ARRADIANCE®

Characteristics of Substrates for MCP's

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Technical Overview: What is an MCP (Microchannel Plate)?

Characteristics

- Amplifies electron signal through secondary electron cascade
  - Very low noise
  - High spatial resolution (~10um FWHM)
  - Fast Response (~100ps FWHM)
  - High Gain (>10^4)
- Lead-glass structure with 10 million microchannels
- Event counting
- Very low dark current
- Sensitivity to photons, ions, electrons neutrals, neutrons, alpha particles

Limitations

- Lifetime – gain degradation
- Non-uniformity and distortion
- Manufacturing Process
  - Limited material / design flexibility (Pb)
  - Process variability; low yield
  - 40 year old process technology
- Counting rate (<100 MHz)
- photocathode for visible range
- High voltage, Vacuum
- Fixed pattern noise
- Not high temperature compatible
- Small pore MCPs and large area MCPs are expensive to produce

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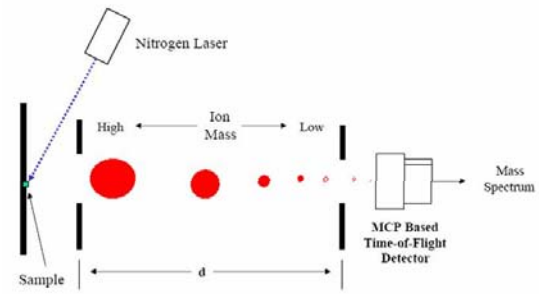
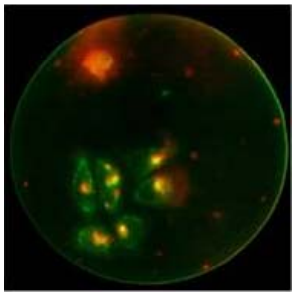
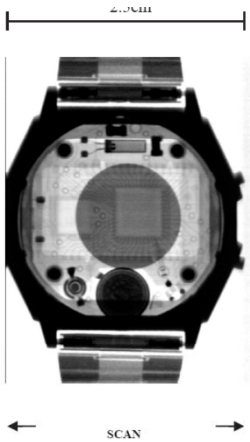
Areas of MCP detector applications

- Night vision goggles
- Mass spectroscopy
- Astrophysics
- Synchrotron instrumentation
- Biomedical research (FLIM, FRET,...)
- X-Ray and UV photon detection
- Neutron radiography and Bragg edge spectroscopy







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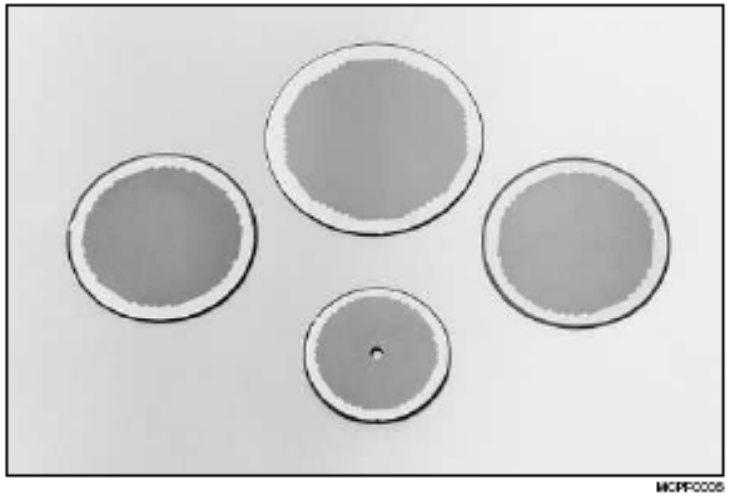
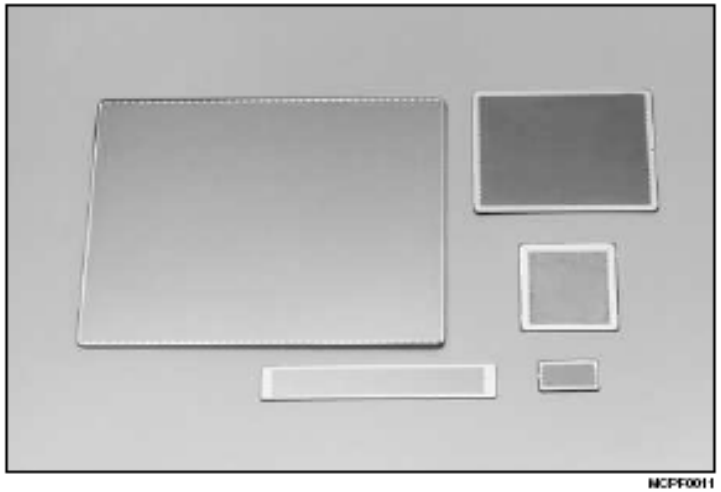
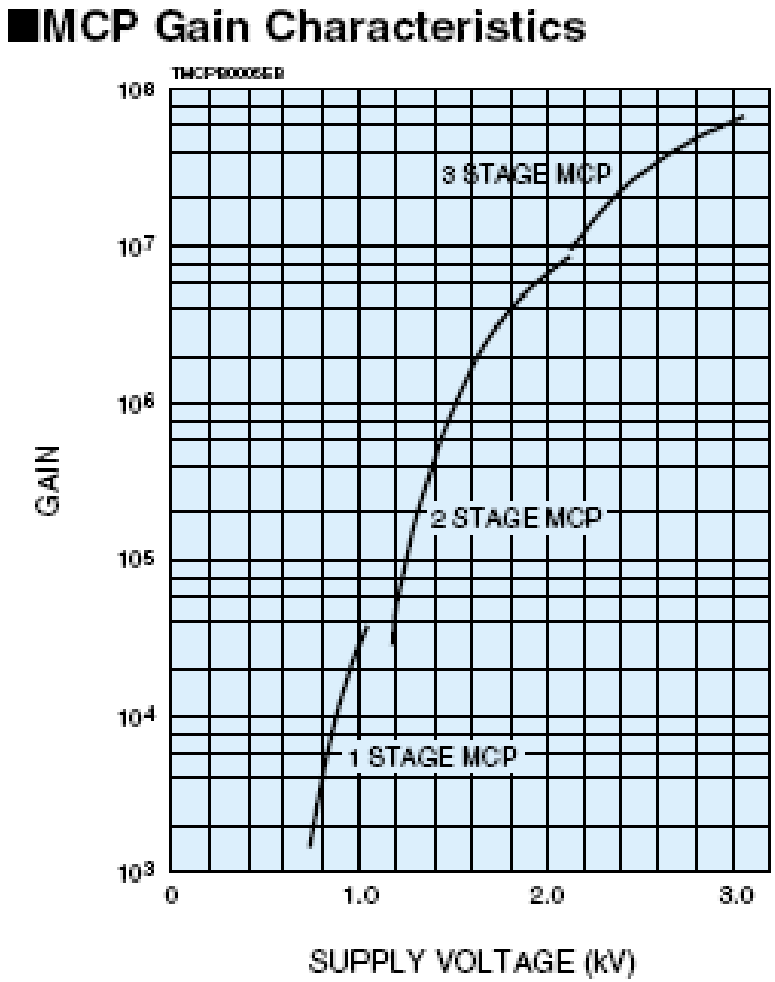
Commercial MCPs: geometry and gain







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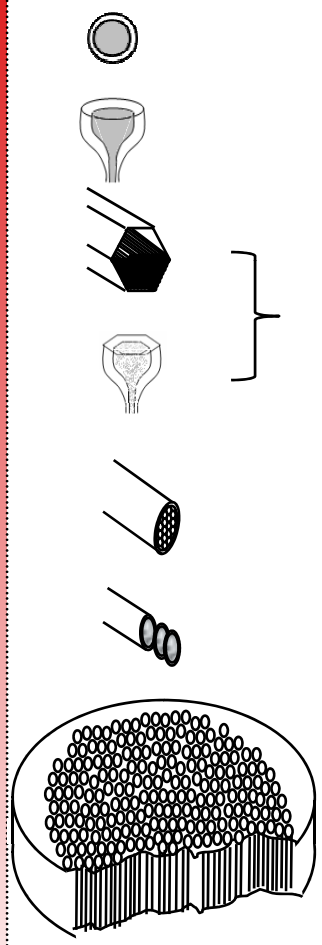
Critical MCP processing: Manufacture

Substrate Fabrication



1” Etch-able Core Lead Glass Rod

Draw Tower

Stacked Draw Tower Repeated

Boule 5-100mm Dia

Diced 0.2-0.3 mm thick

Etched Producing >5M 2-10 um pores

TABLE 2

Elemental composition of MCP glass[a].

Z	Element	Weight percent
82	Pb	47.8
8	O	25.8
14	Si	18.2
19	K	4.2
37	Rb	1.8
56	Ba	1.3
33	As	0.4
55	Cs	0.2
11	Na	0.1

[a] Density – 4.0 g./cm^3.

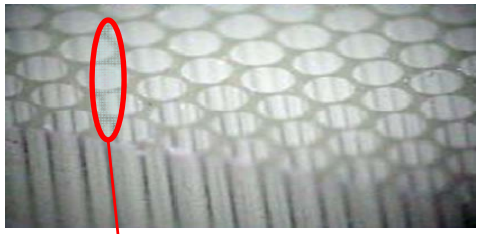
Wiza, Nuclear Inst. & Meth., Vol 162, 1979, 587

(approximate percentages)

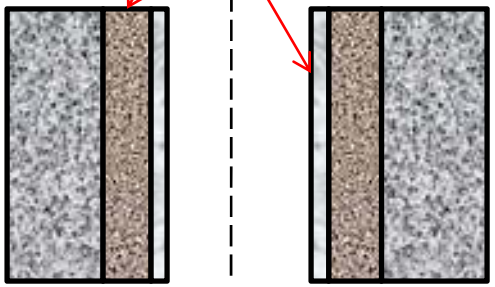
	Conventional 8161 cladding glass	Preferred cladding glass
SiO2	38%	37%
B2O3	0%	2.8%
Al2O3	0.24%	1.35%
Cs2O	0.29%	4.12%
Rb2O	3.7%	0.85%
MgO	0%	0.85%
CaO	0%	2.25%
BaO	2.05%	19.7%
PbO	50.5%	26.6%
Bi2O3	<0.04%	2.48%
As2O3	0%	0.65%
Sb2O3	0%	0.28%
K2O	5.44%	0% (trace)
Na2O	0.34%	0% (trace)
Fe2O3	0.02%	0%

US Pat 6271511

Substrate Functionalize



Furnace H_2 Firing
Both conduction and emission layer produced simultaneously and cannot be optimized independently



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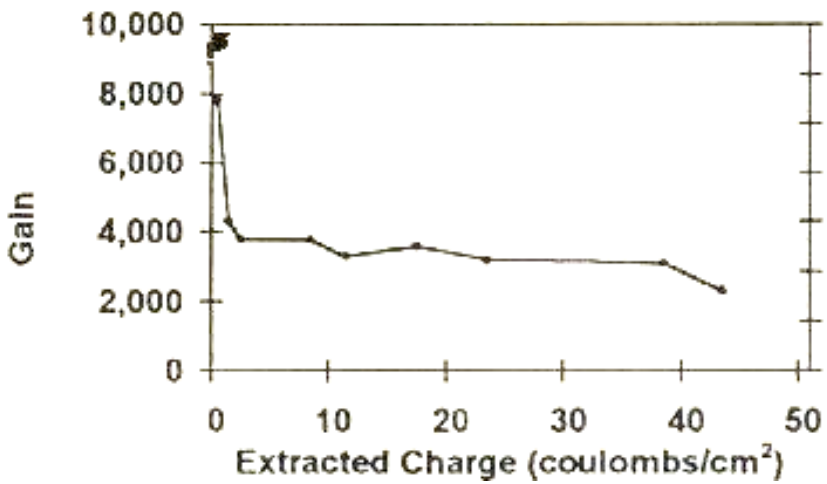
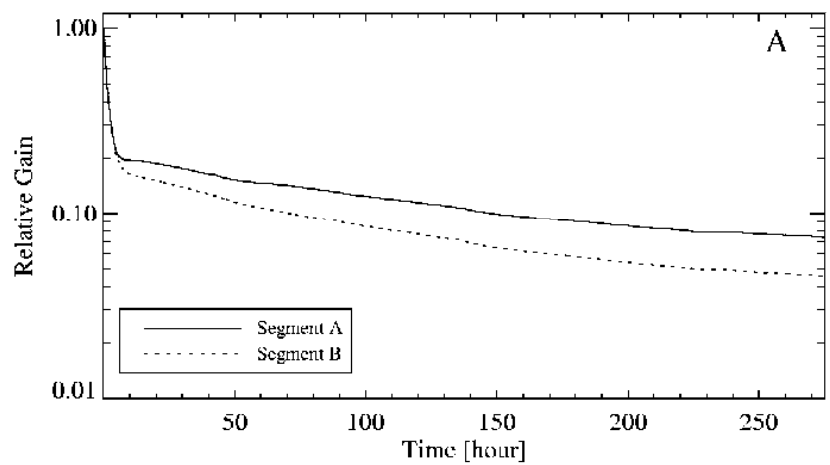
Critical MCP processing: Scrubbing

- "Accelerated" Test conditions (Input Current, Charge extraction rate, duty cycle)
  - Typically High Temp (350C) and High gain operation
- Removes H_2, N_2, H_2O, CO, CO_2, alkalis, residual gases & evil spirits
- Produces stable gain
- Procedures closely held…





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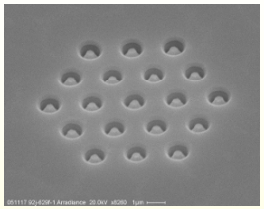
MESA$_{TM}$ Source Components

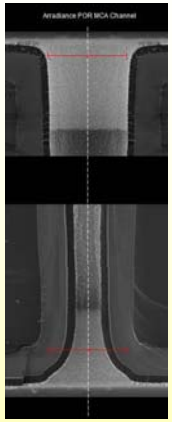
MCA **E**qualized **S**ource **A**rray

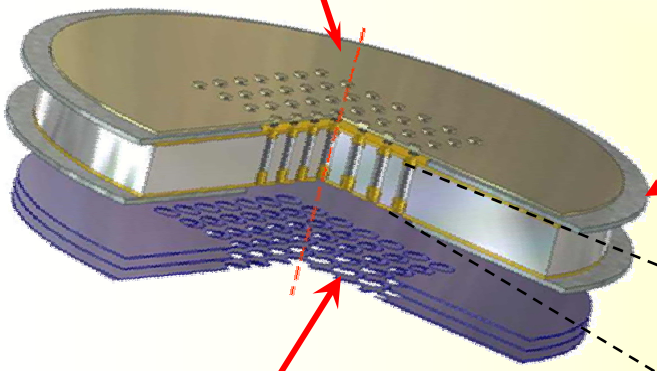
MESA: A switchable densely packed array of bright stable electron beams

