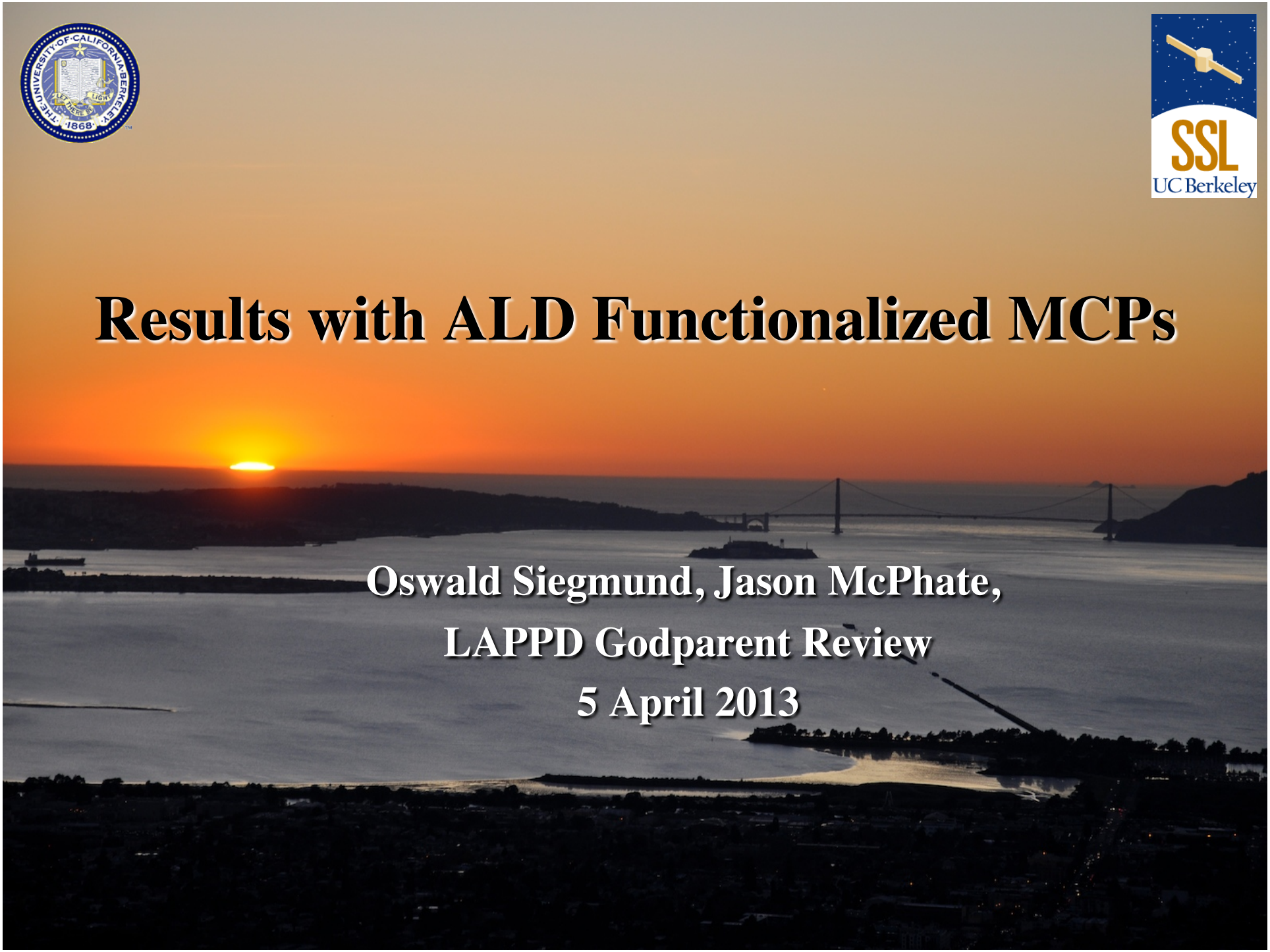


Results with ALD Functionalized MCPs

Oswald Siegmund, Jason McPhate,

LAPPD Godparent Review

5 April 2013

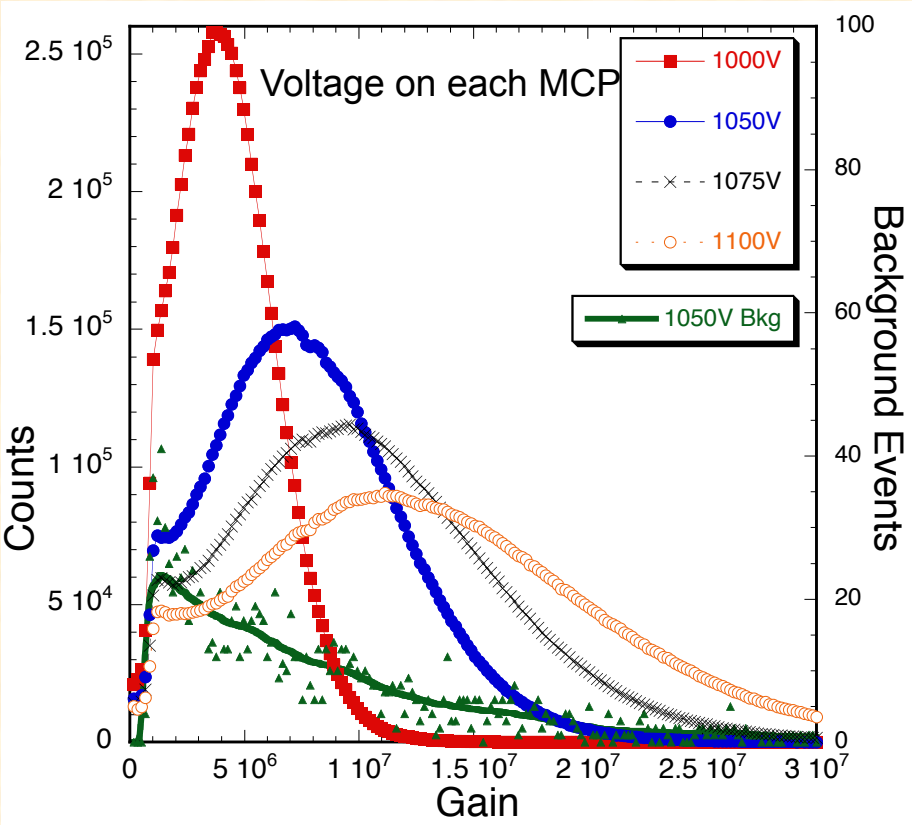
ALD Functionalized MCP Test Tasks

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.

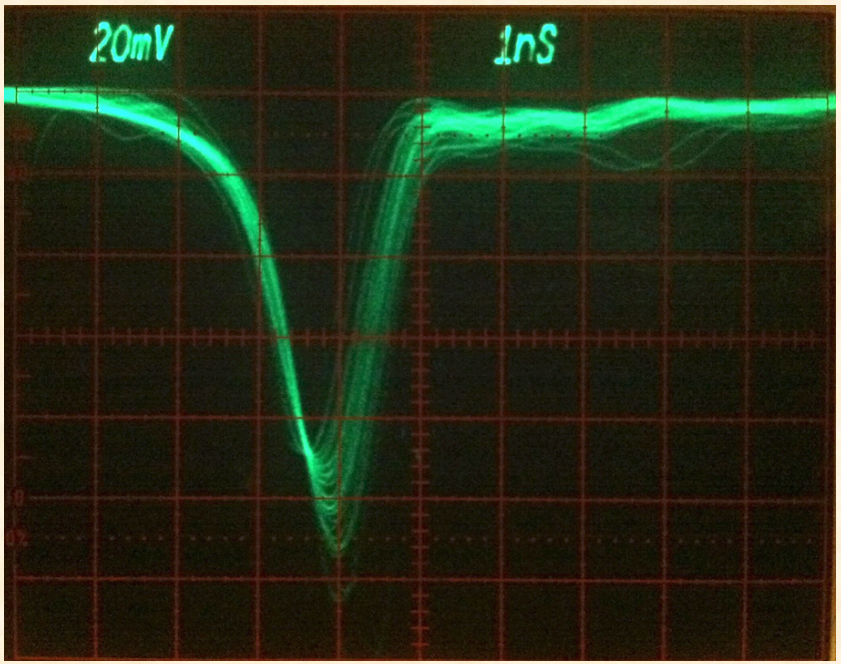
- Full evaluations of 20μm material, 33mm
  - Gain, imaging, background in singles/phosphor
  - Single MCP lifetest characteristics
  - Pairs with XDL, imaging, gain, background, PHD, uniformity
  - High temp vac bake for tube compatibility tests,
  - MCP pair lifetest characteristics – "burn-in"
  - 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
  - Verification of "sealed tube" compatibility

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.

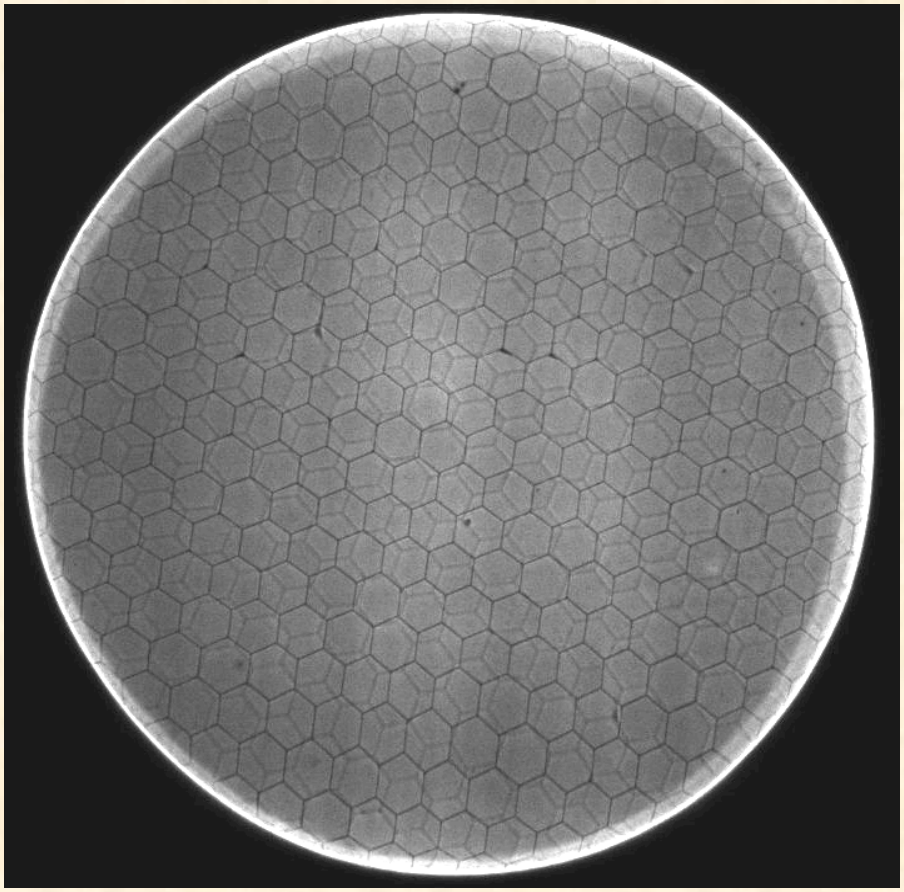
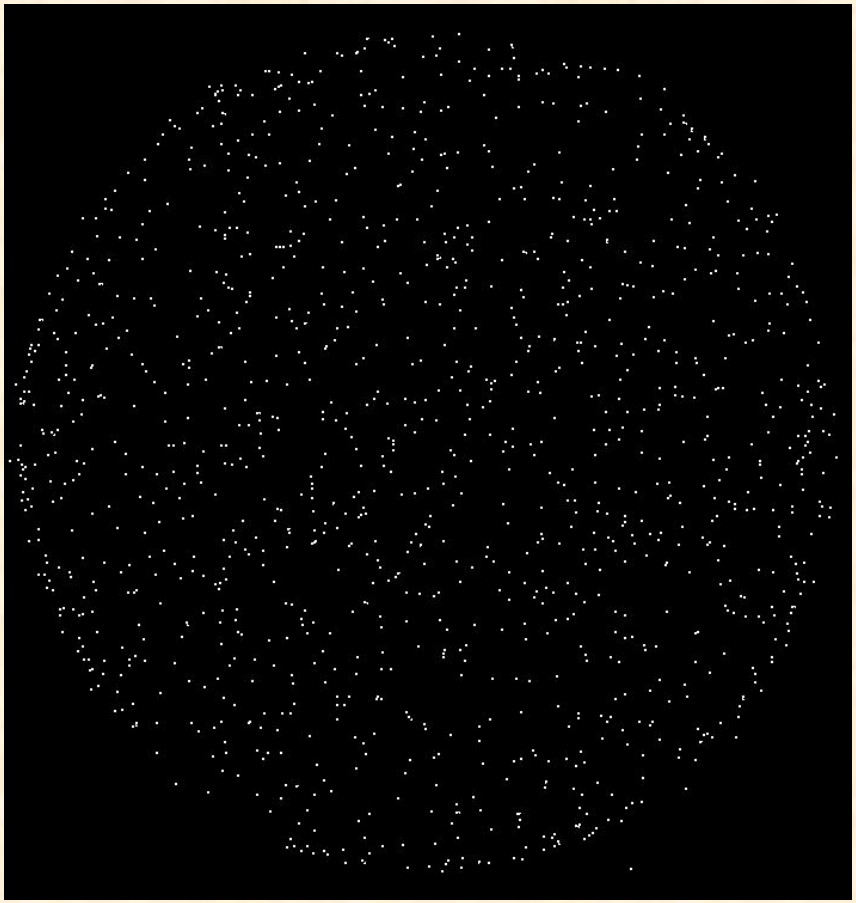


Image of 185nm UV light, shows top MCP hex modulation (sharp) and faint MCP hexagonal modulation from bottom MCP. A few defects, but generally very good. Edge effects are field fringing due to the detector support flange.



