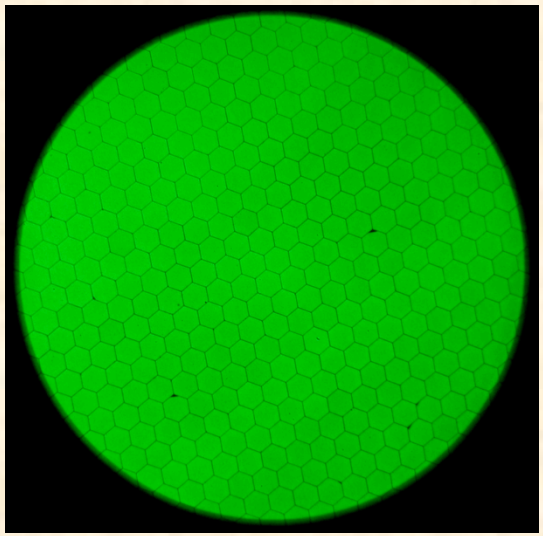
Single MCP tests in DC amplification mode show imaging and gain very similar to conventional MCPs. Sample imaging performance has improved dramatically with substrate and ALD coating process improvements.

Imaging Performance of ALD MCPs, 33mm

Early 2010 2011

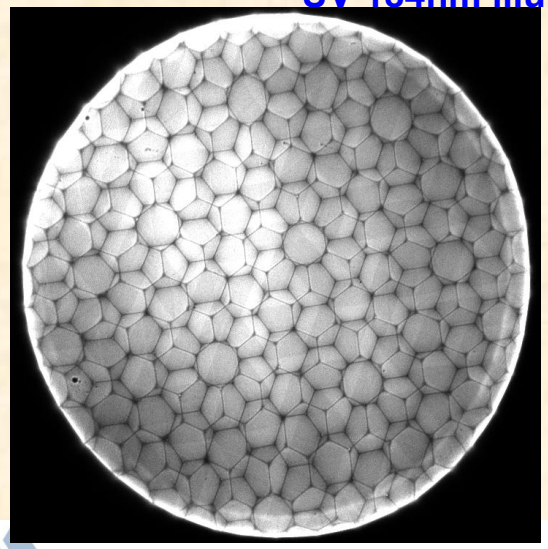
1 MCP, Phosphor readout

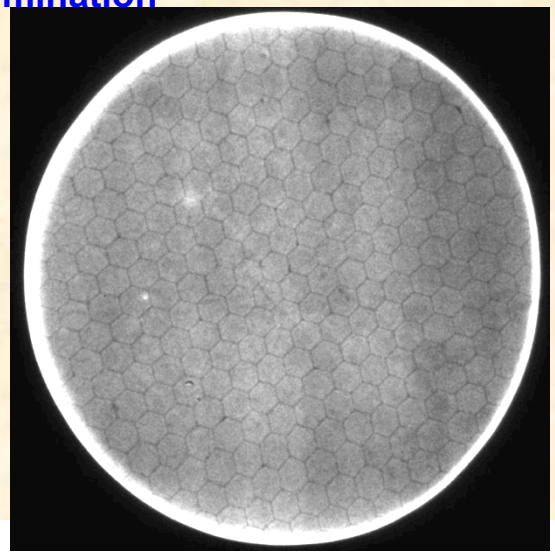




UV 184nm illumination

2 MCPs, Photon counting





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

~1000v applied to each MCP.

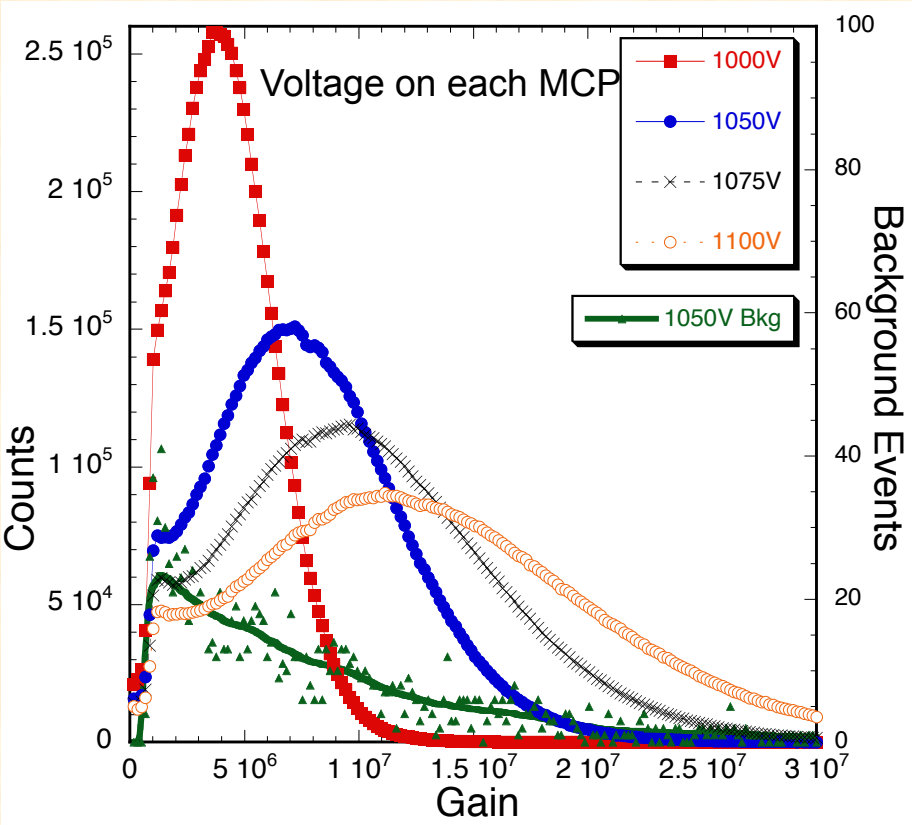
Single MCP tests in DC amplification mode show imaging and gain very similar to conventional MCPs.

MCP pairs operated in photon counting mode also show imaging and gain very similar to conventional MCPs.

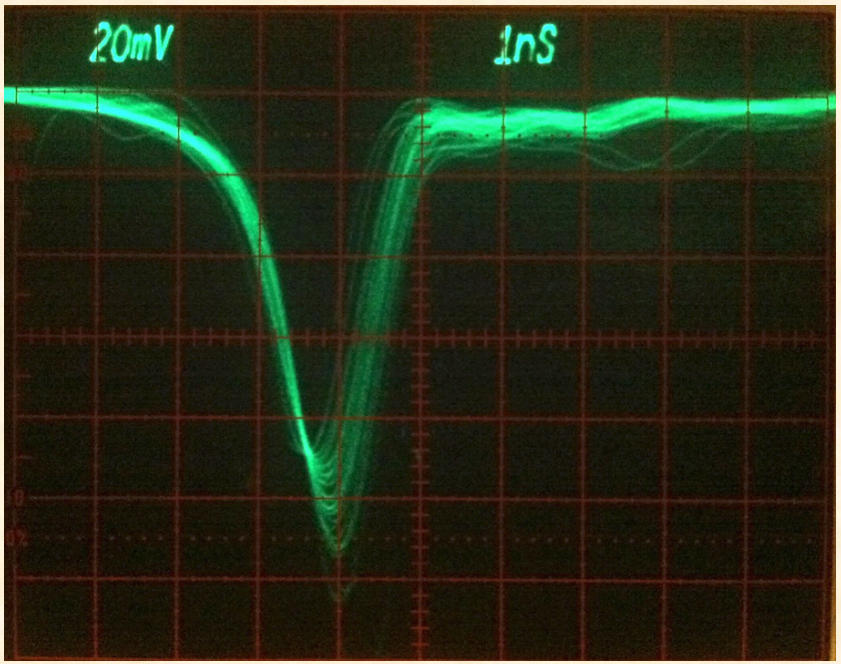
Sample performance has improved dramatically over the last 18 months due to process improvements.

ALD-MCP Performance Tests, 33mm pairs

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. UV and background pulse heights distributions are normal for 60:1 L/d pairs.



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



ALD borosilicate MCP pair, 20μm pore, 60:1 L/d, 8° bias, 0.7mm/1000v MCP gap. Single event pulses are ~1ns wide.

~Typical response for 20μm pore MCPs.