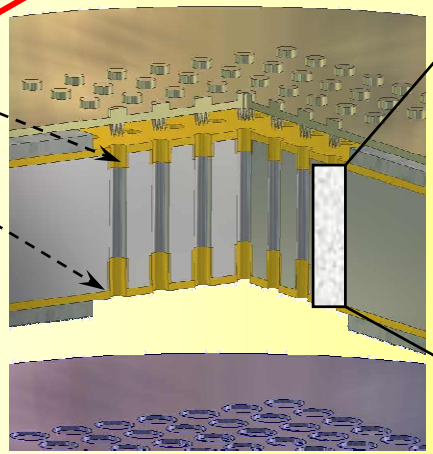
FEA
Field **E**mitter **A**rray
(switchable cold e-source)

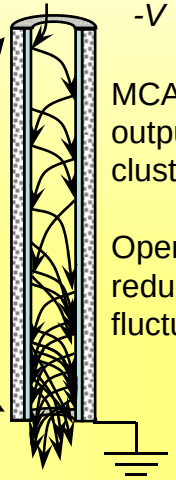


MCA
Micro **C**hannel **A**rray









MCA amplifies current output from each FEA cluster

Operating in saturation reduces FEA output current fluctuation

ELA
Electrostatic **L**ens **A**rray
(Extraction Optics)

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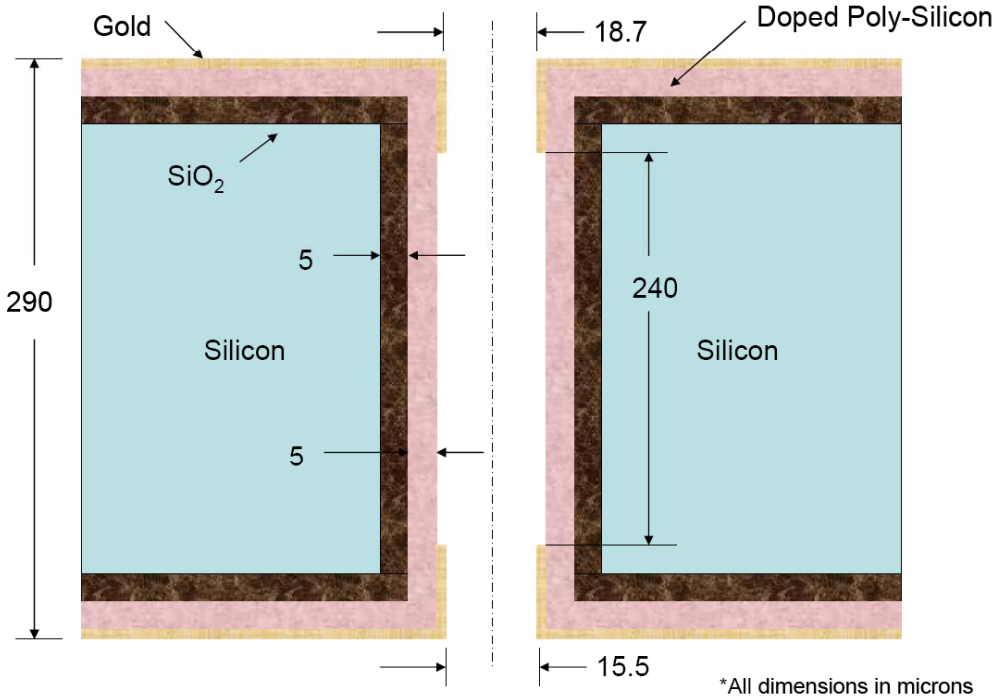
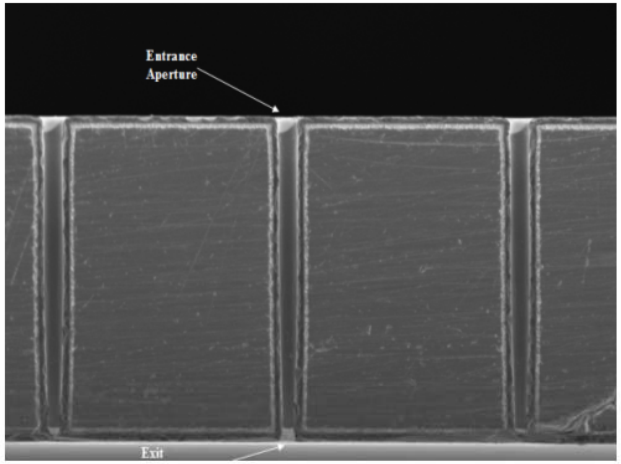
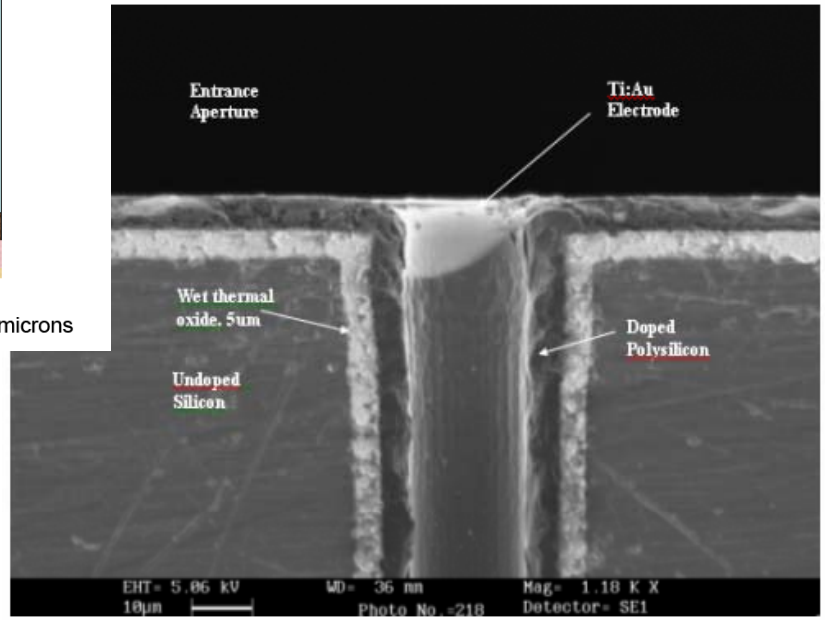
MCA Pore architecture







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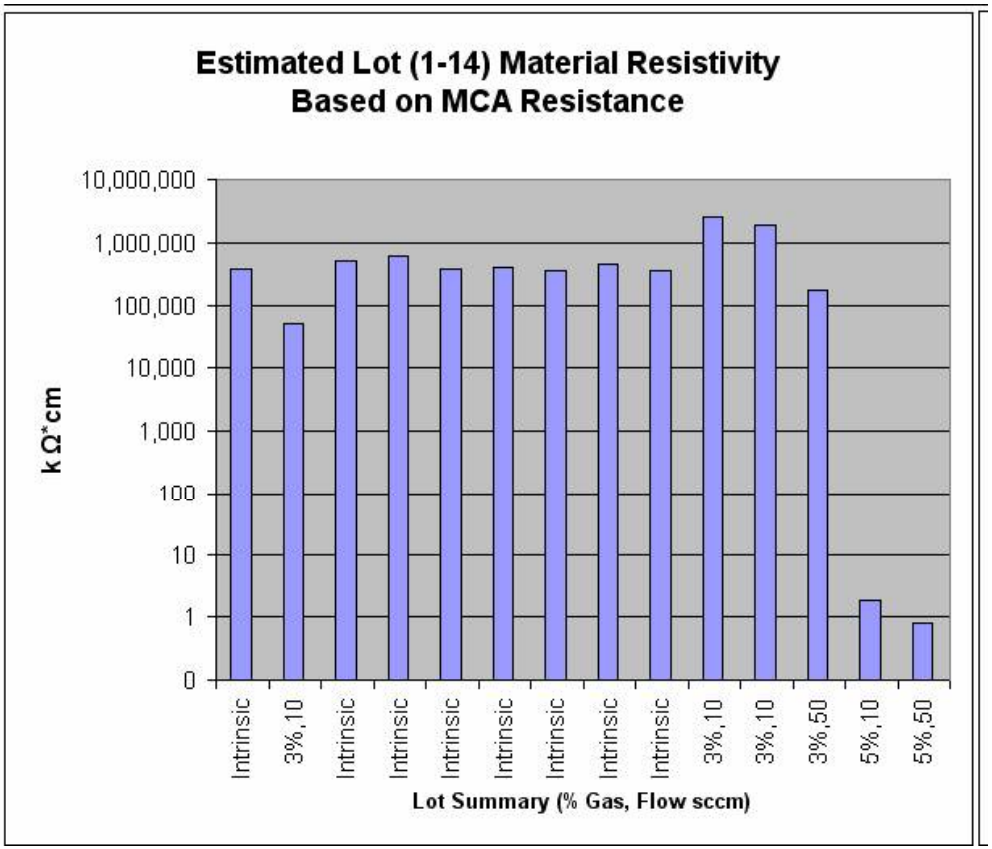
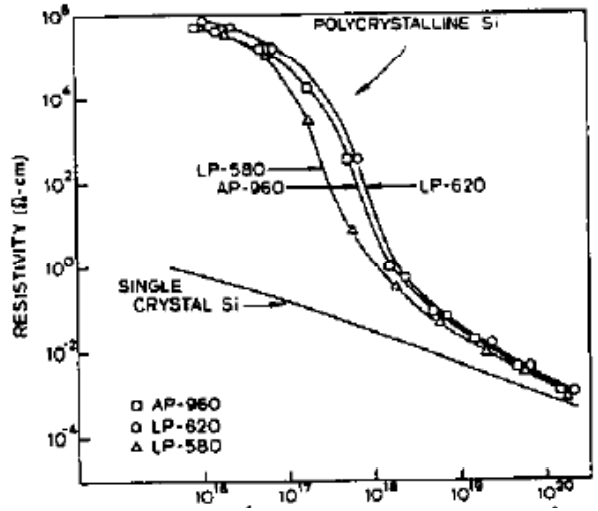
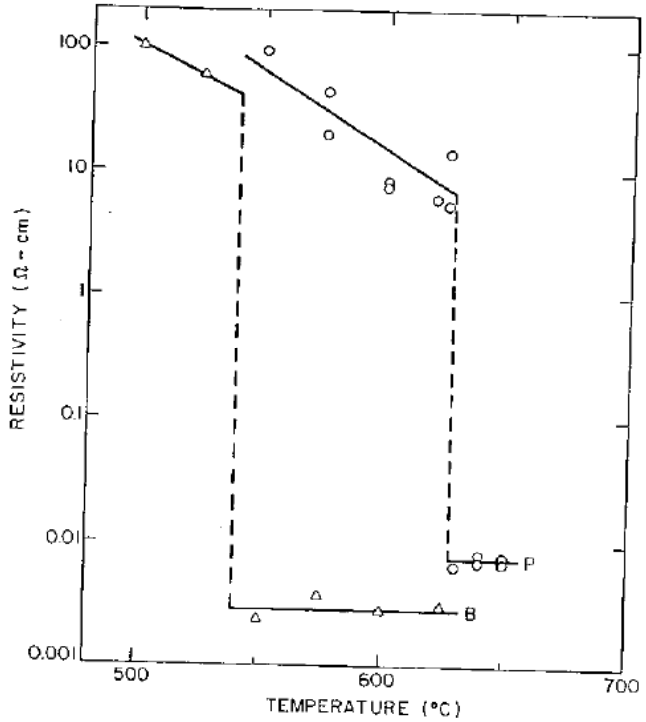
Polysilicon doping for resistance targeting