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

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"

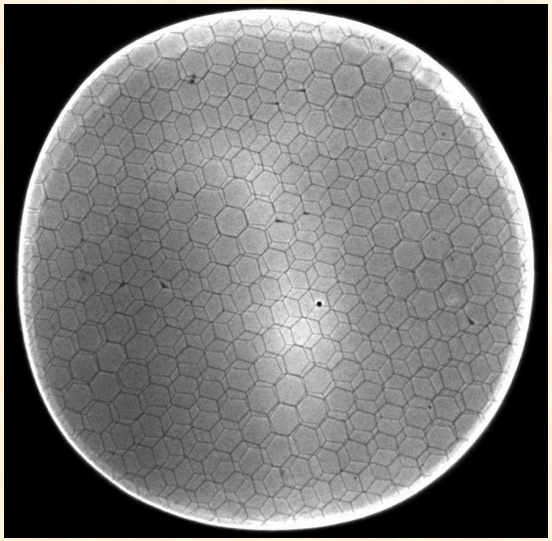
Tests Pre-Post 350°C Vacuum Bake

ANL ALD Chem 2, MgO, MCPs (164/163)

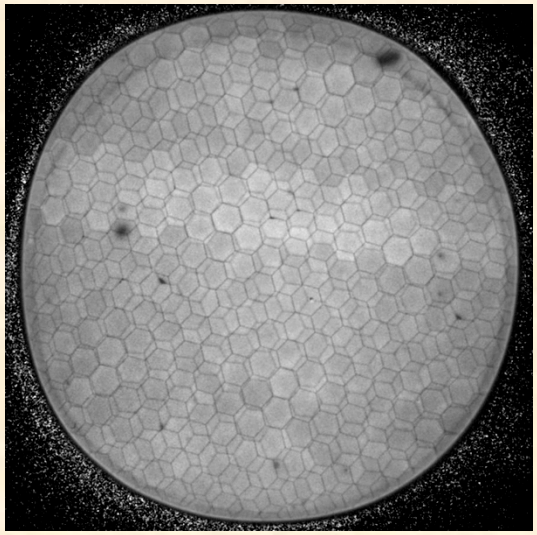
Pre-bake

185nm UV– some MCP defect spots,

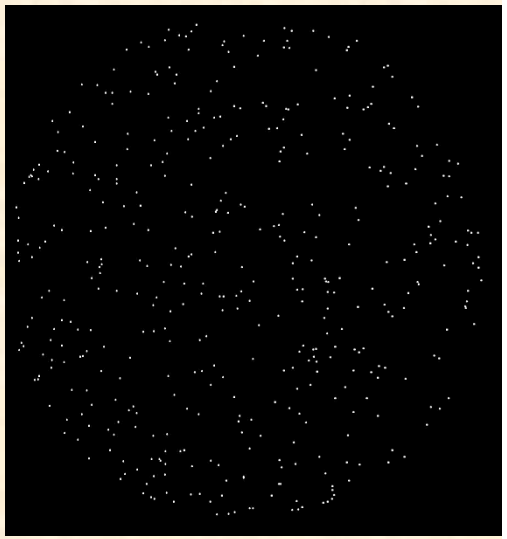
UV non uniform. Shows both MCP multifibers



Image



Gain Map



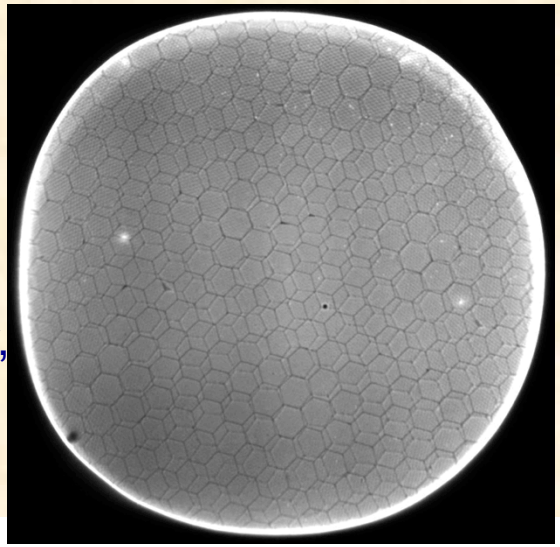
Background

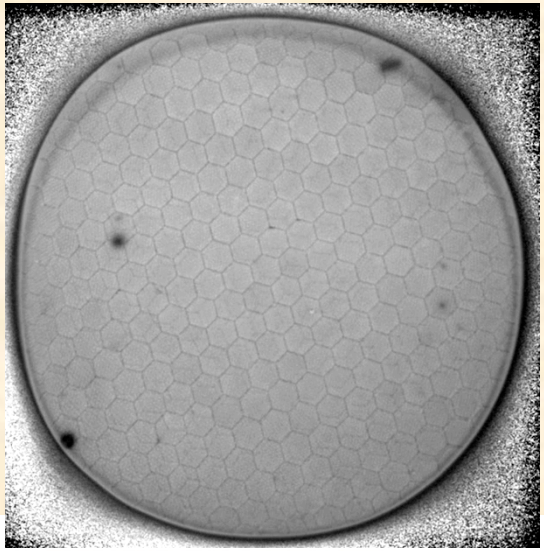
~0.1 events cm^{-2} sec^{-1}

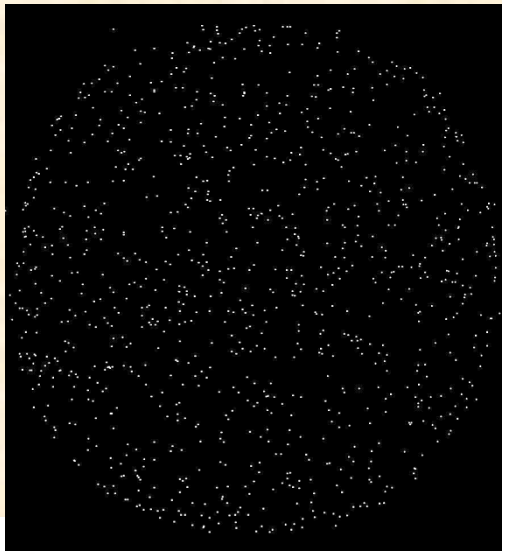
Post-bake

185nm UV– ~same MCP defect spots,

less multifiber, more uniform



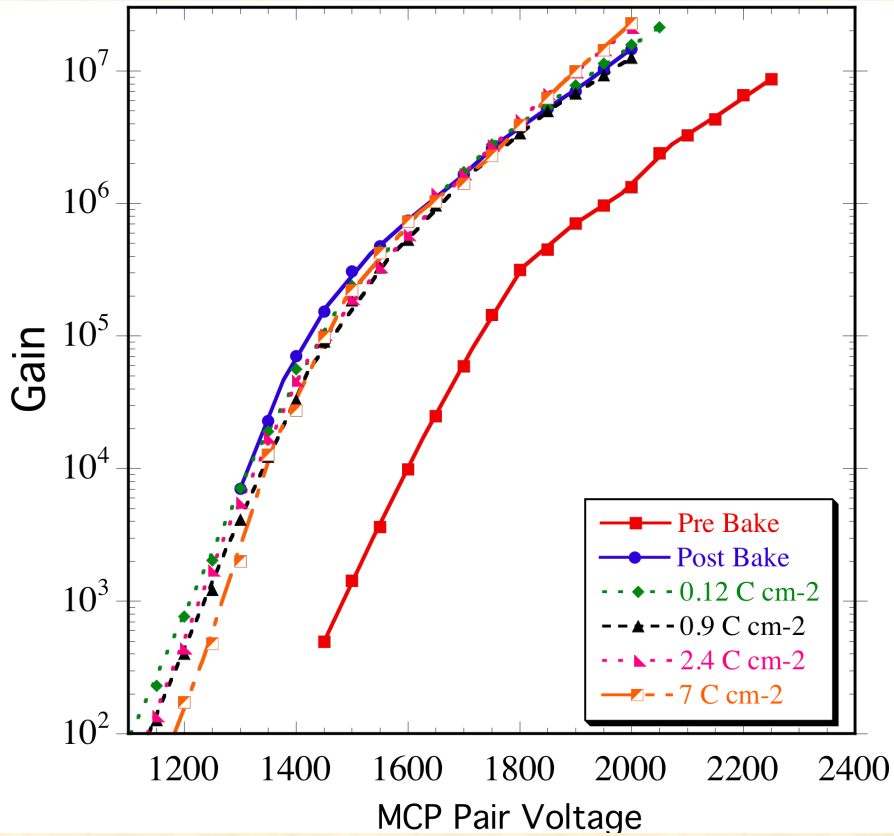




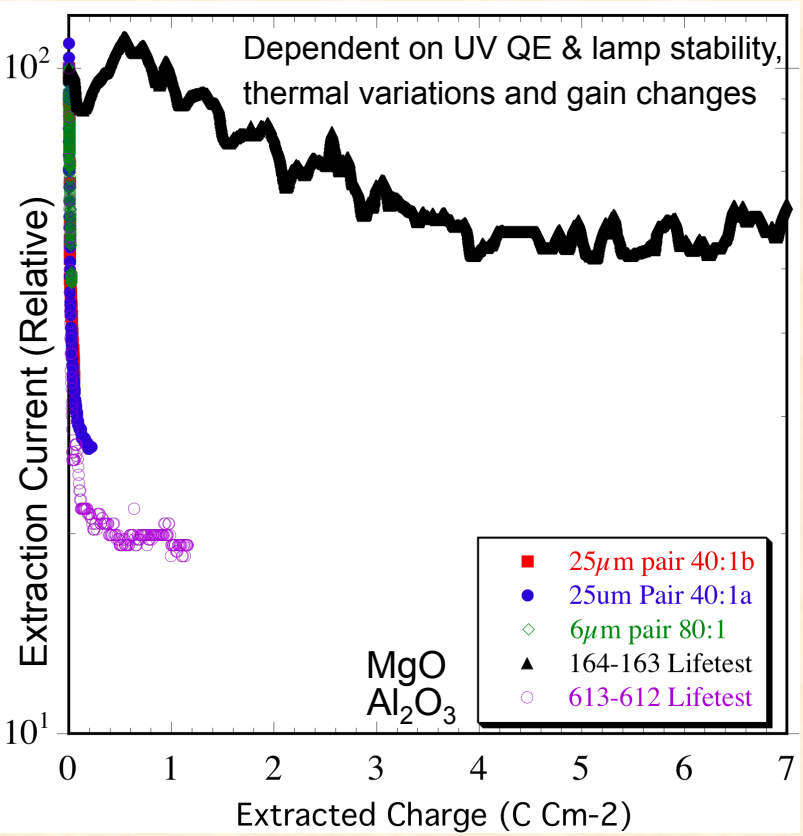
~0.1 events cm^{-2} sec^{-1}

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.

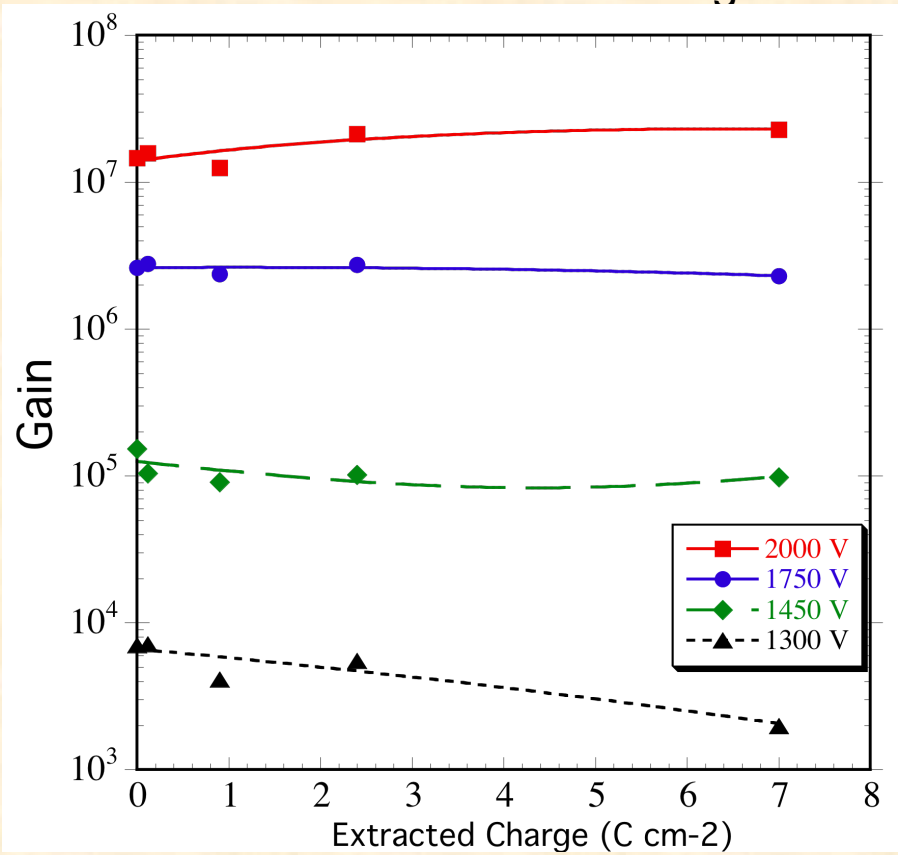


UV "burn-in" of ALD MCP pair 164-163 (20μm pore, MgO, 60:1 L/d, 8° bias) compared with conventional MCPs. Outgas during burn-in < 4 x 10^{-10} torr H_2 for the first 0.05 C cm^{-2}.

