NIR-PHOTOMULTIPLIER TUBES AND THEIR APPLICATIONS

NIR-PMTs (near-infrared photomultiplier tubes) are photodetectors that provide high-speed response and high sensitivity in the near infrared region.
These are ideal for detecting high-speed phenomena occurring at low light levels such as in measurements of photoluminescence, fluorescence lifetime, Raman spectroscopy, cathode luminescence, and singlet-oxygen emissions.
As major NIR-PMT products, Hamamatsu offers the R5509 series photomultiplier tubes (spectral response range: 300 nm to 1400 nm or 300 nm to 1700 nm) and the H10330C series NIR-PMT units (spectral response range: 950 nm to 1200 nm, 950 nm to 1400 nm, or 950 nm to 1700 nm) that contain a thermoelectric cooler and high-voltage power supply. Either type can be used over a wide measurement range from analog detection mode to photon counting mode.
This brochure introduces major applications that utilize the unique features of NIR-PMTs.

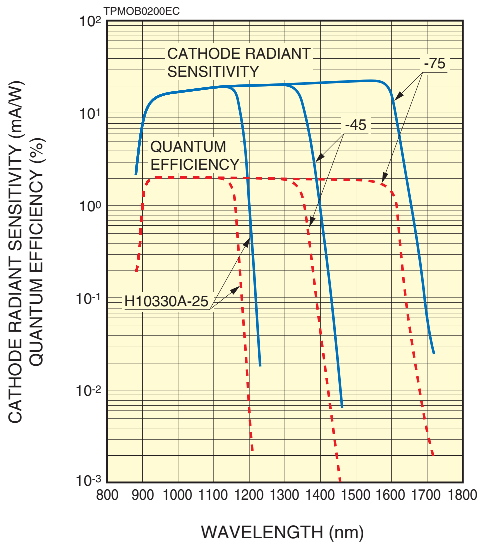
Q. What can we do with near infrared light?

1. Semiconductor quality control and material evaluation – Photoluminescence measurement
2. Evaluation of quantum devices and photonic crystals – Photoluminescence measurement
3. Evaluation of molecular structures – Raman spectroscopy
4. Reactive oxygen study – Singlet-oxygen emission measurement
5. Environment measurement – Light detection and ranging (LIDAR)

THERMOELECTRIC COOLED NIR-PMT UNIT H10330C SERIES

No liquid nitrogen, No cooling water is necessary

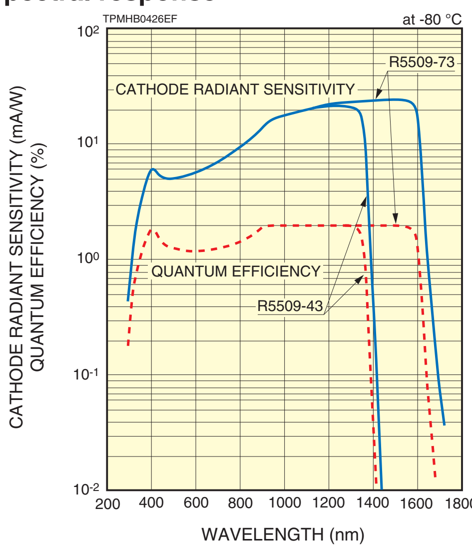
●Spectral response



NIR-PMT R5509 SERIES

Wide spectral response from visible to near infrared

●Spectral response



* C9940 series cooler is necessary for operation.