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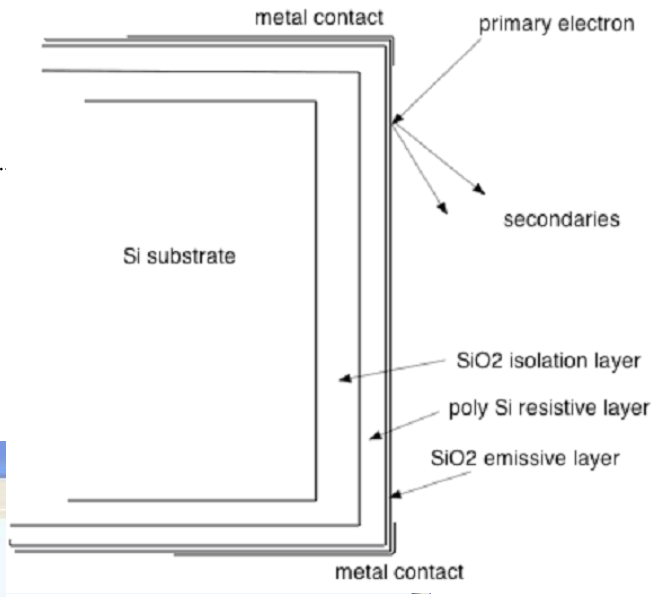
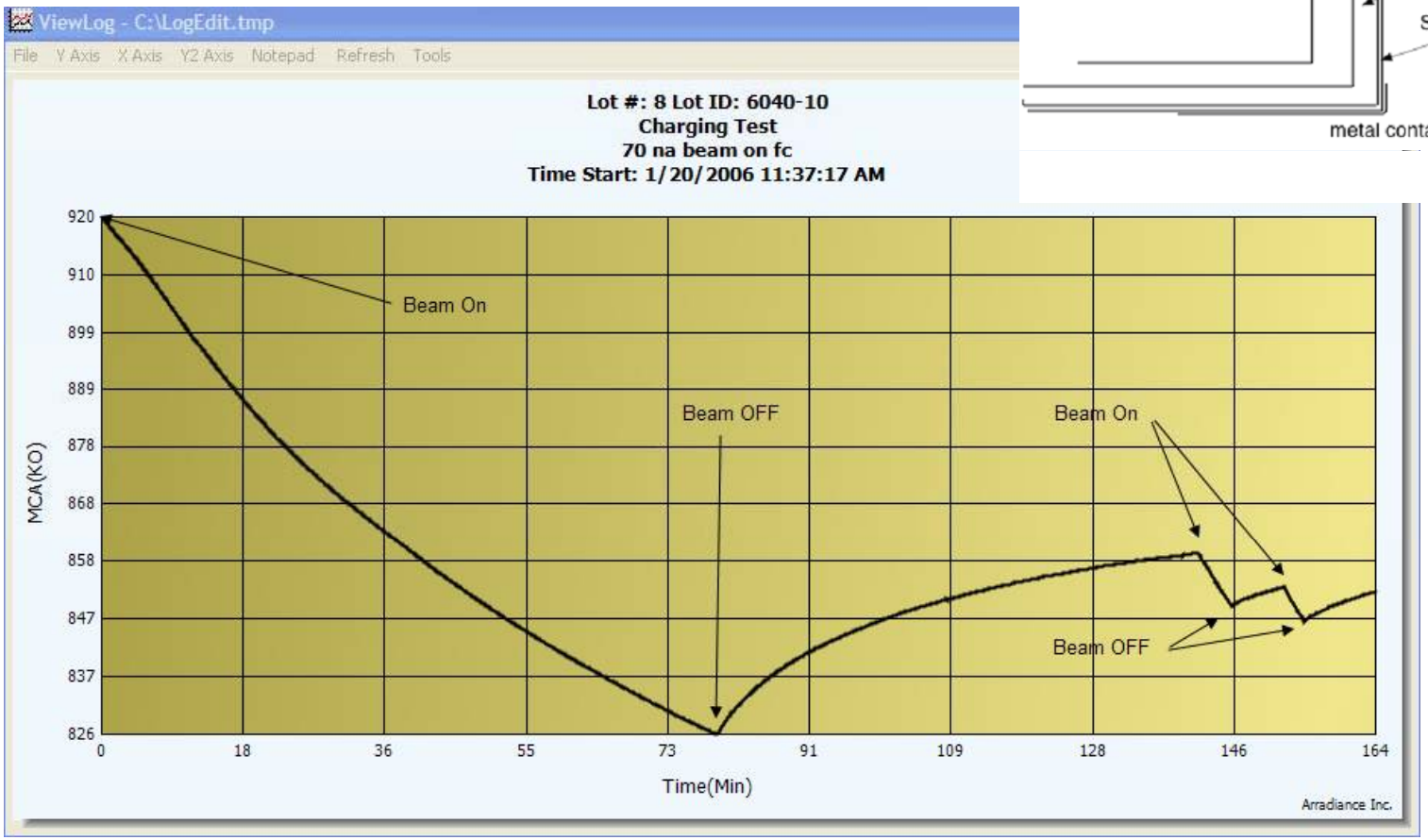
Pore Charging: Effect on Device Resistance





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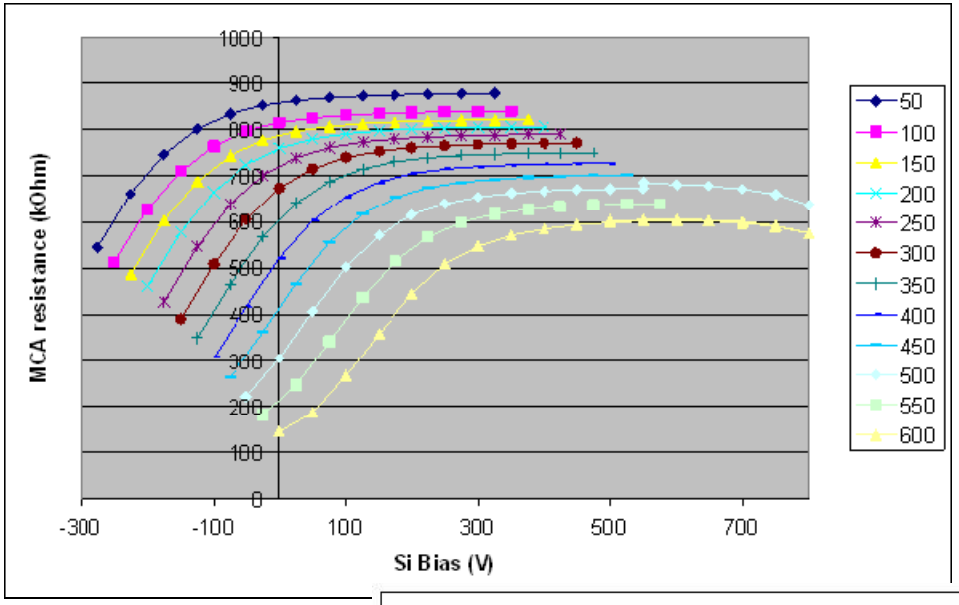
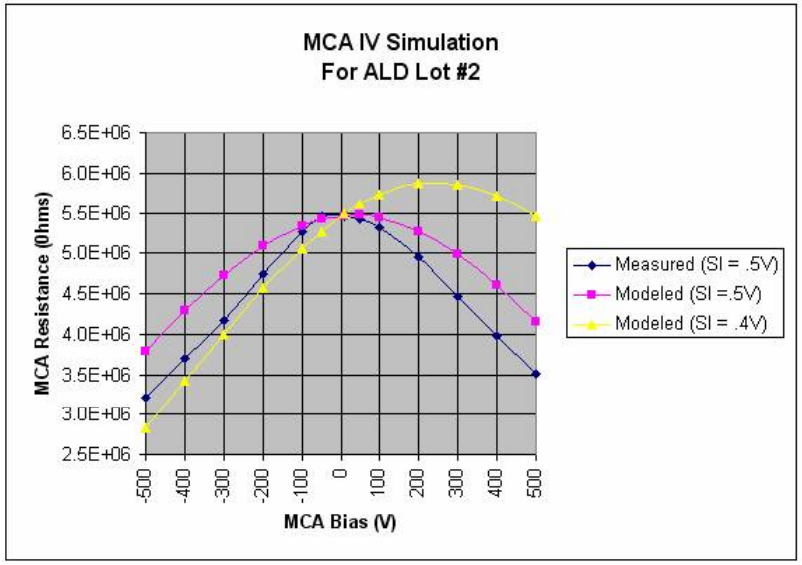
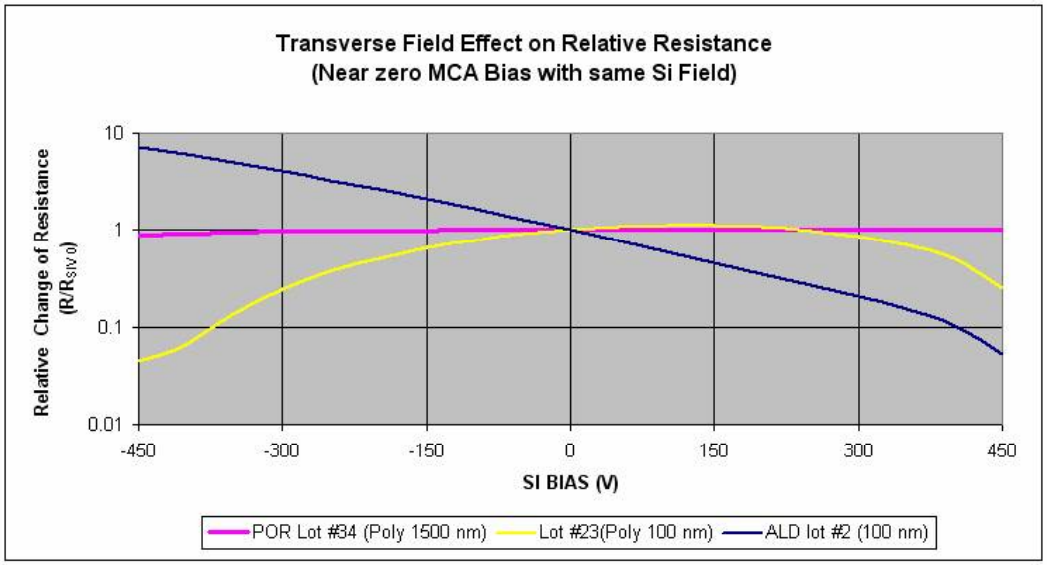
Resistance and Transverse Field







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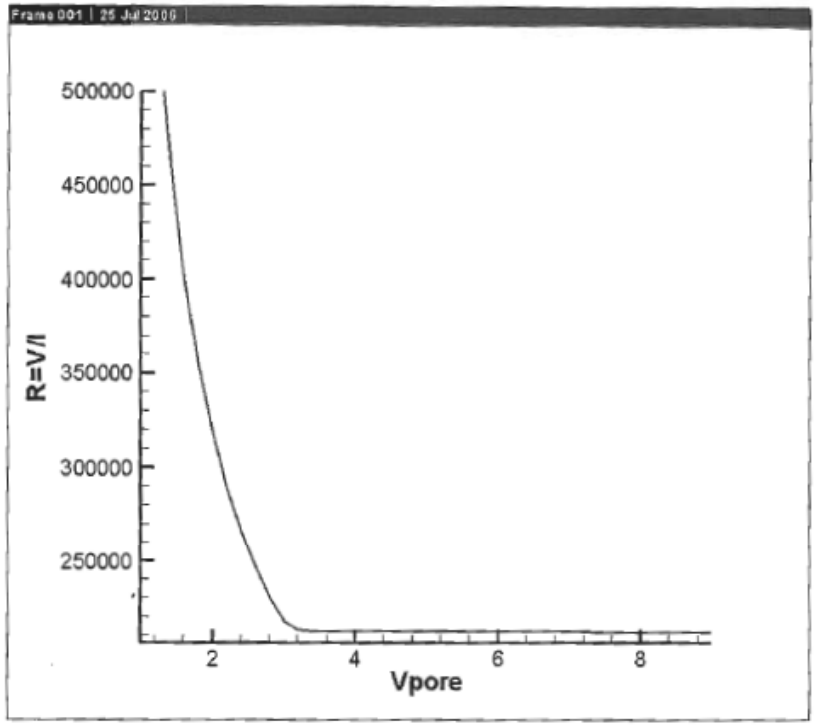
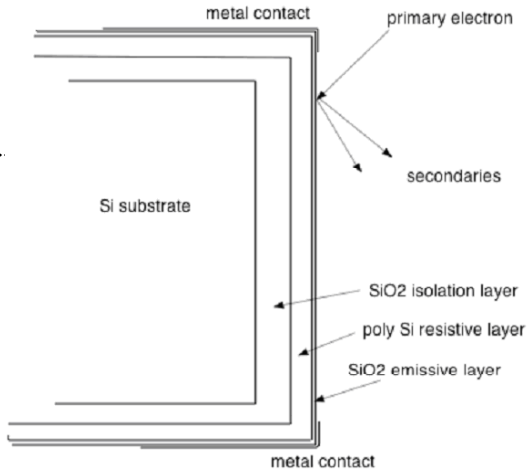
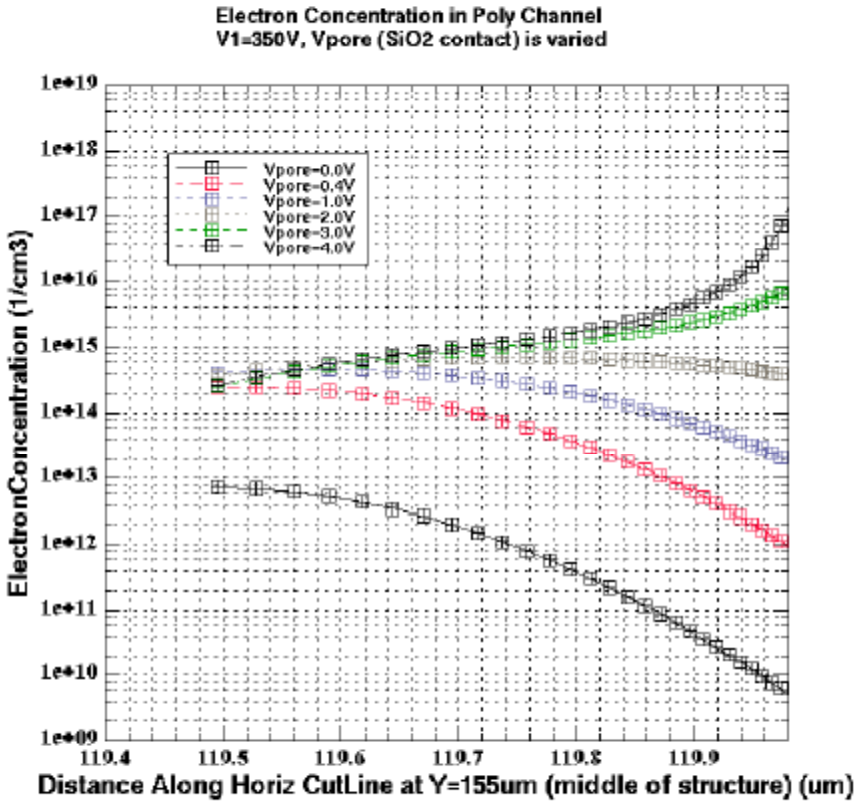
Drift-Diffusion simulation results



(Prof. D. Coles, BU)





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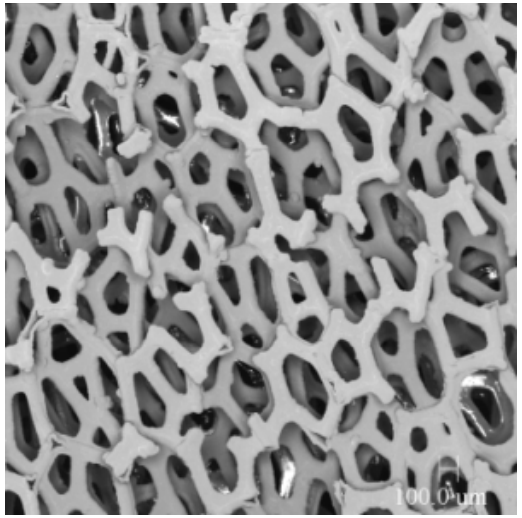
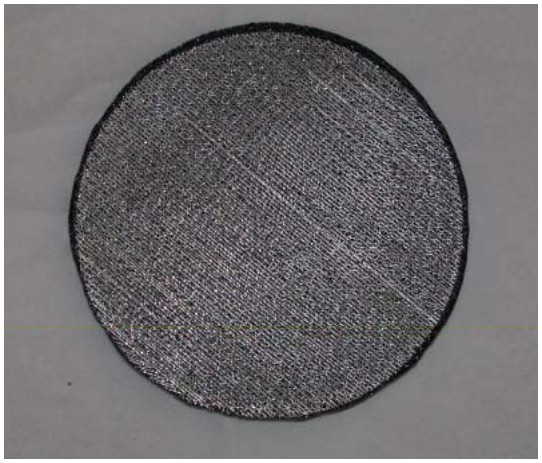
NOVA Scientific Large area detectors