Photon Counting Imaging with MCP Pairs

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

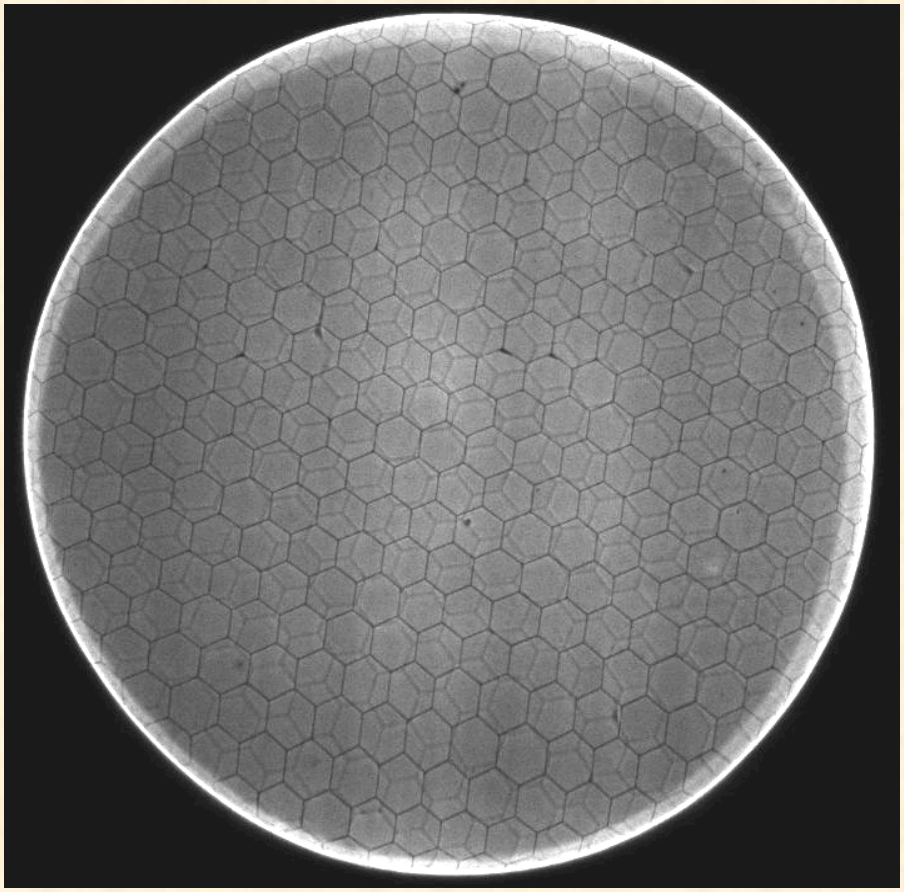
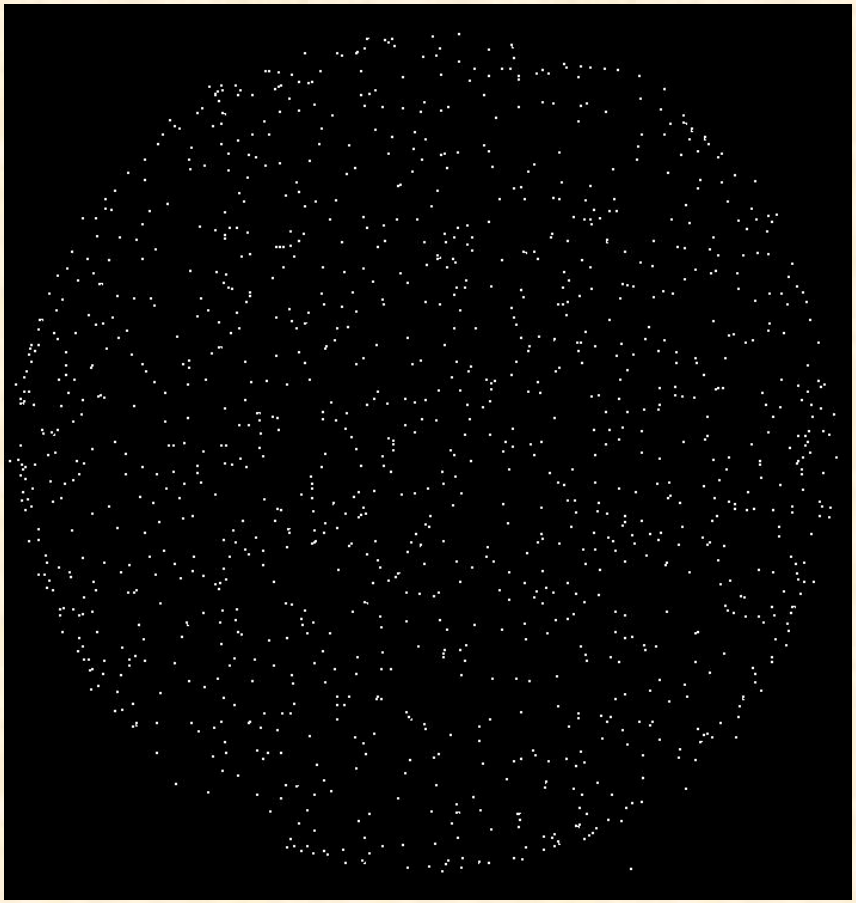


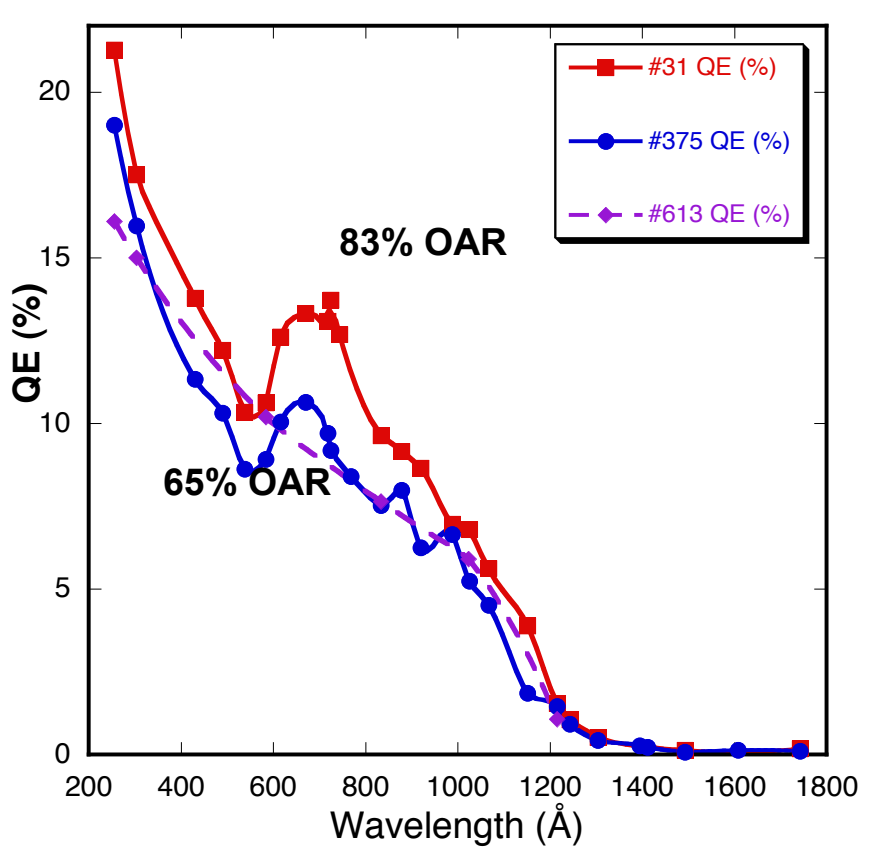
Image of 185nm UV light, shows top MCP hex modulation (sharp) and faint MCP hexagonal modulation from bottom MCP. A few defects, but generally very good. Edge effects are field fringing due to the detector support flange.



3000 sec background, 0.0845 events cm^{-2} sec^{-1} at 7 x 10^6 gain, 1025v bias on each MCP. Get same behavior for most of the current 20μm MCPs

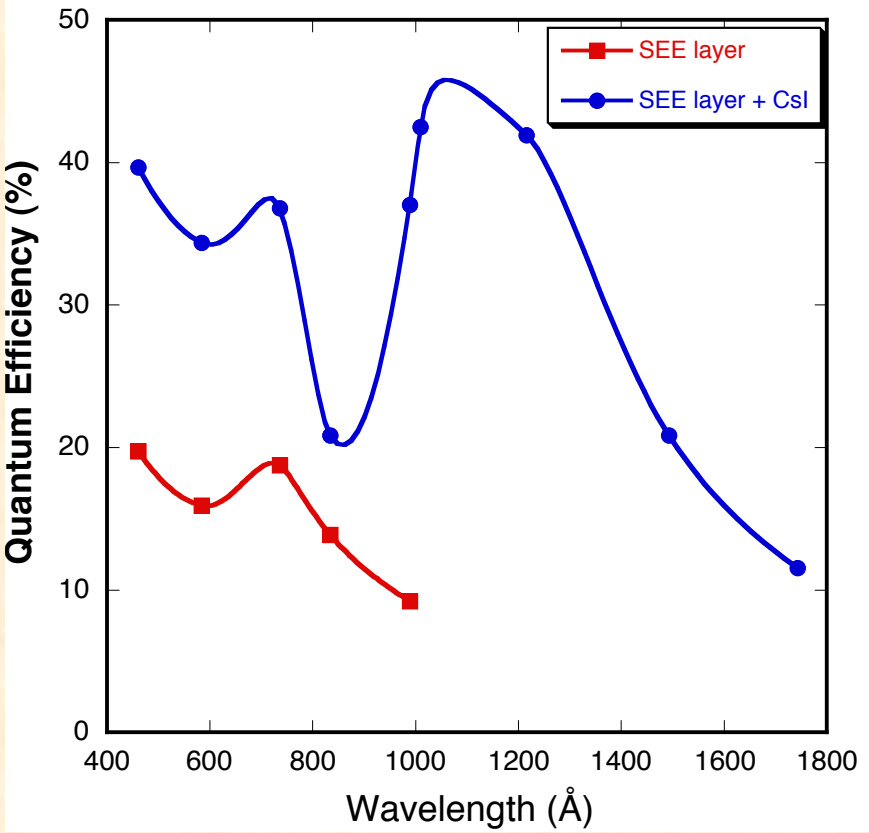
ALD-MCP Quantum Efficiency

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, 60:1 L/d, 83% OAR, shows higher QDE.

ALD – secondary emissive layer on normal MCP gives good "bare" QDE. CsI deposited on this gives a good "standard" CsI QDE.



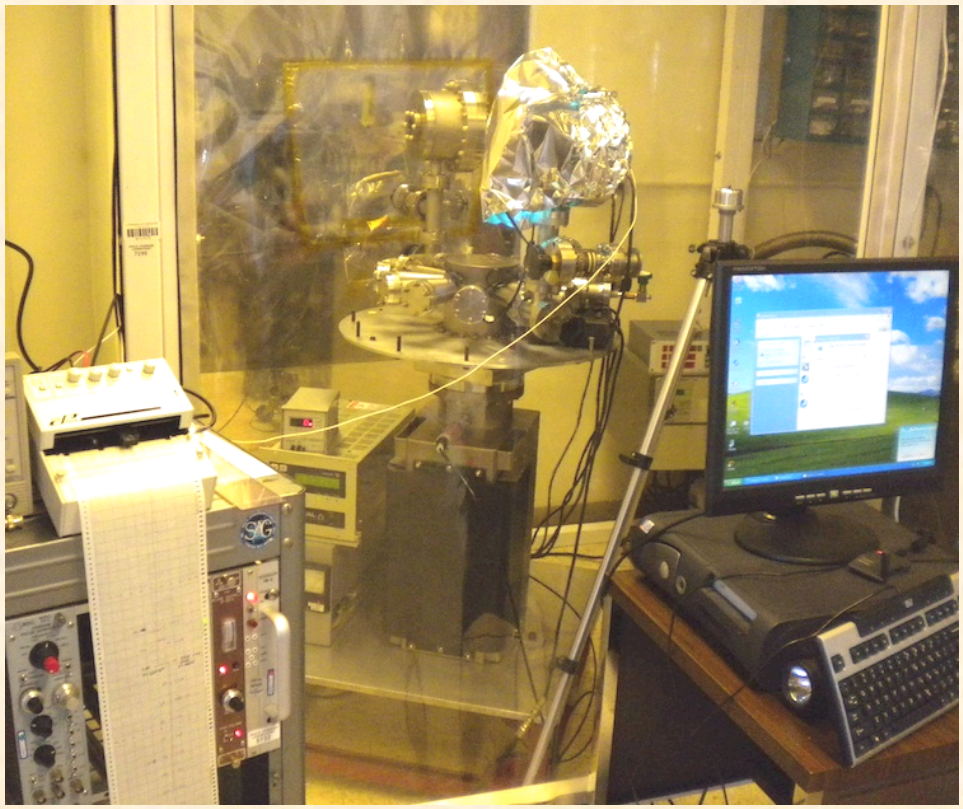
QDE for bare MCP with ALD secondary emissive layer, and with CsI deposited on top of this.

