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Current status of Hamamatsu detectors for High energy physics

Yuto Ohashi

Project promotion group, Business promotion,
Solid State Division,
Hamamatsu Photonics K.K.

Kensuke Suzuki

Business Promotion Group No.1,
Electron Tube Division,
Hamamatsu Photonics K.K

Feb.17. 2022

Company profile

Company profile

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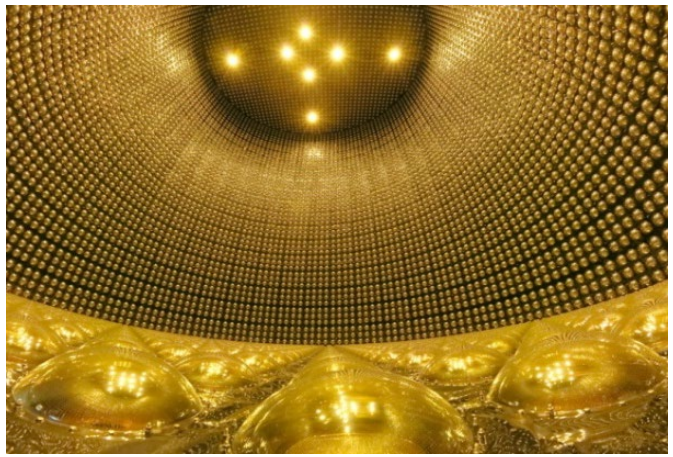
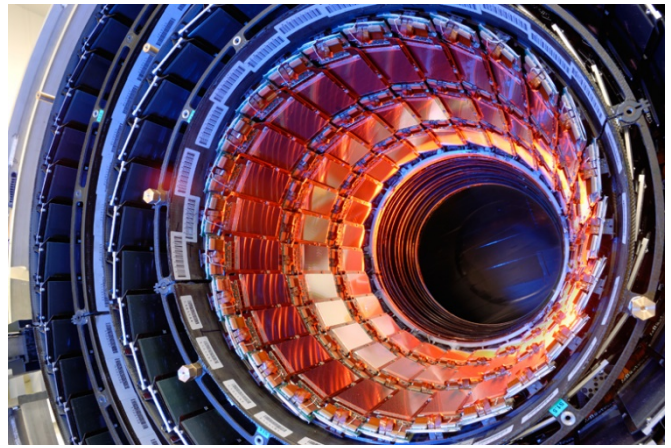
Company Name : Hamamatsu Photonics K.K.
Established : September 29, 1953
Number of Employees : 3,782 (Jan. 1st, 2020)

Main Product Lines :
- **Photomultiplier Tubes**
- **Light Sources, Imaging Tubes**
- **Opto-Semiconductor**
- **Imaging and Analyzing System**

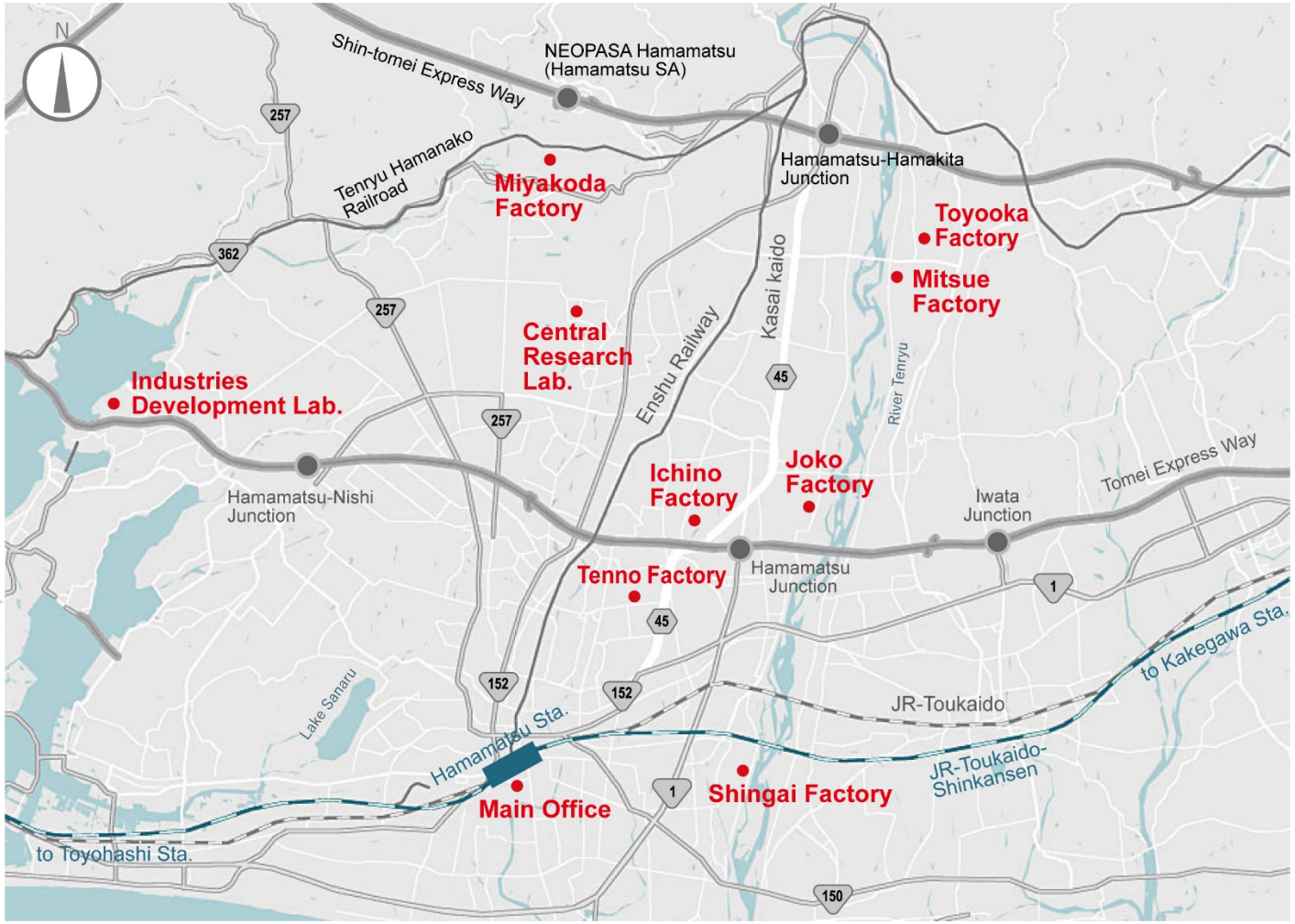


Inside the Super Kamiokande
11,200 PMT are used to catch the neutrinos



22,000 SSDs are used for the CMS tracker

Where We are Located



Division

Electron Tube Division

Solid State Division

Systems Division

Laser Promotion Division

Energetiq Technology

Global Strategic Challenge Center

Central Research Laboratory

Electron Tube Division

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- **Approx. 90% PMT share of the world market.**

Solid State Division

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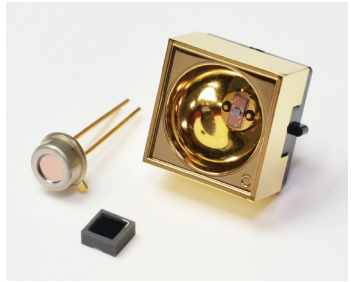
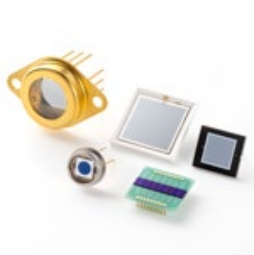
Light Emitters

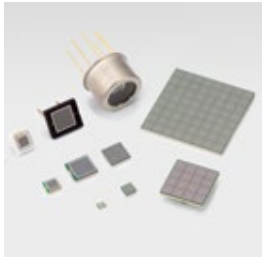

Red LED

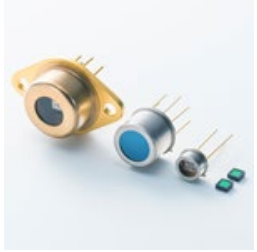

Near infrared LED


Mid infrared LED

Photosensors


Si photodiodes


APD ・ MPPC®


Infrared detectors


MEMS mirrors


Photo IC

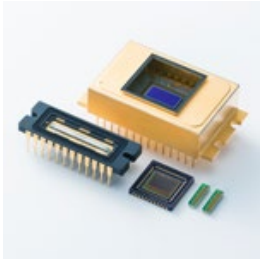
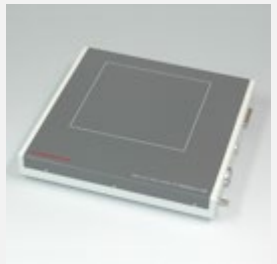


Image sensors


MEMS-FPI spectrum sensors

Modules


Flat panel sensors


FTIR engine


Mini-spectrometers


Circuits for various sensors

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MPPC

MPPC technology overview

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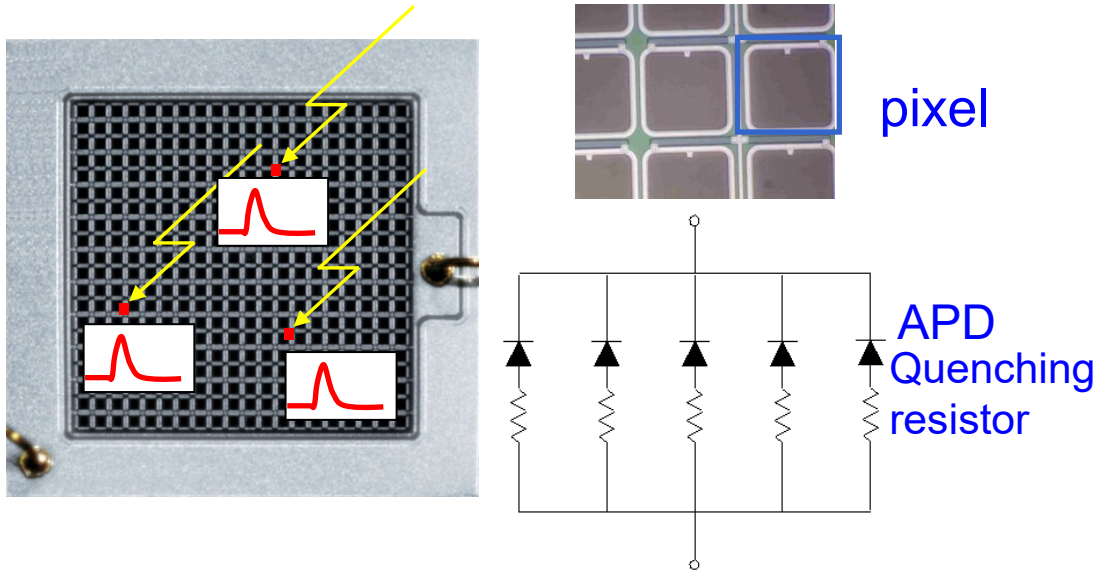
➢What is an MPPC®?