Microsphere Plate

Microreticlated Plate



Microfiber Plate



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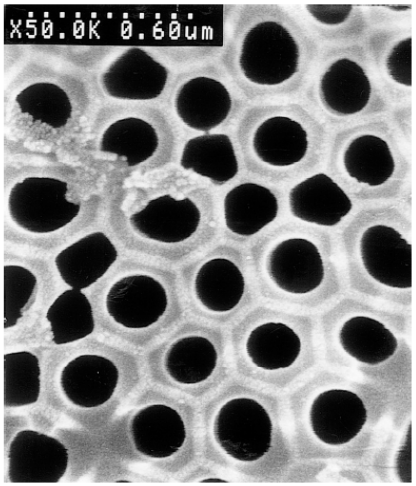
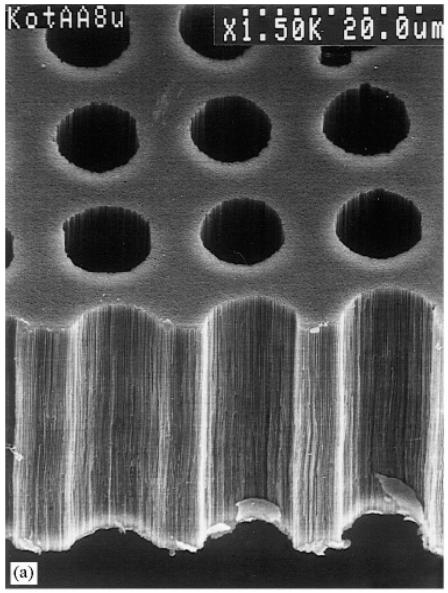
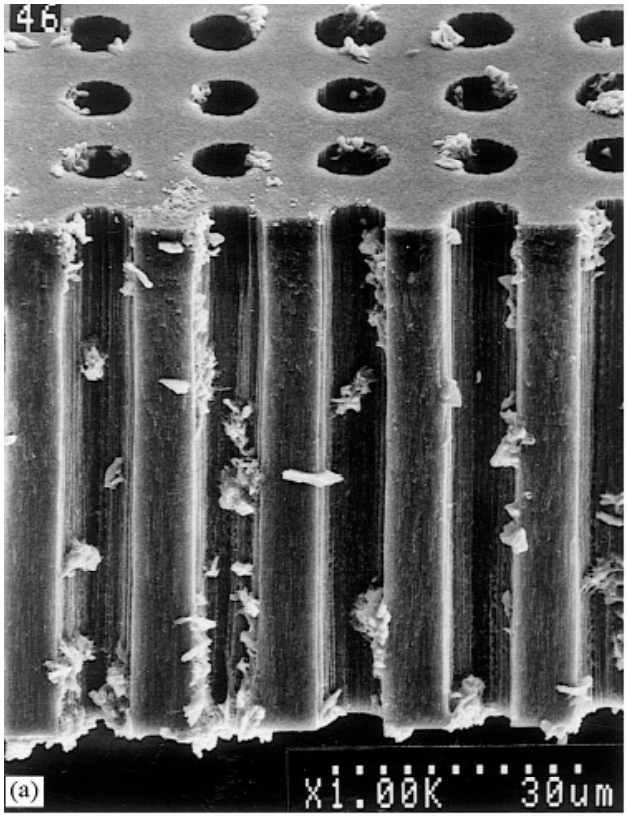
Literature survey: Anodic alumina MCPs



Sub-μm pores in
anodic alumina substrates



Lithographically etched
10 μm pores



Good substrates,
continuous emissive
& resistive films elusive

A. Govyadinov, et al., Nucl Instr. Meth. A 419 (1998) 667

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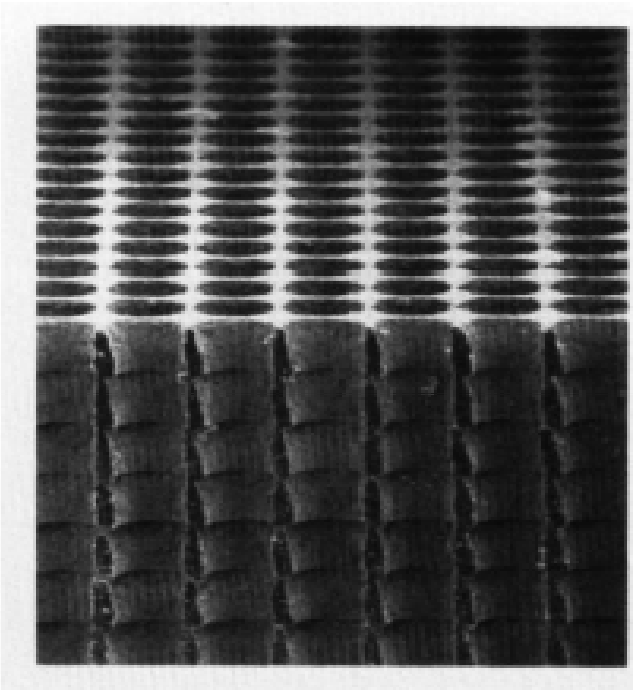
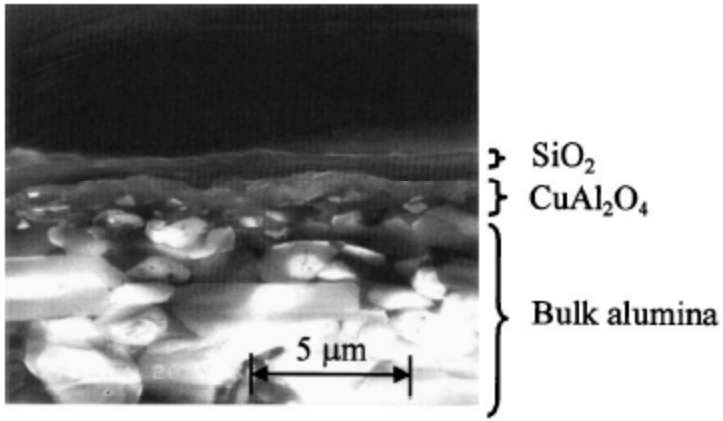
Literature survey : Punched alumina MCPs

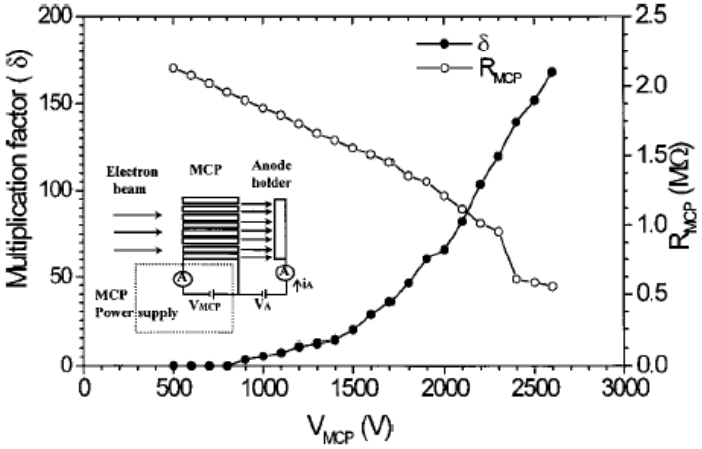


Holes are punched in thin films,
which are laminated into thick structures

Very large pore sizes.
Difficult to manufacture
(stacking many substrates).
Not suitable for imaging.



SEM image of the pore wall



Gain vs. applied bias

Yi Whikun, et al., Rev. Sci. Instr. 71 (2000) 4165

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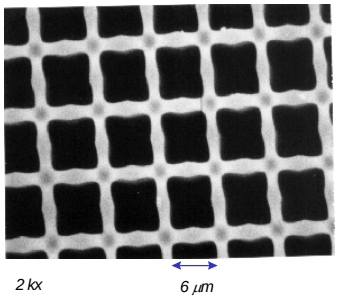
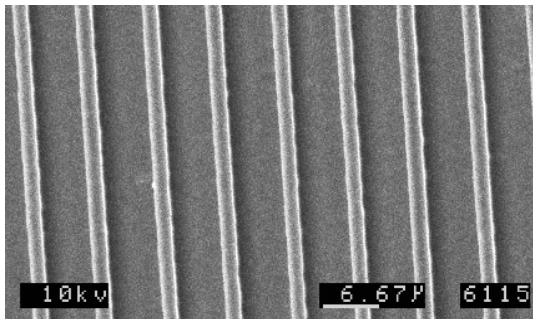
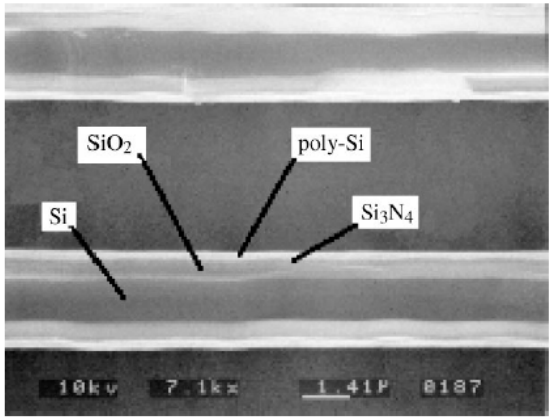
Literature survey: Silicon micromachined MCPs

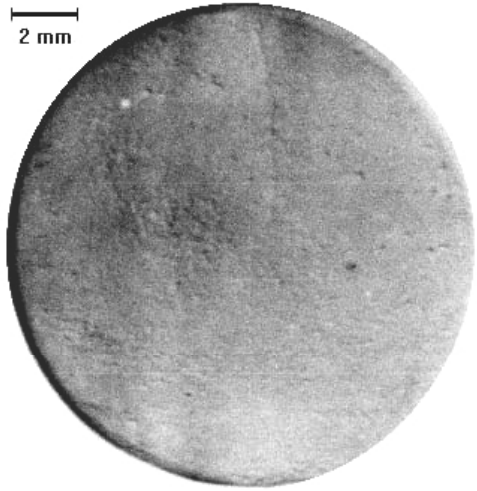




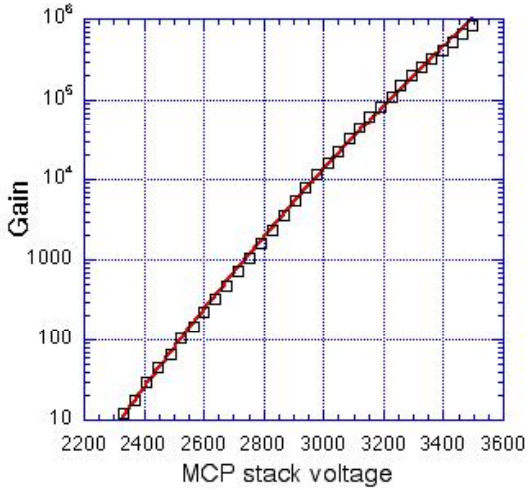


Pore pattern is set by photolithography

CVD growth of conduction layer and emission layer



Full field UV image
(stack of 4 MCPs).
Residual distortions are seen



Gain of 4 MCP stack (40:1 each)

C.P. Beetz, et al., Nucl, Instr. Meth. A 442 (2000) 443

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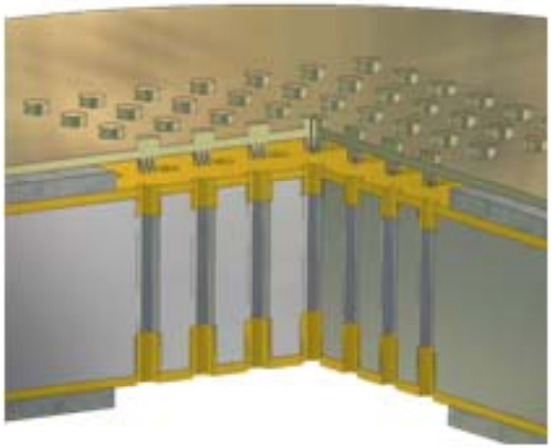
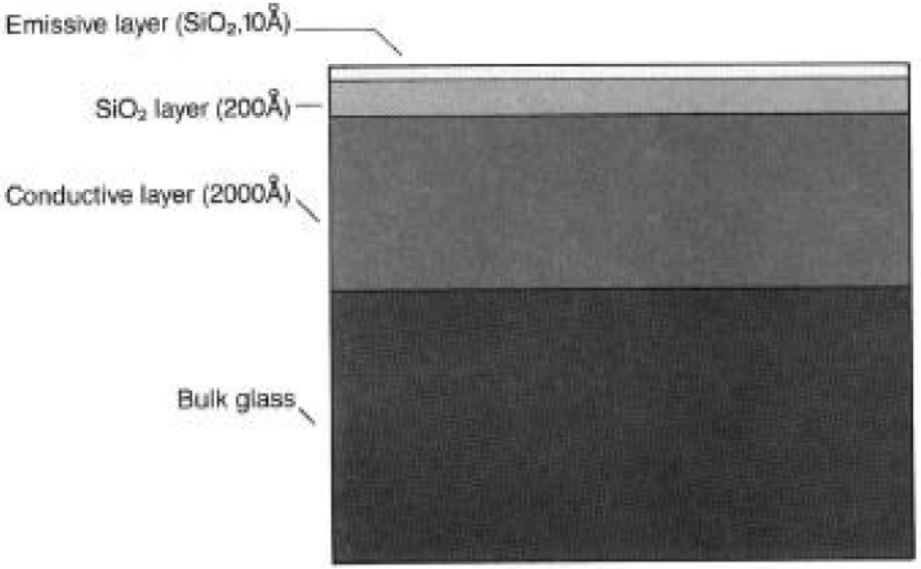
Alternative MCP Substrates: Key Findings