Preconditioning Tests of 33mm, 20μm Pore MCPs

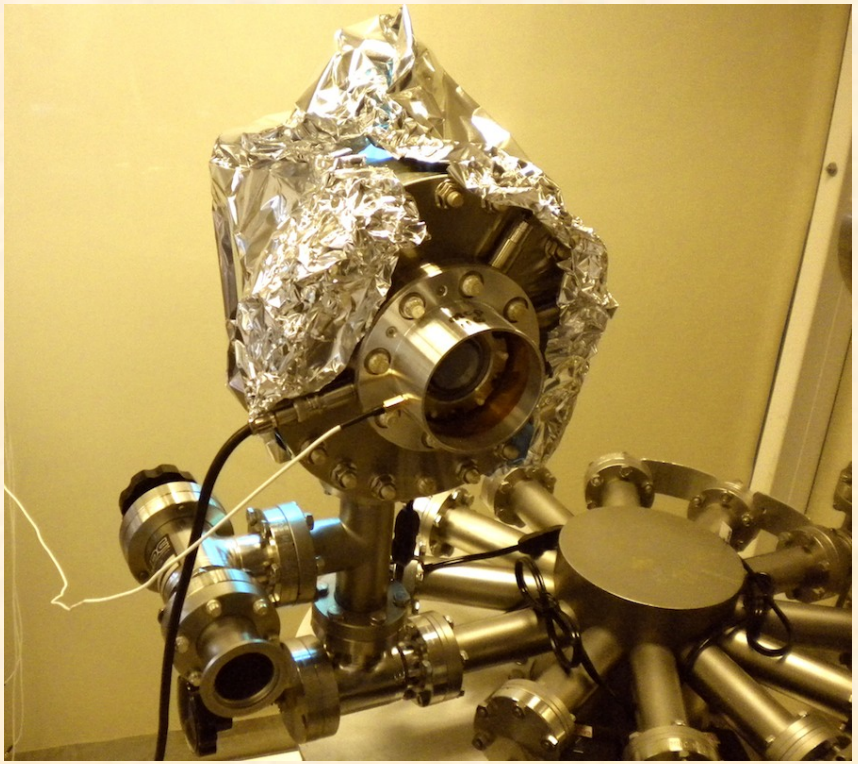
Several preconditioning tests have been done to evaluate how the MCPs will behave under the conditions needed to incorporate them into sealed tubes.

- Arradiance ALD Al_2O_3 MCPs (612/613), 20μm, 60:1, 8° bias.
- ANL ALD MgO MCPs (164/163), 20μm, 60:1, 8° bias.
  - Completed 350°C bake, with RGA scans.
  - Scrub completed with ~7 C cm^{-2} extracted (with RGA scans).
- ANL ALD MgO MCPs (180/141), 20μm, 60:1, 8° bias.
- Several standard MCPs with ALD MgO SEY layer to test "burn-in"

33mm MCP Bake/Lifetest Test Facilities

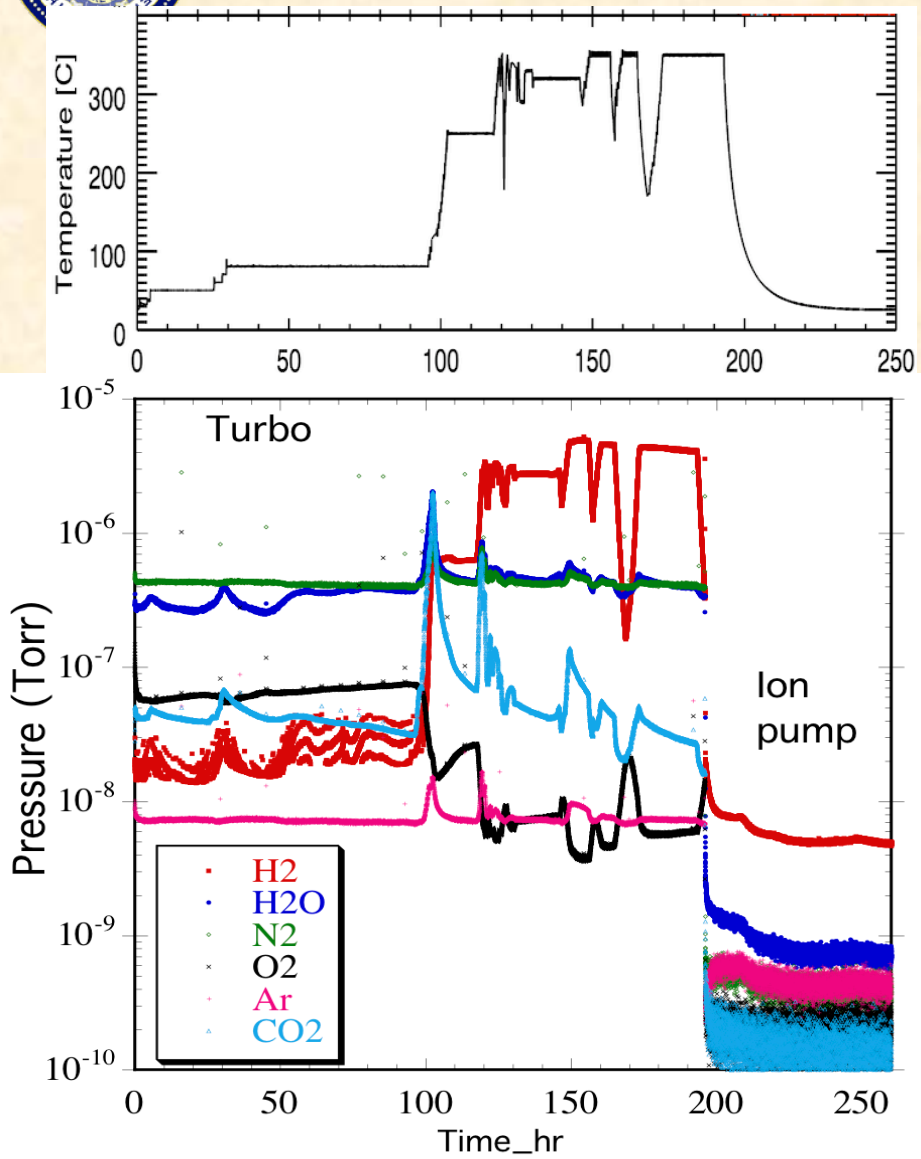


Multiple port UHV lifetest station. Two ports set up for 33mm MCP "burn-in" at ~5 x10^{-9} torr, with UV lamps, electrometer & recorder



Scrub heads have phosphor readout or XDL. Bake to 350°C, measure outgassing with RGA. Can do imaging or DC charge.

Vacuum Bakeout. Time/Temp/Gas Load



Test bake, normal bake is 350°C for 24 to 36 hours. Most of the gas load is the chamber, not the MCPs. However, there was some H_2 evolved from the MCPs in pre-bake tests.

Bake was on Turbo. N_2 and H_2O mostly at turbo limit. H_2 is the major gas load at temperature, and decays slowly.

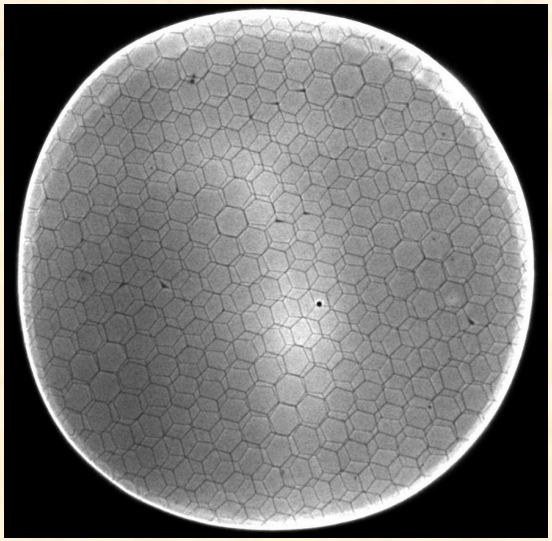
Absence of a standard MCP H_2 firing for ALD MCPs reduces the expected gas load.

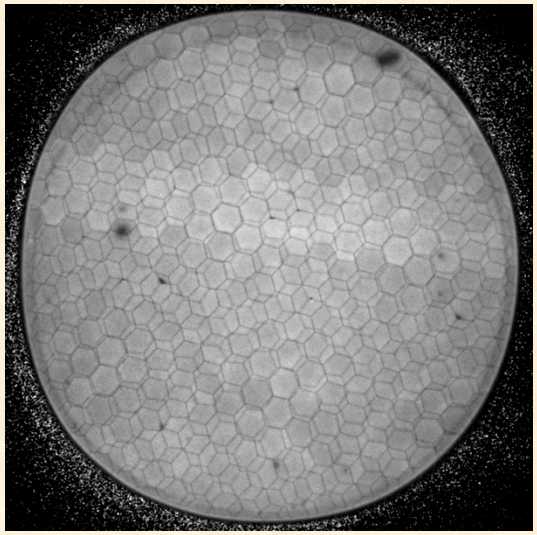
Tests Pre-Post 350°C Vacuum Bake

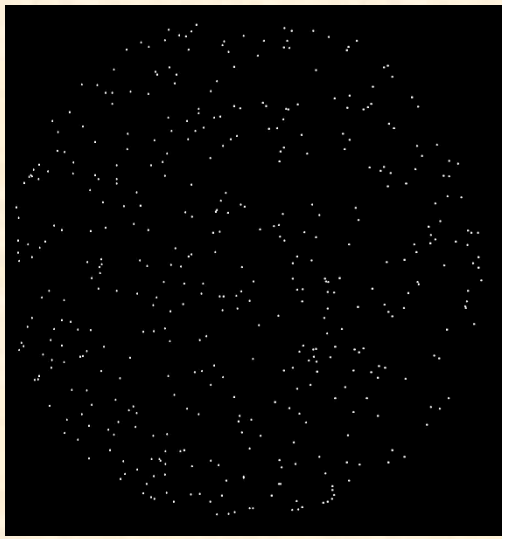
Image | Gain Map | Background ~0.1 events cm^{-2} sec^{-1}

