MCPs and MCP based detectors

Raquel Ortega
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Outline

■ Introduction

■ MCP characteristics:
  ▪ Gain
  ▪ Detection efficiency
  ▪ Time resolution
  ▪ Spatial resolution
  ▪ Detecting different particles (bias angle, coating)
  ▪ Linearity
  ▪ Lifetime

■ Working with MCPs:
  ▪ Choices
  ▪ External conditions

■ MCP based detectors and Applications
  ▪ Beam Profiler
  ▪ Neutron Imager
  ▪ Gateable MCP-PMT
  ▪ Photon counter
  ▪ Cricket...
Overview

- 1200 Employees
- 75+ Years of experience in optical imaging and particle detection
- 6% Annual revenue re-invested in R&D and Innovation
- 100+ Patents for Proven Technology
- Multi-award winning technology

80% DEFENCE
+ Optical Night Vision
+ Digital Night Vision
+ Electronic Counter Measures

20% Science
+ Photonics
+ Analytical Instruments
+ Physics
+ Space
+ Medical Imaging
Worldwide presence

Head quarters
Production sites
History

Photonis

1937 Philips Brive
1963 Hyperlec
1986 RTC Compelec
1990 Philips Components
1992 Philips Photonics
1996 Photonis

DEP

1970 Delft Electronische Producten
1973 Oude Delft
1990 Delft Instruments
1995 Delft Electronic Products BV

Burle

1942 US Navy
1946 RCA Corporation
1986 GE
1987 Burle Industries
1999 Purchase Galileo MCP 1946

2005 Photonis Group

2006 Acquisition of 100% of Antheryon (Optic Fiber)

2007 Opening Merignac Office

2006 Acquisition of 100% of Hi-light Opto Electronics (Power Supply)

2008 Acquisition of Assets related to AVG manufacturing from Brennel

2013 Opening of Frisco office
Creation of Digital Vision BU

3rd IPM Workshop, J-PARC
Introduction
Looking closer
Where we start
Microchannel Plate Manufacturing Process

Glass Monofiber Draw

Billet Fabrication. Billets are Sliced. Slices are ground and polished.

Polished slices are subjected to chemical processing.

Hydrogen Reduction

Electrode Evaporation

Final Test and Inspection

Glass Multifiber Draw
Geometrical limitations

- 75mm active area - 10 µm minimum pore
- 40 mm active area – 5 µm pore, 60:1
- 25 mm active area - 5 µm pore, 60:1
- 18 mm active area – 2 µm pore, 60:1 MP
Gain

Gain Parameters:

- Channel Length/Diameter = Aspect Ratio = $\alpha$
- Number of MCP’s
- Output End-spoiling
  - 0.5 pore dia. Increases effective length

\[
G = \left( \frac{AV}{2\alpha V_0 1/2} \right)^{4V_0^{\alpha^2}/V}
\]
Aspect Ratio

- $\alpha = \frac{L}{d}$ Designed to be between 40-60 (optimized statistical uniformity)

- Gain limitations:
  - Ion feedback
  - Space charge saturation:
    Maximum gain of saturation (for fixed $V$ and $\alpha$ is proportional to the pore diameter)

$G \approx \exp(g\alpha)$
Multiple MCP configurations

- Double MCP (chevron) gain $> 10^6$
- 3 MCP (Z stack) configuration gain $> 10^7$
- Ion feedback decrease
  A Z stack with the same total gain as a Chevron stack (i.e. lower individual $V$) will have less ion feedback
- Gain of multiple MCP configurations is limited by space charge effects (charge loss, saturation)
- Pulse mode (gaussian distribution)
Electroding – “End spoiling”
Single Microchannel Plate Gain as a Function Of Output Endsoiling

Gain % Normalized To .5cd Value

Output Endsoiling Channel Diameters
Detection Efficiency Parameters

- Open Area Ratio
- Electroding
- Specific (Particle dependent)
- Bias Angle
- Coatings
Particle Detection Efficiency

![Detection Efficiency Graph](image)

- **Hard X-Rays**: 8-100 Kev
- **Soft X-Rays**: 0.2-7 nm
- **UV**: 30-115 nm
- **Electrons**: 115-150 nm
- **Positive Ions**: 0.5-3 Kev
- **Energy Ranges**: 0.1-0.5 Kev, 4-100 Kev, 10-50 Kev, 3-10 Kev, 50-200 Kev

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3rd IPM Workshop, J-PARC
Bias angle

Strike Angle optimizations secondary electron creation

- $0^0$ - collimation & filtration
- $5^0$ – Photons
- $8^0$ - Electrons
- $12^0$- Ions
- $19^0$ – Special arrangements
Coatings