- Substrate
  - Mechanical structure
  - Electrically insulating
- Conductive layer
  - Conformal & uniform
  - ~10^{14} Ohms/Sq
  - Low field effect
- Emissive layer
  - Conformal & uniform
  - High secondary yield
- MCP Device
  - High Gain
  - Resistance stability and matching
  - Stable gain following "scrub"





Channeltron electron multiplier handbook (Burle)

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ARRADIANCE®

Operational Experience with ALD-based MCP's

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Outline Part II

- MCP Metrology configuration
- ALD methodology
- Emissive layer
  - Materials
  - Test results
- Resistive layer
  - Material requirements
  - Test results
- Improvement of the glass MCP characteristics
  - Gain
  - Lifetime
  - Ion feedback

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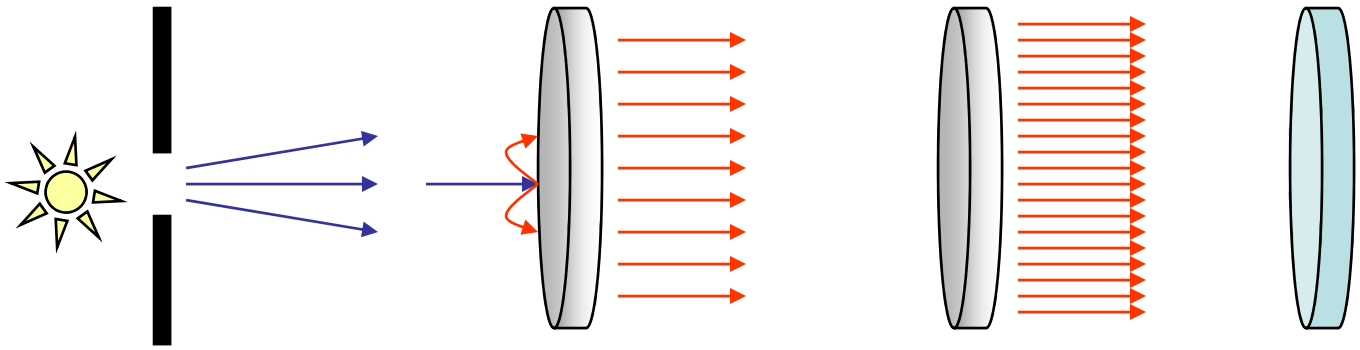
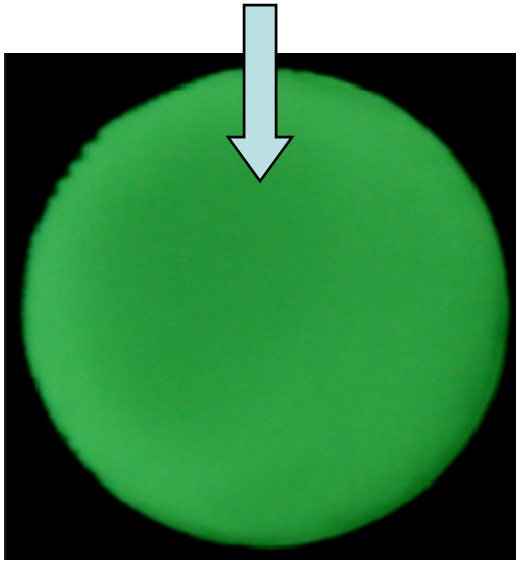
Uniformity of Arradiance coating: functional test





Full field illumination image.

Test MCP is irradiated by a uniform electron flux.

Photograph of the phosphor screen is shown.

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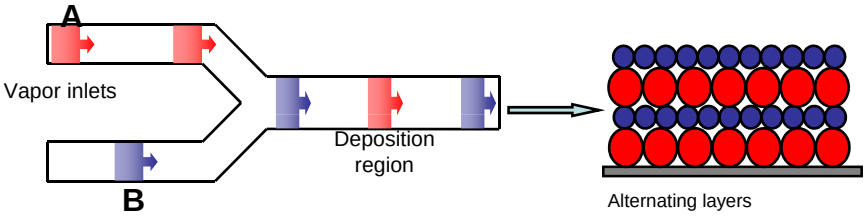
ALD MCP Technology

- MCP performance tied to glass composition
- ALD:
- Device optimization is de-coupled from substrate.
- Semiconductor processes & process control.
- Materials engineering at the nanoscale
- Functional films composed of abundant,non-toxic materials.
- Advantages:
  - High conformality (>500:1)
  - Scalable to large areas
  - Digital thickness control
  - Pure films
  - Control over film composition
  - Low deposition temperatures (50-300°C)

ALD



- Thin film growth that relies on self-limiting surface reactions
- Gas A reacts with a surface
  - excess precursor & reaction by-product removed.
- Gas B is introduced to the evacuated chamber – reacts with surface bound A
  - excess precursor & reaction by-product removed.
- Repetition of A – B pulse sequence to build film layer-by-layer

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Emissive layer materials

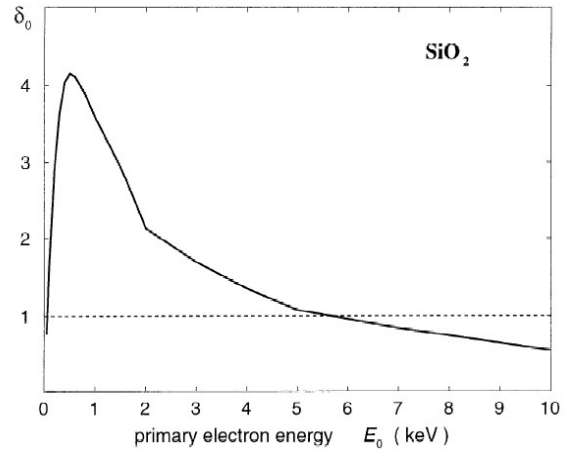
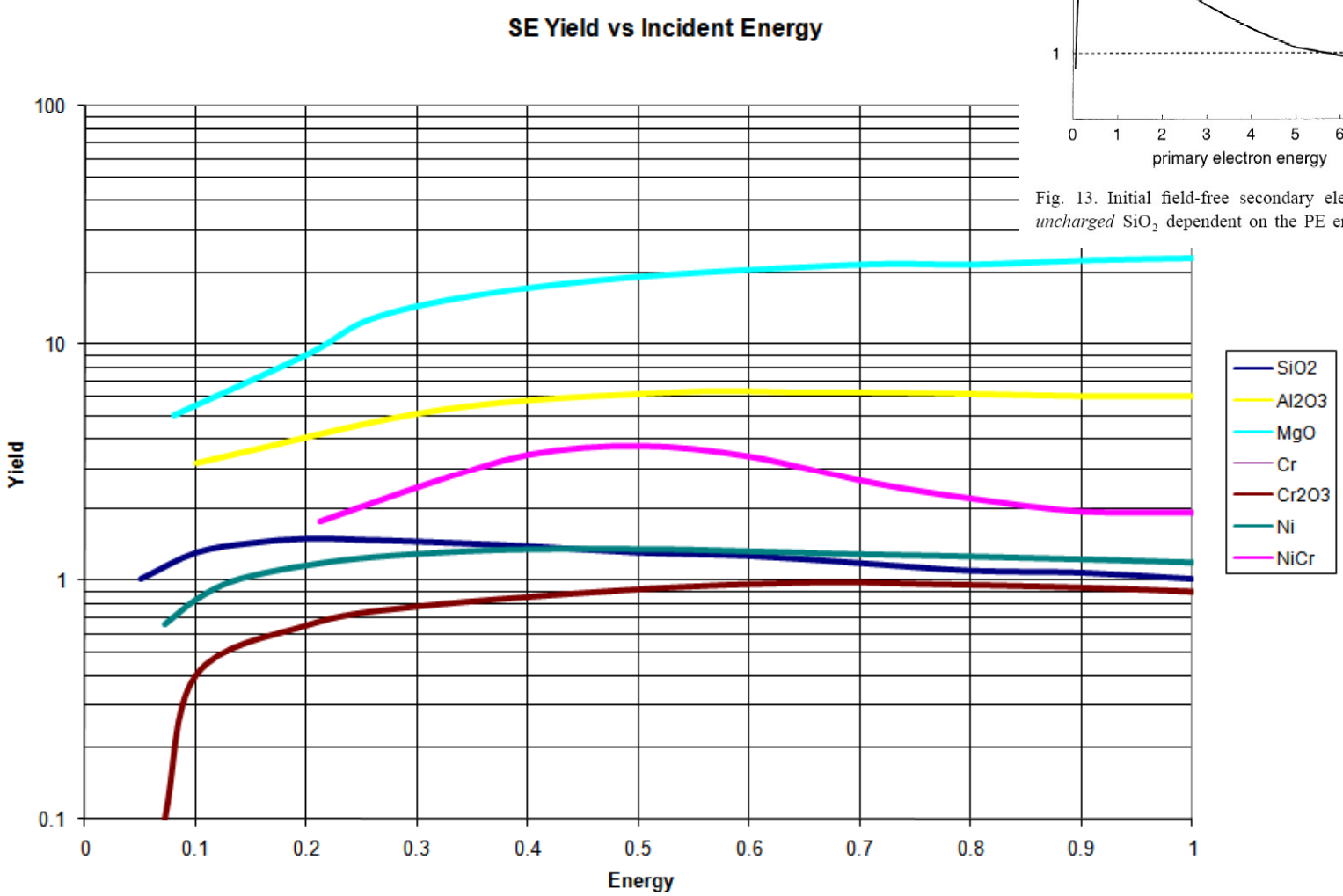


Fig. 13. Initial field-free secondary electron yield $\delta_0(E_0)$ from *uncharged* SiO_2 dependent on the PE energy E_0.



http://www.mc-set.com/bse/mat_list.htm

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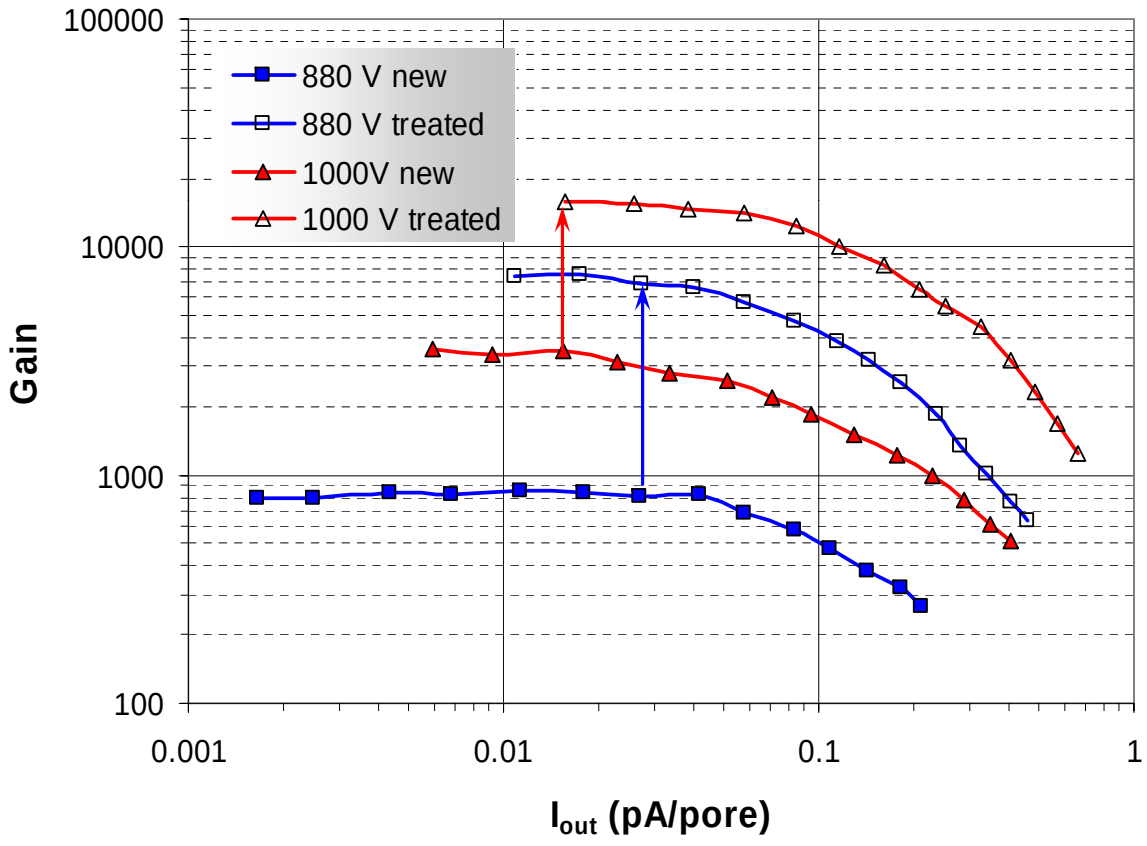
Secondary electron emission layer

Applied over commercial glass MCPs:

50:1 L/D, 4.8 μm pores, ~250 MΩ resistance



5x-10x gain increase

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Scrubbing

- "Accelerated" Test conditions (Input Current, Charge extraction rate, duty cycle)
- Removes H2, CO, CO2, alkalis, gases & evil spirits
- Procedures closely held…

	Current	Bias	Time/Extr. charge	Bake	Reference
Litton/ NGC/L3	25-300 µA /cm2	Vop	"long period of time"	500C	US Pat 6198090, 6437491, 6437491
Litton	~300nA/cm2	Vop	18 hours	415C	US Pat 5845189
ITT				375C	US Pat 5487689, 5314363
Hamamatsu	input 20nA, output 500nA	Maintain Iext	1 hour	350C (50 hrs)	US Pat 4629486
Galileo	$8x10^{-4}$ C/cm2/h (10% strip)	1000V	24-48 hrs, 0.07C extracted	~350C (14 hrs)	US Pat 4978885
LLNL/UC	400 µA /cm2	Vop	4 hours		5408087
SSL, UC-Berkeley	0.1 µA/cm2)	~250V	0.1 C/cm2 (~250 hrs) .	120C, (8 hrs)	Papers by O.Siegmund et. al. and A. Tremsin

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MCP Aging mechanisms

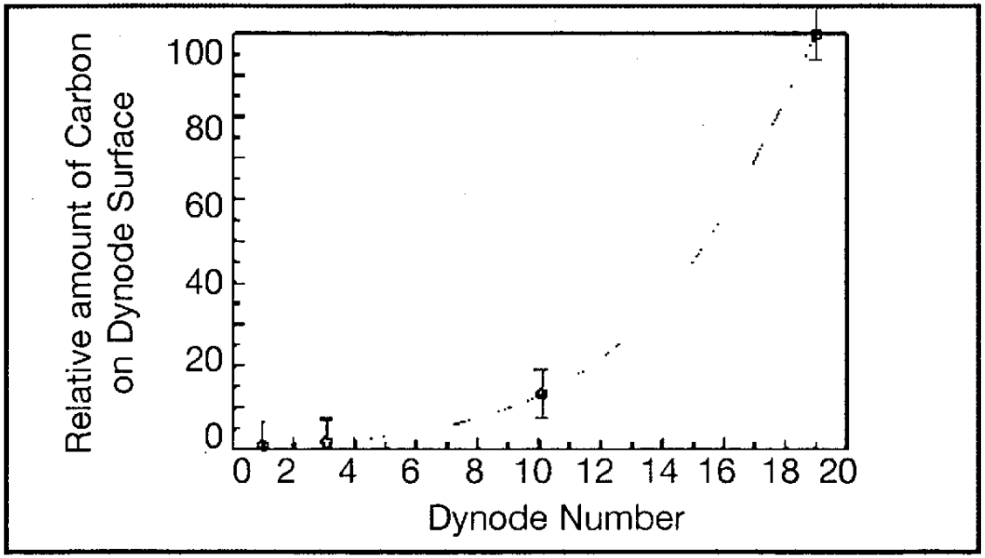

Figure 1 Relative level of carbon contamination on dynode surfaces (dynode #20: last dynode).

