Newly Developed Semiconductor Detectors

- Multi-Pixel Photon Counter (MPPC)

HAMAMATSU PHOTONICS K.K.
Koei Yamamoto
PD07 Kobe June 27th 2007
Multi Pixel Photon Counter (MPPC)

What’s MPPC?
Solid state photon counter having Multi pixelated Geiger-mode APDs with self-quenching resistance

The MPPC (Multi-Pixel Photon Counter) is developed by HAMAMATSU PHOTONICS K. K. and it is one of the products of Si-PM (Silicon Photo multiplier) family which was originally developed in Russia.

HAMAMATSU MPPC is designed as a photon counting device based on structures of a Si APD which was adopted by CERN (CMS).

HAMAMATSU named this product MPPC which is a trademark.
The candidates of name in SiPM family

SiPM (Silicon Photo Multiplier)
SiPMT (Silicon Photo Multiplier Tube)

MRS-APD (Metal Resistive Semiconductor APD)
SPM (Silicon Photo Multiplier)
MPGM APD (Multi Pixel Geiger-mode APD)
AMPD (Avalanche Micro-pixel Photo Diode)
SSPM (Solid State Photo Multiplier)
GM-APD (Geiger Mode APD)
SPAD (Single Photon Avalanche Diode)

MPPC : Multi Pixel Photon Counter
What is the structure of MPPC to improve the performances
Photo Absorption coefficient of Silicon
Photon is our Business

Ionization coefficient for avalanche multiplication

Hamamatsu
Solid State Div.
Schematic representation of the carrier-multiplication process, where the multiplication factor is 8: (a) carrier impact ionization takes place for both carriers; (b) only electron impact ionization takes place.
**Photon is our Business**

**CMS (CERN) APD**

![Diagram of CMS (CERN) APD](image)

**Figure 2: Structure of the selected APD**

![Graph showing spectral response curve](image)

**S8664-55 Gain Uniformity (Typ. M=50)**

**S8664-55 Spectral response curve**

![Graph showing photo sensitivity and QE](image)
The p/n junction is formed in an epitaxial layer with 50μm thickness. Bias 350 to 400V to get gain 50.

Hamamatsu Reverse Structure APD for CMS
Photon is our Business

N/P-Reach through

P/N-Reach through

Back illumination type

HPK Reverse structure
What are the characteristics of MPPC

![Graph showing the MPPC signal (ADC counts) versus entries. The x-axis represents MPPC signal (ADC counts) ranging from 0 to 1600 pixel, and the y-axis represents entries ranging from 0 to 1. The graph includes multiple peaks and a smooth decay.](image)
## Specification of 1mm □, MPPC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1600</th>
<th>400</th>
<th>100</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip size</td>
<td>1.5 x 1.5</td>
<td>mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective active area</td>
<td>1 x 1</td>
<td>mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of pixels</td>
<td>1600</td>
<td>400</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Pixel size</td>
<td>25 x 25</td>
<td>50 x 50</td>
<td>100 x 100</td>
<td>um</td>
</tr>
<tr>
<td>Geometric efficiency</td>
<td>30.8</td>
<td>61.5</td>
<td>78.5</td>
<td>%</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>$\lambda_p / \lambda$</td>
<td>400</td>
<td>nm</td>
<td></td>
</tr>
<tr>
<td>Quantum efficiency</td>
<td>70 min</td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDE</td>
<td>25</td>
<td>50</td>
<td>65</td>
<td>%</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>77±10</td>
<td>70±10</td>
<td>70±10</td>
<td>V</td>
</tr>
<tr>
<td>Gain</td>
<td>2.75E+05</td>
<td>7.50E+05</td>
<td>2.40E+06</td>
<td>Kcps</td>
</tr>
<tr>
<td>Dark count</td>
<td>100</td>
<td>270</td>
<td>400</td>
<td>Kcps</td>
</tr>
<tr>
<td>Terminal capacitance</td>
<td>35</td>
<td></td>
<td></td>
<td>pF</td>
</tr>
<tr>
<td>Time resolution (FWHM)</td>
<td>250</td>
<td>220</td>
<td>250</td>
<td>ps</td>
</tr>
<tr>
<td>Temp coefficient of bias voltage</td>
<td>50</td>
<td></td>
<td></td>
<td>mV/℃</td>
</tr>
</tbody>
</table>

*The last letter of each product number indicates which type of package is used. (U: Can, C: Ceramic)