- **Magnesium Oxide - MgO**
  - Low energy electrons = below 300 eV

- **Cesium Iodide – CsI**
  - UV Photons = up to 200 nanometers

- **Magnesium Fluoride - MgF2**
  - UV Photons from 40 to 65 nanometers

- **Potassium Bromide – KBr**
  - X-rays from 0.2 eV to 9.0 keV
Linearity and Dynamic Range

- Low noise MCPs
- MCP’s produce linear output for 10% of bias current -> saturation level improves with the increase of the Is, i.e. with the decrease of the MCP resistance
- EDR MCP (low resistance) will have 5 to 10X linear output (high rate pulse events allowed)
- It improves with decreasing the pore size (More pores available/Area for next event)
Extended Dynamic Range

**MCP 40/12/10/8 Example**

**Standard MCP**
- Bias Current = 40 µA
- Resistance = 80 Megohms
- Linear Output = 4 µA
- Max. Operating Temperature = 200 °C

**EDR version**
- Bias Current = 200 µA
- Resistance = 10 Megohms
- Linear Output = 20 µA
- Max. Operating Temperature = 80 °C
Time response
Time resolution

- Electron transit time down with the MCP size (electron transit distance)
- Example: Planacon

- Same principle for any device
- Timing results depend on device construction, MCP details...

- Planacon
  - 25 µm MCP ~45 ps
  - 10 µm MCP ~32 ps

TIME SPREAD (TTS) < 50 ps
Spatial Resolution

- Pore Ctr-to-Ctr Distance
- End-spoiling
Spot Size, Deep Endspoiling

Focal Plane
Spatial Resolution – Endspoiling

Limiting Spatial Resolution as a Function Of Output Endspoiling (18mm 9.5µm C-C)

Conditions:
- MCP to Al. Screen Spacing = .6mm
- Phosphor Grain Size 3um
- FOFP Pitch 6um
- Screen Potential 5Kv
MCP Lifetime (gain stability)

- The gain drops as a function of the accumulated extracted charge
- ALD (atomic layer deposition) coating (Aluminum oxide)

Results with multianode MCP-PMTs from PANDA collaboration

Matthew Breuer; Paula Holmes, Ph.D.; John Harper
Photonis Scientific, Inc., Sturbridge, MA
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  - Photon counter
  - Cricket
# Choices

<table>
<thead>
<tr>
<th>Specification</th>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Dimensions</td>
<td>Physical Size</td>
</tr>
<tr>
<td>Pitch/Pore</td>
<td>Spatial &amp; Temporal Resolution</td>
</tr>
<tr>
<td>Bias Angle</td>
<td>Detection Efficiency</td>
</tr>
<tr>
<td>Grade</td>
<td>Gain Uniformity</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>Gain</td>
</tr>
<tr>
<td>Geometry</td>
<td>Robustness &amp; Experiment Need</td>
</tr>
<tr>
<td>Bias Current</td>
<td>Linear Output</td>
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<tr>
<td>Coatings</td>
<td>Detection Efficiency</td>
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<tr>
<td>Multiples</td>
<td>Gain</td>
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<tr>
<td>Flatness</td>
<td>Time Jitter</td>
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### What do we specify?

<table>
<thead>
<tr>
<th>PHYSICAL CHARACTERISTICS</th>
<th>SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Diameter:</td>
<td>50.04mm (1.970&quot;) ± 0.08mm</td>
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<tr>
<td>Quality Diameter:</td>
<td>40.00mm (1.575&quot;) Minimum</td>
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<tr>
<td>Border Width:</td>
<td>2.15mm (.085&quot;) Minimum</td>
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<tr>
<td>Thickness:</td>
<td>0.61mm (.024&quot;) ± 0.03mm</td>
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<td>Material Type:</td>
<td>Long-Life™ MCP-10</td>
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<td>Center-to-Center Spacing:</td>
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<tr>
<td>Pore Size:</td>
<td>10µm Nominal</td>
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<td>Bias Angle:</td>
<td>8° ± 1°</td>
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<td>Open Area Ratio:</td>
<td>55% Minimum</td>
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<td>Electrode Material:</td>
<td>Nichrome (80/20)</td>
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<td>Electrode Diameter:</td>
<td>49.15mm (1.935&quot;) ± 0.13mm</td>
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<td>Electrode Bias Identification:</td>
<td>Input Side</td>
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<td>Electrode Sheet Resistance:</td>
<td>Input: 150 Ohms Maximum</td>
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<tr>
<td></td>
<td>Output: 100 Ohms Maximum</td>
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<tr>
<td>Electrode Penetration:</td>
<td>Input: 0.3-0.7 Channel Diameters</td>
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<td></td>
<td>Output: 1.7-2.3 Channel Diameters</td>
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<table>
<thead>
<tr>
<th>ELECTRICAL CHARACTERISTICS</th>
<th>SPECIFICATIONS</th>
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<tr>
<td>Gain @ 900 Volts:</td>
<td>400 Minimum</td>
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<tr>
<td>Gain @ 1200 Volts:</td>
<td>10,000 Minimum</td>
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<tr>
<td>Bias Current Range @ 1200 Volts:</td>
<td>8-79 Microamps</td>
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<tr>
<td>Resistance (For Reference Only):</td>
<td>15-150 Megohms</td>
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<tr>
<td>Maximum Specified Operating Voltage:</td>
<td>1200 Volts</td>
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<tr>
<td>Test/Inspection Level:</td>
<td>Imaging Quality</td>
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</table>