Pre-bake

185nm UV– some MCP defect spots, UV non uniform. Shows both MCP multifibers



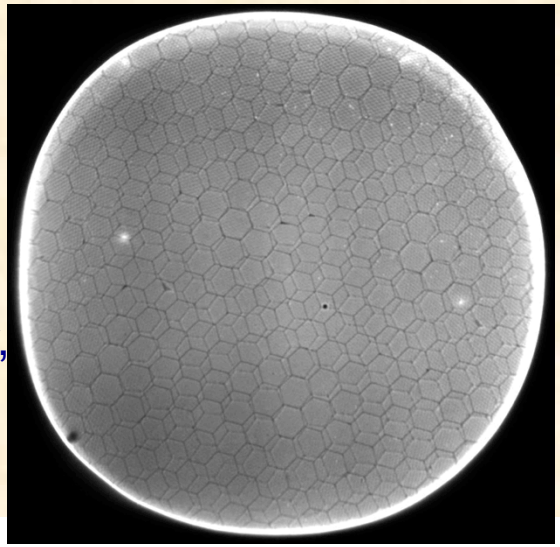


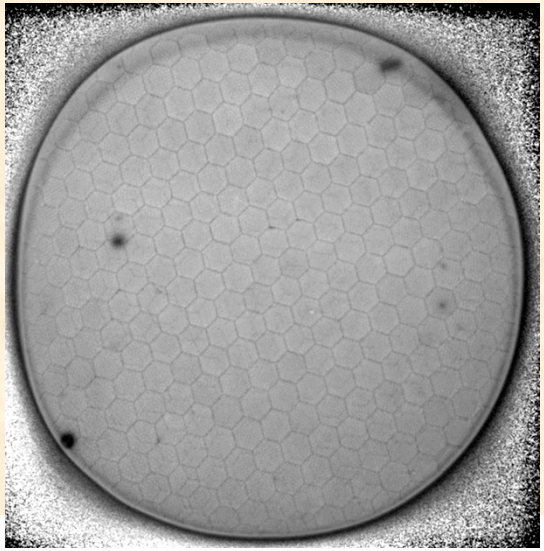


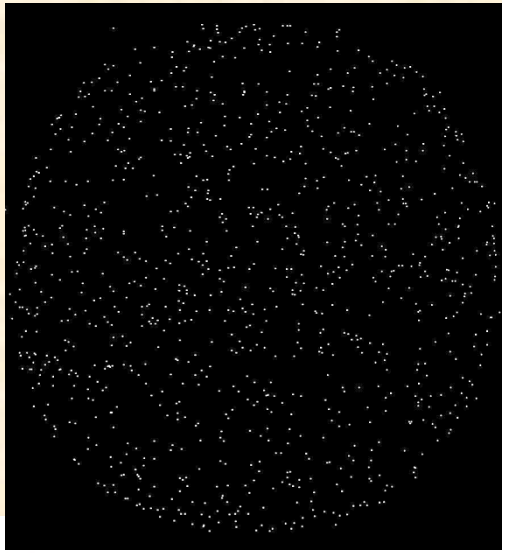
Post-bake

185nm UV– ~same MCP defect spots,

less multifiber, more uniform



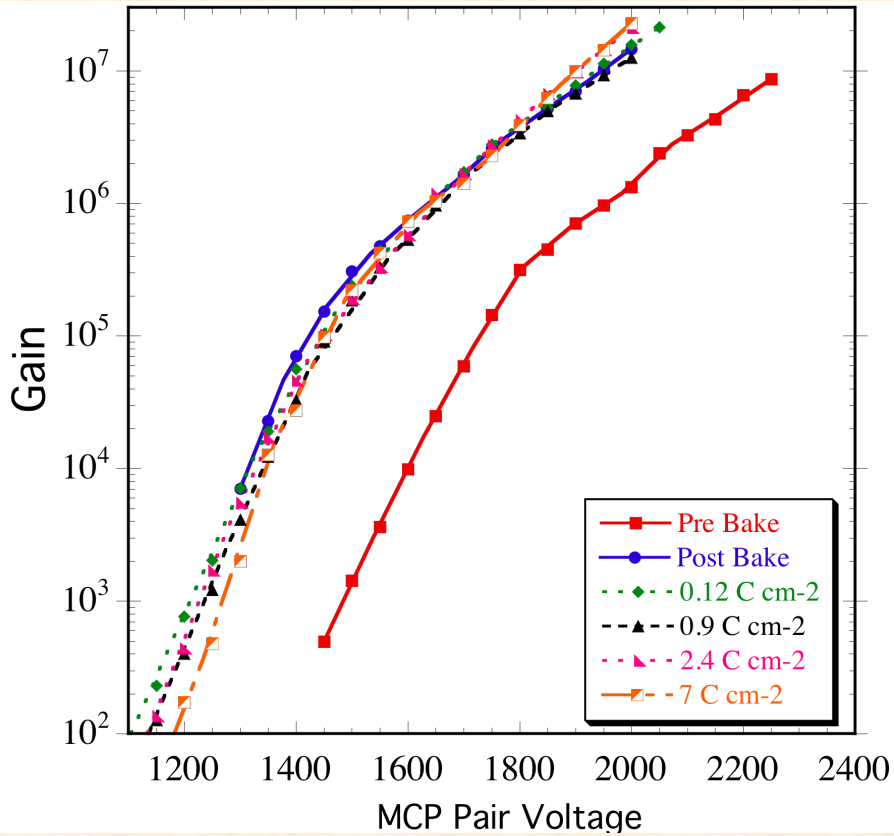




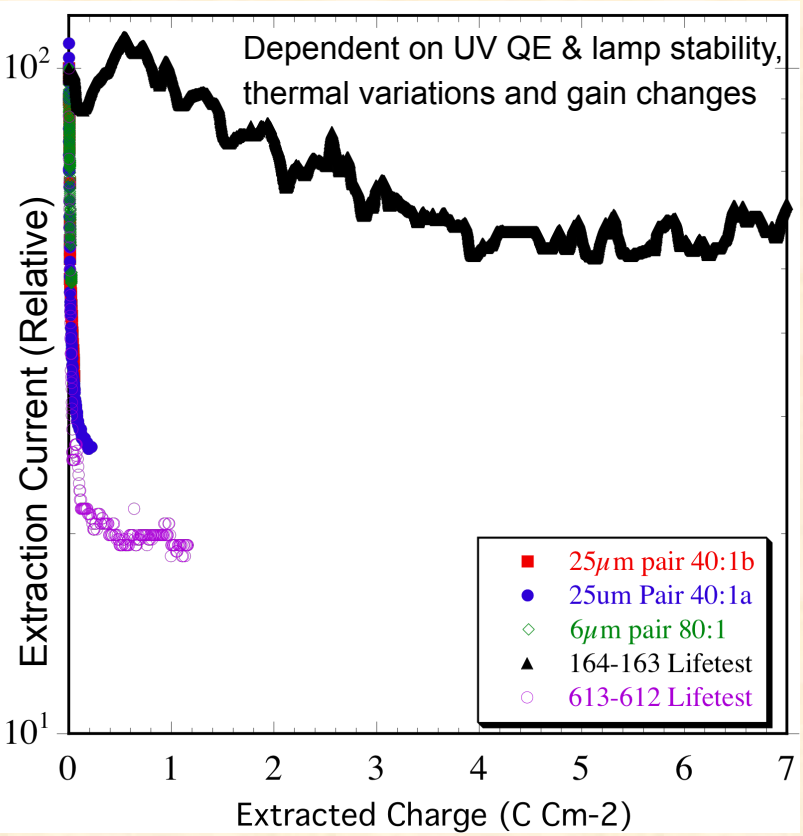
~0.1 events cm^{-2} sec^{-1}

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.

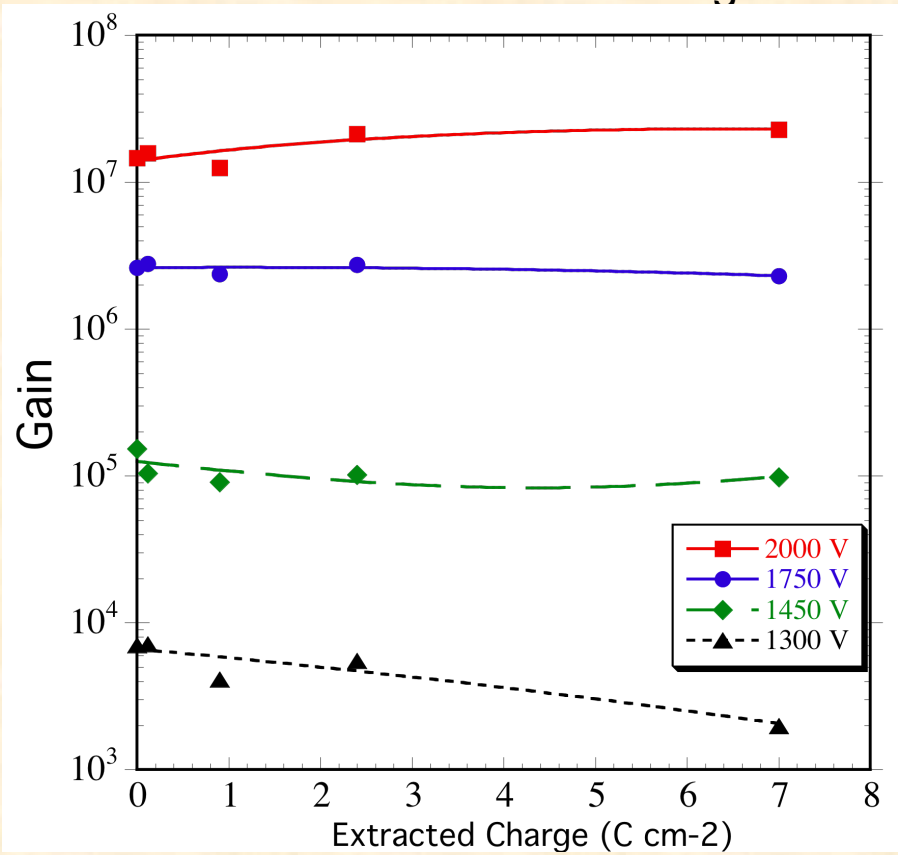


UV "burn-in" of ALD MCP pair 164-163 (20μm pore, MgO, 60:1 L/d, 8° bias) compared with conventional MCPs. Outgas during burn-in < 4 x 10^{-10} torr H_2 for the first 0.05 C cm^{-2}.