33mm ALD-MCP Preconditioning Tests

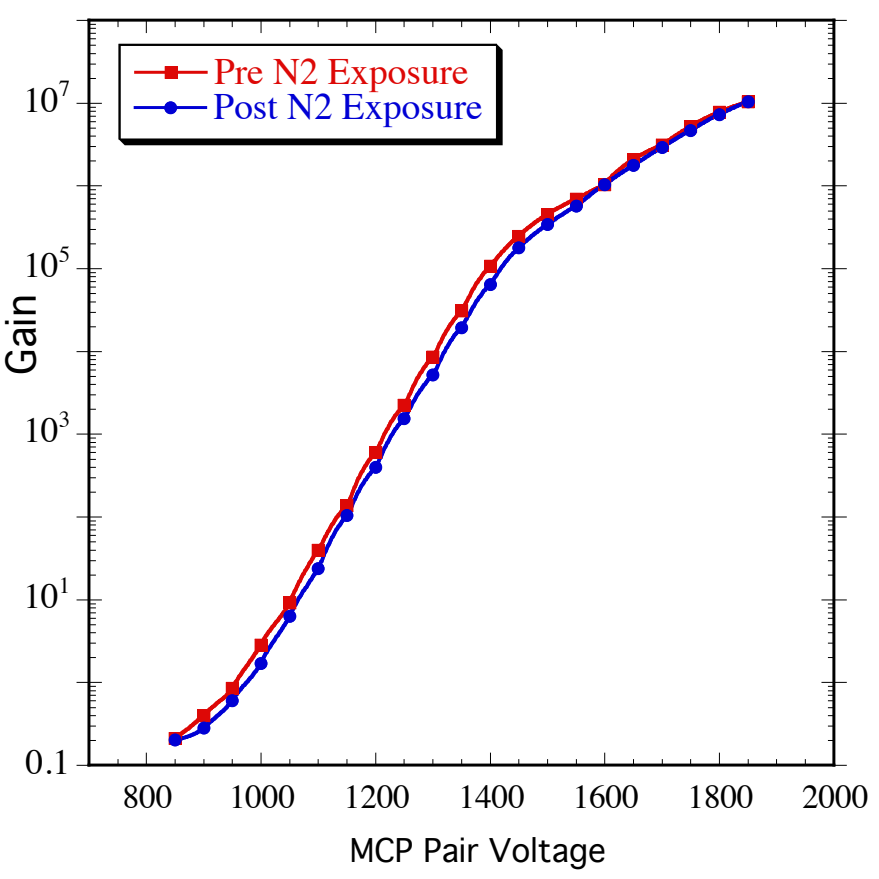
Vacuum 350°C bakeout and "burn in".

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



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

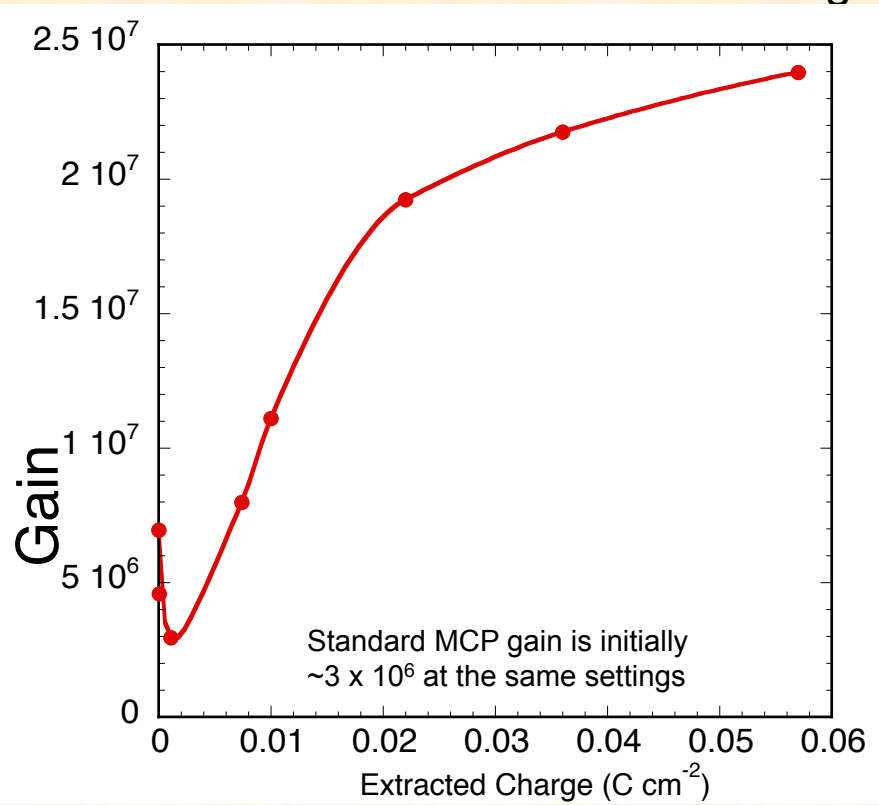
Exposure to dry nitrogen for 15 min after the lifetest shows no appreciable change in gain after re-pumpdown.



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

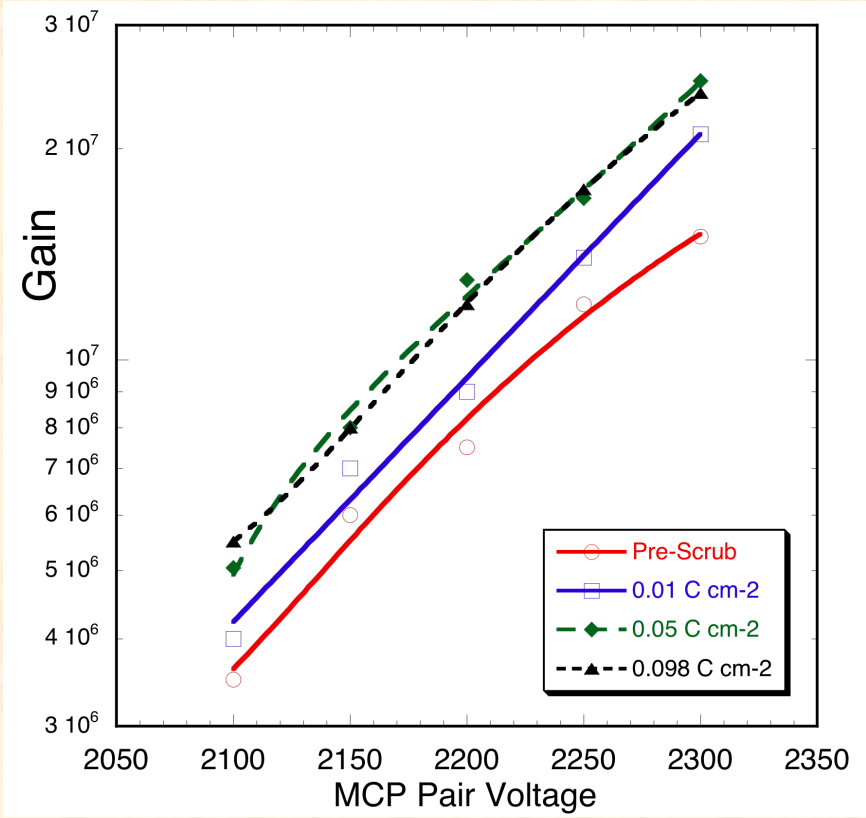
33mm ALD-MCP Preconditioning Tests with **NO** vacuum bake

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.

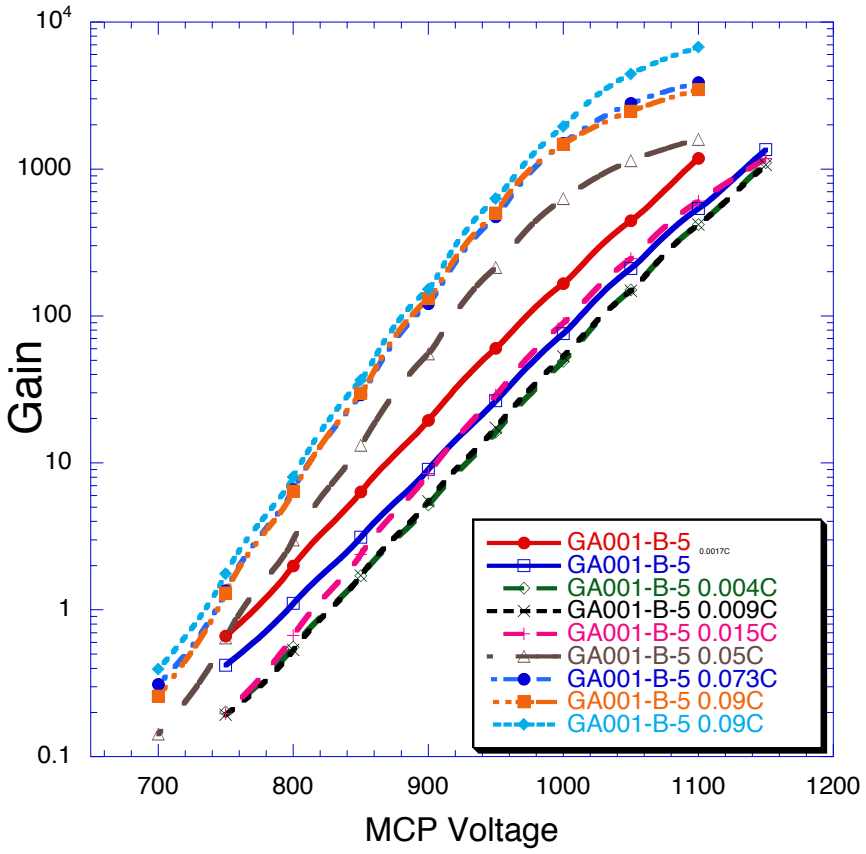
Absolute gain curves for ALD borosilicate MCP pair. Gain rises with use.

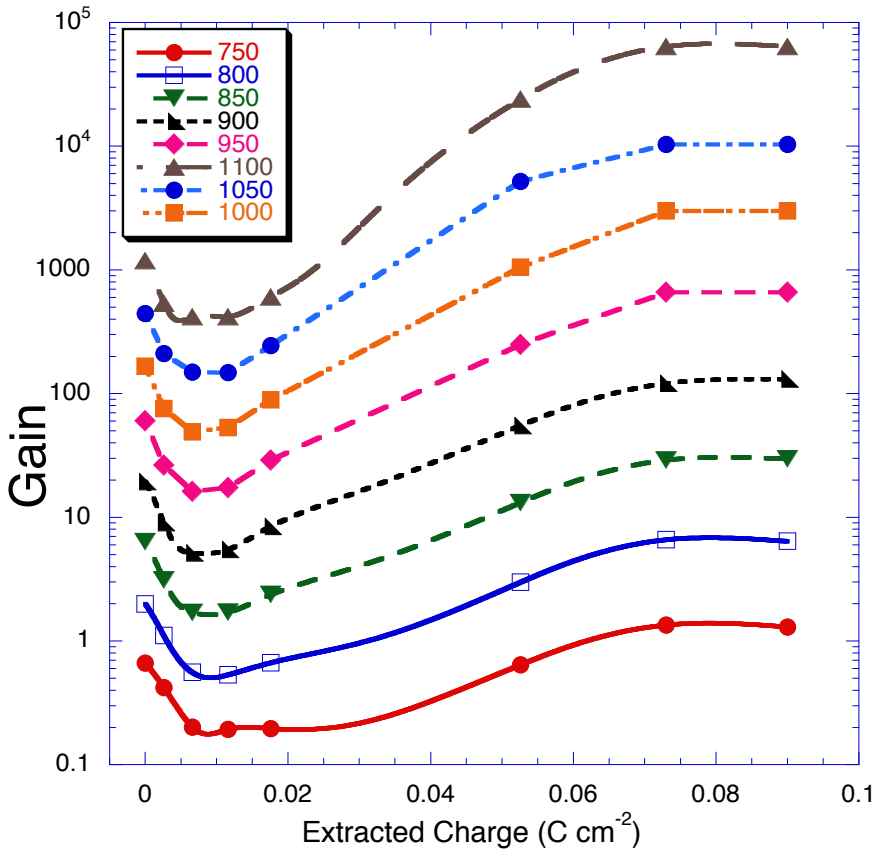


UV scrub gain curves for ALD MCP pair 180-141 (20μm pore, 60:1 L/d, 8° bias).

