Microchannel plate single photon imaging detectors for astronomy

Do they need to be replaced?

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Microchannel Plate

electron amplifier that retains position information

Pore size ~ 2 to 40µm
Gain ~ 10 to 10^8
Time Jitter ~ 30 ps
Microchannel Plate Detector

Photon counting, imaging, with event time tagging

- Photocathode converts photon to electron
- MCP(s) amplify electron by $10^4$ to $10^7$
- Rear field accelerates electrons to anode
- Patterned anode measures charge centroid
MCP Detectors at SSL Berkeley

COS FUV for Hubble (200 x 10 mm windowless)

18 mm Optical Tube

GALEX 68 mm NUV Tube

200+ “detector years” in space including mission to Pluto

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Microchannel Plate Sensor Applications

Biological lifetime fluorescence imaging (UCLA)

Low Light Ladar - 3D imaging

UV Astronomy (GALEX)

33ms period, 250µs resolution

Ponderosa Pine 3D data cube - RULLI, LANL

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High Speed Imaging Astronomy

Crab Pulsar  B band light curve
(1 m telescope on Moonlit night)

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Meteor & Satellite Detection

Meteor track in AH-Her field

5 ms to cross 6’ FOV.
~11 km/sec if at 30 km

2 ms time frames
Meteor & Satellite Detection

Satellite track in FL-Vir field
~8.5 km/sec in low earth orbit

5 ms frames
Photon Counting MCP Detectors

Advantages

- **Spatial resolution**: < 12μm FWHM
- **Temporal resolution**: < 100 ps
- **Format**: > 100 mm
- **Dynamic range**: > $10^8$
- **Radiation hard**
- **Curved focal planes**
- **Room Temperature**

Disadvantages

- **Vacuum operation**: pumps, tubes or space
- **Lifetime**: ~ Coulombs cm$^{-2}$
- **Photoelectric QE**: ~ 50% to 10$^{-12}$
Performance examples

Photocathode QE

- GaN
- GaAs
- SuperGenII
- S20

Wavelength (nm)

Quantum Detection Efficiency (%)

Temporal resolution

MCP timing jitter ~100 ps FWHM measured with pulsed laser

Photocathode types for UV, visible & NIR are improving.

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Readout Anode Types (partial list)

Cross Delayline (XDL)
4 amps
Gain ~ $10^7$
Rate ~ 200kHz
$\Delta t \sim 100\text{ps}$

Cross Strip (XS)
2 x N amps
Gain ~ $10^6$
Rate ~ 2MHz
$\Delta t \sim 100\text{ps}$

Medipix ASIC
N x N amps
Gain ~ $10^4$
Rate ~ 200MHz
$\Delta t \sim 1\text{ ms}$
Cross Strip Anode Designs

45mm square Cross Strip Anode with 0.64 mm finger period. All metal and ceramic.

22mm round cross strip showing vias and connector.
Imaging tests - resolution

40 mm - 0.5 x 0.5 mm pinhole grid

Zoomed - 20 µm FWHM avg.
Medipix/Timepix x-ray imager

- Pixelated 300 μm thick Si detector chip (256 x 256 pixels, 55 μm pitch)
- Detector bias voltage (~100V)
- Read-out ASIC chip TimePix

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Medipix/Timepix ASIC readout

- 256 x 256 array of 55 µm pixels
- Integrates *counts*, not charge
- 100 kHz/pixel
- Frame rate: 1 kHz
- Low noise (100e⁻) = low gain operation (2 ke⁻)
- GHz global count rate
- ~1 W watt/chip, abuttable
- Developed at CERN

~ 500 transistors/pixel
Aside: Timepix readout of APD arrays?

Require gains of > 1000 but < 200000
Input pitch is 55µm
256 x 256 array
Can cool CMOS chip to 77K
  (but 1W per chip is a high load)
Cannot bias pixels separately
Input takes holes or electrons,
  (can sink up to 10nA/pxl)
Old WWII watch movie

66 MHz input rate
Old WWII watch movie 2

Bkgd

0.002 ct/pixel/s

Room Temp

(radium dial)
MCP pores (10 on 12 micron)
## Evolution of MCP detectors

<table>
<thead>
<tr>
<th></th>
<th>1985</th>
<th>2010</th>
<th>Improvement</th>
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<tbody>
<tr>
<td>Count rate (cps)</td>
<td>5000</td>
<td>$5 	imes 10^6$</td>
<td>1000</td>
</tr>
<tr>
<td>Spatial Resolution (µm)</td>
<td>100</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Lifetime (cts/mm)</td>
<td>$10^9$</td>
<td>$10^{12}$</td>
<td>1000</td>
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<tr>
<td>Optical QE (%)</td>
<td>~15</td>
<td>~30</td>
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</tr>
<tr>
<td>Size (mm)</td>
<td>100</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>Pore diameter (µm)</td>
<td>12</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Lifetime (C/mm)</td>
<td>.01</td>
<td>.01</td>
<td>1</td>
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*Limited by MCP technology!*
Atomic layer deposition (ALD)

Allows engineering of surfaces after MCP pores are fabricated
- Optimize secondary electron coefficient for gain
- Optimize resistivity

Separates microchannel fabrication from surface preparation
- MCPs can be made from any glass, alumina, plastic
- Lithographic techniques for larger arrays of pores

Photocathodes deposited on MCP(?)
- Passivated \((\text{Al}_2\text{O}_3)\) surfaces
- Higher QE of opaque photocathodes
Borosilicate glass MCP

33 mm substrate from INCOM
Resistive, SEC, and conductive coatings by Arradiance

Microscope image showing 40 µm holes in hexagonal array with L/d ratio of 40
Results from ALD coated Incom glass

ALD coating done by Arradiance Inc. (www.arradiance.com)
SSL-UCB, ALD/Incom MCP Test

It works!

700v

800v

Bright scratch on phosphor

UV light

1000v

900v

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Psec Timing Project
(P.I Henry Frisch, U. Chicago, Argonne)

Large area (8”x8”) MCP image tubes for Cherenkov arrays and PET detectors

Delayline readout, specialized ASICs

Pulse timing to 1 ps (multiple photon)

Thousands of tubes

Inexpensive design
8 inch image tube
Concluding Remarks

MCP detectors “in the field” demonstrate what can be done with an imaging photon counting detectors.

They are prevalent in the UV because of their historical QE advantage.

Modern electronic techniques are expanding their niche applications.

New developments in optical/near IR photocathodes are pushing this technology to longer wavelengths.

Other know weaknesses (lifetime, cost, etc.) are being addressed with new materials and methods.

There is still life in this old war-horse!
Thank You

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