Advances in microchannel plate detectors for UV/visible Astronomy

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Advances in:-
Photocathodes (GaN, Diamond, GaAs)
Microchannel plates (Silicon MCP’s)
Readouts (Cross strip)

Are changing the tools and performance of photon counting imaging detectors available for future UV missions achieving better QE, lower background, higher resolution, better uniformity, linearity and better lifetimes.

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EUV Photocathodes, 100Å - 2000Å

Alkali Halide UV Photocathodes have improved substantially as a result of better fabrication techniques and geometrical optimization.

Opaque Alkali Halide Photocathodes - MCP substrate

Opaque Alkali Halide Photocathodes - metal substrate
EUV Photocathodes, 100Å - 2000Å

Diamond Photocathodes on Silicon and Si MCP’s

Polycrystalline boron doped diamond, band gap - 5.47 eV (227 nm) - Solar blind. Hydrogenated and cesiated diamond exhibit NEA. Cathodes are air stable (<10% drop in 18 hours) and are very mechanically robust. Can be ultrasonic cleaned in water and alcohol. Re-hydrogenation restores QE.
EUV Photocathodes, 100Å - 2000Å

Diamond cathodes have been grown on Si MCP’s, appropriately for EUV sensors

Activation of diamond indicates that very high EUV DQE’s are possible

At smaller incidence angles than 90° the QE improves significantly for planar layers
GaN Photocathodes, 1000-4000Å

Potentially high UV QE and cutoffs from 350nm to 450nm
Basic strategy is to achieve NEA using Cs activation.
Material, cleaning & activation processes all under study.
Working with Northwestern U. (Ulmer, Wessels).

Early GaN photocathode comparisons [Ulmer 2001]

Opaque GaN photocathodes on Sapphire
UCB supplied samples, Nanosciences processing
GaN UV Photocathodes, 1000-4000Å

Development of opaque GaN photocathodes on sapphire substrates, with Cs activation

GaN Opaque Photocathodes
First tests showed poor QE with Cs activation - except at short wavelength.

Initial sealed photodiode tubes were slightly better, and showed no degradation over >6 months.

Improvements in processing have improved the QE substantially.

Cutoff is quite sharp at 370-390nm.

As NEA improves the longer wavelength QE and enhances the cutoff characteristics.

~40% QE for <250nm is significantly better than CsI or CsTe, and shows promise for further >250nm improvements.
GaAs has high visible/NIR QE (50%), and noise is ≈10 events/sec at -20°C. Can adjust bandpass blue end response. Photon counting with time response ~1ns. No cosmic ray background effects. Can combine with high spatial resolution large area imaging MCP readouts. Astronomy - interferometry, time resolved spectroscopy and imaging.

GaAs photocathode efficiency (courtesy ITT)

GaAs photocathode blue variants (courtesy ITT)
Silicon MCP Developments

Silicon MCP’s

Silicon MCP’s are made by photo-lithographic methods
Photolithographic etch process - very uniform pore pattern
No multifiber boundaries & array distortions of glass MCP’s
Large substrate sizes (100mm) OK, with small pores (5µm)
High temperature tolerance - CVD and “hot” processes OK
UHV compatible, low background (No radioactivity)
Development in collaboration with Nanosciences.

Typical Silicon microchannel plates in test program
25mm diameter (75mm currently feasible)
40:1 to 60:1 L/D (>100:1 possible)
7µm pore size, hexagonal and square pore
~2° bias and 8° bias, resistances ~GΩ, to <100MΩ possible
Working on processing techniques to improve uniformity
Techniques for gain & QE enhancement under investigation
Many Si MCP’s of 25mm diameter with ~7µm pores have been tested. The performance is improving as production is being refined. Gain is similar to glass MCP’s. Open area ratio is up to >75% for hexagonal pores. Gain decrease during scrub is smaller and faster than glass MCP’s.

Gain evolution of single Si MCP’s

MCP gain as a function of extracted charge, for one Si MCP.
Silicon MCP Performance Characteristics

Gain and pulse height very similar to glass MCP’s, stacks of Si MCP’s (4) with gain up to $10^6$
Quantum detection efficiency is similar to good bare glass MCP’s (COS, EUVE, 12/10/6µm)
The background rate is lower (0.02 events cm$^{-2}$ sec$^{-1}$) than normal or low background glass
Gain and response uniformity are reasonably good. No “hex” modulation!

Contrast enhanced image of the fixed pattern response to a Hg vapor lamp with a stack of 4 Si MCP’s. ~14mm
area, $10^7$ counts, ~50µm resolution XDL.
Cross strip anode readout

Cross strip is a multi-layer cross finger layout. Fingers have ~0.5mm period on ceramic. Charge spread over 3-5 strips per axis, Event position is derived from charge centroid. Can encode multiple simultaneous events. Fast event propagation (few ns).

32mm x 32mm XS anode, 0.5mm period

Anodes up to 32 x 32mm have been made. Signals are routed to anode backside by hermetic vias. Packaging can be compact with amp on anode backside. Overall processing speed should support >> MHz rates. Compact and robust (900°C).
Cross Strip Anode Electronics Chain

Basic encoding sequence

X Fingers ➔ Preamp ➔ Shaper ➔ 50 Ohm Driver ➔ ADC

Small, low power ASIC encoding with sparsification reduces data throughput requirements

Cross strip anode position encoding electronics test-bed system. All signals amplified and digitized. Can choose up to 12 bits per signal.

Anode backside showing connectors for the external board where preamplifier chips are mounted. Currently amplifiers have ~600e- rms noise.
**Cross Strip Anode Readout**

**Outstanding Spatial Resolution/Linearity**

~7µm pores are resolved, <3 µm electronic resolution with 10 bit encoding electronics

Image linearity is ~1µm level and shows pore misalignments and multi-fiber boundaries

Gain required is <4 x 10^5, allows higher local event rates than normal readouts

Lower gain means longer overall MCP lifetime due to reduced scrubbing

Flood image of 12µm pore MCP pair at 4 x 10^6 Gain, ≈1mm square area.

Similar image of 7µm pore MCP pair at 2 x 10^6 Gain.
Resolution of Cross Strip MCP Sensors

Gain $1.3 \times 10^6$

1.1 x $10^6$

4 x $10^5$

1.8 x $10^5$

7µm pore MCP pair

10µm pore MCP pair
Advanced MCP Sensors for Astrophysics

Developing Detector Prospects

High QE cathodes (Diamond, GaN, GaAs) with ~50%QE covering 20nm - 850nm
Si MCP’s with low fixed pattern noise, <5µm pores, background 0.02 events cm⁻² sec⁻¹
Cross-strip readouts with <5µm resolution, >50mm formats, >10k x 10k “resels”
Packaging is shrinking while spatial resolution & QE are increasing dramatically.

GALEX 65mm sealed tube XDL detector

COS 2 x 85mm XDL detector