33mm ALD-MCP Preconditioning Tests

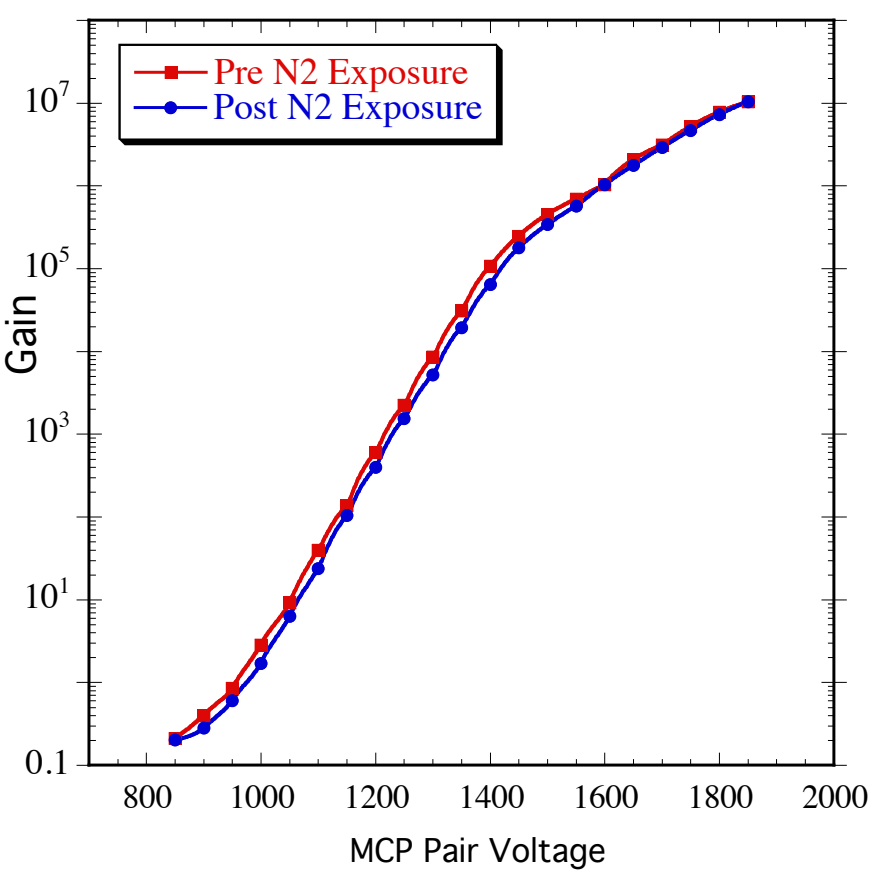
Vacuum 350°C bakeout and "burn in".

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



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

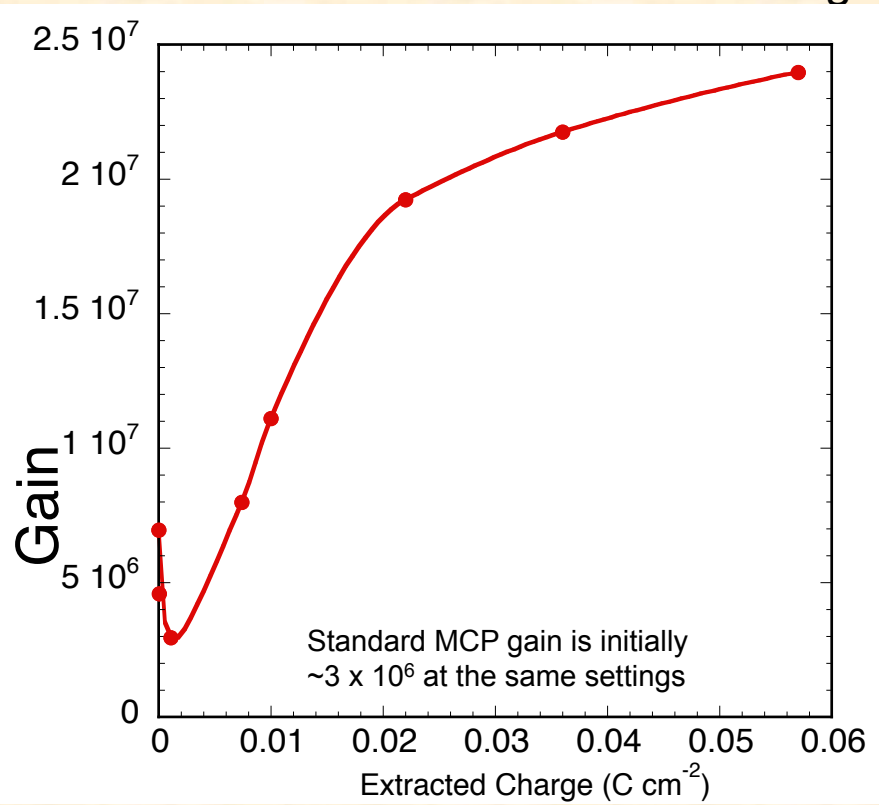
Exposure to dry nitrogen for 15 min after the lifetest shows no appreciable change in gain after re-pumpdown.



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

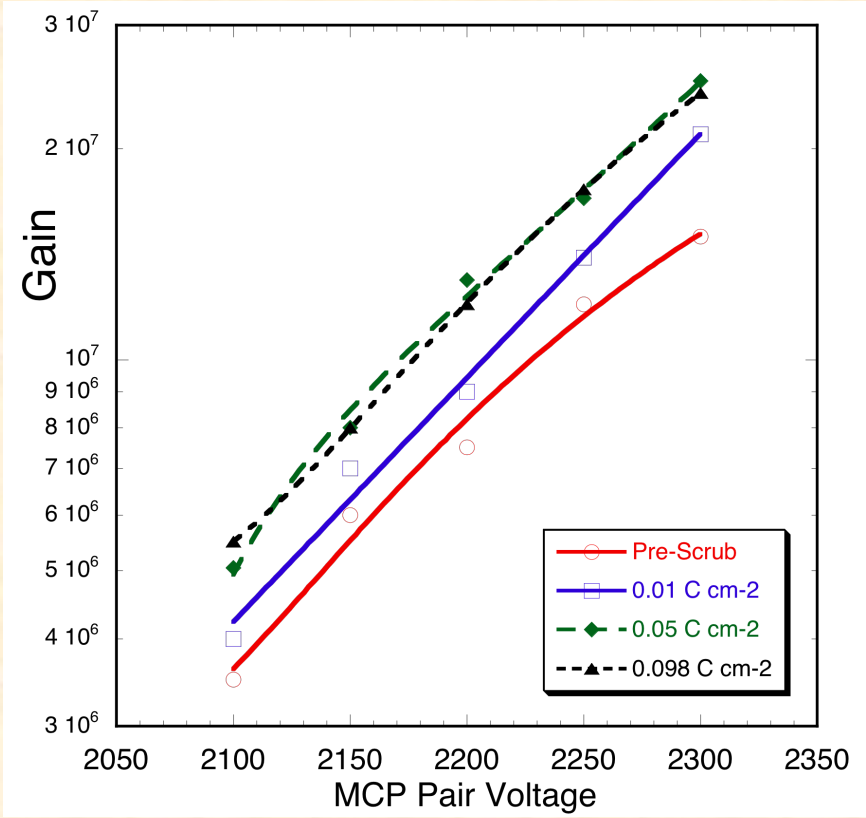
33mm ALD-MCP Preconditioning Tests

Scrub test for ALD MgO layer on standard glass MCP shows that the gain increases from a standard MCP value to ~10x higher



MCP pair gain with MgO SEY layer on bottom MCP as a function of charge extracted.

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



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

33mm ALD-MCP Test Summary

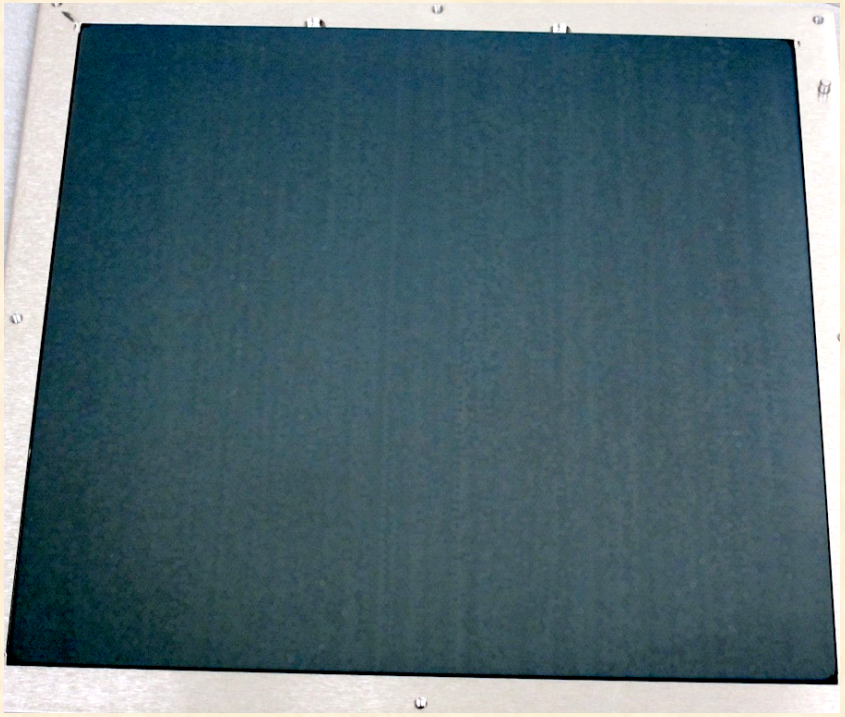
Achievements and implications

- Micro-capillary arrays in borosilicate glass with 20μm material offer a robust, adequately low distortion/defect substrate for atomic layer deposited MCPs, and quality is still improving.
- Gain, imaging, and detection efficiency same as standard MCPs
- Background rate is a factor of >4 better than standard MCPs
- High temp vac bake for tube processing has very positive effects
  - Factor of 10x 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 N2 exposure thereafter
- ALD functionalized borosilicate MCPs are a good match to the 20cm sealed tube process and may afford significant improvements in tube/cathode lifetime and in reduction of the tube fabrication/processing turn around time.

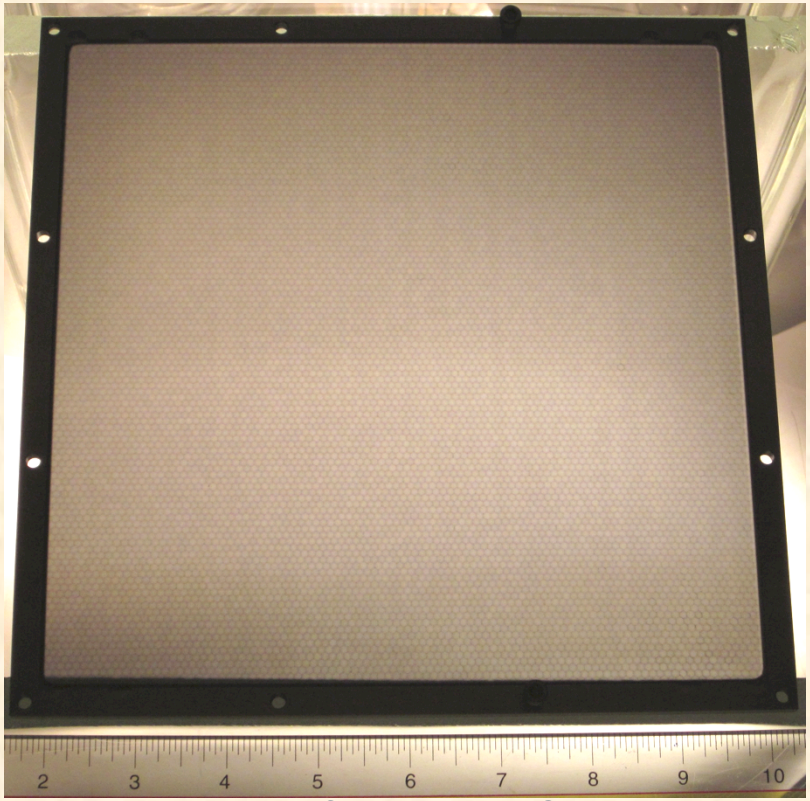
Progress with 20cm ALD MCP Development

Interactive development with Incom and Argonne Lab. to assess borosilicate substrates and ALD processes on 8" format.