<table>
<thead>
<tr>
<th>ELECTRICAL CHARACTERISTICS</th>
<th>SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chevron™ Gain @ 2400 Volts:</td>
<td>1 x 10³ Minimum</td>
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<tr>
<td>Chevron™ Bias Current Range @ 2400 Volts:</td>
<td>8-79 Microamps</td>
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<tr>
<td>Chevron™ Resistance (For Reference Only):</td>
<td>30-300 Megohms</td>
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<tr>
<td>Matched Bias Currents (2 MCPs) @ 1200 Volts:</td>
<td>Within 10%</td>
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<tr>
<td>Chevron™Dark Count @ 2400 Volts:</td>
<td>3 cts/sec/cm² Maximum</td>
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<tr>
<td>Chevron™ Pulse Height Dist. @ 2400 Volts:</td>
<td>100% FWHM</td>
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<tr>
<td>Maximum Specified Operating Voltage:</td>
<td>2400 Volts</td>
</tr>
<tr>
<td>Test/Inspection Level:</td>
<td>Imaging Quality</td>
</tr>
</tbody>
</table>

*Note: MCP Set Tested as a Chevron™ is tested with a 50 micron interplate spacing.
External conditions (I)

- Relative Immunity to Magnetic field:
  MCPs can be operated in strong magnetic fields up to 2T
  Maximum disturbance when perpendicular to the MCP pores (if possible choose smaller pores and B ‖ to pores)

- Operating Temperature is important:
  MCP Glass resistance goes down as temperature goes up (thermal Coefficient of Resistivity 0.8% -per-degree C)
  T needs to be monitored: T increases -> Resistance decreases-> lower gain
  Bias Current above 25 µA/cm² leads to thermal runaway (MCP is overheated and damaged)
External conditions (II)

- Pressure:

Works at Pressures up to $10^{-2}$ Torr. At Pressures higher than the dark count rate starts to increase due to the increase of ion feedback.

With poor vacuum operating conditions, the noise increases and damage can occur (discharge...).
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  - Photon counter
  - Cricket
MCPs detection characteristics

- Highest Speed Detectors Available
- Ideally Suited for TOF
- Work at Pressures up to $10^{-2}$ Torr.
- High Gain up to 100,000,000
- Low Noise 1 ct/sec/cm$^2$ after scrub
- Position sensitive
- Bipolar Detector
Beam Profiler concept

Electron generator Array (EGA)
Resistive glass Plate
Beam
Imaging MCP set
Anode
Beam Profiler

A tightly focused beam

A poorly focused beam

A beam de-focused by a time-varying magnetic field with many ions off target.

Camera zooming allows real-time magnification of regions of interest.
Neutron Imager

- If the MCP glass is doped with enriched $^{10}\text{B}$, it becomes neutron sensitive ($n+{\text{B}}\rightarrow \text{Li}+\alpha$)
- Detection efficiency $\approx 50\%$ for thermal neutrons, $70\%$ for cold neutrons

First images taken at the Reactor Institute Delft (NL) with thermal neutrons, and at HFIR, Oak Ridge National Lab, with cold neutrons.
Neutronic (Large Area Neutron imager)

Active Area: 10cm x 10cm

<table>
<thead>
<tr>
<th>Technical Specifications</th>
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<tbody>
<tr>
<td>Imaging Resolution</td>
<td>50 µm</td>
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<tr>
<td>Electron Gain @ 1000 Volts</td>
<td>&gt; 1000</td>
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<tr>
<td>Dark Counts at Gain Voltage</td>
<td>&lt; 0.1 counts/second/cm² Max</td>
</tr>
<tr>
<td>Vacuum Base Pressure</td>
<td>&lt; 1E-6 Torr</td>
</tr>
</tbody>
</table>

Figure 1: The top image shows a Siemens star on a Gd mask. Using the cold neutron imaging beamline at Oak Ridge National Lab, the Neutronic [I] is able to provide high resolution images at 50 µm as seen in the inner-most circle of the bottom image.
Photocathodes
Extremely low noise

- The Dark count rate of the new PHOTONIS High QE S20 photocathodes is extremely low, 20-30 cps/cm² compared to conventional S20 photocathodes, 1000-2000 cps/cm²
- typical 25 cps/cm²
- maximal 50 cps/cm²

D.A. Orlov et al. 2016 JINST 11 C04015
MCP-PMT with integrated gating unit

General Description
18mm double MCP based gateable MCP-PMT with a low noise Hi-QE Green photocathode on Quartz input window and single anode. Potted with bleeder chain for single HV operation. The MCP-PMT is fitted with a gating unit.