A.D. Cutter etal, 42nd Conf. Mass Spec 1994

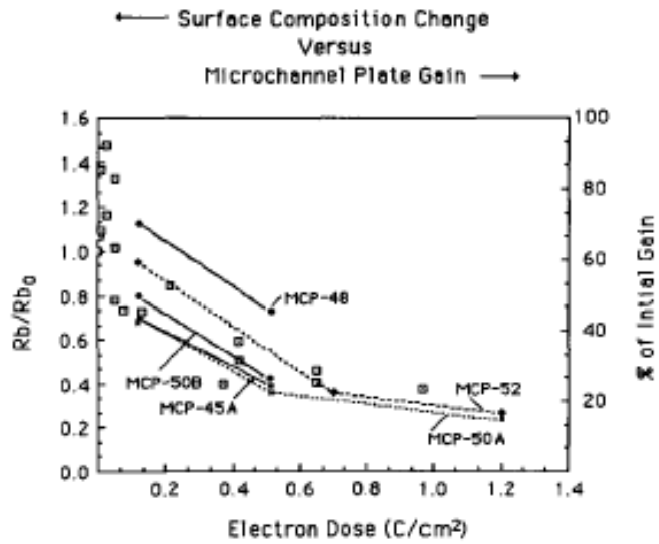

Fig. 7. The dose-dependent changes in the gain of various MCP devices (solid connected points), and the Rb surface concentration on acid-etched and reduced fracture surfaces (open points); the MCPs and the fracture surfaces are (Cs, Rb)–lead silicate.

A.M. THEN and C.G. PANTANO Journal of Non-Crystalline Solids 120 (1990) 178-187

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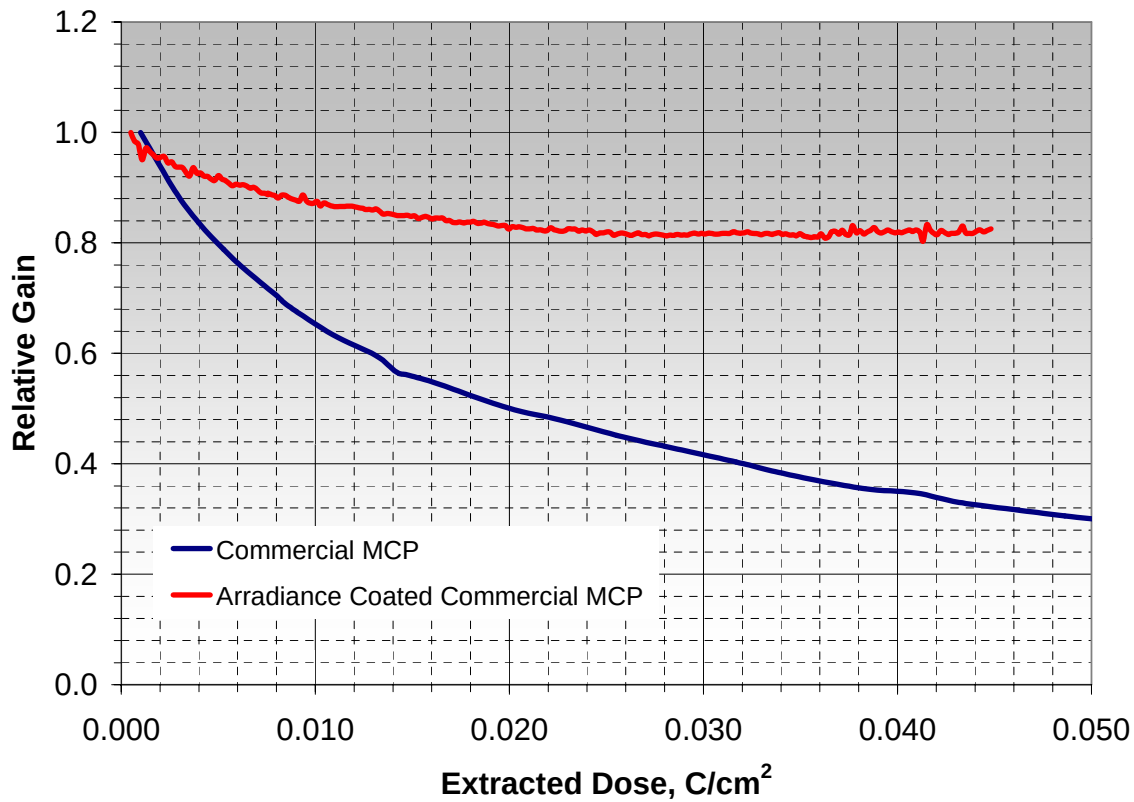
Secondary electron emission layer

Improved lifetime, Relaxed detector preconditioning



50:1 L/D
Bias 880 V
18 mm active area
4.8 μm pores
R ~ 100-200 MΩ
I_{out} ~ 10-20% I_{strip}

Applied over commercial glass MCPs

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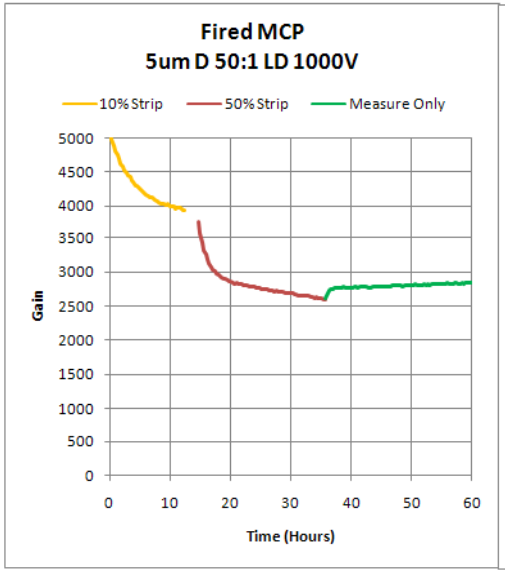
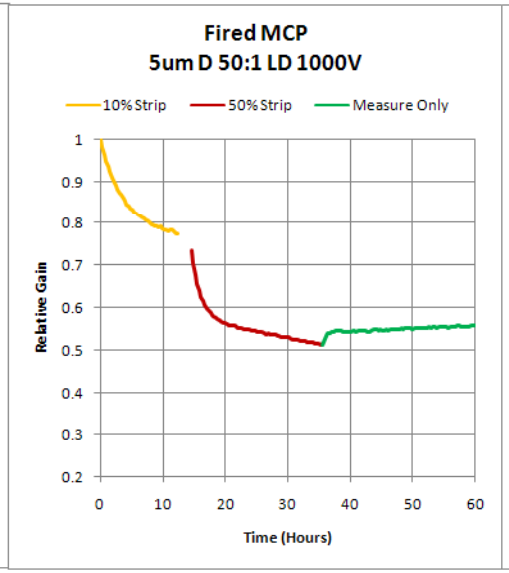
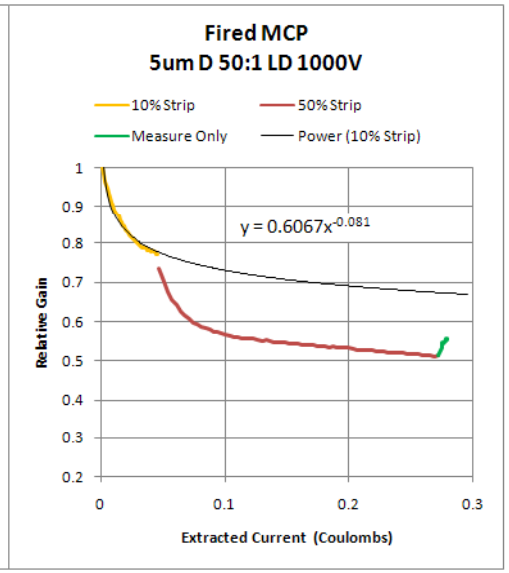
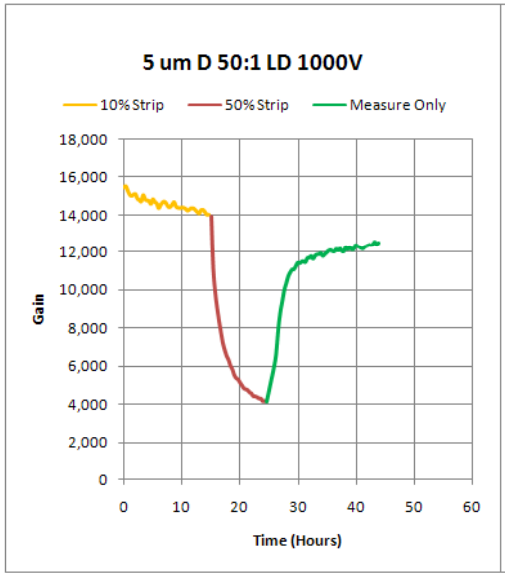
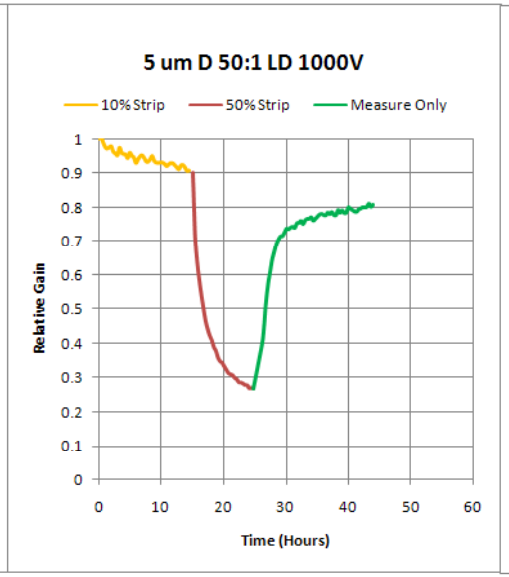
High Flux Stress induced charging: Measurements