HAMAMATSU
PHOTON IS OUR BUSINESS

THERMOELECTRIC COOLED
NIR-PMT UNIT
H10330C-25/-45/-75

OVER VIEW

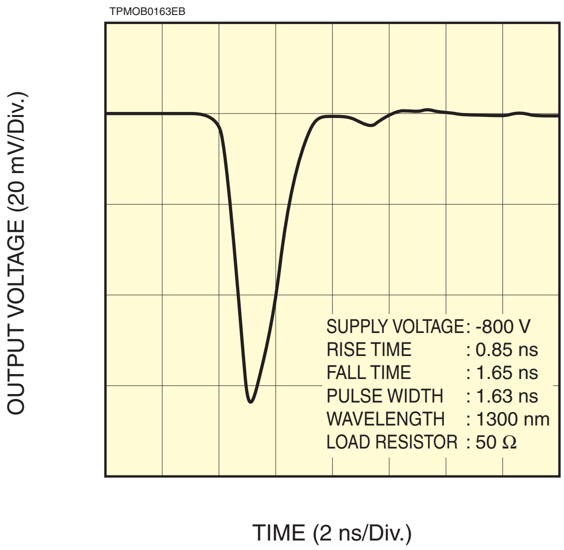
The H10330C series is the NIR-PMT unit using a compact NIR-PMT (near-infrared photomultiplier tube) developed by our advanced photocathode technology. The NIR-PMT is contained in a thermally insulated sealed-off housing evacuated to a high vacuum. The internal thermoelectric cooler eliminates the need for liquid nitrogen and cooling water.

The light input window of these units use a condenser lens to provide a virtually larger photosensitive area allowing easy optical coupling. Adapters for connection to an optical fiber and monochromator are also available as options.

FEATURES

- **Compact and lightweight due to vacuum sealed-off thermal insulation technology**
- **High sensitivity (Applicable to photon counting)**
- **Fast time response**
  Rise time: 0.9 ns, T.T.S.: 0.4 ns
- **Simple operation by air cooled TE cooler**
  No liquid nitrogen, No cooling water is necessary
- **Operable in 20 min after switched ON**
- **Large detection area**
  ϕ18 mm for collimated light
- **HV power supply with interlock function**
- **Optional adapters are available**
  For optical fiber
  For monochromator