Standard MCP + MgO
Gain vs Charge Extraction Test

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

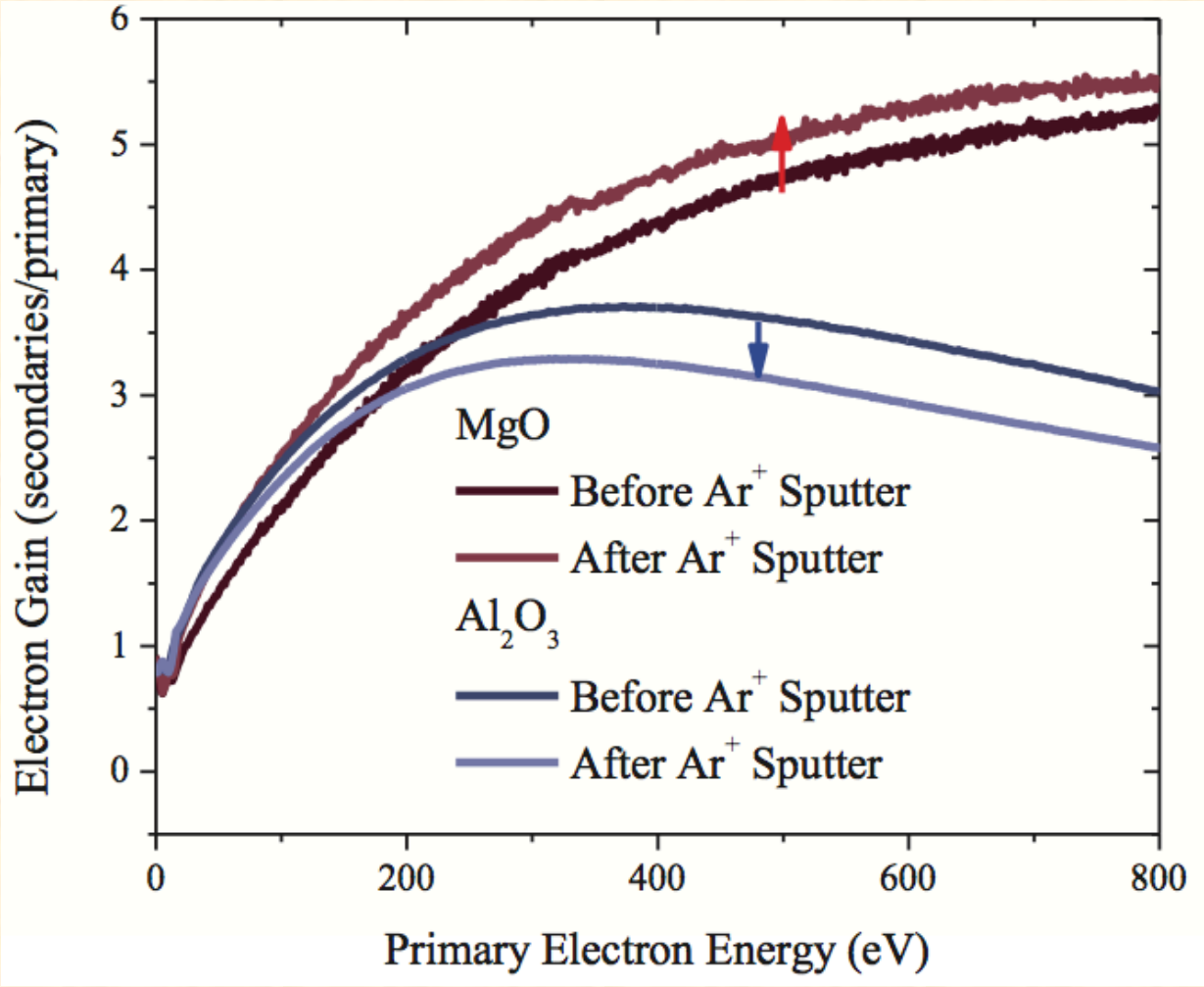




Slight gain drop (x2) at scrub initiation with significant gain increase thereafter

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

Al_2O_3 and MgO ALD SEY Tests

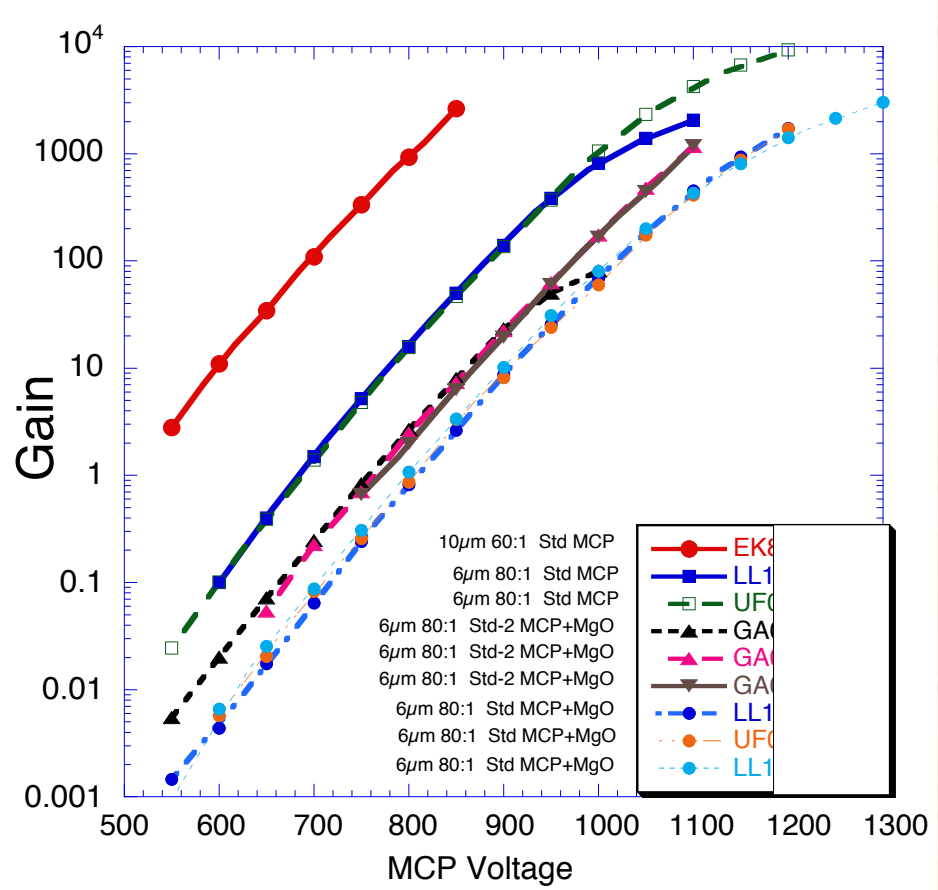


Slade Jokela, Physics Procedia **37**, 740 – 747 (2012) .

SEY increases with surface cleaning for MgO, but decreases with surface cleaning for Al_2O_3. Also MgO has low initial SEY for low electron energies. Makes qualitative sense when comparing results for bake and scrub on ALD SEY layers.

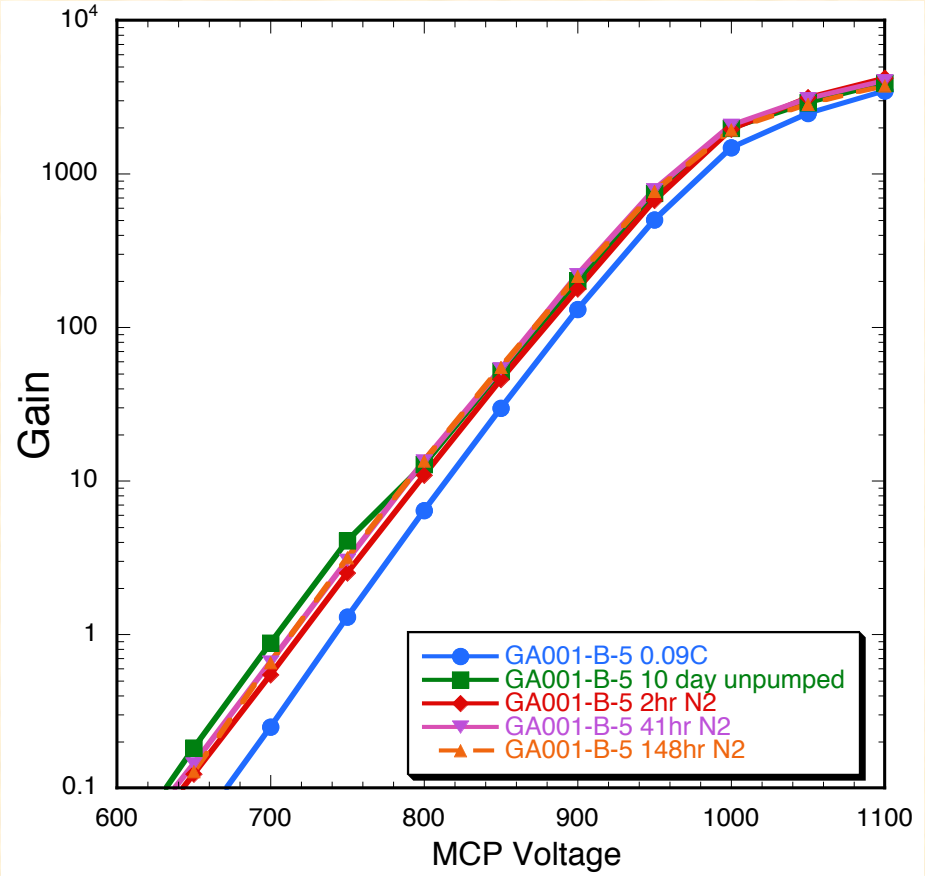
MgO ALD-MCP Gain, Un-pumped and N_2 storage

Gain for various standard MCPs



Conventional MCP gains compared with two types of conventional MCPs coated with MgO. Gain very repeatable, MgO coated MCPs are down by x10 before bake or scrub actions. UF/LL solid edge. GA soft edge.

GA001-B-5 MCP with 6μm pores, 80:1 L/D, MgO coating (annealed)

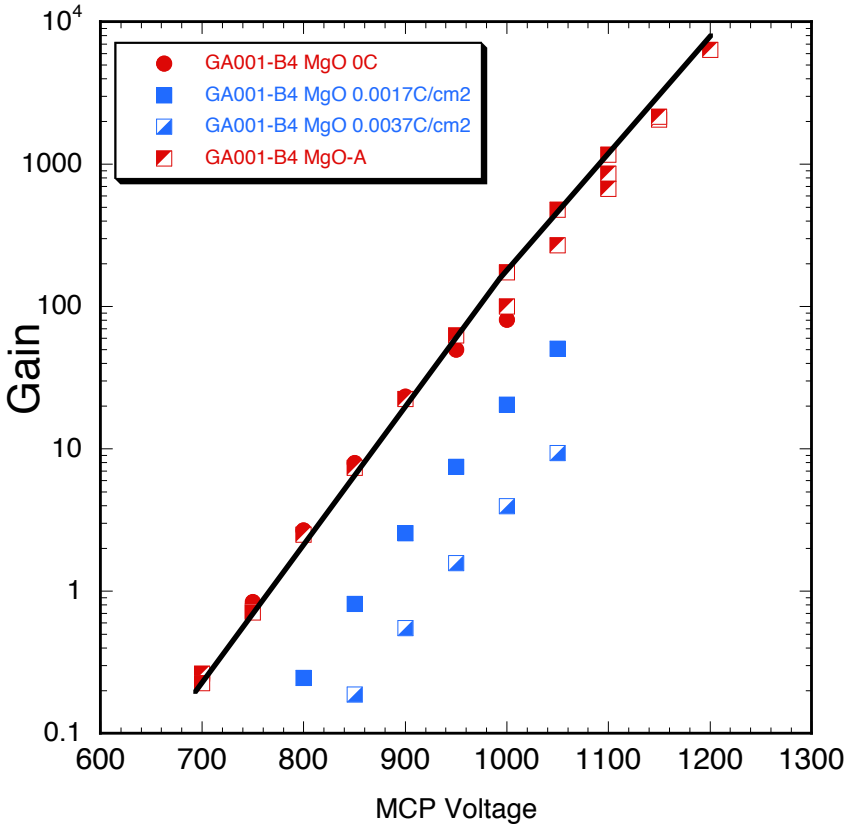


After 10 days at poor vacuum (rose to 400mTorr) the gain is higher, at the operating voltages (~900v, ~ 50%), then after 2 hours at dry N_2 the gain drops slightly (10% @ 900v). After 41hr and 148hr dry N_2 exposures nothing changes.

ALD SEY Layer-MCP Gain Behavior

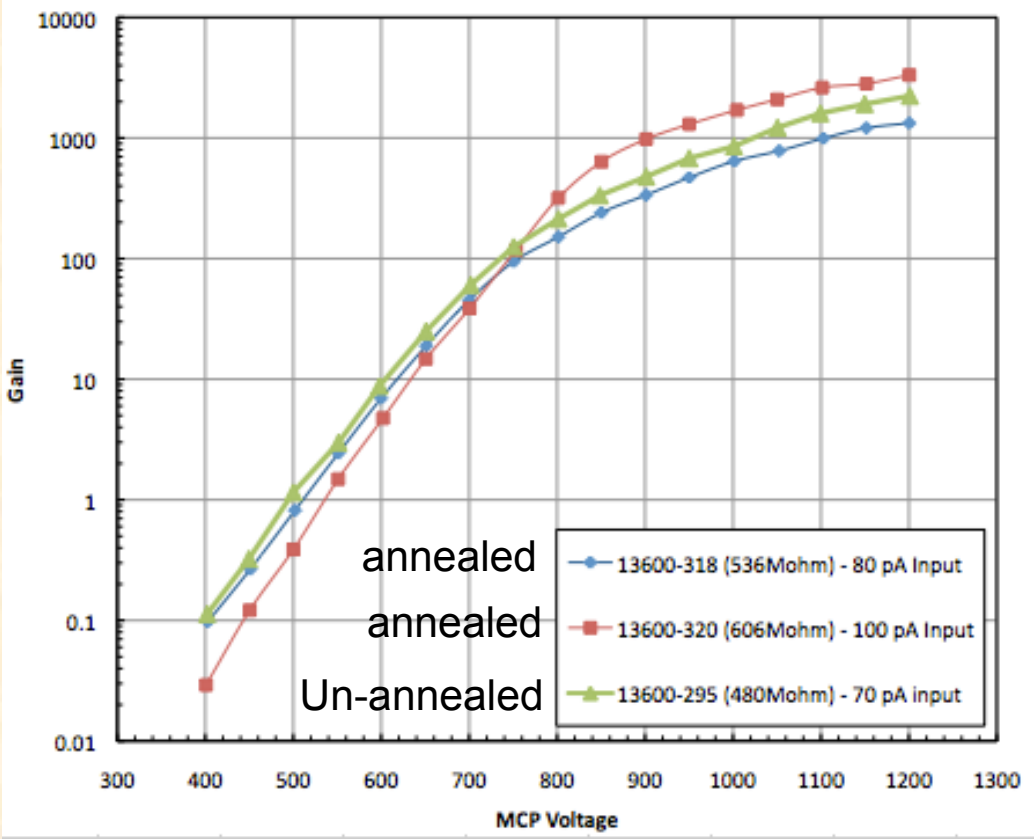
With/Without annealing MgO gain **~same……..BUT**

Without annealing MgO gain drops badly



MgO (not annealed) scrubbing on standard 6μm pore 80:1 L/D MCP.