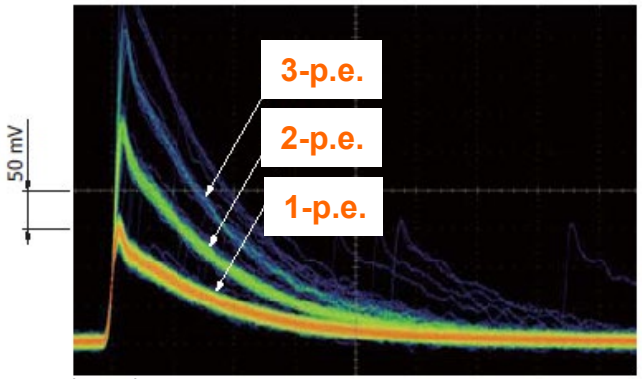
- **M**ulti-**P**ixel **P**hoton **C**ounter
  a new type of photon-counting device
  made up of multiple APD pixels
  operated in Geiger mode



Output is summation of all pixel output

➢Features

- High gain: 10^5 to 10^6
- Small size / light weight
- Low bias operation : ～60V
- Room temperature operation
- Excellent timing resolution
- Insensitive to magnetic fields
- Simple readout circuit operation



$$Q_{out} = N_{fired} \times C_{pixel} \times (V_{op}-V_{BR})$$

$$N_{fired} = PDE \times N_{photon}$$

History of MPPCs

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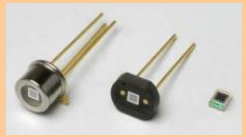
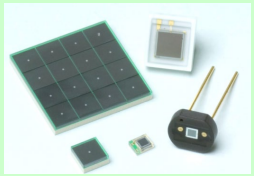
2007
S10362 series

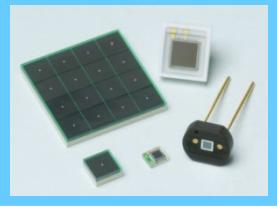


2013
S1257x series



Low afterpulse

2015
S1336x series



Low crosstalk & High Fill factor

2016
S1337x series for VUV detection
- High sensitivity for Liq.Ar and Liq. Xe

2017
S1416x series for PET
- Low operation voltage
- HWB

2018
S14160 series with **wide dynamic range**
- Low operation voltage
- Small pixel (pixel pitch 10, 15um)

2021
S15639-1325PS for LiDAR
- High sensitivity for NIR (905nm)

The experiments with MPPCs

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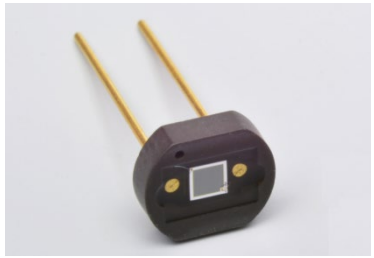
2008

T2K experiment

Near detector(ND280)

S10362-13-050C



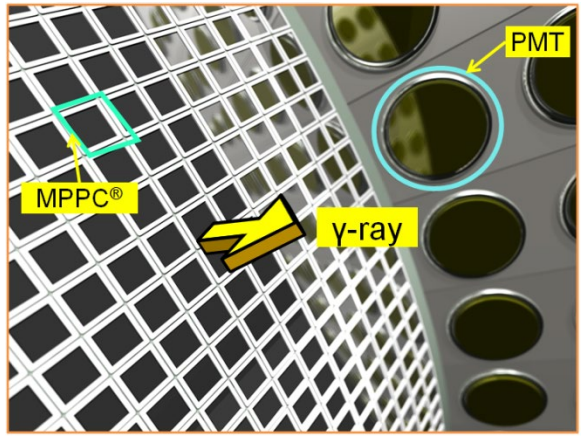
- Coupling with WLS fiber
- High PDE for WLS emission

New MPPCs will be used for ND280 upgrade

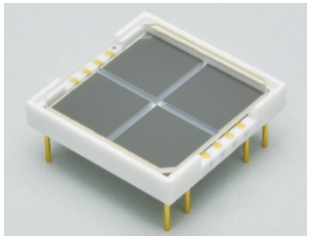
2014

MEG II experiment

Liquid Xe γ ray detector



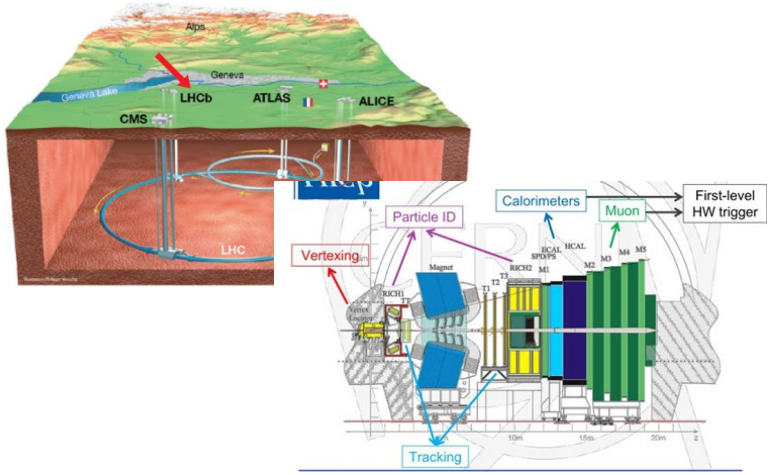
S10943-4372



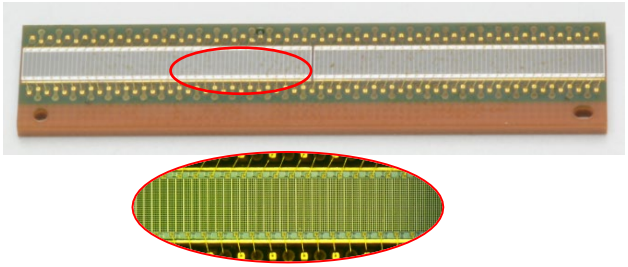
- Designed for cryogenic condition (Liq.Xe)
- High PDE for VUV (175nm)

2018

LHCb SciFi Tracker



S13552



- 128ch custom MPPC array
- Coupling with fiber array

MPPC customization for HEP

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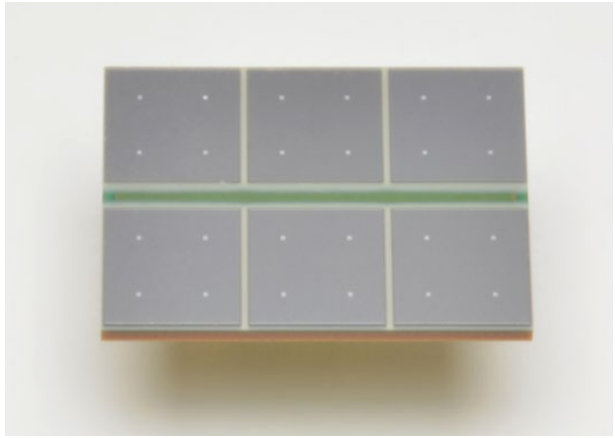
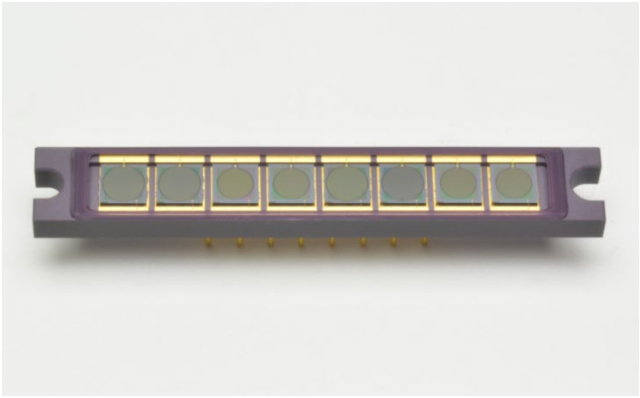
- ✓ Chip design
- ✓ Package
- ✓ Large size array
- ✓ Connector output
- ✓ Temperature sensor assembly

:



MPPC array for Mu2e calorimeter



MPPC array for CMS calorimeter

MPPC array for the ASTRI gamma-ray astronomy project

- 8x8 ch. (7x7mm/elements)
- High sensitivity for Cherenkov light

Improvements of MPPCs

Line up

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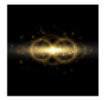
Measurement wavelength	 Academic research	 Measuring instruments (flow cytometers, microscope etc.)	 PET scanners	 LiDAR
VUV/UV	For academic research experiments			
VIS	For wide dynamic range S14160 series ↓		For PET scanners S14160/S14161 series ↓	
	For precision measurement S13360/S13362 series ↓			
	For precision measurement (TSV type) S13360/S13361/S13363 series ↓			
VIS to NIR		For visible light S14420/S14422 series ↓		
NIR				For near infrared S15639-1325PS ↓

