Scientific contribution and Industrial applications of Photon detectors on Hamamatsu Photonics

38th ICHEP August 2016 Chicago
Company Information: Hamamatsu Photonics K.K.

- Established: September 29, 1953
- Stock listing: Tokyo Stock Exchange (1st Section, ID number: 6965)
- Capital: 35 Billion YEN
- Turnover FY15: 120 Bio Yen net sales / 1 Bio US$
- Number of employees: > 4400

Where is Hamamatsu
Hamamatsu Photonics K.K. - Divisions:

**Photomultiplier Tubes, Light Sources, Fiber Optics Plates, Image Sensors, X-ray Products, etc.**

**Photodiodes, Photo ICs, Image Sensors, Infrared Sensors, X-ray Sensors, Solid State Emitters, etc.**

**Imaging & Measurement Instruments in the diverse fields such as biological/medical/pharmaceutical fields, semiconductor, spectroscopy and industry**

**High Power LD, CW LD, QCL, etc.**
Optical Sensors (Photomultiplier Tubes)

Over 90% PMT share of the world market.
Optical Sensors (Head-on PMT)

- The No.1 choice in academic research fields including high energy physics.
- Striving to develop new sensors by merging the features of semiconductors and electron tubes.
- Makes the world’s most sensitive and responsive optical sensors in the near infrared range.

- Flat panel PMT
- Metal package PMT (high energy physics experiments)
- Near infrared PMT (biological function measurement)

Here, a total of 11,200 of 20-inch dia. PMTs are used to catch neutrinos and monitor proton decay.
Optical Sensors (microPMT)

Extremely miniaturize with keeping the high performance. Practicable for miniaturizing the instrument, hand held measuring instruments.
X-Ray Related Products

**Microfocus X-ray source**
( non-destructive X-ray inspection)

BGA joint

IC bumps (50μm)
X-Ray Related Products

- **Scintillator**
  - Scintillator: CsI(Tl)
  - Amorphous-Carbon: ACS
  - Aluminum Plate: ALS

- **FOS (Fiber Optics Plate with CsI scintillator)**
- **ACS (Amorphous-carbon plate with CsI scintillator)**
- **GPXS (Great Performance X-ray CsI scintillator)**
- **ALS (Aluminum plate with CsI scintillator)**

- **Chest examination**
  - FPD-DR
  - CCD-DR

- **Mammography**

- **Dental examination**
Low Light Cameras for Life Science

- **Scientific CMOS Camera ORCA-Flash 4.0 V2**
  ORCA-Flash 4.0 V2 is the new generation camera featured by low noise, high speed and high resolution.

  - High-speed Ca2+ imaging of cardiomyocyte derived from human iPS cell stained with Fluo8-AM. Sequential images were obtained every 10 ms.

- **Electron Multiplying CCD camera ImagEM**
  ImagEM is ideal for bio-medical imaging requiring very high speed and high sensitivity.

- **Time Image Splitting Optics W-VIEW GEMINI**
  Simultaneous dual wavelength imaging by a single camera.

Copyright © Hamamatsu Photonics K.K. All Rights Reserved.
Hamamatsu Photonics assists developing new drugs by synthesizing large amounts of chemical compounds using new technical breakthroughs by offering high-speed, cell-based assay screening systems as well as functional analysis and screening systems.

- Kinetic Plate Reader for Cell-based Assay Screening
- Cell-based Assay System corresponding High Throughput

- Digital slide scanner for pathology and cytology
The NanoZoomer 2.0 converts glass slides into the digital form

- NanoZoomer-XR (Process up to 320 slides automatically)
- NanoZoomer-SQ (Desktop and light weight)
Semiconductor QC and Process

Failure detection and analysis
This system locates, visualizes and analyzes failures inside semiconductor devices by detecting weak light emissions, heat emissions or electrical changes caused from the failures.