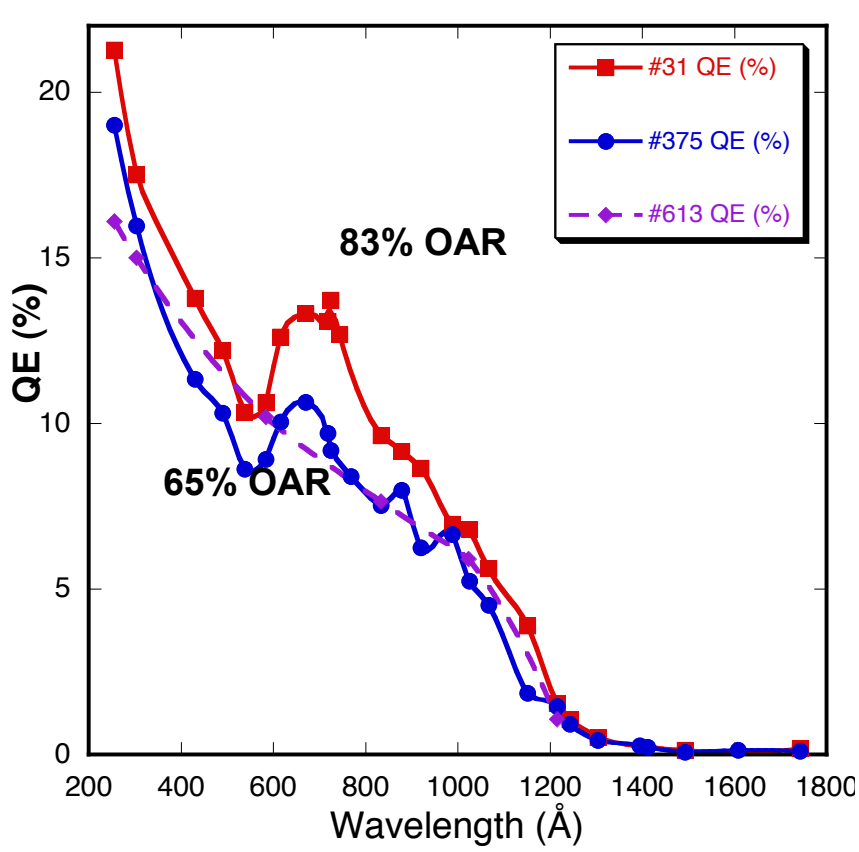
With/Without annealing Al_2O_3 gain **~same**



Gain for Al_2O_3 annealed/un-annealed Chem 1 MCPs

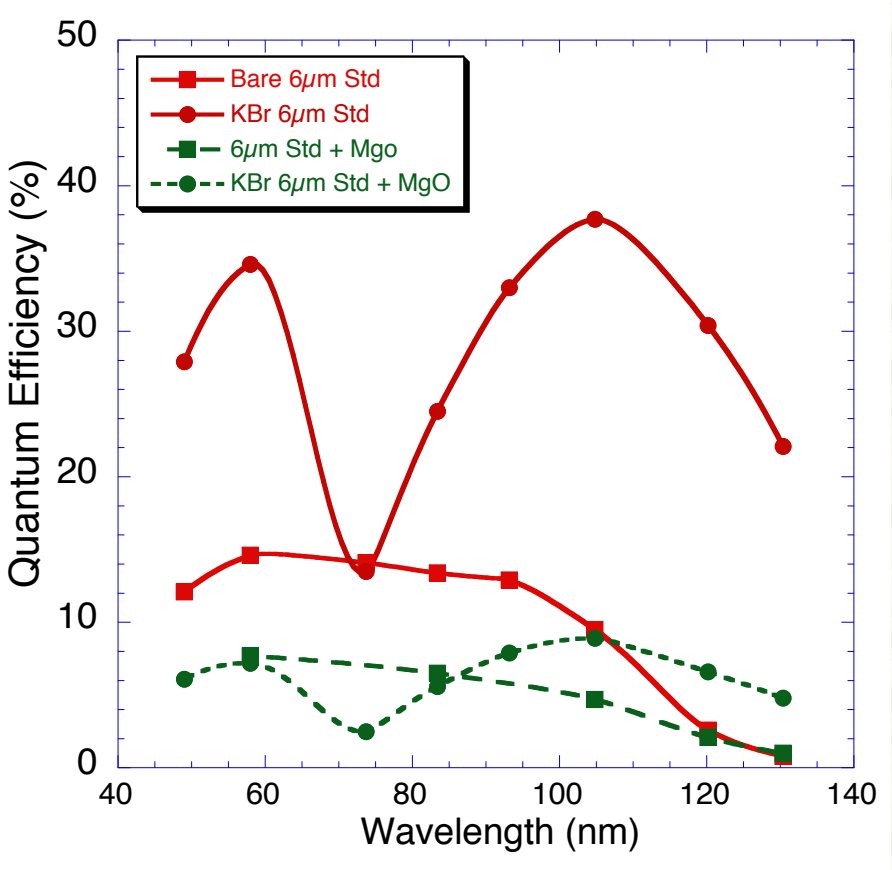
ALD Layer-MCP Quantum Efficiency

ALD Al_2O_3– borosilicate MCP photon counting quantum detection efficiency, normal NiCr Electrode, 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 – MgO secondary emissive layer on normal MCP gives bad "bare" QE. KBr deposited on this gives bad QE.



QE for bare MCP is good and gives good QE with a KBr photocathode.

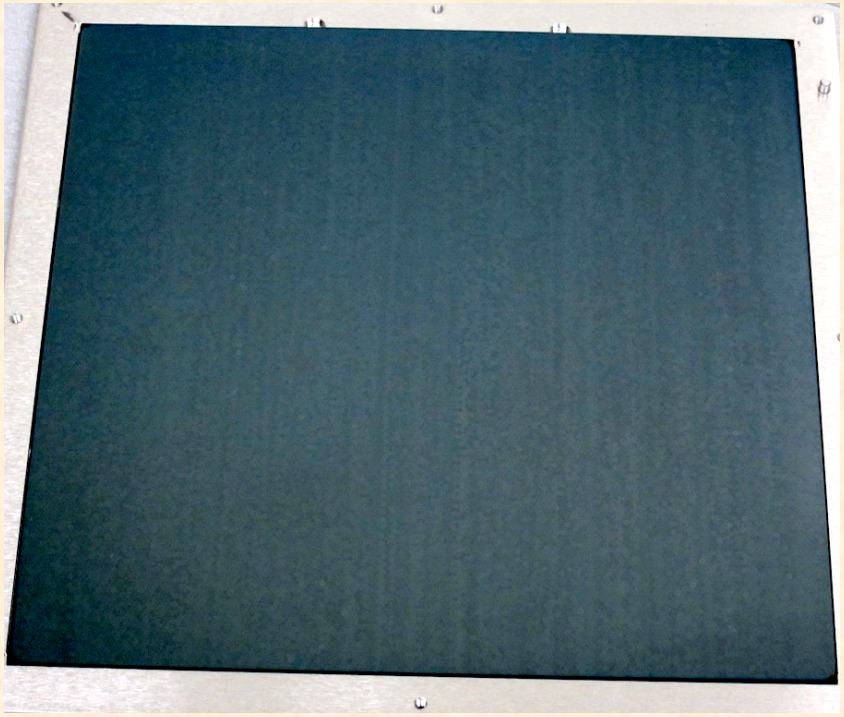
33mm ALD-MCP Test Summary

Achievements and implications

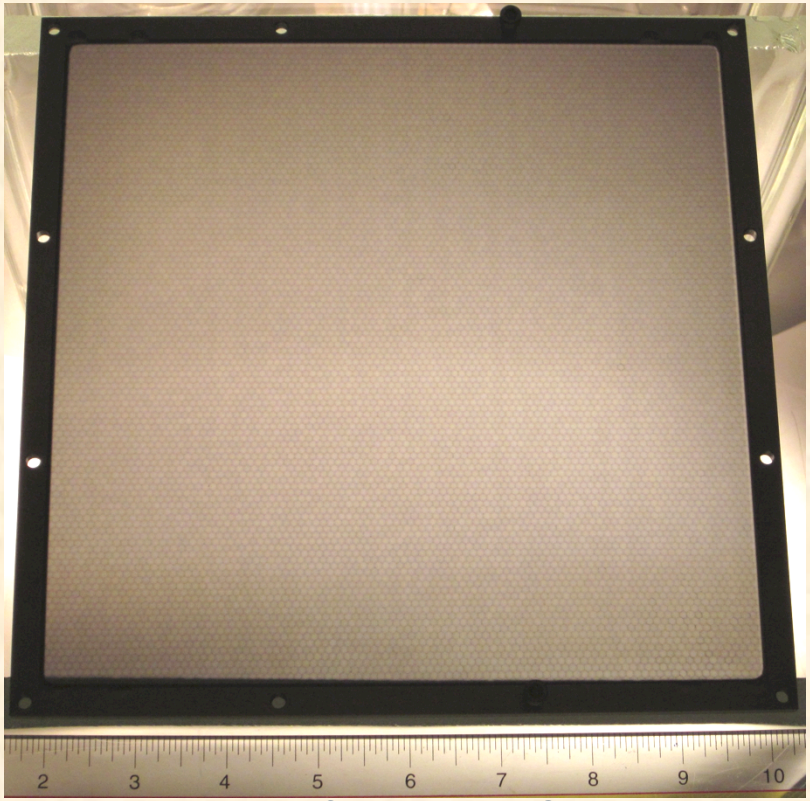
- Micro-capillary arrays in borosilicate glass with 20μm material offer a robust, adequately low distortion/defect substrate for atomic layer deposited MCPs, and quality is still improving.
- Gain, imaging, and detection efficiency same as standard MCPs
- Background rate is a factor of >4 better than 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 MgO 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) 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.



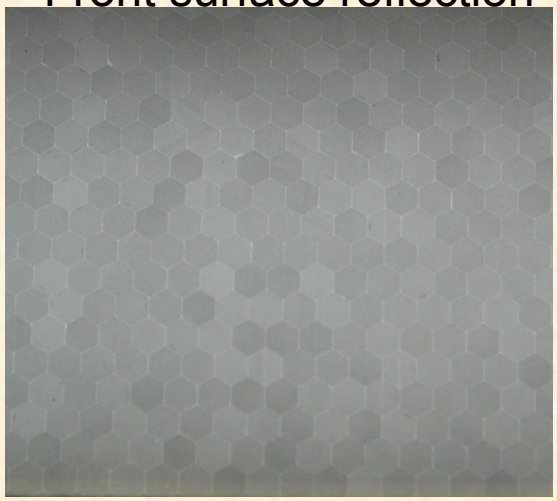
20cm ALD MCP photo showing the patterns of multifibers and stacking arrangement.

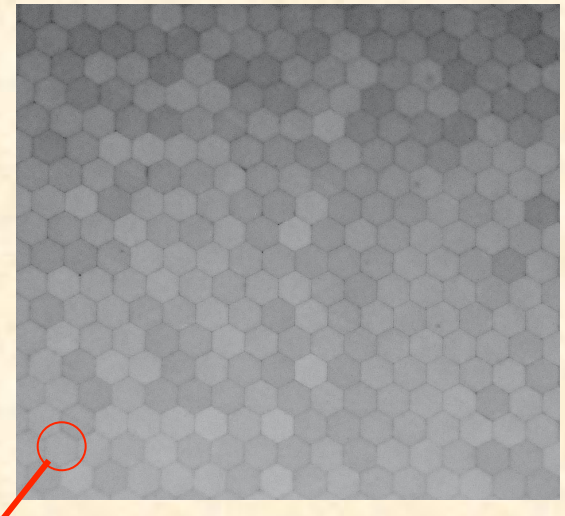


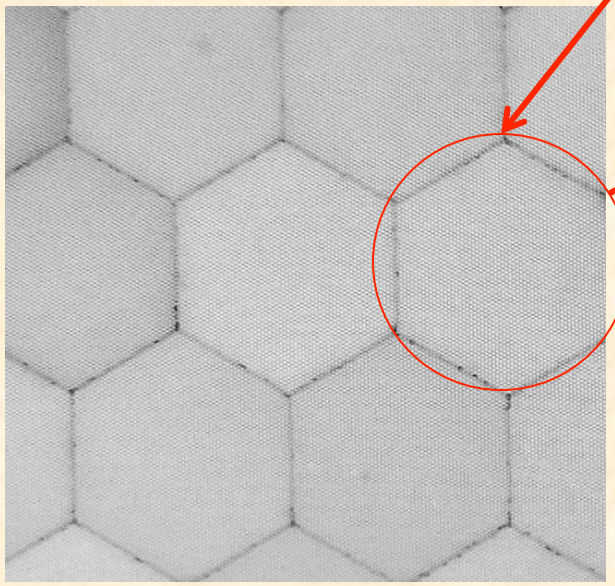
Backlit photo of a 20cm MCP showing the multifiber stacking arrangement.