*1: The figures in PDE (Photon Detection Efficiency) include cross-talk and after pulse.
Bias vs. Gain

S10362-11-025U/C  S10362-11-050U/C, -100U/C
Photon is our Business

Bias vs. Dark count

25 μm 1600 pixels

50 μm 400 pixels

100 μm 100 pixels

S10362-11-025U/C

S10362-11-050U/C, -100U/C
Photon Detection Efficiency (PDE)

- 100 μm Pixel (100 pixel type)
- 50 μm Pixel (400 pixel type)
- 25 μm Pixel (1600 pixel type)

including the cross-talk and after pulse
Output signal of MPPC

Photon counting by pulse height
(liner Amp.)

Photon counting by output charge
(charge Amp.)
Energy Resolution

MPPC: 50mm pitch, 3mm square
LSO: 3mm x 3mm x 20mm
FWHM @511keV: 13%
Gain uniformity
(400 pixel, 100 samples)
PDE uniformity
(400 pixel, 100 samples)

PDE Delta V : 400 pixel 100 samples

Delta V [V]
1600 pixel Microscopic view
Laser Scan in One Pixel

- Pin-point scan: YAG laser ($\lambda = 532$ nm) with spot size $\sim 1 \, \mu m$.
- Variation of photon sensitivity and gain in one pixel are evaluated.
- Observed variation is $2 \sim 5\%$ in a sensitive area for the 100 / 400 / 1600 pixel MPPCs.

1600 pixel Sensitivity

1600 pixel Gain

Variation $\sim 3\%$

Variation in photon sensitivity and gain in one pixel.
Time resolution at center in different pixel

MPPC: MPPC:1mm²  50 μm pitch

<table>
<thead>
<tr>
<th></th>
<th>FWHM (ps)</th>
<th>FWTM (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>199</td>
<td>393</td>
</tr>
<tr>
<td>2</td>
<td>197</td>
<td>389</td>
</tr>
<tr>
<td>3</td>
<td>209</td>
<td>409</td>
</tr>
<tr>
<td>4</td>
<td>201</td>
<td>393</td>
</tr>
<tr>
<td>5</td>
<td>195</td>
<td>383</td>
</tr>
</tbody>
</table>
Photon is our Business

Time resolution in one pixel

MPPC: 1mm²  50 μm pitch

![Graphs showing FWHM values for different channel numbers.](image)

- **FWHM = 263 ps**
- **FWHM = 294 ps**
- **FWHM = 192 ps**

HAMAMATSU  
Solid State Div.
Package Developments
Plastic PKG (1mm × × 1ch.)

3.2

4.2

1.3
SMD PKG (1mm ~ 1ch.)

1.0

1.9

2.4

[mm]
SMD PKG (3mm × 3mm × 1ch.)
CERAMIC PKG (3mm x x 1ch.)

Dimensions:
- Height: 2.0
- Width: 5.9
- Length: 7.2

Hamamatsu
Solid State Div.
CERAMIC PKG (3mm ~ 4ch.)

Dimensions:
- Width: 8.1 mm
- Height: 2.0 mm
- Depth: 8.95 mm
Photon is our Business

- MPPC’s future plan

- Increase reproducibility and uniformity
- Large sensitive area, Array and Matrix
- Enhance PDE
- Suppress after pulse and cross talk
- Quenching resistance optimization
- Package development (small, cheap, rugged)
- Custom design (pitch, package, array)
Al optical separation and Trench etching

Al optical separation

Trench etching
MPPC Module

Features
- Employs a Geiger-mode multi-pixel APD (MPPC)
- Integrates a signal readout circuit ideal for MPPC
- Built-in high-voltage circuit and temperature-compensated circuit
- Three types of output: analog, comparator, pulse calculation value
- USB interface for easy handling: driven by USB bus power
- Compact and light weight
**MPPC Module block diagram**

- **MPPC Module**
  - **MPPC Controller**
  - **High-Voltage Generator**
  - **Microcomputer**
  - **Comparator**
  - **Counter**
  - **Current-to-Voltage Conversion Amp**
  - **Temperature Sensor**

**Outputs**
- **Output-1**: Analog output
- **Output-2**: Comparator output
- **Output-3**: Pulse calculation value

**Power**
- Use USB bus power
Characteristics (analog output)

C10507-11-025U

C10507-11-050U
Characteristics (temperature stability of Gain)
Photon is our Business

www.hamamatsu.com