- PHEMOS series
- ESD damage localization
- FET rush current caused by a short or open circuit
- Metal wiring defect analysis using the IR-OBIRCH method

High resolution and high light collection efficiency
NanoLens (solid immersion lens)

- Objective lens
- Laser light collection
- Large N.A.
- Pattern side

IR imaging of internal structures
- Imaging of Chip internal
- Imaging of SOI wafer Void
Products of laser group

We develop every part of our semiconductor lasers ourselves, from epitaxial growth to chip assembly to drivers. The finished products offer high reliability for many applications.

- Laser diodes
- High power laser diode bar modules
- Direct diode laser (DDL)
- Fiber output laser diode (FOLD)
- Quantum cascade lasers (QCL)
- LD irradiation light source (SPOLD)
Applications of laser diodes

**Processing**
- 1D(line) welding
- 3D welding
- Plastic welding
- Soldering

**Range measuring**
- Distance meter
- Anti-collision

**Medica**
- OCT (Optical coherence tomography)

**Academic**
- Laser fusion research
Products of integral optics

- Microchip laser
- Solid-state laser
- Ultrashort pulsed laser “MOIIL-ps L11590”
- Tera-Hz spectrophotometer
- Laser analysis equipment
- Portable Raman spectrometer module
Industries development laboratory

- Working to achieve laser fusion generation

Promoting high-power semiconductor laser (LD) research and bringing applications for high-power output lasers to the industrial front

Laser irradiation building for research

- A 50-stack high-power LD module

- High-intensity femtosecond lasers

- Solid-state laser driver excited by high-power LDs
Products of Solid State Division

- Si photodiodes
- APD/ MPPC
- Photo ICs
- Image sensors
- PSD
- Infrared LED/detectors
- Visible sensors
- Color sensors
- LED
- Optical communication
- Flat panel sensors
- spectrometers
- Opto- Modules
- Automotive devices
- LCOS-SLM
X-ray detector for medical CT

Si PD Array

Multi Slice (ID to 2D)
X-ray Baggage Inspection

Si photodiode array with scintillator

2D BT-PD array

Single Energy

Dual Energy

S11212-121
S11299-121

Copyright © Hamamatsu Photonics K.K. All Rights Reserved.
**Basic Operation**

- Each pixel operates separately in Geiger-mode
- Each pixel outputs a same amplitude pulse
- Pulse generated by multiple pixels are output while superimposed onto each other (detected at the same time)
- No position information
MPPC Module for PET Application
# TOF PET Module

<table>
<thead>
<tr>
<th>Specifications</th>
<th>New (2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRT</td>
<td>280 ps</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>&lt;15 %</td>
</tr>
<tr>
<td>Crystal material</td>
<td>LFS (Lutetium Fine Silicate)</td>
</tr>
<tr>
<td>Crystal dimensions</td>
<td>4.14 x 4.14 x 20 mm 12 x 12 array</td>
</tr>
<tr>
<td>MPPC type</td>
<td>LCT type</td>
</tr>
<tr>
<td>Detector dimensions</td>
<td>4.0 x 4.0 mm 12 x 12 Array</td>
</tr>
<tr>
<td>Pixel size</td>
<td>75 μm</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>24V</td>
</tr>
<tr>
<td></td>
<td>Require Local Power Supply</td>
</tr>
<tr>
<td>Consumption power</td>
<td>5 W</td>
</tr>
<tr>
<td>Interface</td>
<td>High Speed Serial</td>
</tr>
</tbody>
</table>

- **Power Consumption**: 3mW/ch
- **Timing Resolution**: ~200ps
- **Process**: 0.18 CMOS

#### 12 x 12 LFS Array

#### MPPC Array + ASIC
Dental Application

Intra-Oral

Pan/Ceph

CT

パノラマ画像

セファロ画像

Solid State Division

CsI
Scientific Contribution
Contribution to Nobel Prize

2002  Masatoshi Koshiba, professor emeritus of University of Tokyo, was awarded the Nobel Prize in physics, as a result of research conducted at the Kamiokande using Hamamatsu 20” PMT

2013  Professors emeriti François Englert and Peter Higgs won the Nobel Prize in Physics. (Our SSDs, APDs, and PMTs helped to detect the Higgs boson)