Set up testing equipment/techniques to evaluate performance and feed back data for iterative process development.



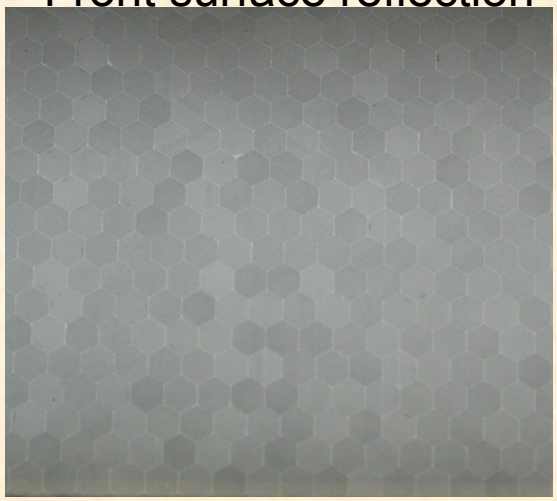
20cm ALD MCP photo showing the patterns of multifibers and stacking arrangement.

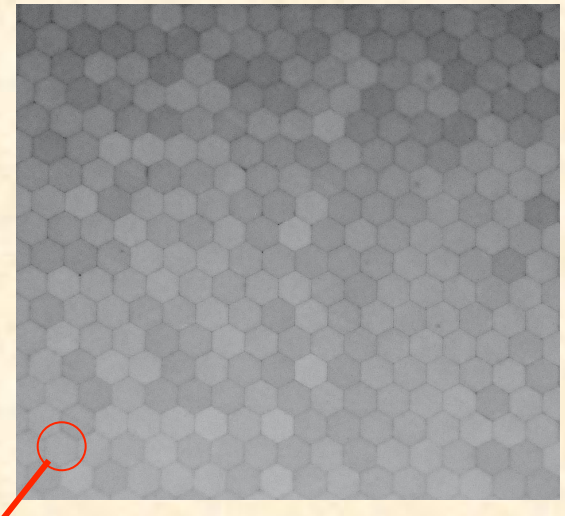


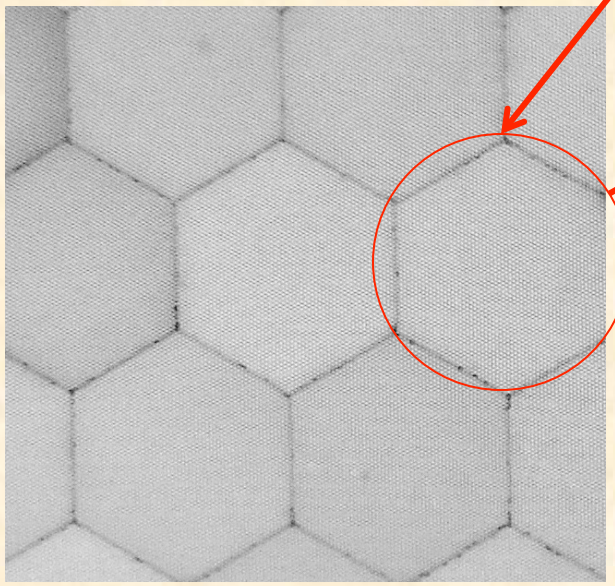
Backlit photo of a 20cm MCP showing the multifiber stacking arrangement.

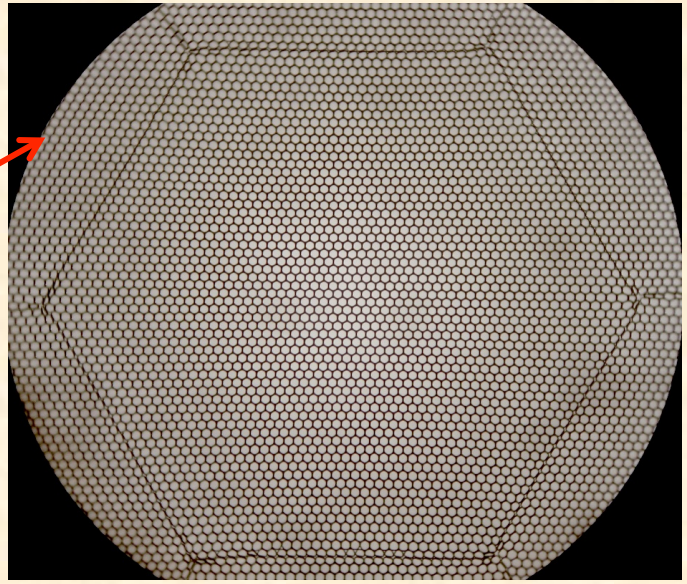
Borosilicate Substrate Atomic Layer Deposited Microchannel Plates

Front surface reflection







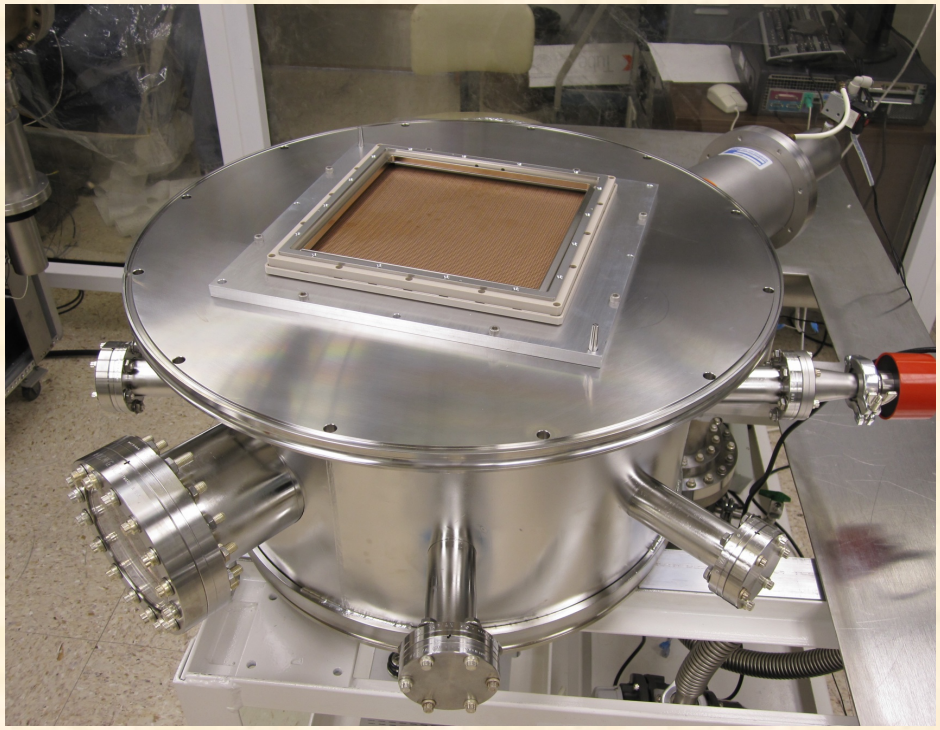


Visible light transmission for a 20 μm pore 65% open area borosilicate micro-capillary ALD 20cm MCP.

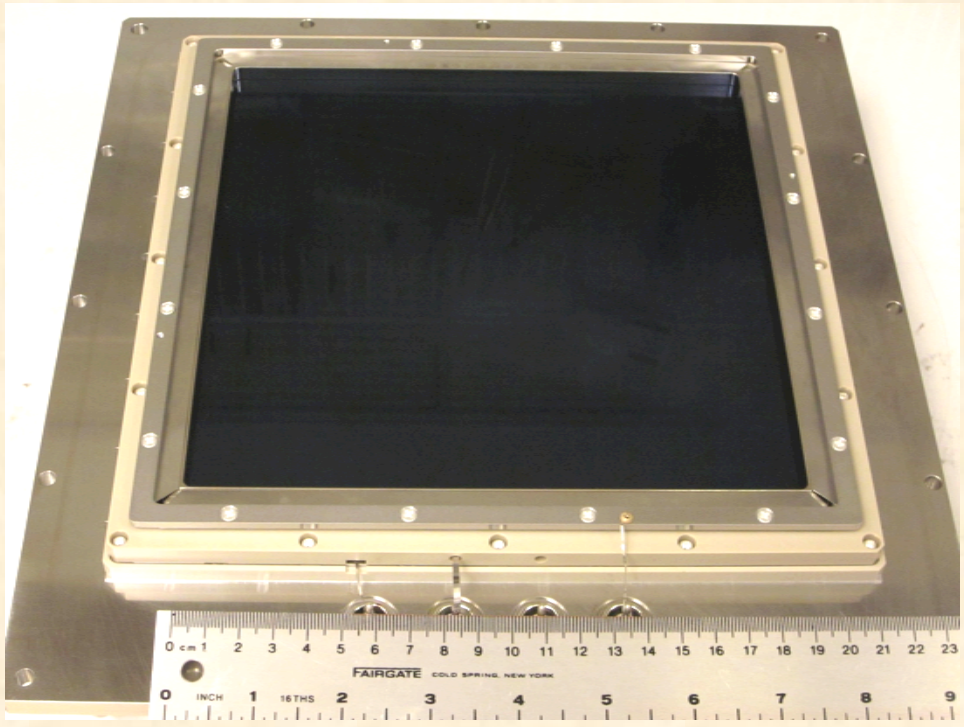
Brightness differences from multifiber to multifiber imply small changes in the pore open area ratio.

Pore distortions at multifiber boundaries, otherwise very uniform.