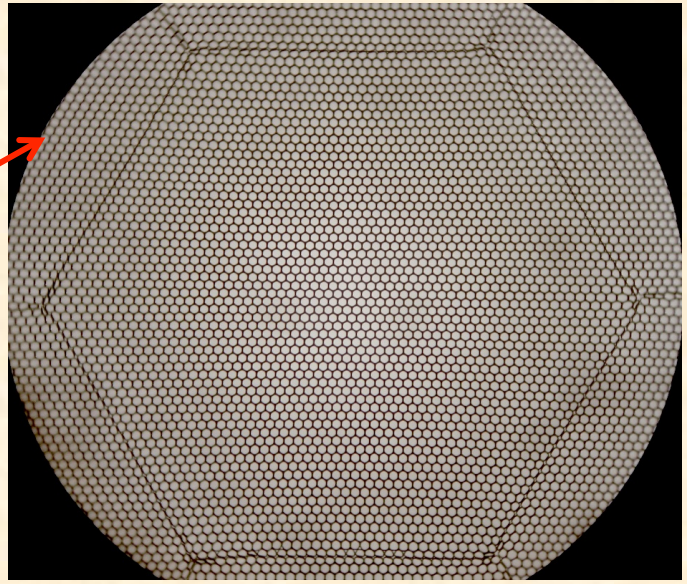
Borosilicate Substrate Atomic Layer Deposited Microchannel Plates

Front surface reflection







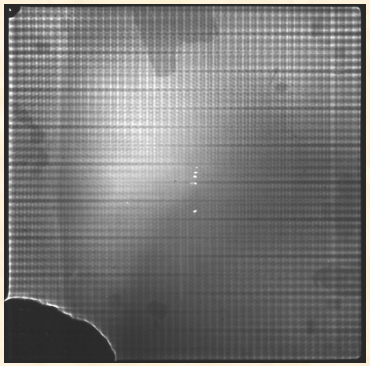
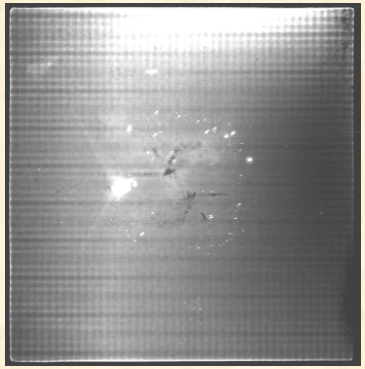
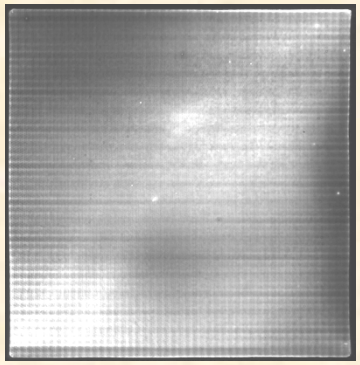
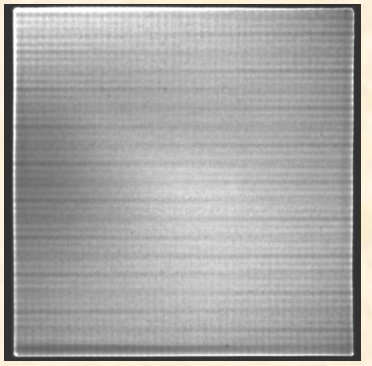
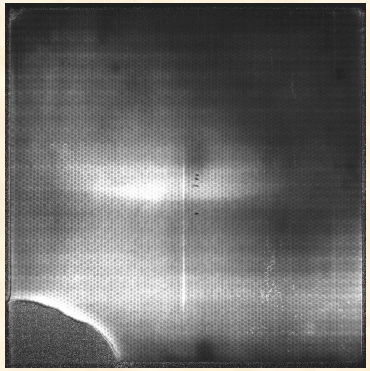
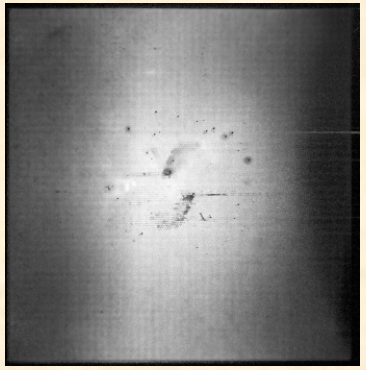
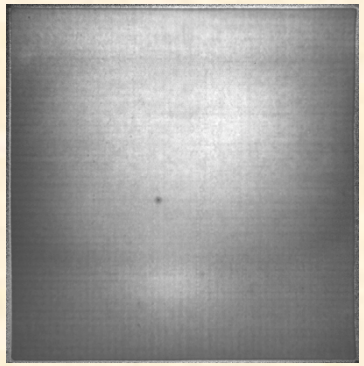
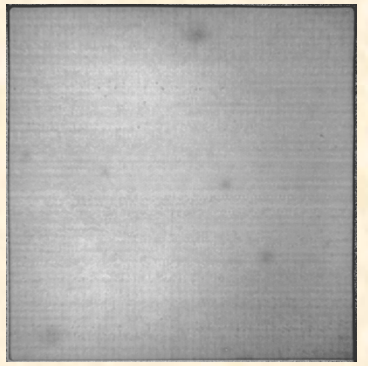
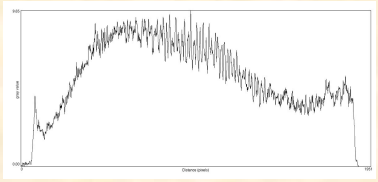
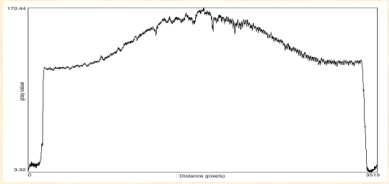
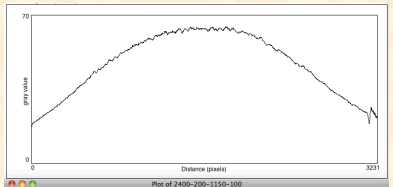
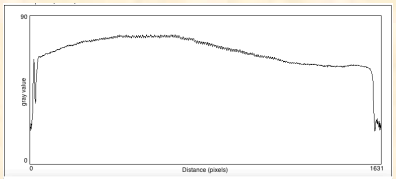
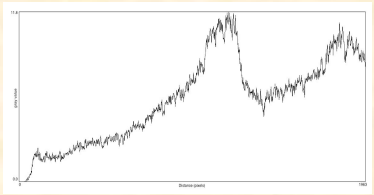
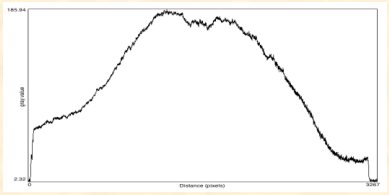
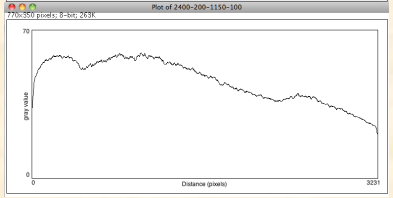
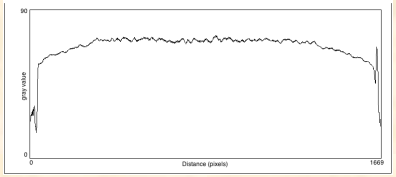


Visible light transmission for a 20 μm pore 65% open area borosilicate micro-capillary ALD 20cm MCP.

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

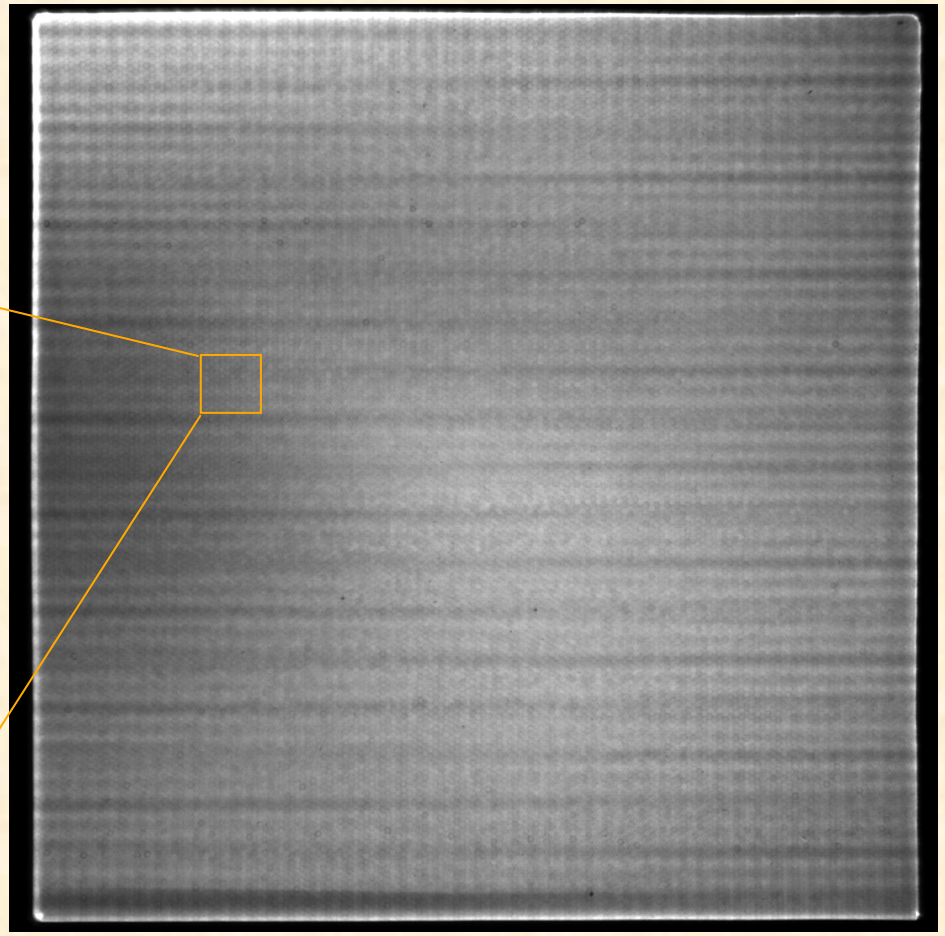
Pore distortions at multifiber boundaries, otherwise very uniform.

20cm ALD MCP Development Progress

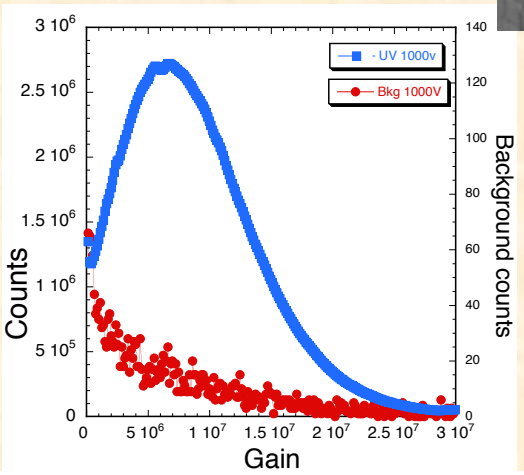
	11874-216 on 218 10/2011	12258-536 on 544 2/2012	13600-015 on 010 6/2012	13600-089 on 081 11/2012
UV Image				
Gain Map				
Gain uniformity X				
Gain uniformity Y				

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.

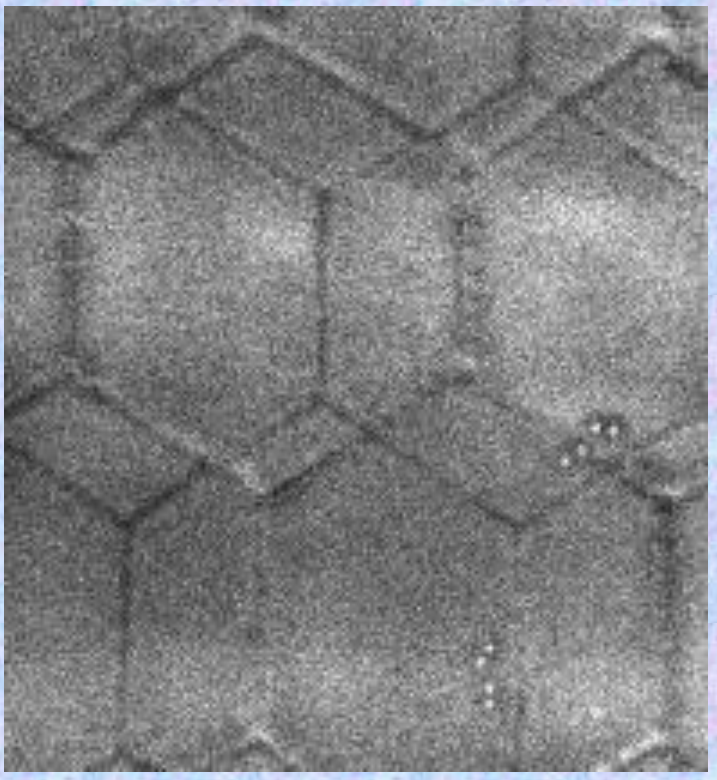
8” 20µm MCP Pair High Resolution Gain Map