2015  Takaaki Kajita, professor of University of Tokyo, was awarded the Nobel Prize in physics, as a result of research conducted at the Super-Kamiokande facility using 20” PMT from Hamamatsu Photonics.
“Super Kamiokande” There are 11,200 PMT with 50cm diameter Inside
ATLAS - SSD

- SSD provided from CERN experiment groups
ATLAS

Central tracking detectors & SCT module

provided from CERN experiment groups
CMS
Si tracker and SSD

1 Sensor on 6 inch wafer

S9153, S9154 series

provided from CERN experiment groups
Specifications and Structure of APD

- Blue sensitivity improved by SiN-AR coating
- low-capacity by spreading the depletion layer into the N side
- V-Groove for less increase of surface leakage current due to the irradiation damage.

### Specifications (Ta = 25°C)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>active area</td>
<td>5 x 5 mm²</td>
</tr>
<tr>
<td>breakdown voltage (VB)</td>
<td>&gt; 325 V</td>
</tr>
<tr>
<td>Operating Voltage (VR)</td>
<td>300 – 450 V</td>
</tr>
<tr>
<td>Difference VB-VR</td>
<td>&gt; 25 V</td>
</tr>
<tr>
<td>Dark current at VR</td>
<td>&lt; 50 nA</td>
</tr>
<tr>
<td>Capacitance at VR</td>
<td>65 – 85 pF</td>
</tr>
<tr>
<td>Quantum efficiency at VR, 430nm</td>
<td>75 ± 5%</td>
</tr>
<tr>
<td>Passivation layer</td>
<td>SiN</td>
</tr>
<tr>
<td>Protective coating</td>
<td>Epoxy Resin</td>
</tr>
</tbody>
</table>
Fully depleted back illuminated CCD

- NIR high sensitivity
- Low noise (4erms@133kHz)

SUBARU observatory at Hawaii

Observation of outer galactic space
Quantum Efficiency

Spectral Response Characteristics at Room Temperature

Wave Length (nm)
Quantum Efficiency (%)
HAYABUSA brought back Itokawa’s sample after 7 years long and traveling about 2 billion kilometers journey.

HAYABUSA had two of detectors on board developed by Hamamatsu to observe the surface materials of Itokawa. One was CCD for fluorescence X-ray spectrometer and other was Infrared Spectrometer.
Total strip detectors: 11,000pcs
Each strip are: 8.95x8.95 mm
228μm pitch
New Developments
Recent Development for HEP

- Large Size
- PMT
- Fast Time Respons
- Low Temp. & Low R.I.
- High QE

Copyright © Hamamatsu Photonics K.K. All Rights Reserved
## Future Experiments for PMT (1/2)

<table>
<thead>
<tr>
<th>Category</th>
<th>Experiment</th>
<th>Experimental Site</th>
<th>Delivery</th>
<th>Type of PMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutrino</td>
<td>Hyper-Kamiokande</td>
<td>Kamioka/Japan</td>
<td>2018~</td>
<td>R12860 (20-inch) ASSY</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R5912 (8-inch) ASSY</td>
</tr>
<tr>
<td></td>
<td>NuPRISM</td>
<td>J-Parc/Japan</td>
<td>2020~</td>
<td>R12199 (3-inch)</td>
</tr>
<tr>
<td></td>
<td>KamLand2-Zen</td>
<td>Kamioka/Japan</td>
<td>2018~</td>
<td>R12860 (20-inch) ASSY</td>
</tr>
<tr>
<td></td>
<td>JUNO</td>
<td>Jiangmen/China</td>
<td>2016~</td>
<td>R12860 (20-inch)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2017~</td>
<td>R12199 (3-inch)</td>
</tr>
<tr>
<td></td>
<td>KM3NeT</td>
<td>Mediterranean Sea</td>
<td>2014~</td>
<td>R12199 (3-inch)</td>
</tr>
<tr>
<td></td>
<td>Baikal-GVD</td>
<td>Lake Baikal</td>
<td>2015~</td>
<td>R7081-100 (10-inch)</td>
</tr>
<tr>
<td></td>
<td>PINGU/IceCube</td>
<td>the South Pole</td>
<td>2018~</td>
<td>R12199 (3-inch)</td>
</tr>
</tbody>
</table>
## Future Experiments for PMT (2/2)