8” MCP Test Detector and Vacuum System

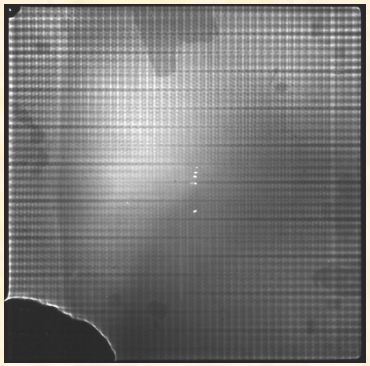
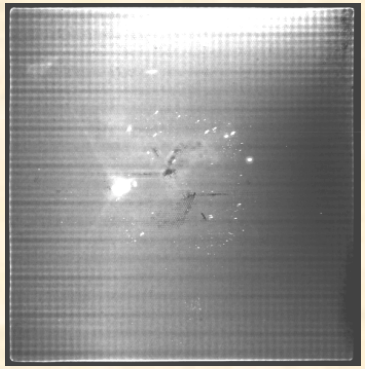
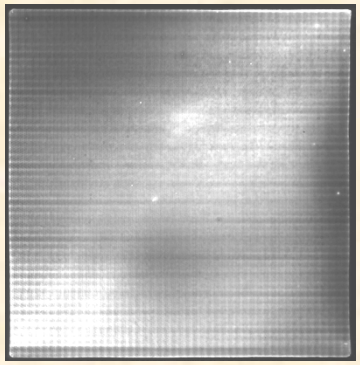
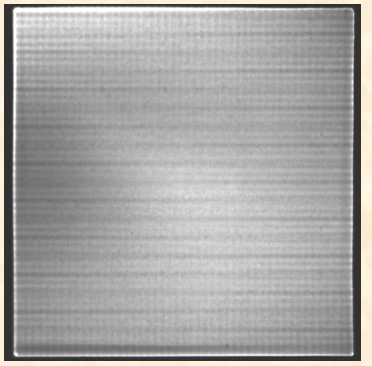
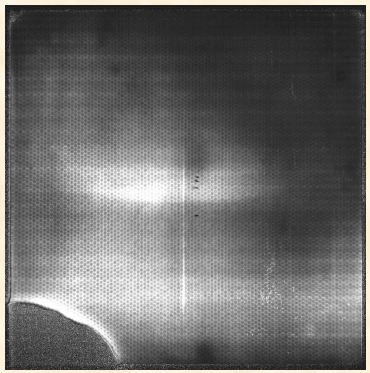
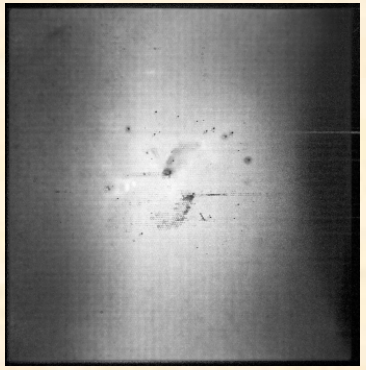
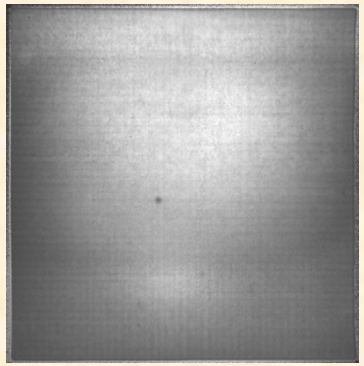
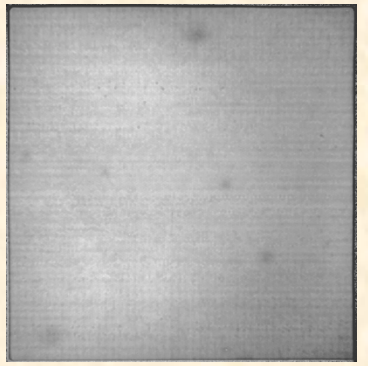
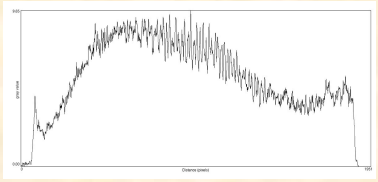
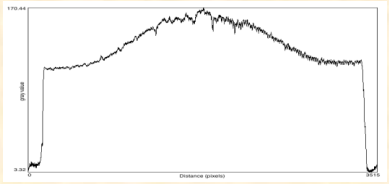
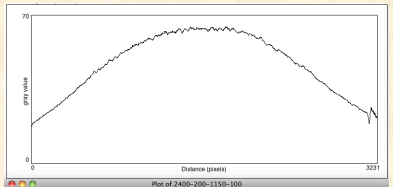
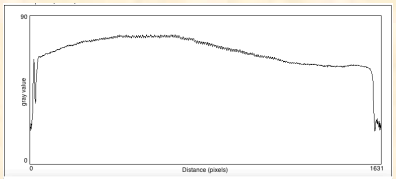
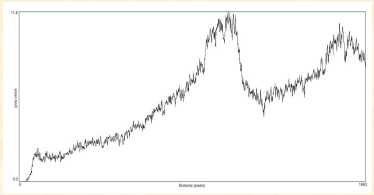
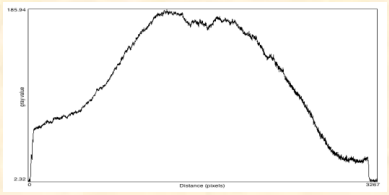
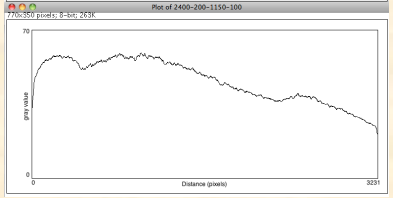
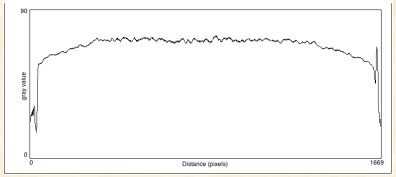


Vacuum test chamber system for testing the 8” MCPs is operational. We achieve <100μm spatial resolution for evaluation of 8” MCPs and can record a wide range of performance parameters in a short period of time.



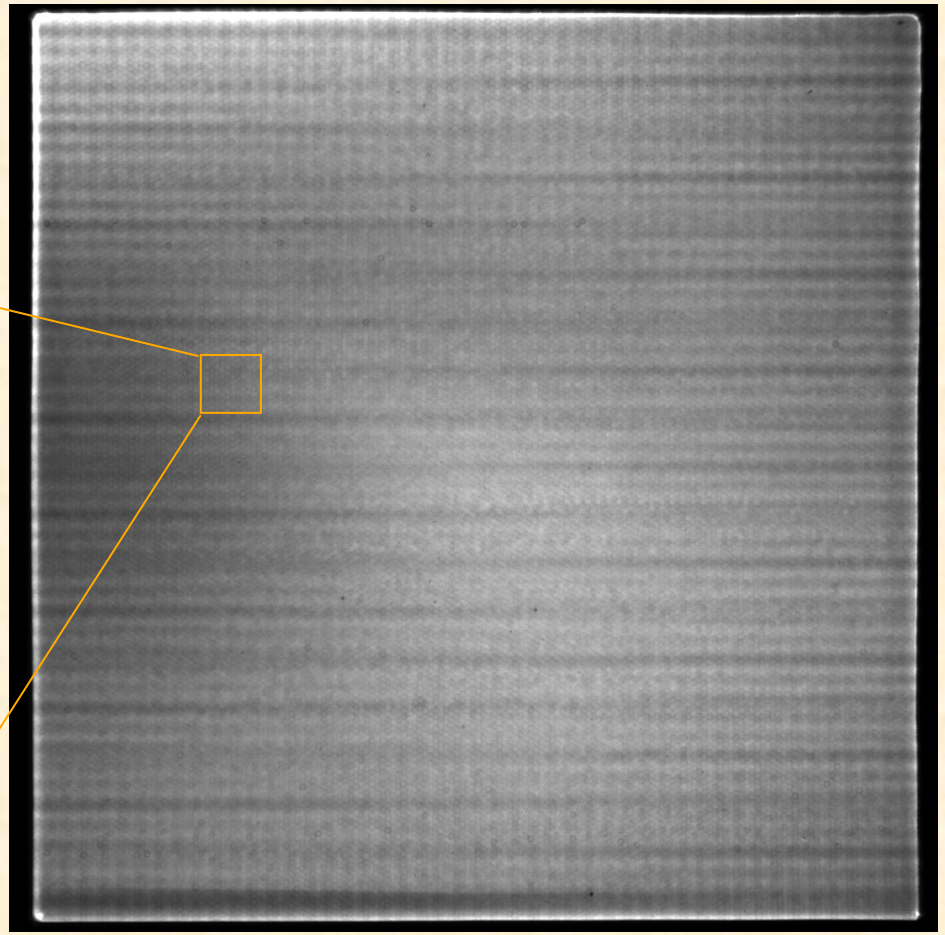
20cm electroded ALD 20μm pore MCP pair in a photon counting detector assembly with a cross delay line imaging readout.

20cm ALD MCP Development Progress

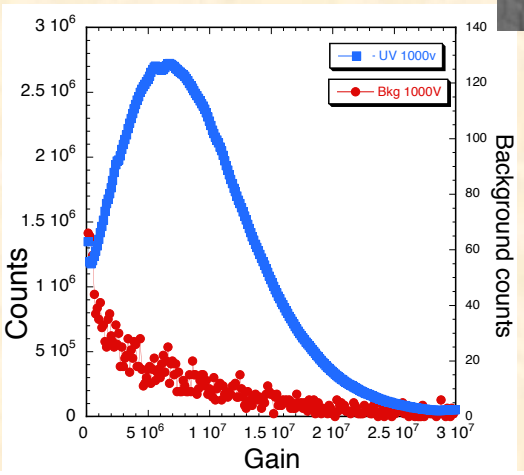
	11874-216 on 218 10/2011	12258-536 on 544 2/2012	13600-015 on 010 6/2012	13600-089 on 081 11/2012
UV Image				
Gain Map				
Gain uniformity X				
Gain uniformity Y				

Imaging 20cm, 20μm pore ALD-MCP Pairs

A number (>25) of 20cm MCP substrates have been functionalized by ALD at ANL, re-electroded at UCB-SSL and put through detailed tests.



Expanded area view showing the mutifiber edge effects.