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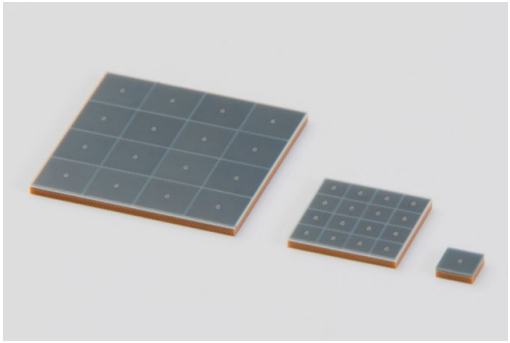
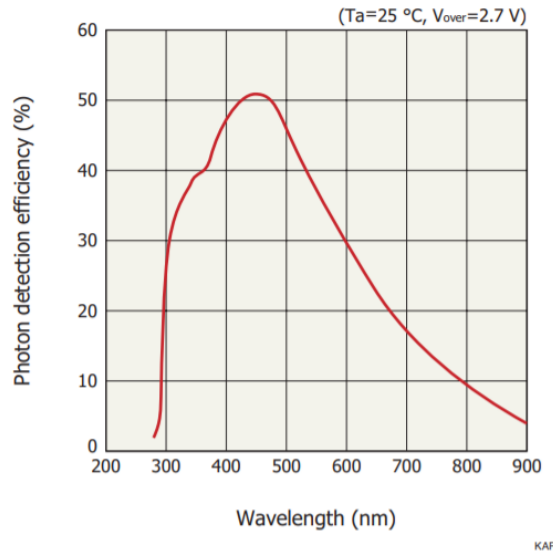
S14160/S14161 series for PET scanner

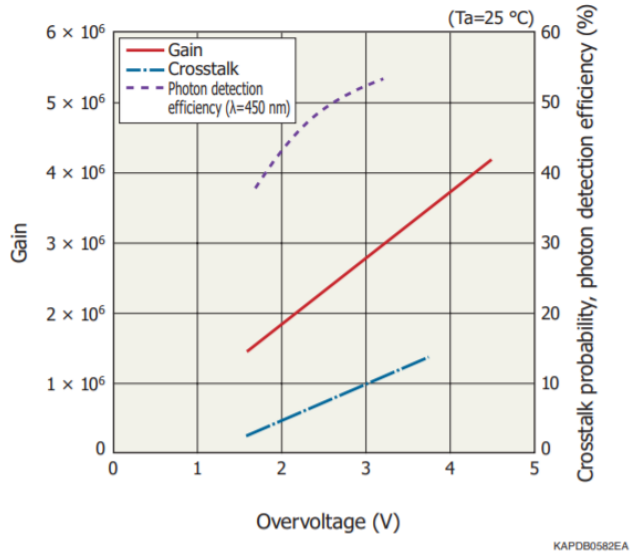
- Higher PDE (50% at λ=450nm)
- Small dead space in effective photosensitive area
- Low operating voltage (VB=38V typ.)
- Resistance to a magnetic field environment



■ Photon detection efficiency vs. wavelength (typical example)



■ Gain, crosstalk probability, photon detection efficiency vs. overvoltage (typical example)



New MPPC for PET

UNDER DEVELOPMENT

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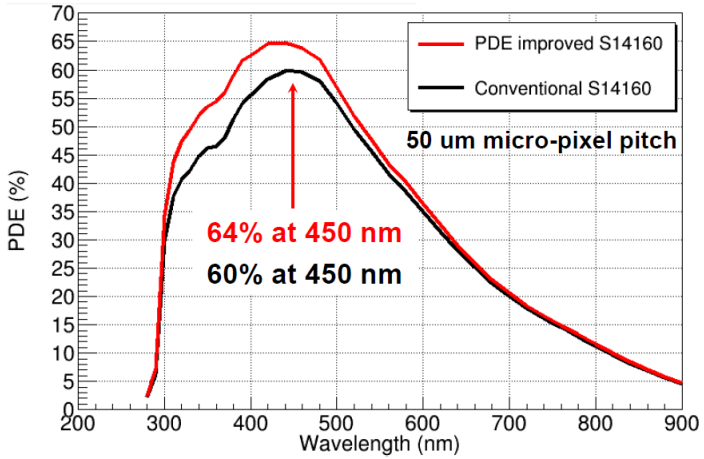
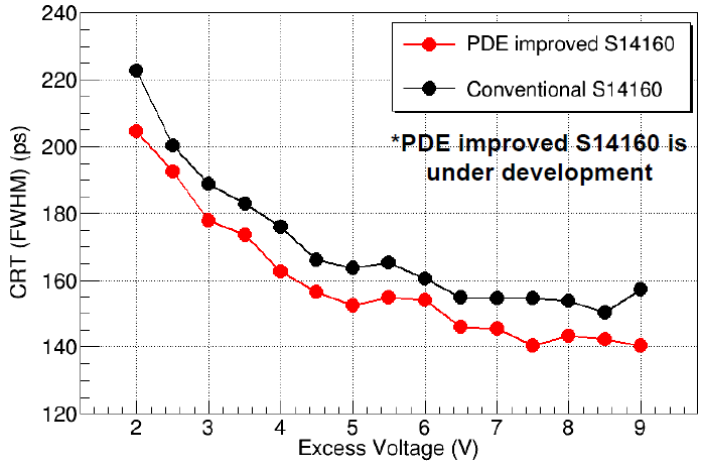
New MPPCs for PET based on S14160 series are under development

- Pixel pitch 50 μm
- PDE at 450 nm is 64% (S14160-3050HS : 60%)
- Improved CRT



PDE comparison at 7.0V excess voltage



CRT comparison with One-channel readout and 20mm scintillator

MPPCs with wide dynamic range

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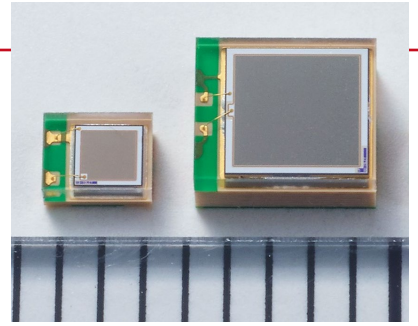
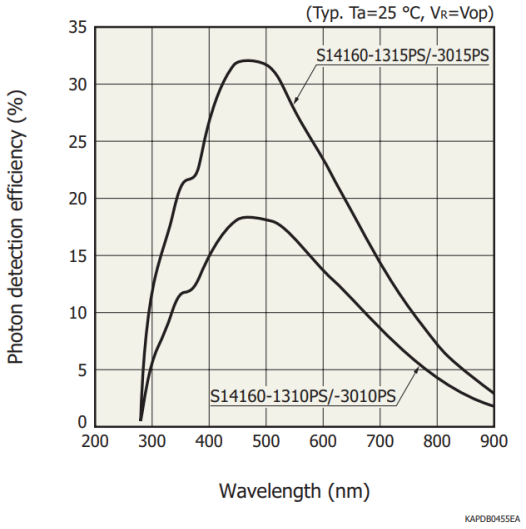
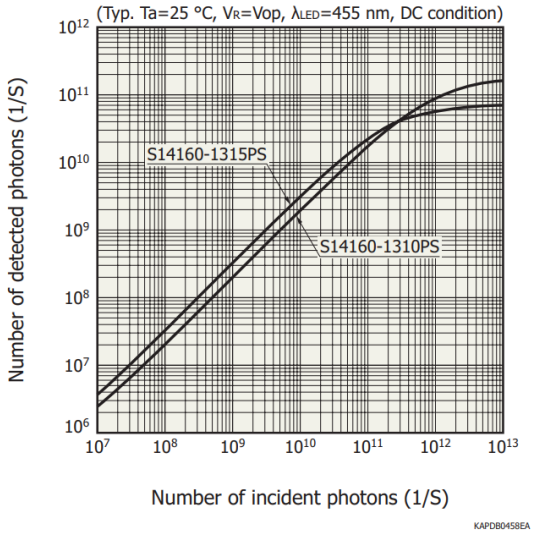


S14160 series with small pixels

- Small pixel pitch : 10μm, 15μm
- Wide dynamic range
- High fill factor & High sensitivity
- Low operating voltage (VB=38V typ.)
- Photosensitive area : 1.3x1.3mm^2, 3x3mm^2



PDE vs. Wavelength

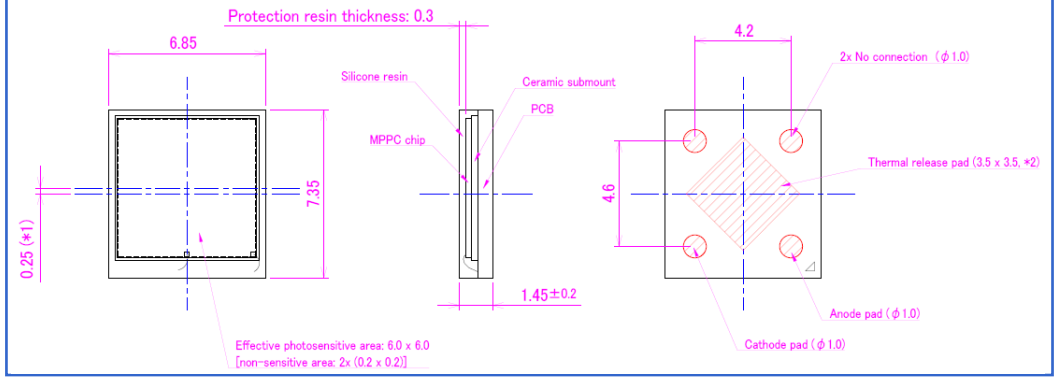


Linearity
(Photosensitive area :1.3x1.3mm^2)