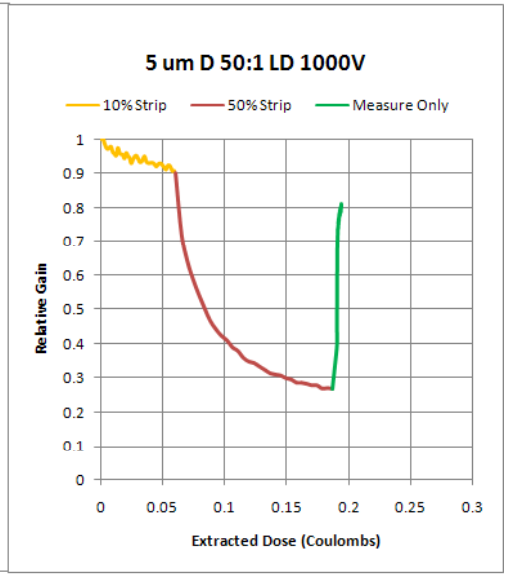












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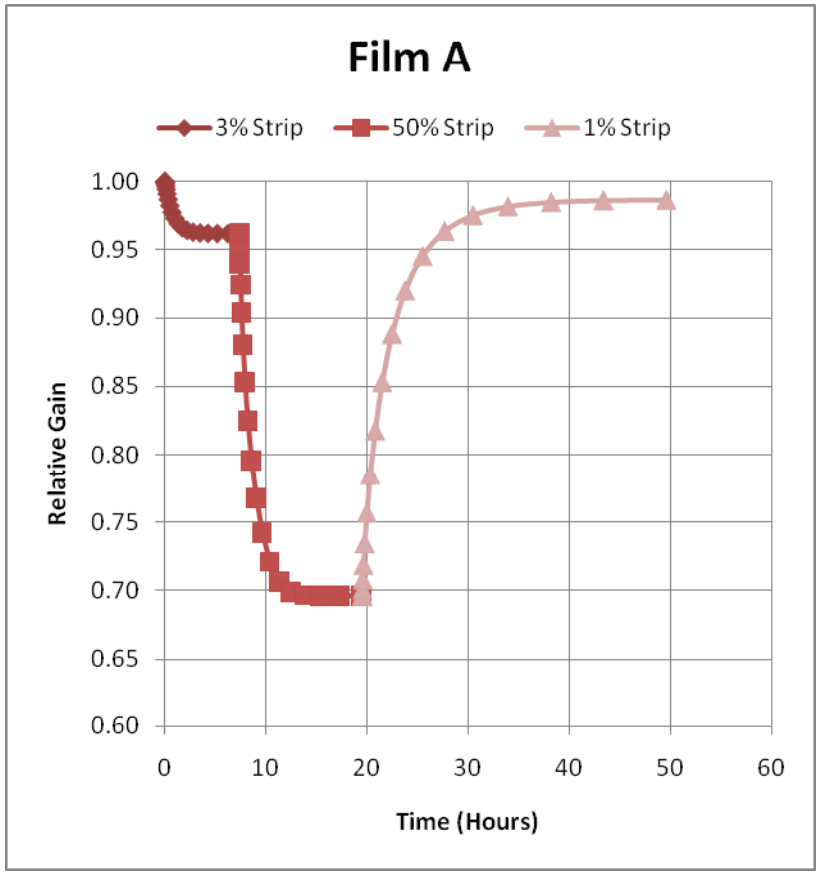
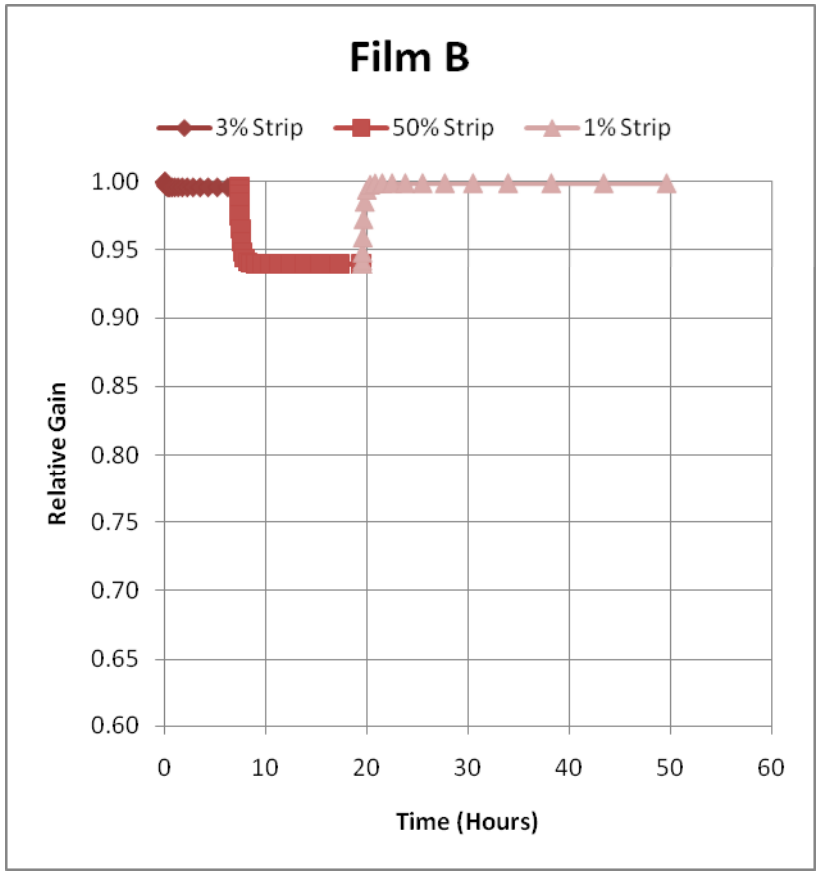
High Flux Stress induced charging: Simulation





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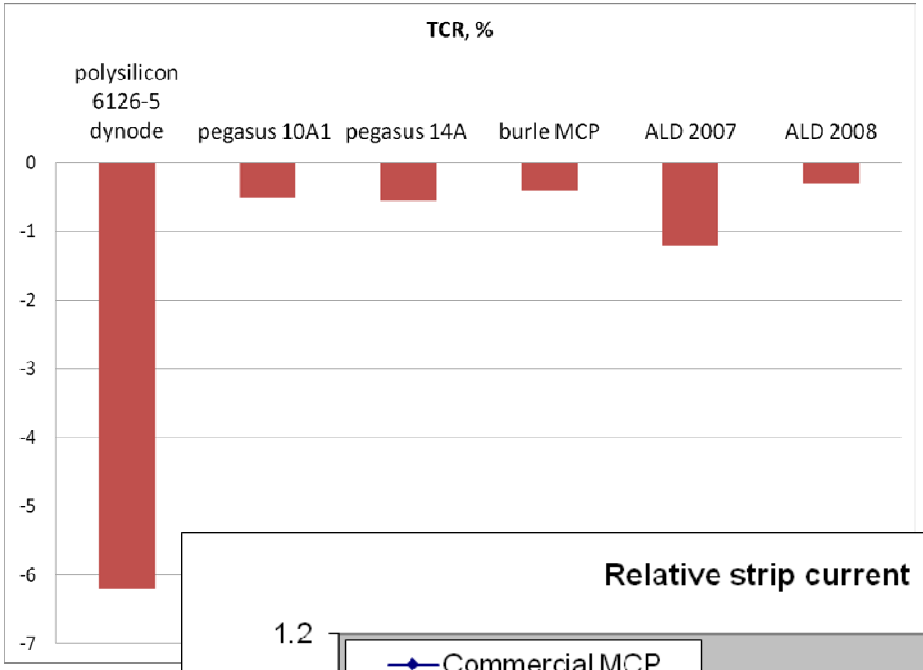
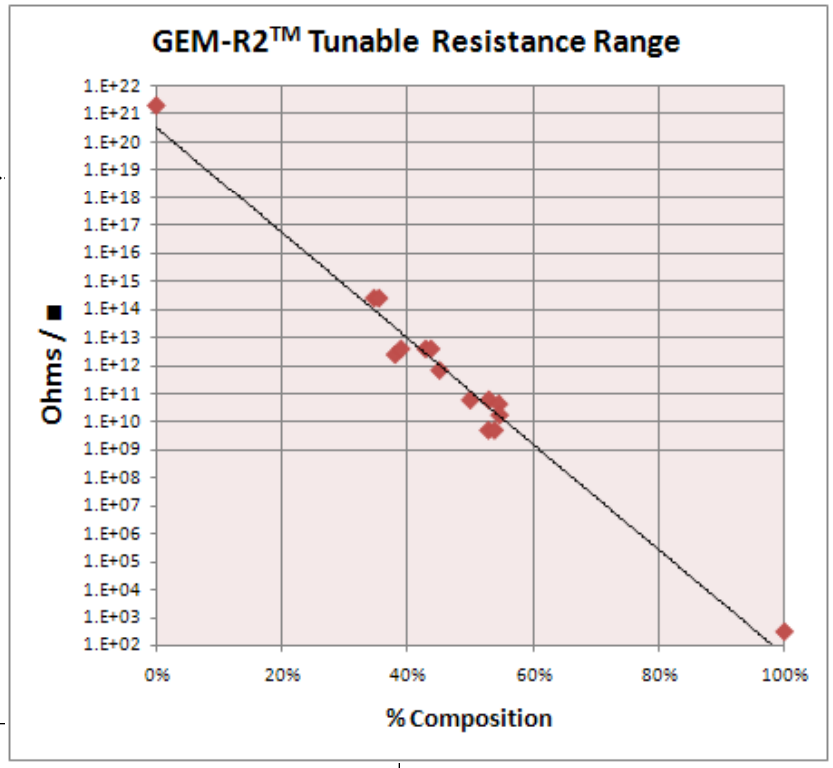
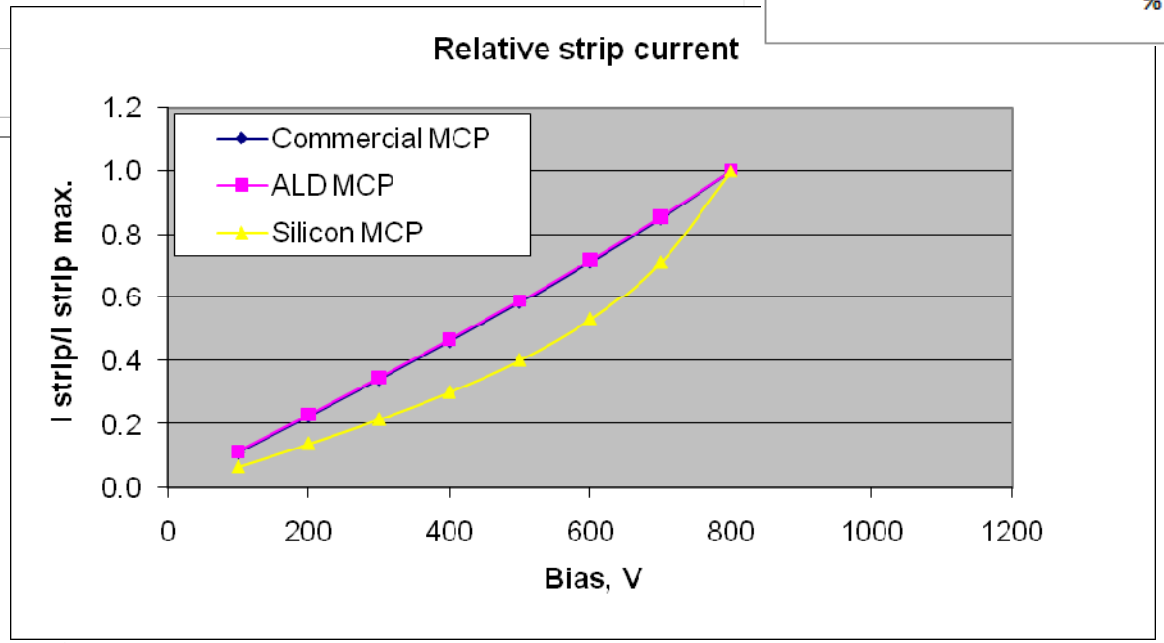
Conductive layer materials







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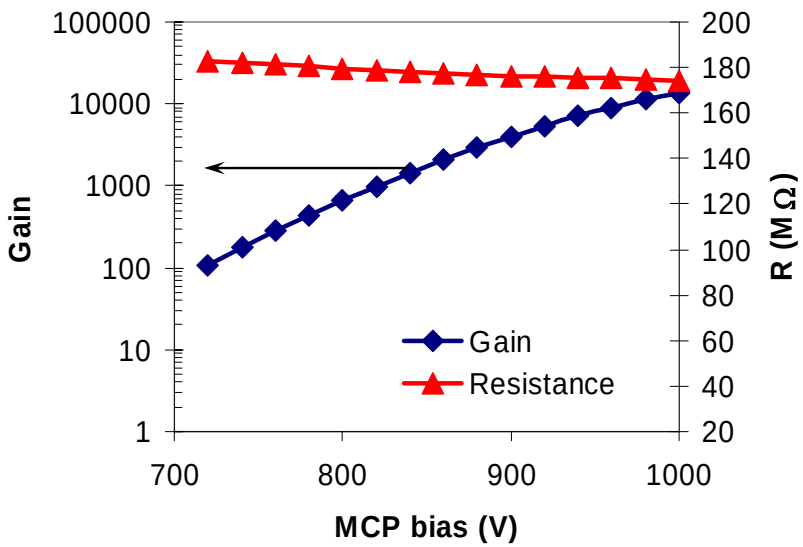
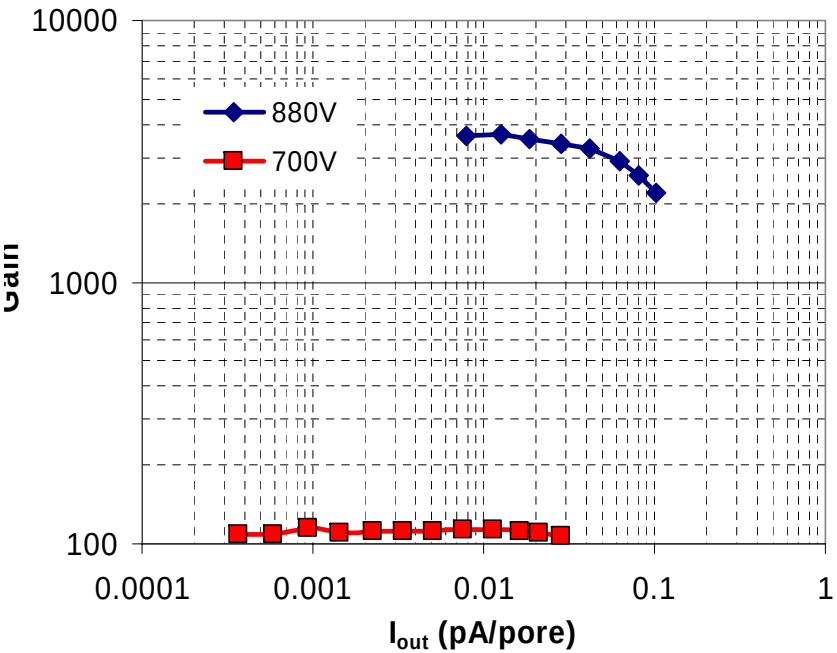
MCPs with conduction and emission films

4.8 μm pore substrate, 50:1 L/D, R~170 MΩ,
gain under electron bombardment





- Stable resistance
- Typical exponential gain increase with bias
- Good gain ~ 14000 at 1000V
- Good TCR (comparable to glass MCP values)

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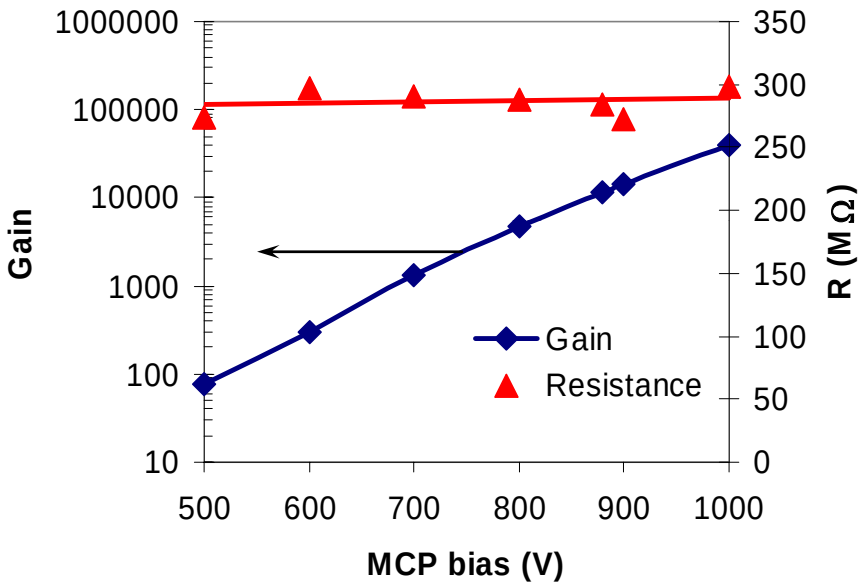
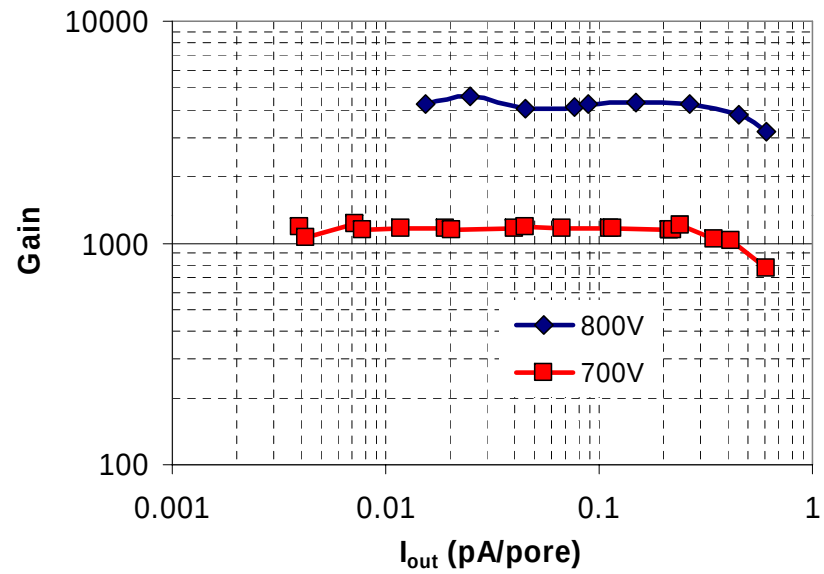
MCPs with conduction and emission films