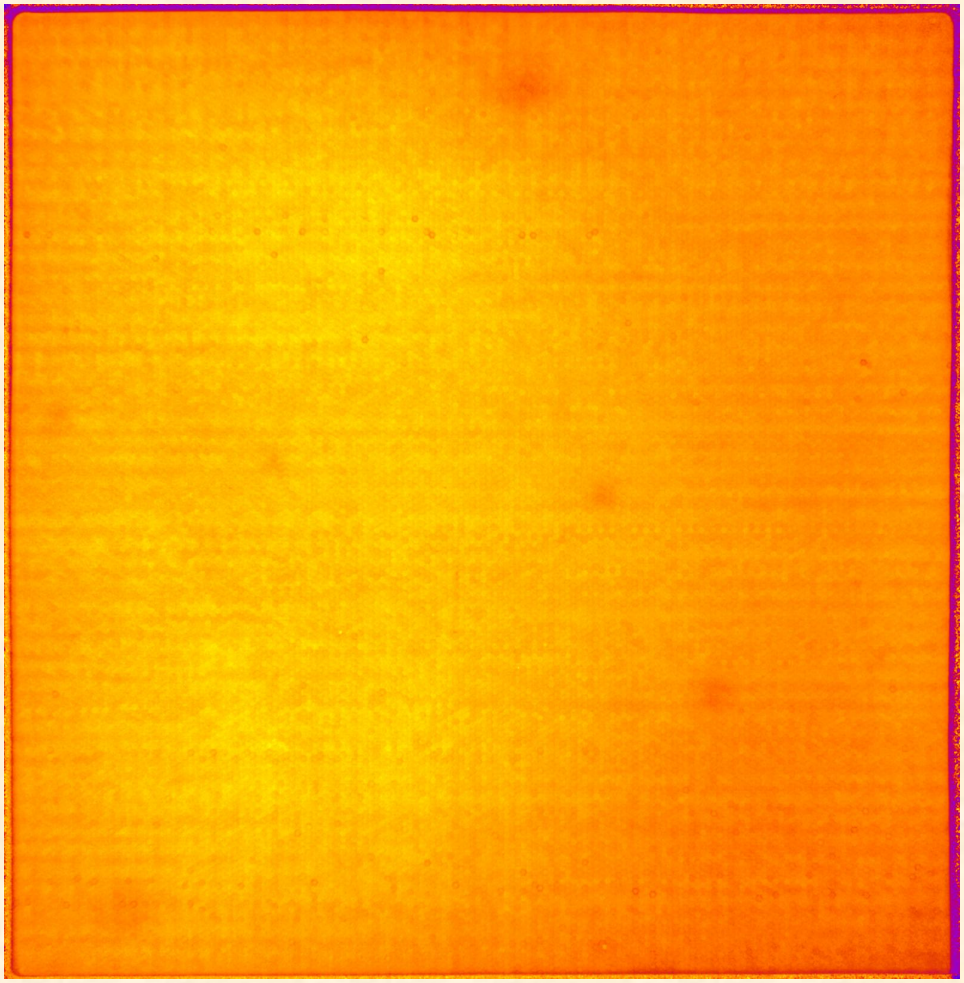


Pulse height distributions for UV and background.

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

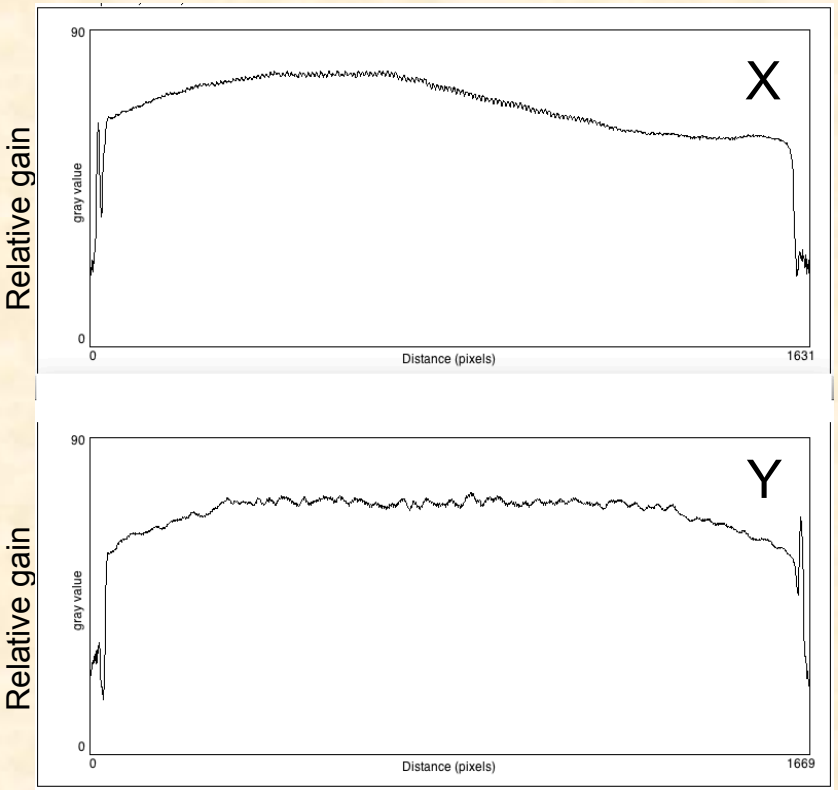
Mean gain ~7 x 10^6



8” MCP pair average gain map image

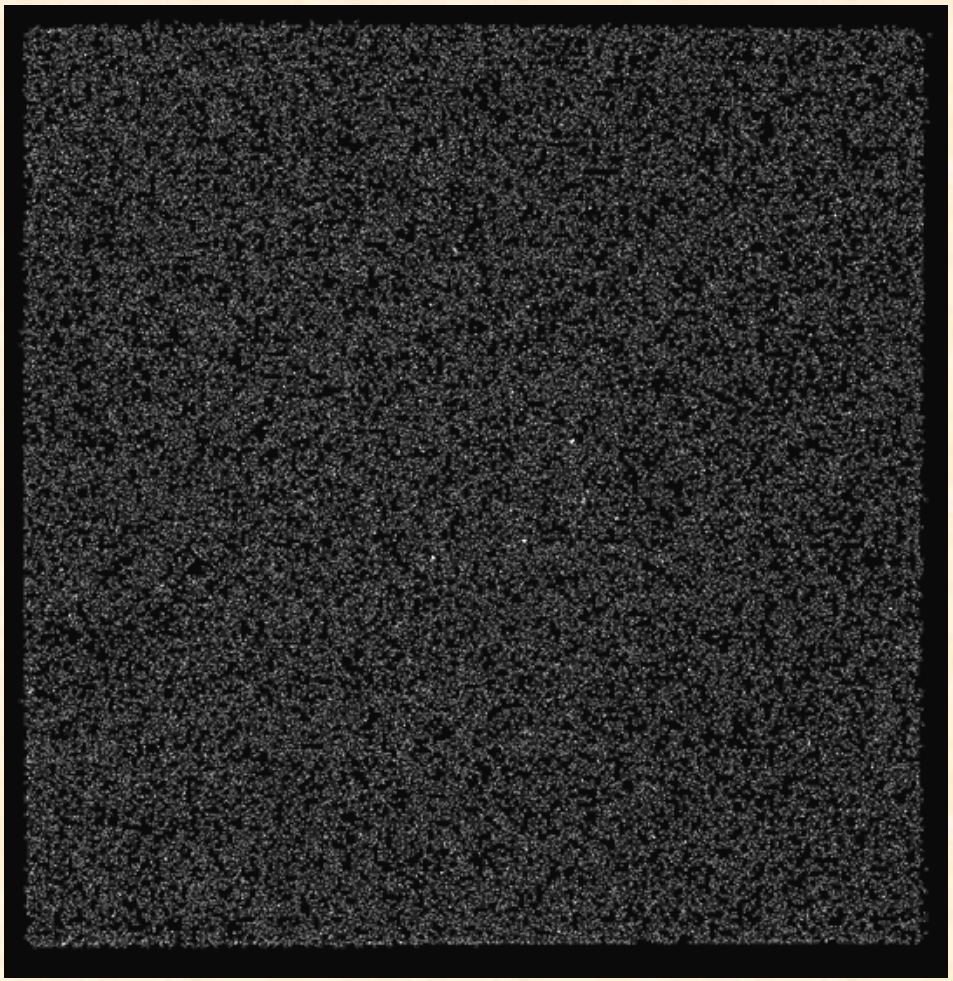
20µm pore, 60:1 L/d ALD-MCP pair.

Average gain image map shows the MCP gain variations are adequate for use in a sealed tube application.



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

Borosilicate -ALD MCP Summary

- ALD functionalized MCPs using borosilicate glass microcapillary arrays have been successfully made in 33mm and 20cm formats with 20μm and 40μm pores and 8° bias.
- Many of the performance characteristics are similar to standard commercial MCPs both in analog and photon counting modes.
- MCP preconditioning shows very good gain, low outgassing, and good stability with favorable implications for tube fabrication & lifetime.
- Background rates are low, <0.1 events cm^{-2} sec^{-1}.
- With these large MCPs, fabrication of 20cm sealed tube is possible.

MCP Near Term Development Plan

- MgO SEY application on 8” Chem 1 MCPs for evaluation
- 33mm MCP Chem 1 + MgO lifetesting
  - Vacuum bake to assess outgassing and performance
  - Then “burn-in” to verify gain stabilization and outgassing
- Testing of 8” MCPs in ceramic body for first trial “run through” of tube processing
  - Vacuum bake to assess outgassing and performance
  - Then “burn-in” to verify gain stabilization and outgassing

- Selection and implementation of MCP pairs for the first complete sealed tube process runs

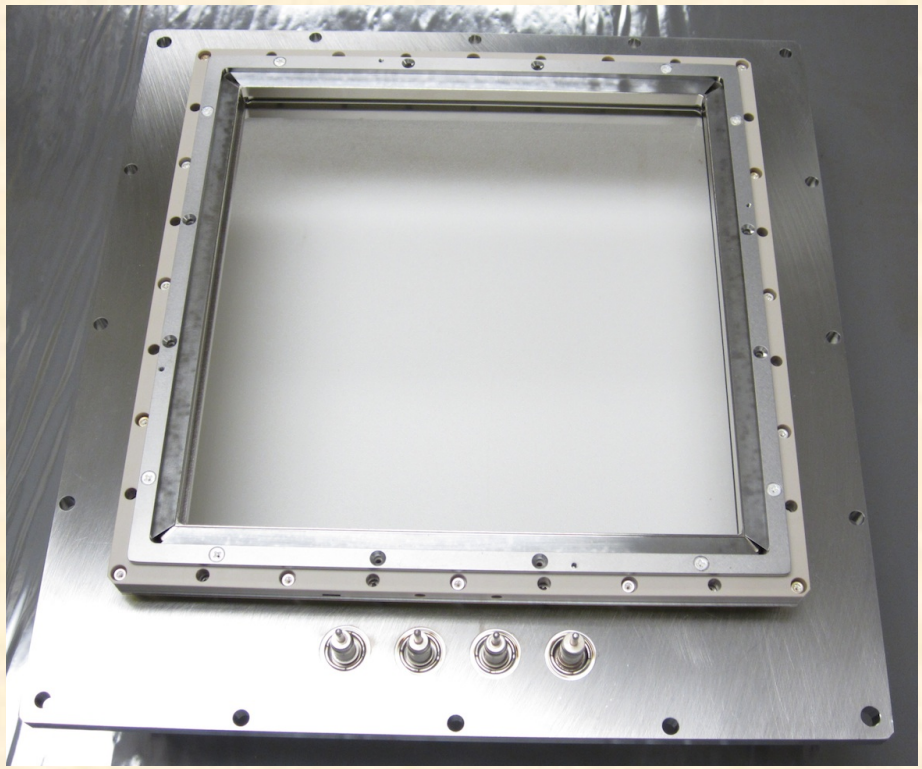
Backup Viewgraphs

8” Phosphor Readout Detector

P43 phosphor covers full area, take images with CCD camera

Designed for rapid evaluation of single 8” MCP uniformity

Detector and phosphor are built and ready to test



Complete detector unit on flange