UNDER DEVELOPMENT

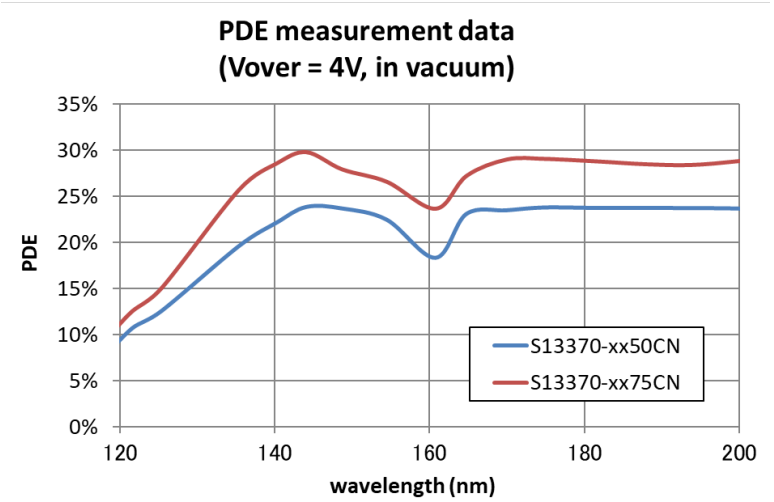
New MPPCs

- Photosensitive area : 6x6mm2
- Thermal pad to release heat generated by detecting light



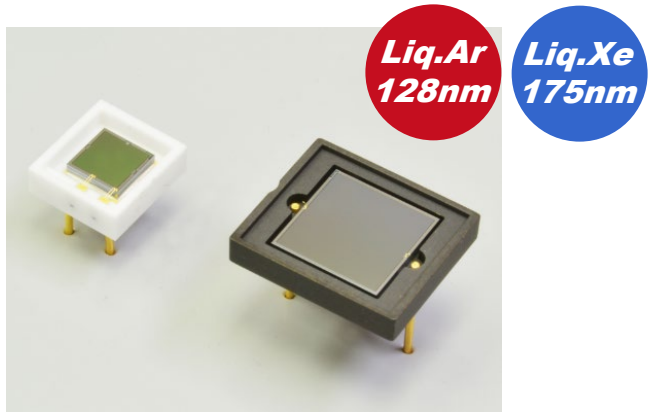
MPPCs for VUV and UV detection

VUV MPPC

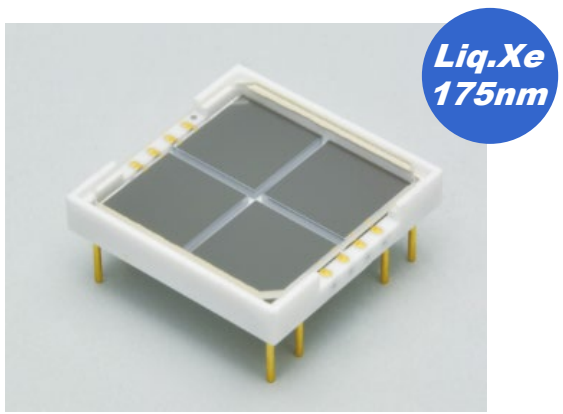


- **For Neutrino and Dark matter experiments using Liq. Ar or Liq. Xe**
- VUV-MPPC (4th generation: VUV4) has VUV-sensitivity down to 120nm.
- Optical cross-talk is suppressed by the inter-pixel trench structure.
- Photon-counting capability is confirmed down to -196℃ at HPK.

Standard (S13370 series)



For *MEG II* experiment (S13371-6050CQ-02)



VUV MPPC next gen.(VUV5)

UNDER DEVELOPMENT

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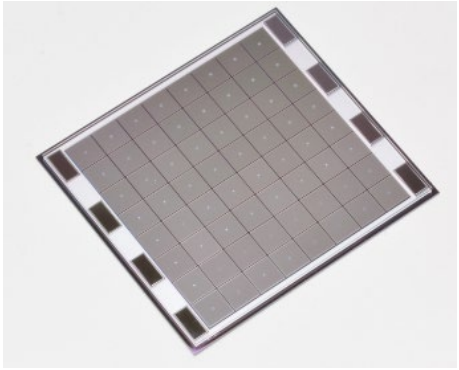
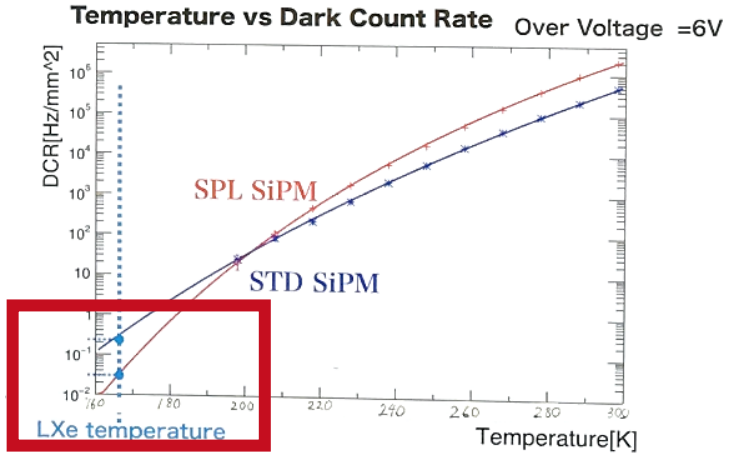
- ✓ **Higher PDE for VUV**
  - 27% for 175nm (VUV4 : 24%)
- ✓ **Low RI level package**
  - Suitable for cryogenic condition
  - TSV multi-channel
  - Surface mount type
- ✓ **Low dark count rate**
  - Low dark count trend in cryogenic condition
  - Nagoya Univ. evaluated plot types



Silicon package MPPC array (TSV type)
8x8 channel (3x3mm / element)



Data from the poster* in TAUP2019

**Characterization of new photo-detectors for the future dark matter experiments with liquid xenon*

New MPPCs for UV detection

UNDER DEVELOPMENT

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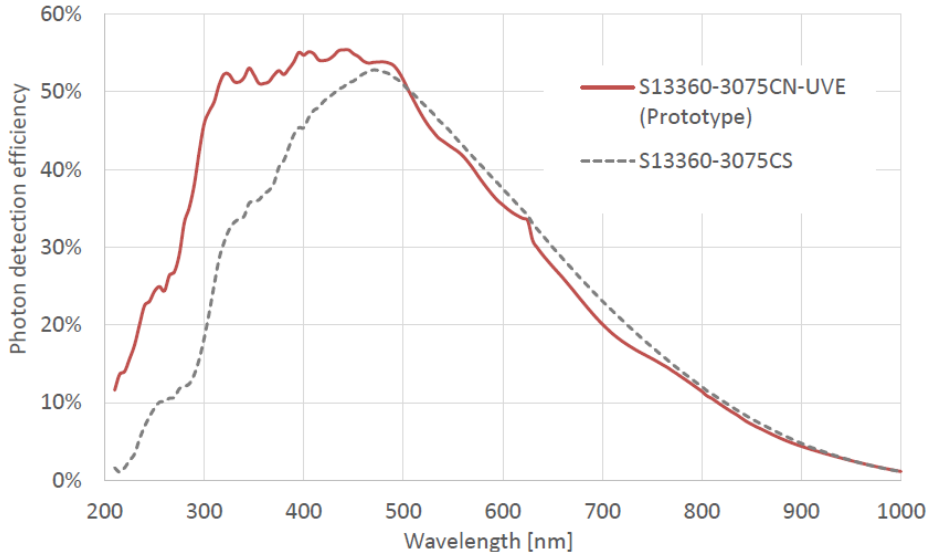
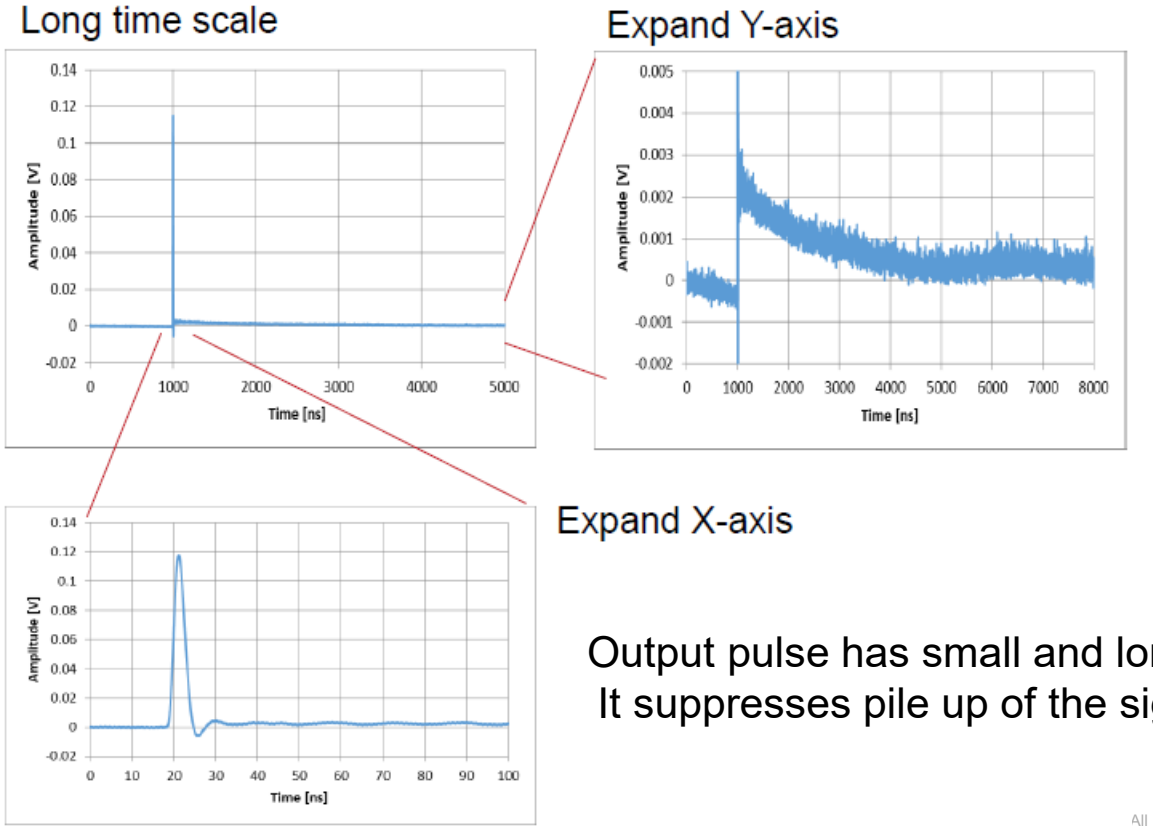
New MPPCs for Cherenkov telescope experiments

- Higher PDE : 50% at 350nm
- Faster pulse : FWHM 3ns (small but long tail)
- Pixel pitch : 75μm (based on S13360 series)



New MPPCs have higher PDE for UV range than S13360 series



Output pulse has small and long tail.
It suppresses pile up of the signals.