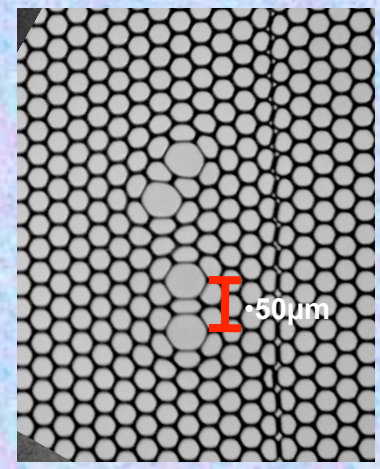
Bottom MCP
Bias direction

Top MCP
Bias direction

MCP 13600 – 016, 102 MΩ – Top

MCP 13600 - 016, 109 MΩ - Bottom





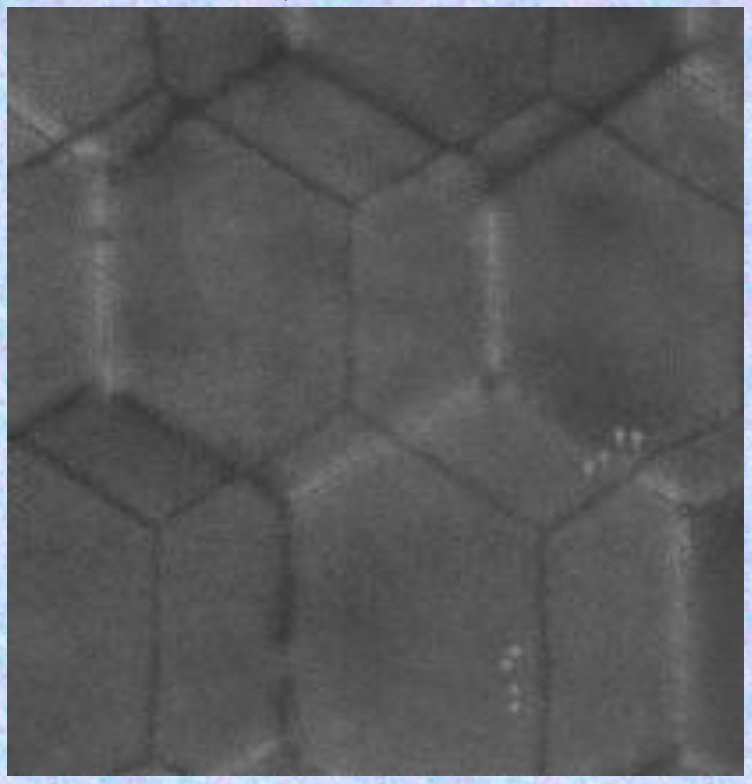


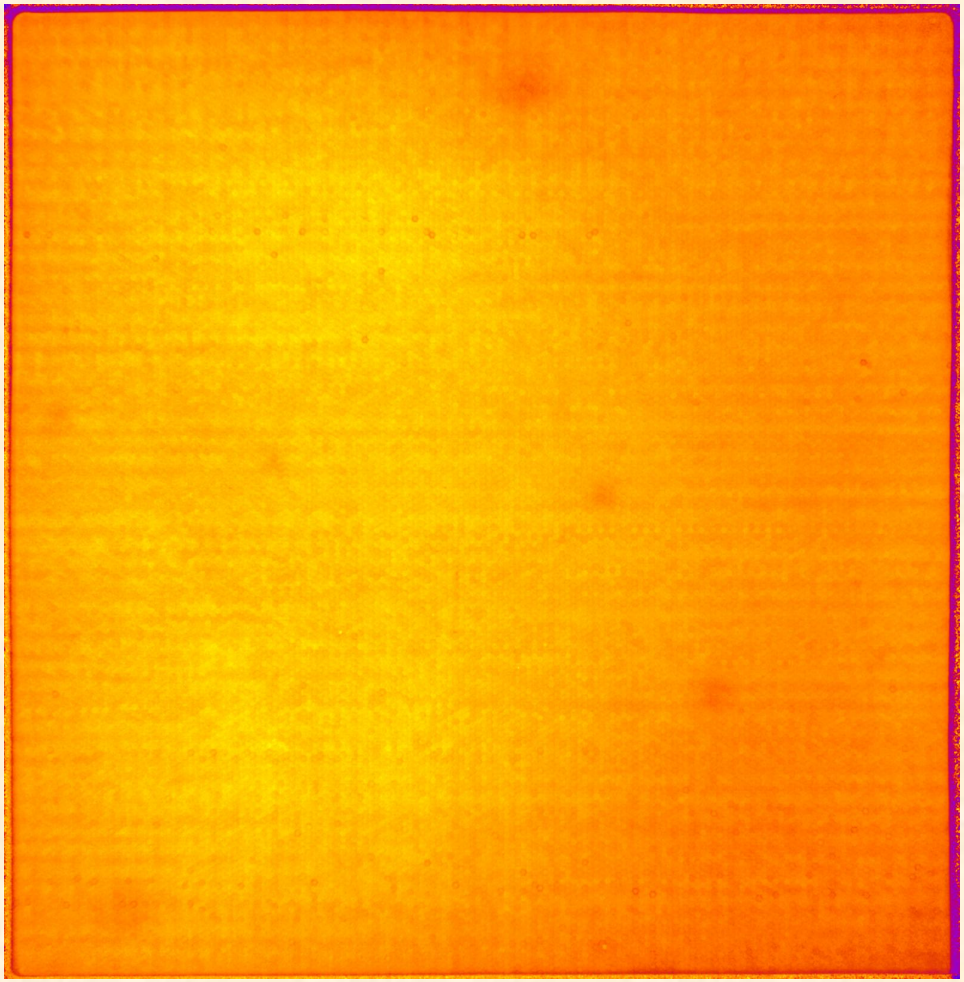
Image with 12µm pixels

Gain map with 12µm pixels

The repeating four large pore pattern is resolved and shows they have higher gain and higher Brightness, effectively 40µm pores with 30:1 L/D.

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

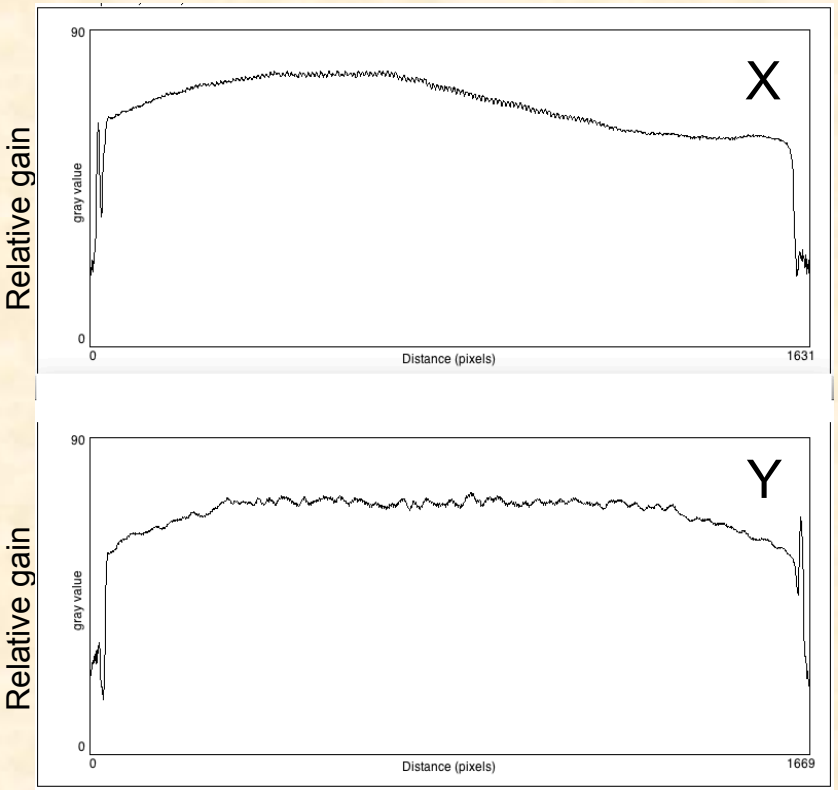
Mean gain ~7 x 10^6



8” MCP pair average gain map image

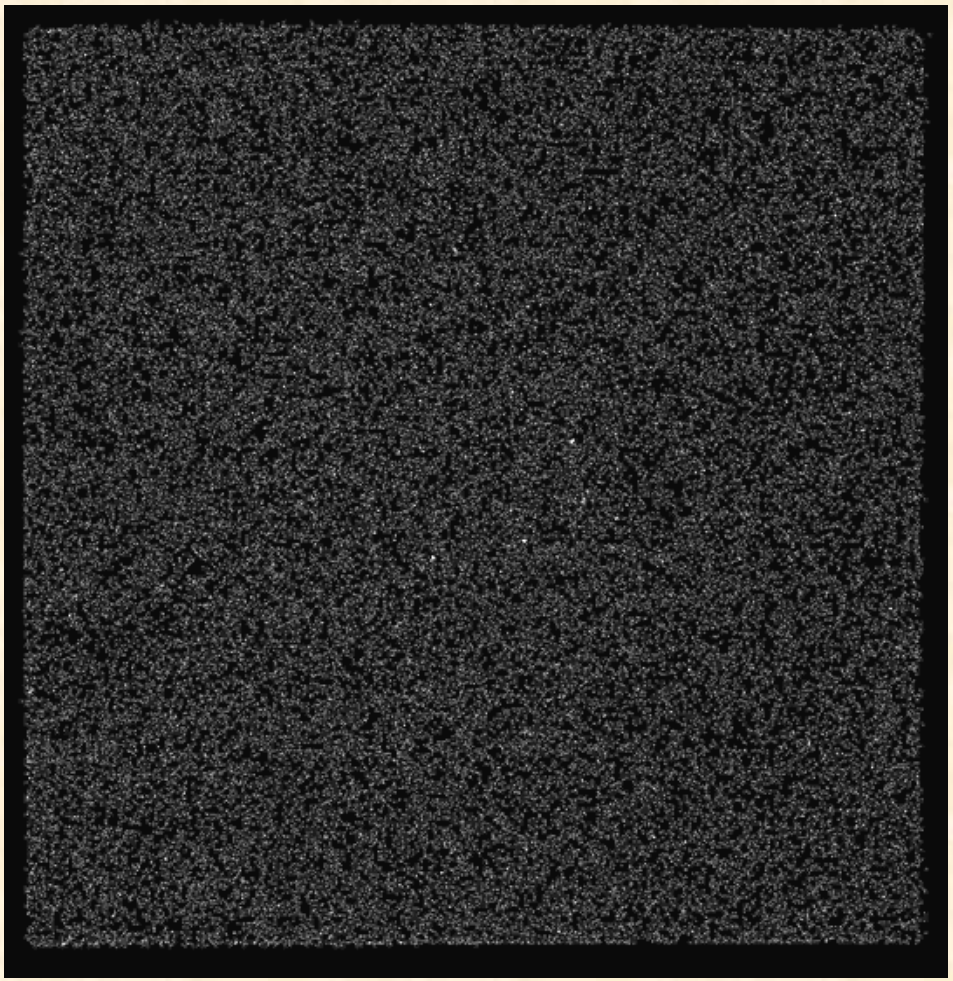
20µm pore, 60:1 L/d ALD-MCP pair.

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.
- MgO 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 Test Plans

- 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

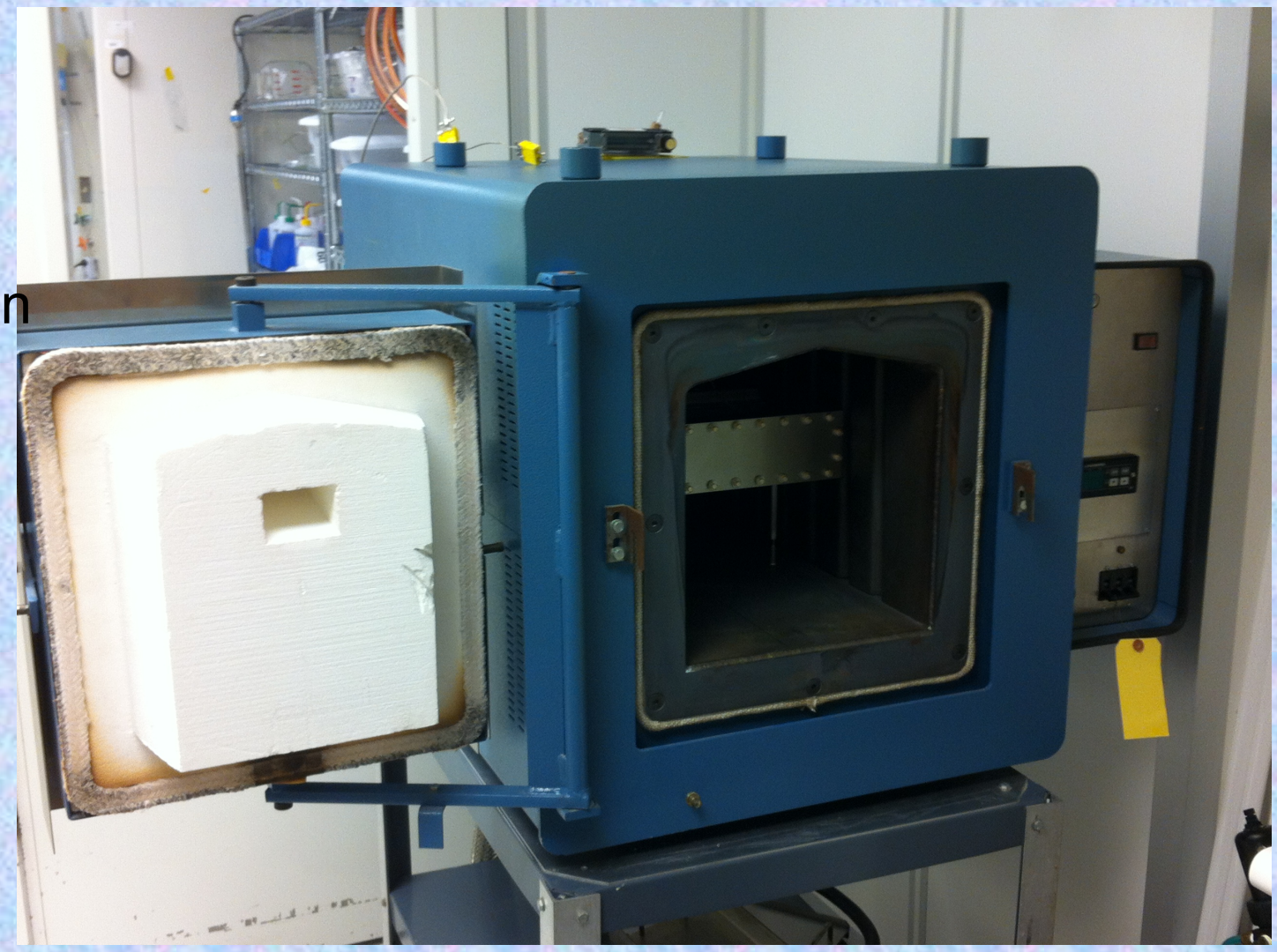
- Selection and implementation of MCP pairs for the first complete sealed tube process runs

Backup Viewgraphs

Innovative Flame Annealing of MCPs at SSL

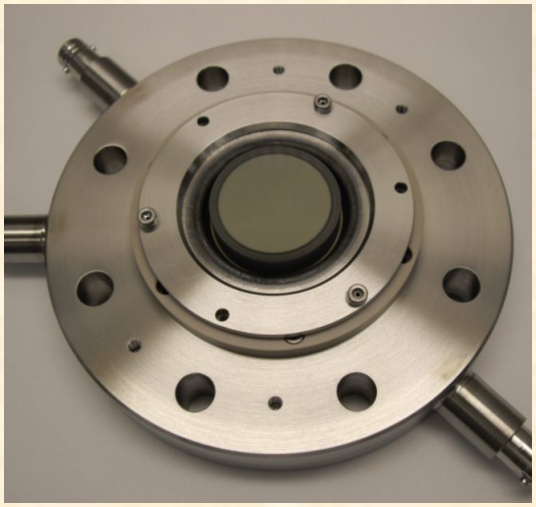
1200°C Annealing Furnace with UHV Insert

Going through final commission tests. Should be a clean, but slow, means to anneal MCPs.