Hi-QE Photocathode
Based on conventional S-20 processes, a new series of high quantum efficiency (QE) photocathodes has been developed that can be specifically tuned for use in the ultraviolet, blue, green or red regions of the spectrum. The QE values exceed 30% at maximum response, and the dark count rate is found to be as low as 30 Hz/cm² at room temperature. This combination of properties along with a fast temporal response makes these photocathodes ideal for application in photon counting detectors, which is demonstrated in this MCP-PMT PP236S series for single and multi-photon detection.

Hi-QE Photocathode Technology
Page 1 of 5
184-6707A1

Supply Voltages

<table>
<thead>
<tr>
<th>Name</th>
<th>Unit</th>
<th>Min</th>
<th>Nom</th>
<th>Max</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>MCP-PMT</td>
<td>Vdc</td>
<td>2400</td>
<td>2600</td>
<td></td>
<td></td>
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<tr>
<td>Gate Unit</td>
<td>Vdc</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td></td>
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<tr>
<td>Gate on</td>
<td>Vdc</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Gate off</td>
<td>Vdc</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
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<tr>
<td>Supply current</td>
<td>mA</td>
<td>150</td>
<td></td>
<td></td>
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</tbody>
</table>

Specification

Input window Quartz
Photocathode type Hi-QE Green
MCP double, chvron, 6µm pore size, 50:1 L/D
Output single anode, SMA connector
HV Supply HV BNC connector
Gate unit supply SMB connector
Gate on/off input SMA connector

Specification at 20°C MCP-PMT

<table>
<thead>
<tr>
<th>Input useful diameter</th>
<th>Minimal</th>
<th>Typical</th>
<th>Maximal</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>mm</td>
<td>17.5</td>
<td></td>
<td></td>
<td>mm</td>
</tr>
</tbody>
</table>

Photocathode sensitivity

- Quantum efficiency: @380 – 480nm 26 %
- Collection Efficiency: 95 %
- MCP Gain: 150,000 - 150,000
- Average anode current: 1 µA
- Anode dark current: 30 µA
- Dark count rate: 150 cps

Phostonics Scientific Detectors
PHOTONIS
3rd IPM Workshop, J-PARC
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Imaging Photon Counter

MCP detector combined with specially designed electronics unit with a unique combination of capabilities.

✓ Wide field of view (18 mm)
✓ Single photon counting
✓ High spatial and temporal resolution. The system has picosecond timing and micro meter spatial resolution
✓ No read-out noise
✓ Up to 5MHz input rates
✓ Newly introduced high quantum efficiency photocathodes with ultra low dark noise additionally boost the IPC performance
The IPC detector head:
The MCP tube is enclosed in an air tight aluminum housing with thermoelectric coolers and temperature sensors. C-type mount allows attachment of lens, a microscope phototubes or any desired optics.

Photocathode converts photon to electron

6 µm MCP(s) with L/D=80 amplify electron by $10^4$ to $10^7$

Cross strip anode (32 X+32 Y)

O. Siegmund et al., NIM-A 504 (2003) 177
XS anodes (32 Y + 32 X strips) are 2.5 mm behind the second MCP allowing charge collection over several strips (optimal centroid calculation).

✓ The spatial resolution achieved in X and Y direction is the same and equal to about 40 µm FWHM.

✓ The timing resolution is below 100 ps
✓ The current electronics can process up to 5 MHz input event rate.
What is inside of an intensifier matters
Cricket is a self-contained unit, equipped with C-mount connections that enable the user to simply connect to any scientific camera and attach to any lens or microscope to begin capturing intensified images. Cricket’s internal structure provides power to the embedded image intensifier and maintains proper alignment and focus to provide a full 18mm intensified image for analysis. Cricket supports detection ranges from 200 to 900 nm and can be used with most EMCCD, CCD, CMOS or sCMOS cameras.
What is inside cricket?

- Complete plug and play system, including:
  - Image intensifier
  - Power supply
  - Focus adjustments
  - Optional Gating Unit
  - Gain control

- C-mounts for easy connection to camera and lens
References
Operation principle PHOTONIS Gate units
Voltage and timing diagram

Gate-in (external connection)

Gate-out to photocathode contact (internal connection)

+50V gate off

-200V gate on