Conclusions

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■ Improvements of MPPCs

- High sensitivity and Low CRT for PET
- Wide dynamic range with large photosensitive area

■ New MPPCs for VUV and UV detection

For Neutrino and dark matter experiments (VUV)

- High sensitivity and low dark count in cryogenic condition
- Low background package

For Cherenkov telescope experiments (UV)

- Higher sensitivity for UV range with faster output pulse

Direction

- Flexible for requirement to HEP field

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Photomultiplier Tube

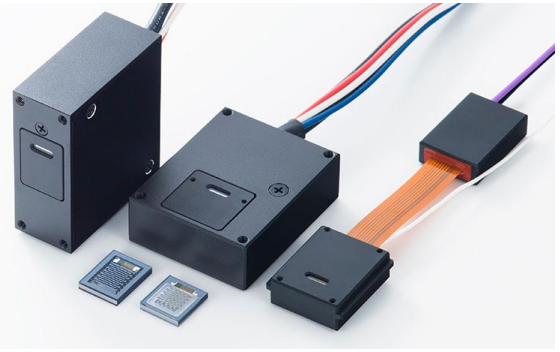
Photomultiplier tube（PMT）

PMT

Size：3/8 inch (1 cm)～20inch(50.8 cm)

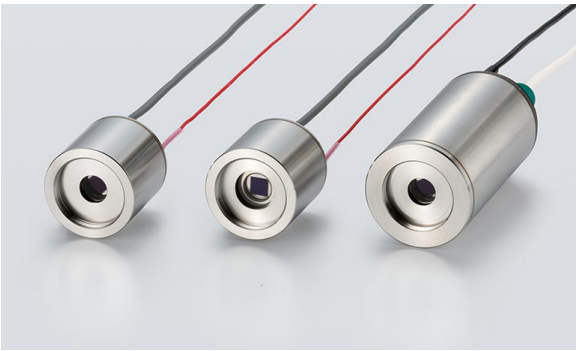
PMT modules

μPMT



PMT assemblies

HPD(Hybrid Photo-Detector)



Basic principle of **P**hoto**M**ultiplier **T**ube [PMT]

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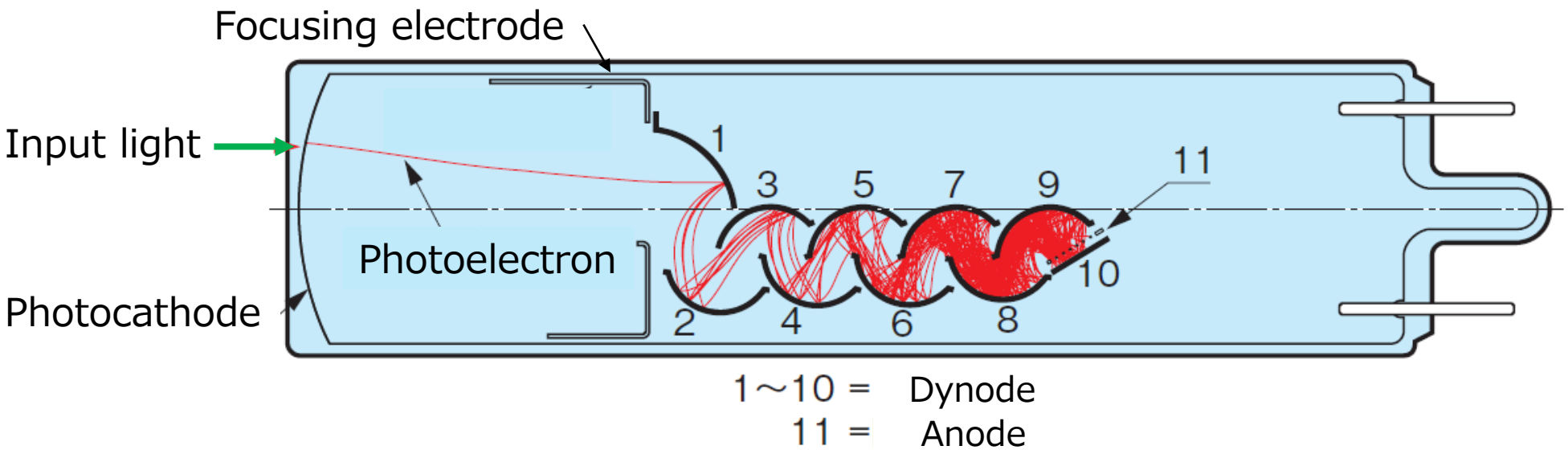
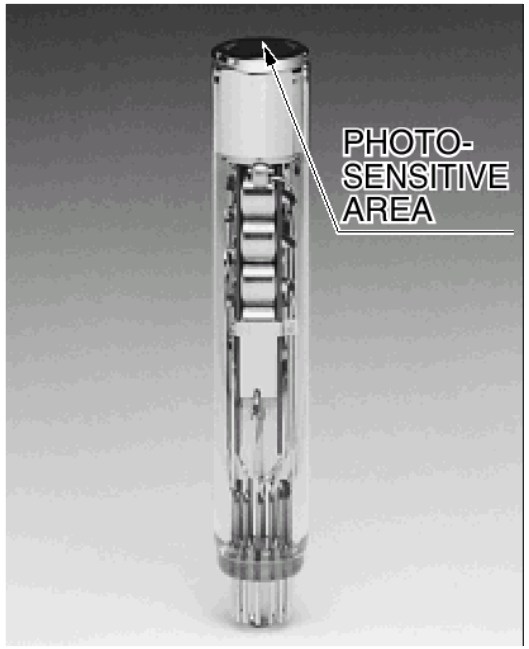
Photons are converted to electron and multiplied in vacuum tube.

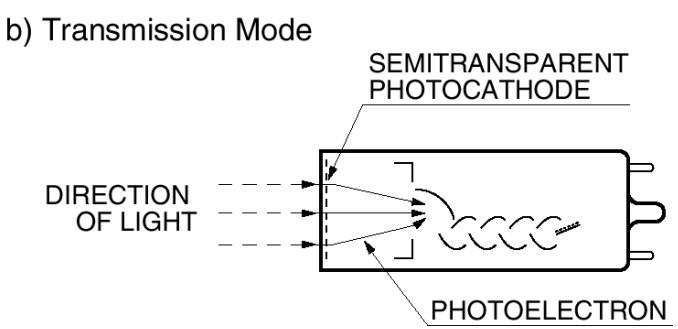
1 electron is multiplied ~10^6 - 10^7 times!



Structure of PMT

Head-on PMT





Size : 10mmφ～500mmφ

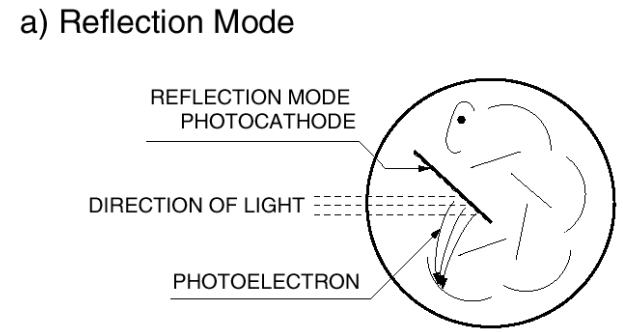
Application:

- Nuclear medicine
- Radiation monitor
- High energy physics etc.

- Photon enter to the top of tube
- Photocathode is inside of the tube

(Transmission mode photocathode)

Side-on PMT



Size : 13mmφ、28mmφ

Application:

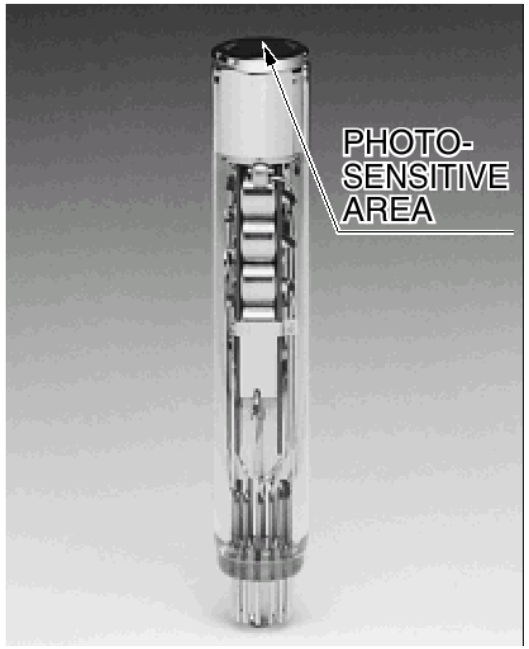
- Spectroscopic analysis
- Bioscience etc.