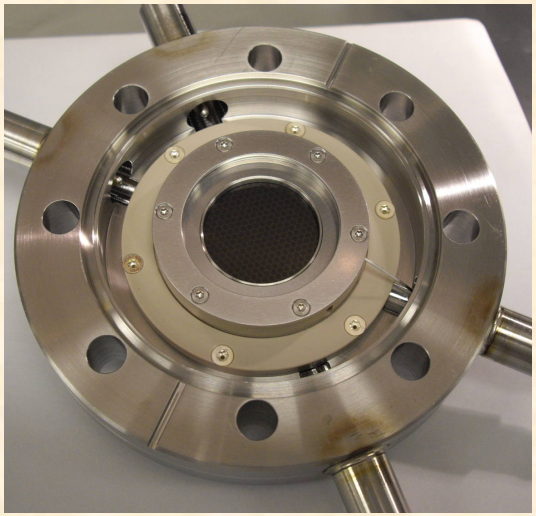


XDL & Phosphor Test Detectors
33mm MCP Pair and Single MCP Tests

Double chamber UHV test station

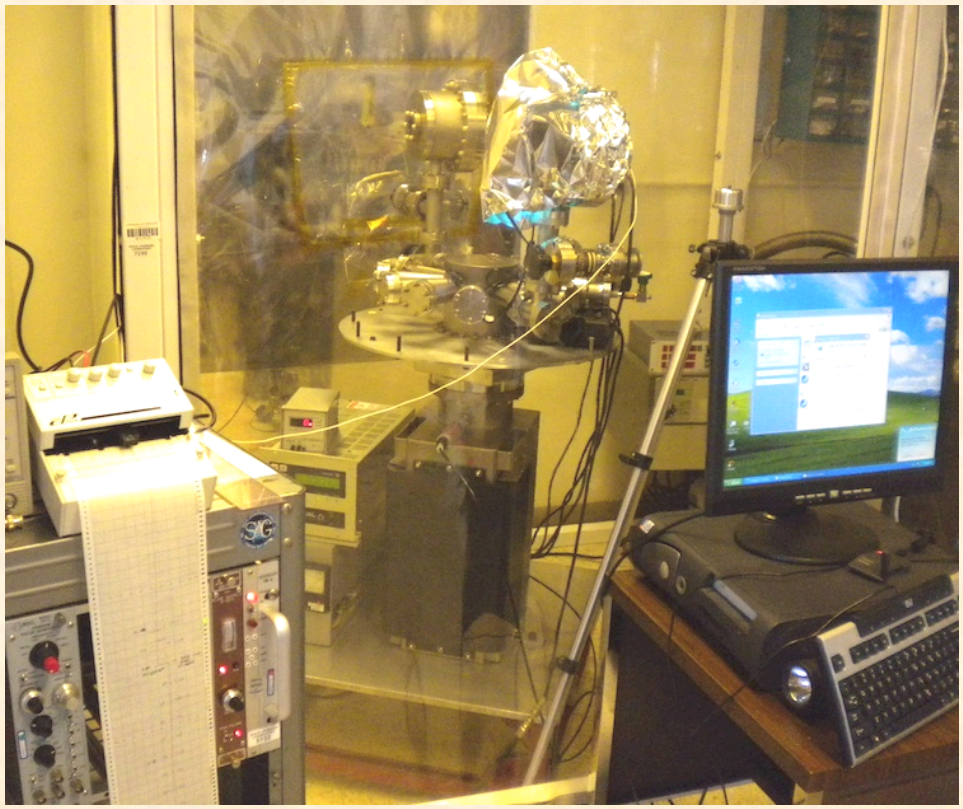


25mm phosphor screen detector with Nikon camera/electrometer

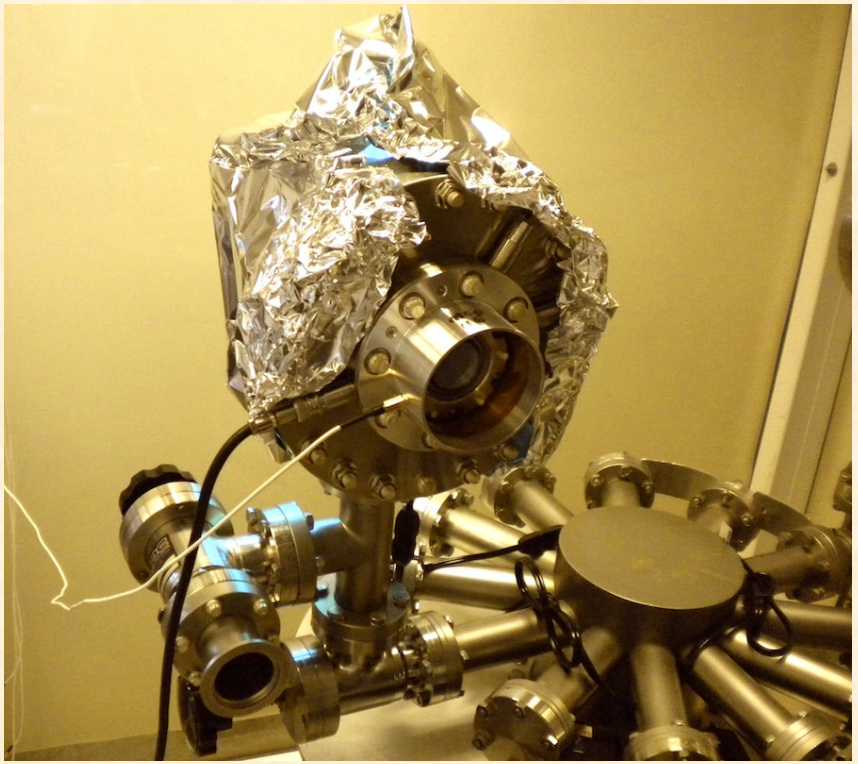


25mm XDL photon counting detector with Amp/TDC and PC Acq/display

33mm MCP Bake/Lifetest Test Facilities

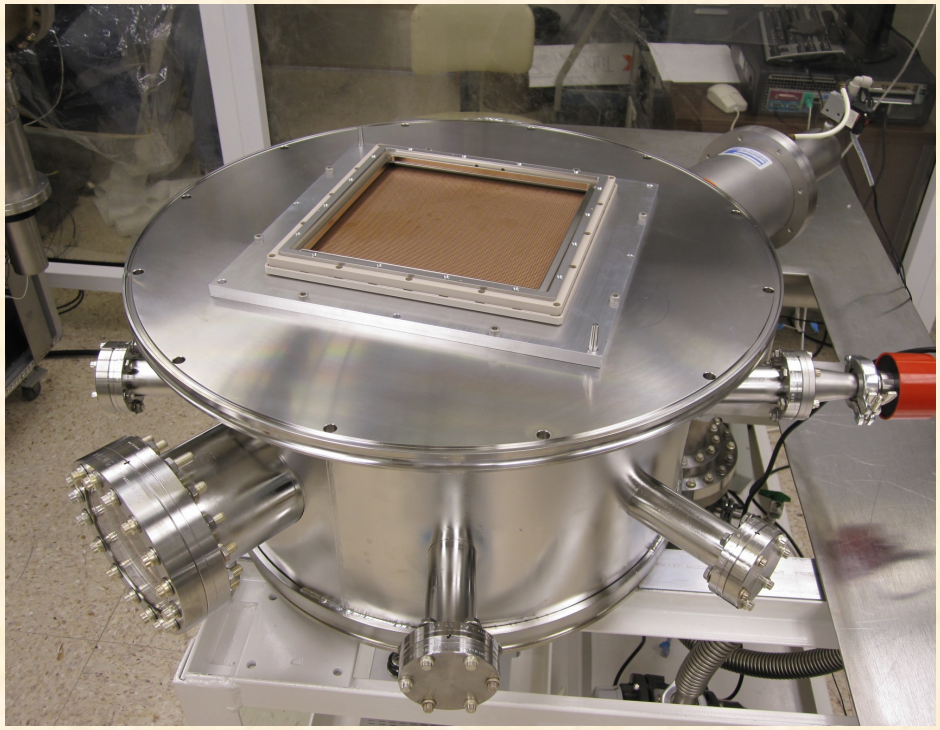


Multiple port UHV lifetest station. Two ports set up for 33mm MCP "burn-in" at ~5 x10^{-9} torr, with UV lamps, electrometer & recorder

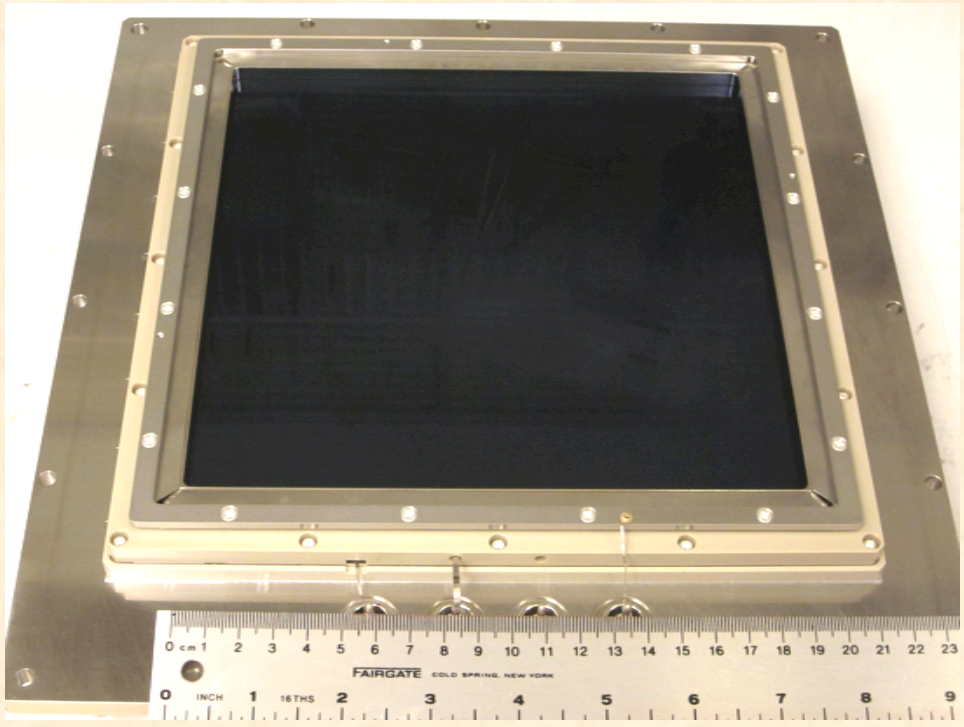


Scrub heads have phosphor readout or XDL. Bake to 350°C, measure outgassing with RGA. Can do imaging or DC charge.

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.



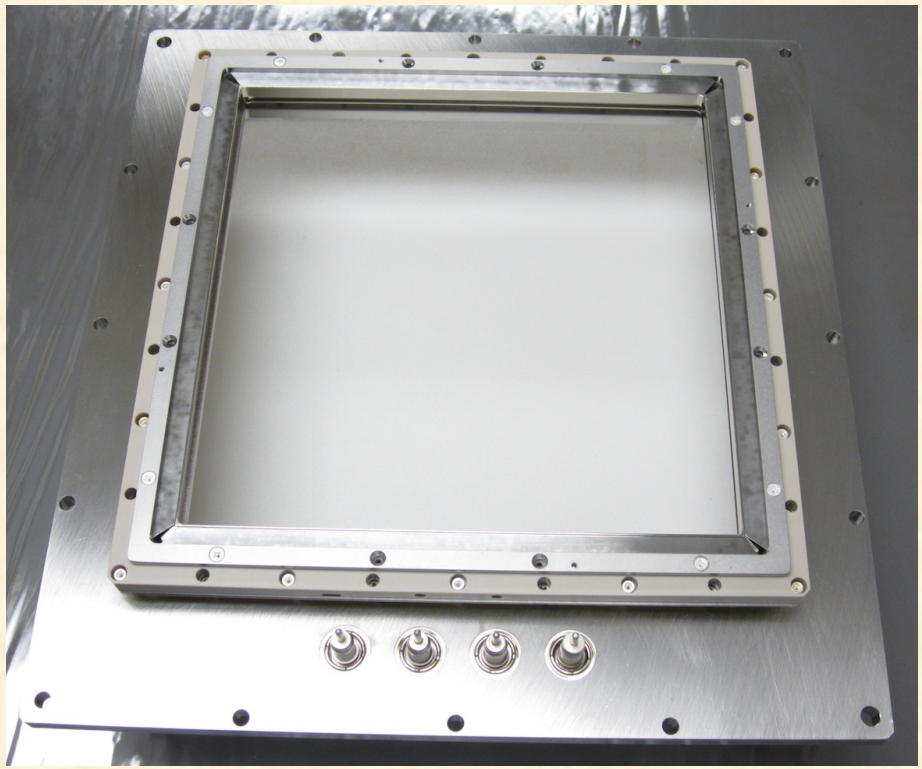
20cm electroded ALD 20μm pore MCP pair in a photon counting detector assembly with a cross delay line imaging readout.

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