10 μm pore Soda Lime glass substrate, 40:1 L/D, R~280 MΩ, gain under electron bombardment





- Stable resistance
- Typical exponential gain increase with bias
- Good gain ~ 40000 at 1000V bias
- Good TCR (comparable to glass MCP values)

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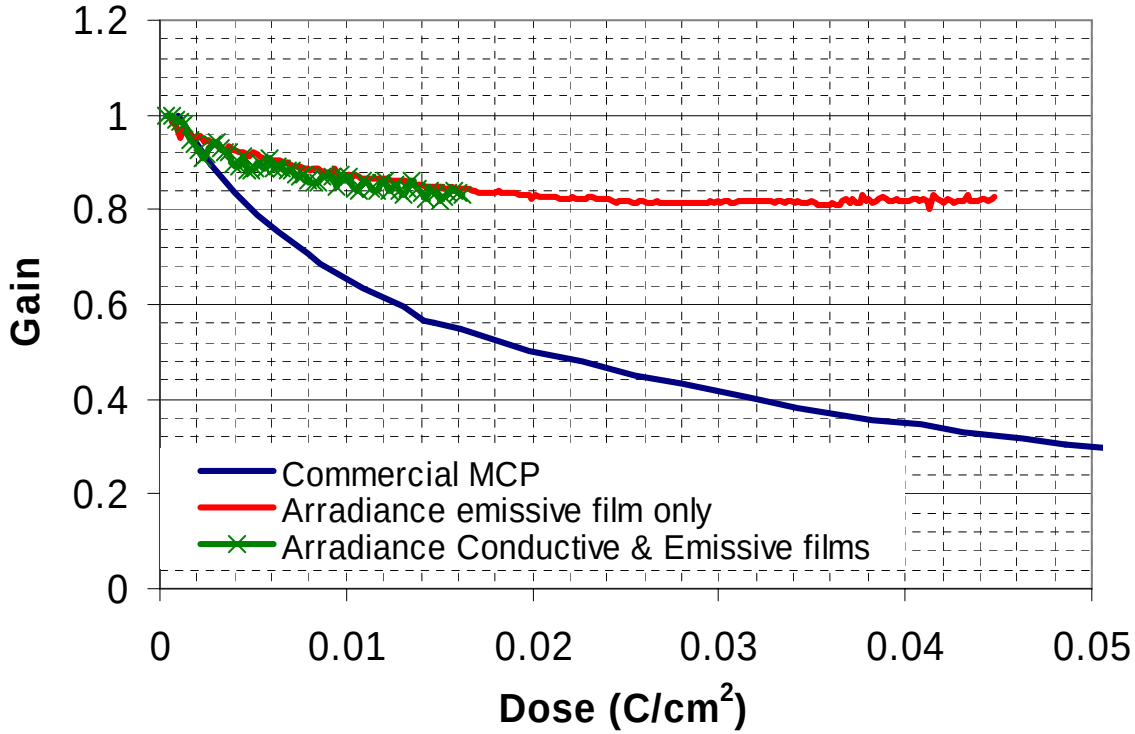
MCPs with conduction and emission films

10 μm pore NO LEAD glass substrate, 40:1 L/D, Bias = 880V, I_{out}~0.4 pA/pore, gain under electron bombardment



Quickly reaches stable gain

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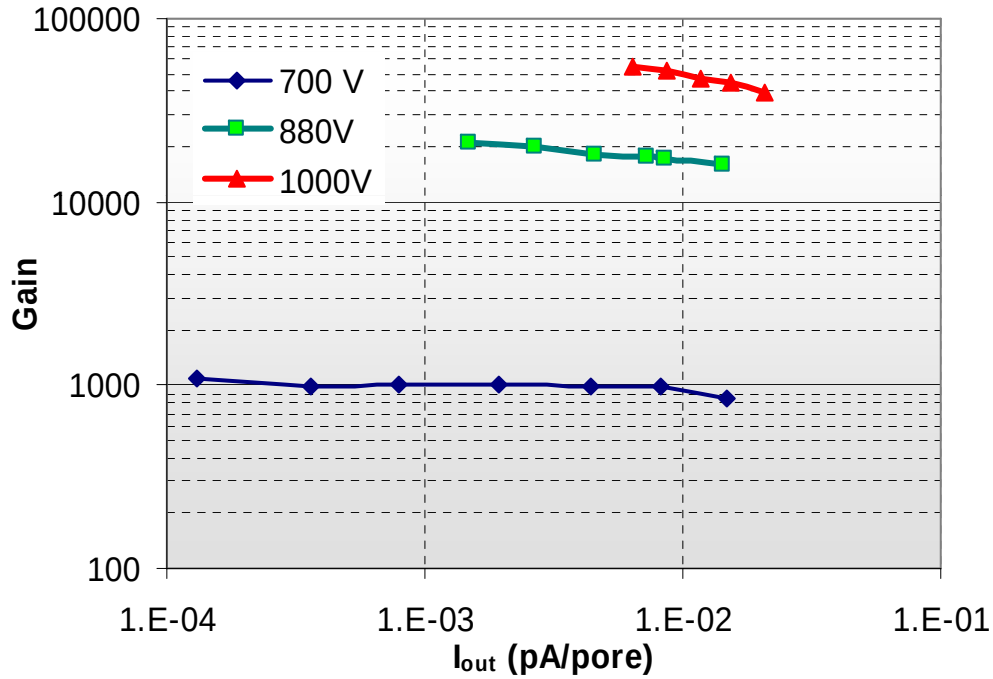
MCPs with conduction and emission films

4.8 μm pore substrates, 50:1 L/D,
gain under electron bombardment



Typical count rate saturation at output equal to ~10% of strip current

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MCP CASCADE Simulation

About the model:

- MCP Cascade model is a single electron event Monte Carlo simulation of a an MCP pore and extraction parameters
- At a microscopic level, the model accounts for the following.
  - 3D geometry and potential array for flight characteristics within, and outside the pore
  - End spoiling (extraction) fields and penetration
  - Material SE characteristics including yield and SE energy
  - Cosine angular distribution of SE including normal vector correction of surface strikes based on geometry
  - Real time (event based) beam potentials and effects on SE creation
  - Real time (event based) wall charging potentials and effects on SE creation

The model predicts and reports:

- Single event gain based on input geometry, materials, and MCP bias potentials and extraction potentials
- Particle output statistics at the end of the pore, and remote anode including
  - Energy distributions
  - x', y', and r' angle distribution
  - x, y, and z velocity distribution
  - x, y, and z positions and distribution
  - Time of flight distribution
  - Tab delimited particle output files

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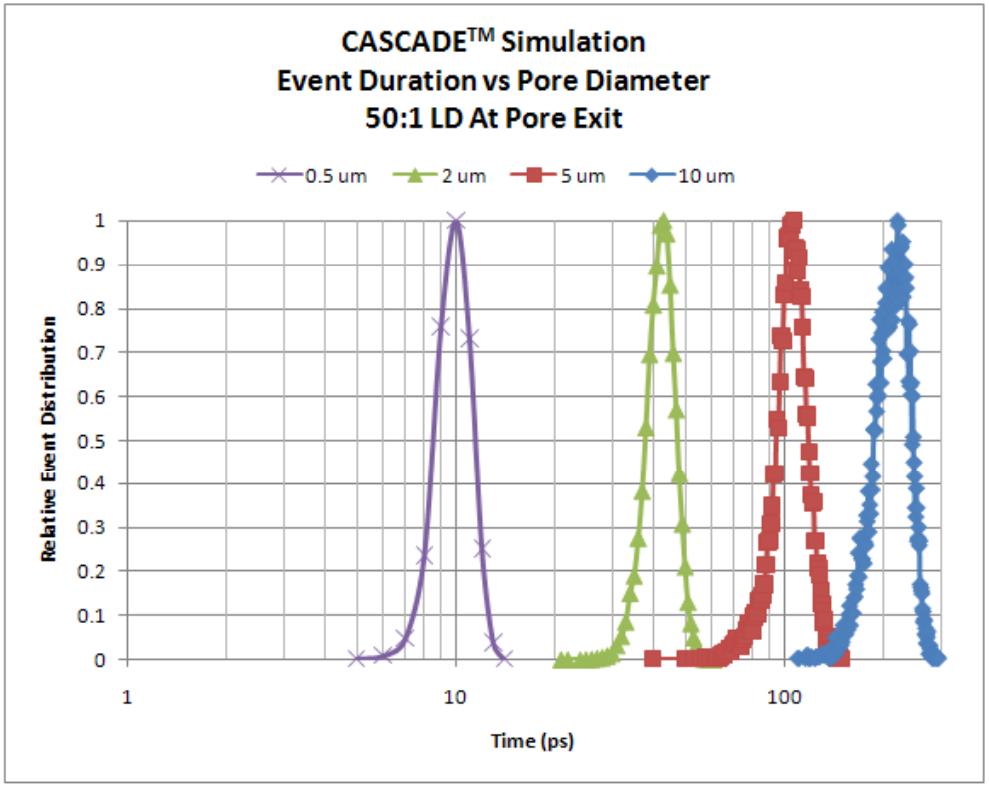
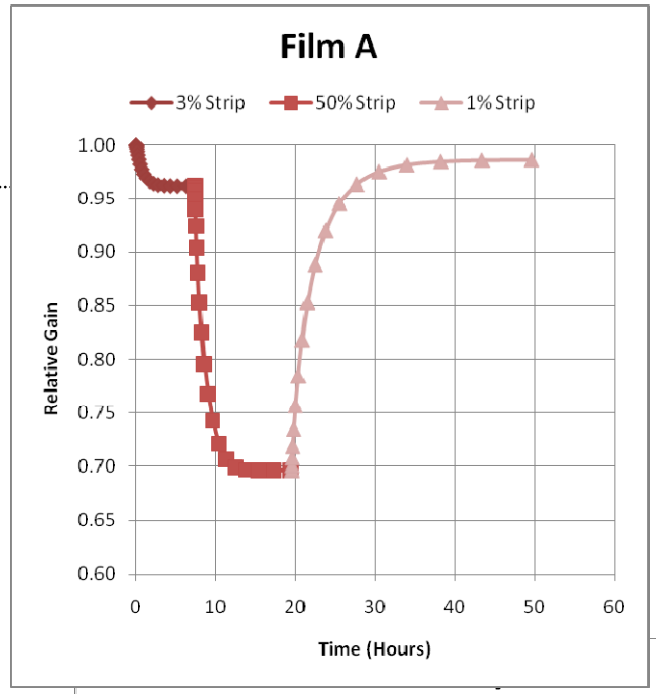
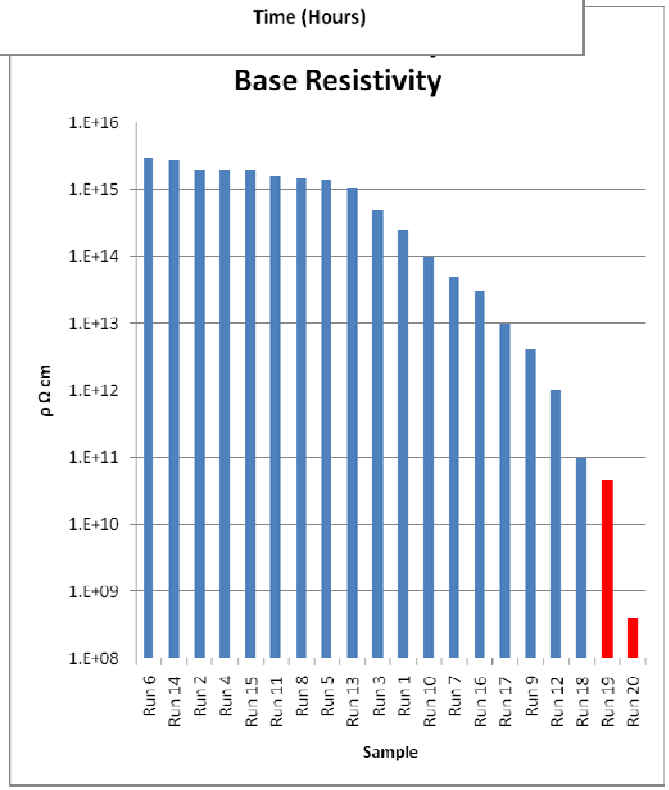
MCP pore simulation







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Alternative substrate MCPs: Status

- Emissive Layer
  - Optimized SE yield for application
  - Conductivity tailored for application
    - Gain stability (night vision)
    - Speed – analytic and detection applications
- Conductive layer
  - “Ohmic” conduction
  - Low TCR
  - Similar conductivity – along and across pore
- Substrate - Mechanical
  - Uniformity
  - Stability
  - Tailored for application
    - High temperature capable
    - Reactive (e.g. nuclear)

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Summary

- Emission and conduction layers for MCP technology have been developed
- Emission layer improves the performance of glass MCPs
  - High gain
  - Longer lifetime
  - Reduced outgassing / ion feedback
- Substrate independent conduction and emission films open new possibilities
  - Large area micromachined and plastic substrates
  - Temperature compatibility over a wide range
  - Novel photocathode materials/configurations
  - Low noise – no radioactive traces
  - Better uniformity / reproducibility / spatial resolution

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