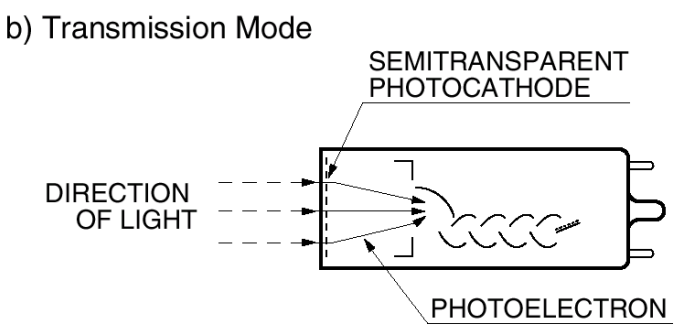
- Photon enter to the side of tube
- Photocathode is inside of the tube

(Reflection mode photocathode)

Features of each PMT

Head-on PMT





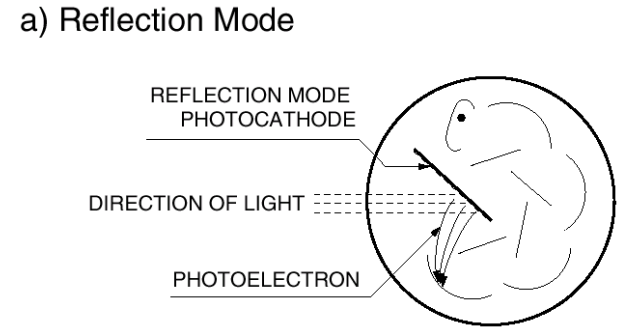
Size : 10mmφ～500mmφ

Application:

- Nuclear medicine
- Radiation monitor
- High energy physics etc.

- **Wide variety** for Active Area
- **Good Uniformity**
- **High Collection Efficiency**

Side-on PMT



Size : 13mmφ、28mmφ

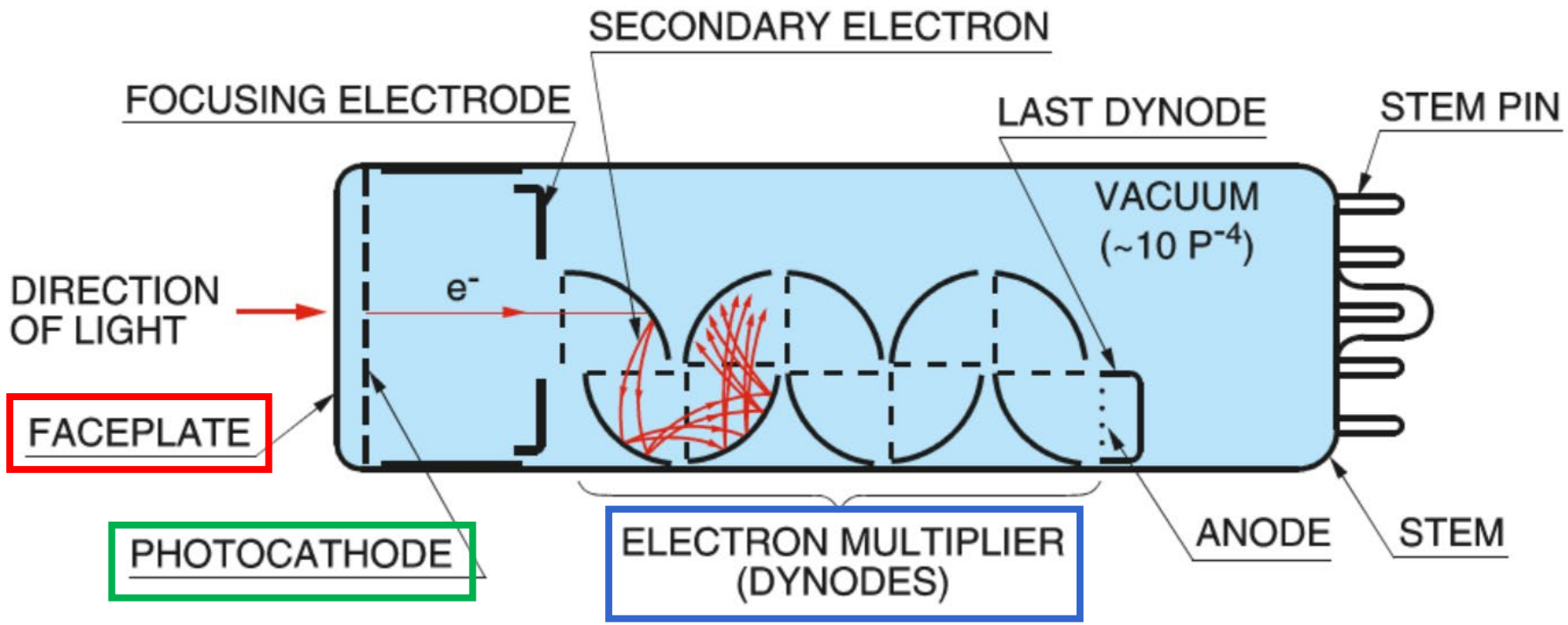
Application:

- Spectroscopic analysis
- Bioscience etc.

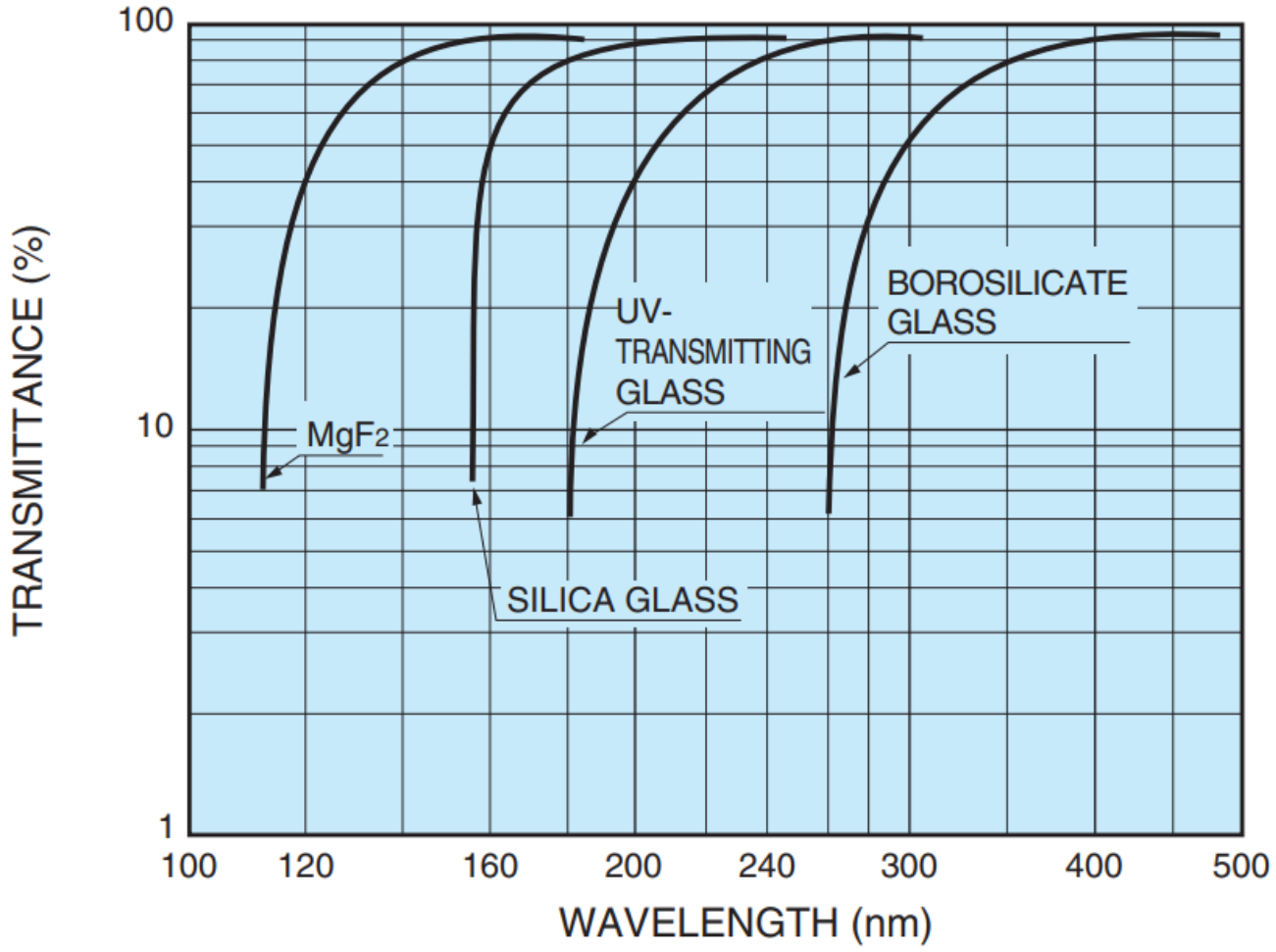
- **Compact** against Light Axis
- **Pin Compatible**
- **High Sensitivity(QE)**