<table>
<thead>
<tr>
<th>Category</th>
<th>Experiment</th>
<th>Experimental Site</th>
<th>Delivery</th>
<th>Type of PMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision Experiment</td>
<td>RICH/LHC-B</td>
<td>CERN</td>
<td>2015~</td>
<td>1-inch Square MA-PMT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2-inch Square MA-PMT</td>
</tr>
<tr>
<td></td>
<td>RICH/CBM</td>
<td>GSI/Germany</td>
<td>2015~</td>
<td>2-inch Square MA-PMT</td>
</tr>
<tr>
<td>Dark Matter</td>
<td>LZ7</td>
<td>SURF/USA</td>
<td>2016~</td>
<td>3-inch Metal Bulb PMT</td>
</tr>
<tr>
<td></td>
<td>XENON-1T/-nT</td>
<td>Gran-Sasso/Italy</td>
<td>2015~</td>
<td>3-inch Metal Bulb PMT</td>
</tr>
<tr>
<td>Gamma-ray Telescope</td>
<td>CTA</td>
<td>North-La Palma</td>
<td>2015~</td>
<td>R12992 (1.5-inch)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South-Chile</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Multi-Anode PMT**
- R11265 (1-inch)
- R12699 (2-inch)
- R12992 (1.5-inch)

**High QE and Low Noise**
- Concave-Convex Window
- R12992 (1.5-inch)

**Metal Bulb PMT**
- R11410 (3-inch)
- Ultra Low RI
MPPC for Cherenkov Telescope Array

Required Properties
- High PDE @350nm
- High Gain
- Low cross talk
- Low dark count
- Large sensitive area
- Less sensitivity in visible

![Graph showing PDE and Crosstalk as functions of Overvoltage](image)

- **PDE (%)**
  - Blue line: MPPC Standard
  - Green line: MPPC NIR suppress
  - Black line: Cherenkov photons
  - Orange line: Night sky background photons

- **Crosstalk (%)**
  - Red line: 6x6mm 50μm
MPPC for CMS HCAL upgrade (HB/HE)

Required properties
- Low dark count
- Radiation hardness
- High PDE
- Wide dynamic range

Sensitive area: φ3.3mmx8ch 15μm pitch
MPPC for LHCb SciFi Tracker

Required Properties
- Coupled with SciFi matrix
- 64x2ch fine pitch MPPC array
- High position accuracy
- High PDE @400nm
- Area: 0.23x1.5mm p0.25mm
MPPC for VUV detection

1. Search for the $\mu^+ \rightarrow e^+ + \gamma$ decay
   - MEG experiment
     - 6mm sq. – 2x2ch. x 6,000pcs
     - LXe (178nm) sensitivity & Low temperature resistive PKG

2. Dark matter search
   - DARWIN
     - LAr or LXe sensitivity
   - ANKOK
     - LAr (128nm) sensitivity
   - ArDM
     - LAr sensitivity or WLS

3. Precise neutrino experiment
   - DUNE
   - nEXO
     - LXe direct detection, Low RI PKG
   - NEXT
     - WLS, Low RI PKG
New improvements to a specialized Multi-Pixel Photon Counter (MPPC) for neutrino less double-beta decay and dark matter search experiments

- Improvement for VUV sensitivity (VUV4)

- Packaging technology for physics experiment with liquid scintillator

- Ultralow-RI for indirect VUV detection

- Ultralow-RI for direct VUV detection
Sales by Application

Sales share in major application

HPK Total

- Analytical: 4%
- Medical: 29%
- Measurement: 9%
- Transportation: 11%
- Industrial: 5%
- Academic research: 4%
- 38%

Solid State Division

- Analytical: 1%
- Medical: 46%
- Measurement: 8%
- Transportation: 8%
- Industrial: 8%
- 25%
- Academic research: 4%
- 8%
Thank for Your attention

HAMAMATSU
POHOTON IS OUR BUSINESS