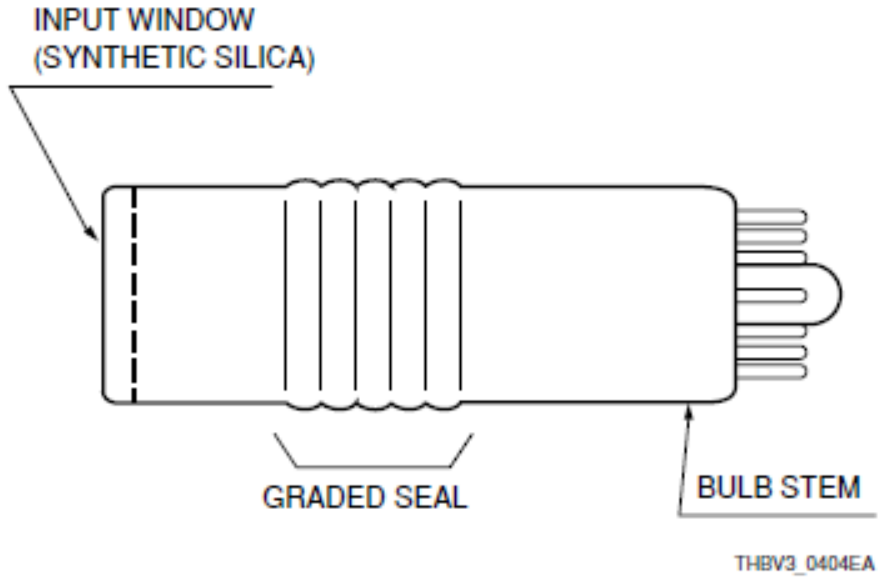
PMT Components

1. Window(Faceplate)
2. Photocathode
3. Dynode



Transmittance of Window Materials

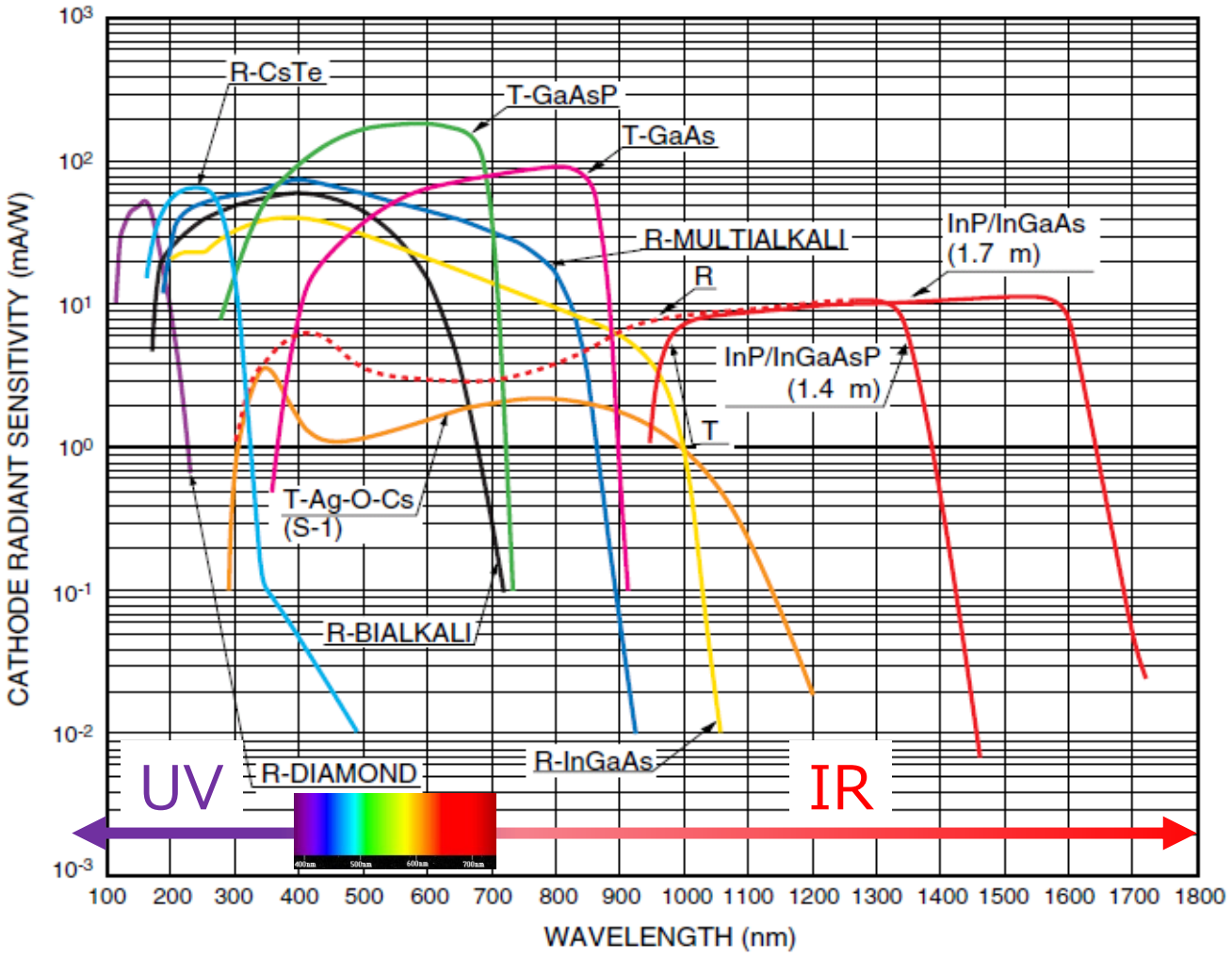


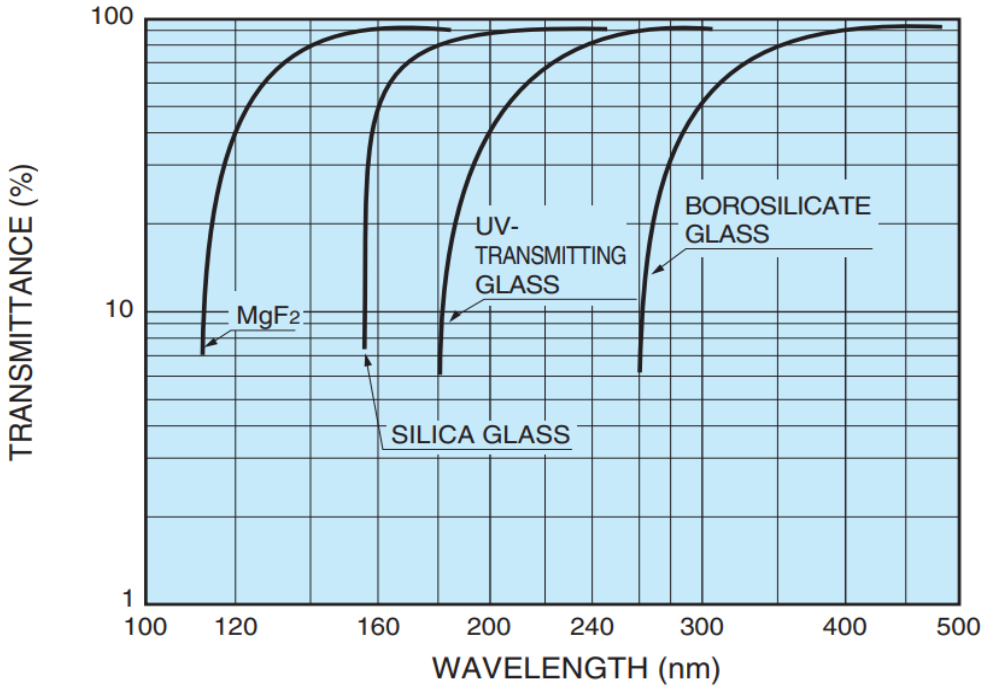


200 nm 380 nm

VUV (Vacuum UltraViolet) UV (UltraViolet) Visible (380nm~780nm)

Spectral Sensitivity of Photocathode

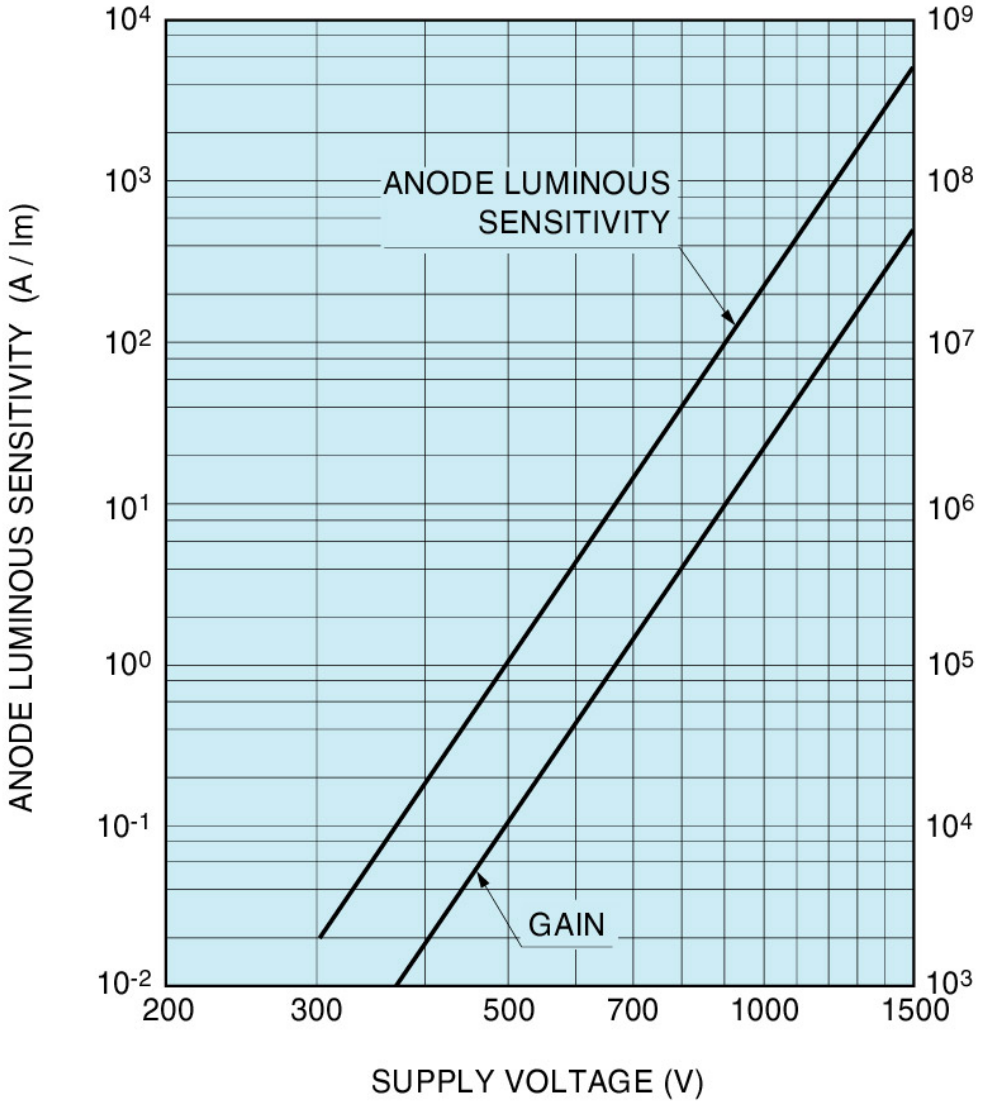




Sensitive wavelength of PMT

115 nm (VUV) – 1700 nm (NIR)

Gain characteristics of PMT



Typical spec for PMT *Depends on species of PMT

Supply voltage : 1000V
Gain : 1.0E+06 (10^6 times)

- Signal current can be controlled by supplying voltage

(1.0E+03 ～ 1.0E+07)

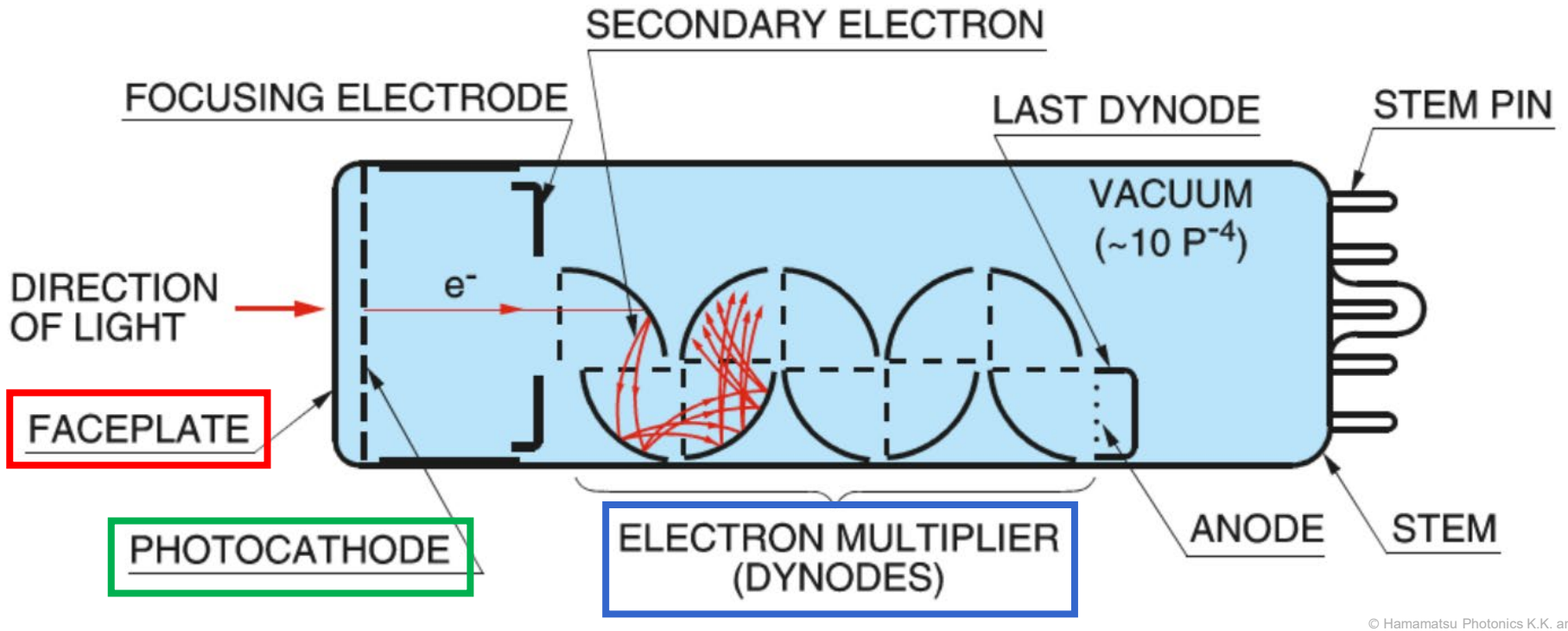
Wide Dynamic range

Usable for
Single Photon Counting ～
Large Amount of Light Detection!

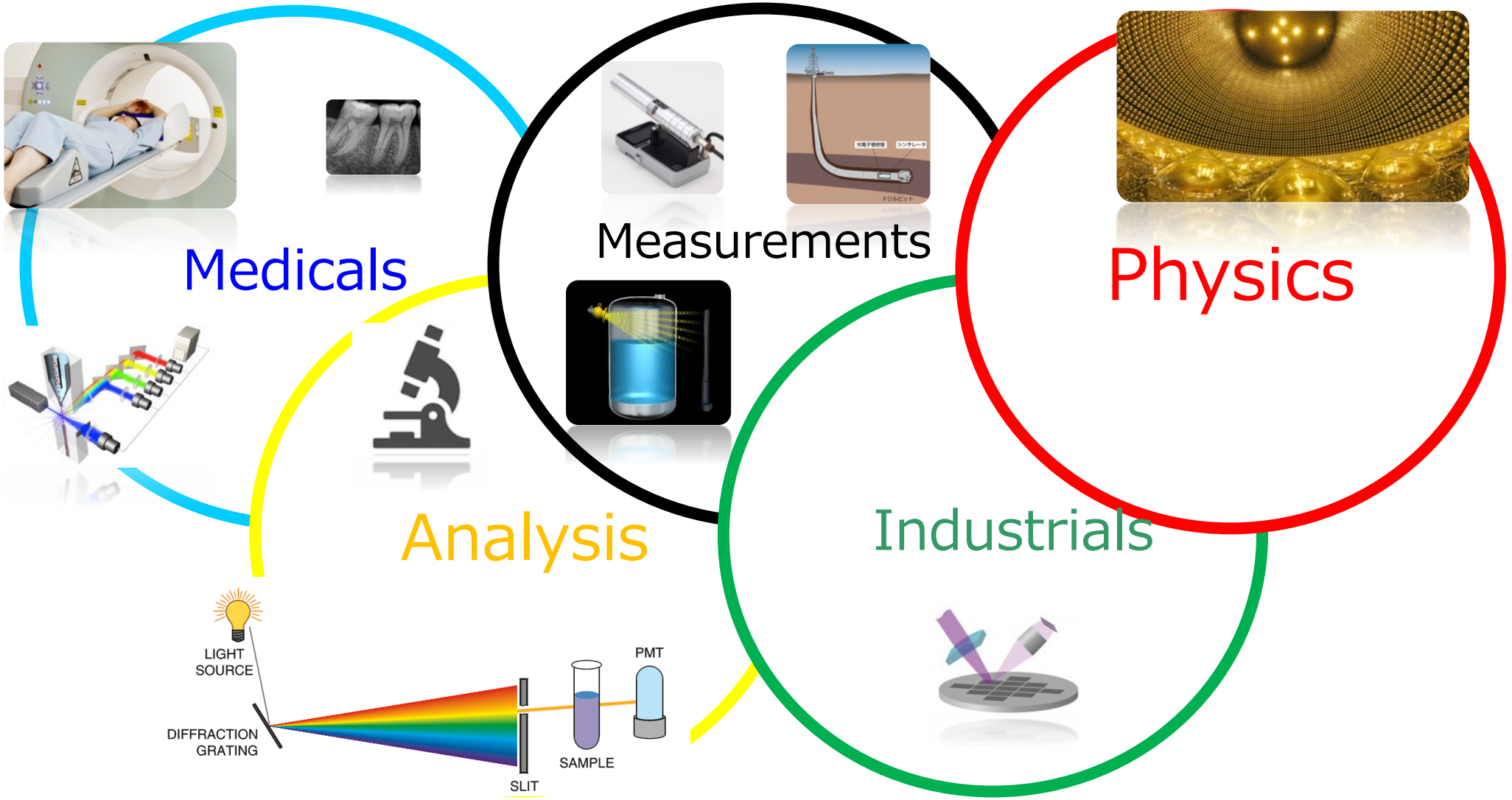
PMT

Photodevice for detecting single- to multi-photon event with containing the following contents.

1. Window(Faceplate) : Transmittance of the incident light
2. Photocathode : Sensitivity to each wavelength
3. Dynode : Gain of PMT



Applications



High Energy Physics

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In general, PMT in Neutrino experiments is used with water, ice or liquid scintillator to detect Cherenkov light/scintillation light by interaction with neutrino.

Super Kamiokande

11,200 pcs of 20-inch PMT were settled in Super-K tank

IceCube

5,160 pcs of 10-inch were deployed in south pole

KamLAND

~2,000 pcs of 17-inch/20-inch were used for KamLAND Project.

High Energy Physics – Related Products

8-inch: R5912, 10-inch: R7081, 20-inch: R12860

Features

- Spectral Response: 300-650 nm
- High Gain:1E+07
- Good Time Characteristics
- Low Dark Count

High Energy Physics – Related Products

3-inch: R14374, 3.5-inch: R14689

Features

・Spectral Response: 300-650 nm
・High Gain:1E+07
・Good Time Characteristics
TTS(FWHM): 1.3–1.5 ns Typ.

8-inch: R14688

Features

・Spectral Response: 300-650 nm
・High Gain:1E+07
・Good Time Characteristics
TTS(FWHM): 1.0 ns Typ.

High Energy Physics – Related Products

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Parameter		Datasheet		Unit
		R5912	R14688	
Diameter		202 / 8		mm/inch
Minimum Effective Area		Φ 190		mm
Cathode Luminous Sensitivity	Typ.	80		uA/lm
Cathode Blue Sensitivity index	Typ.	10		-
Radiant at 420 nm	Typ.	80		mA/W
Quantum efficiency at 390 nm	Typ.	25		%
Typical Gain	Typ.	1.0E+07		-
Applied voltage for gain of 1E+07	Typ.	1500	1750	V
Dark count (After 15 hours storage in darkness)	Typ.	4000		s^{-1}
	Max.	8000		s^{-1}
After Pulse	Max.	10		%
Rise Time	Typ.	3.6	**2.2**	ns
Electron transit time	Typ.	54	**37**	ns
Transit time spread(FWHM)	Typ.	2.4	**1.0**	ns

Rise Time, Transit Time and Transit time spread of R14688(new 8-inch PMT) are better compared to those of R5912(conventional 8-inch PMT)

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Distributor for Southeast Asia

Hakuto Singapore Pte. Ltd.

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