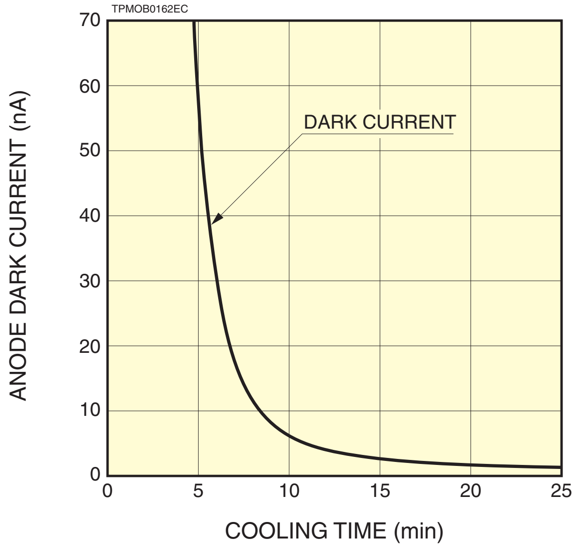
OUTPUT WAVEFORM



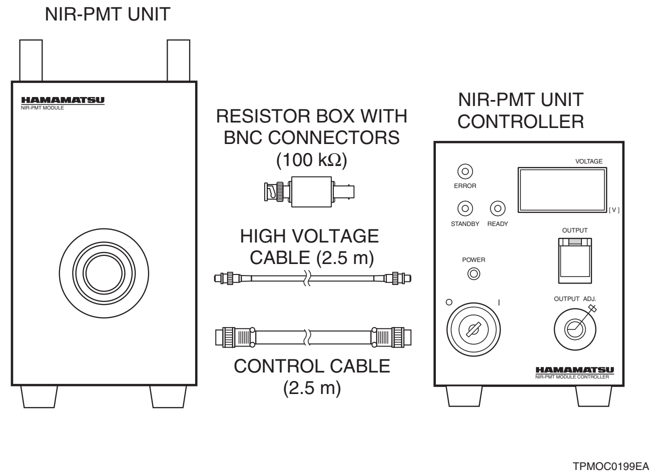
SELECTION GUIDE / SPECIFICATIONS

Type No.		H10330C-25	H10330C-45	H10330C-75
Spectral response		950 nm to 1200 nm	950 nm to 1400 nm	950 nm to 1700nm
Photocathode material		InP / InGaAsP		InP / InGaAs
Detection area for collimated light		ϕ 18 mm		
Effective area of PMT		ϕ1.6 mm		
Cathode sensitivity	Quantum efficiency	2 % Typ.		
Gain		1×10^6		
Time response	Anode pulse rise time	0.9 ns		
	Anode pulse fall time	1.7 ns		
	Transit time spread (T.T.S.)	0.4 ns		
Main application		YAG laser (1.06 μm) measurement, Si Photoluminescence, Laser rader (LIDAR)	Singlet-oxygen emmision measurement, Si Photoluminescence	Optical communication device evaluation, Laser rader (LIDAR)

TEMPERATURE / DARK CURRENT vs. COOLING TIME (H10330C-45)

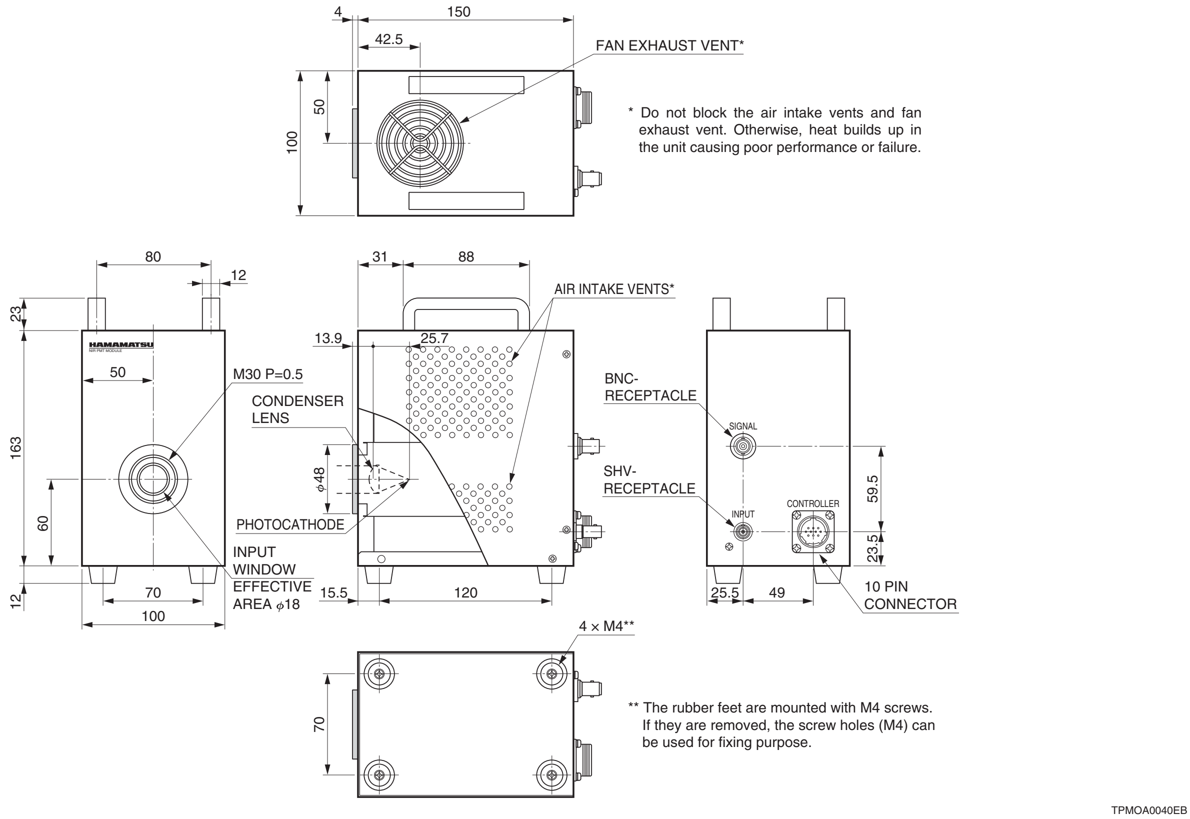


SYSTEM CONFIGURATION (CONNECTION DIAGRAM)

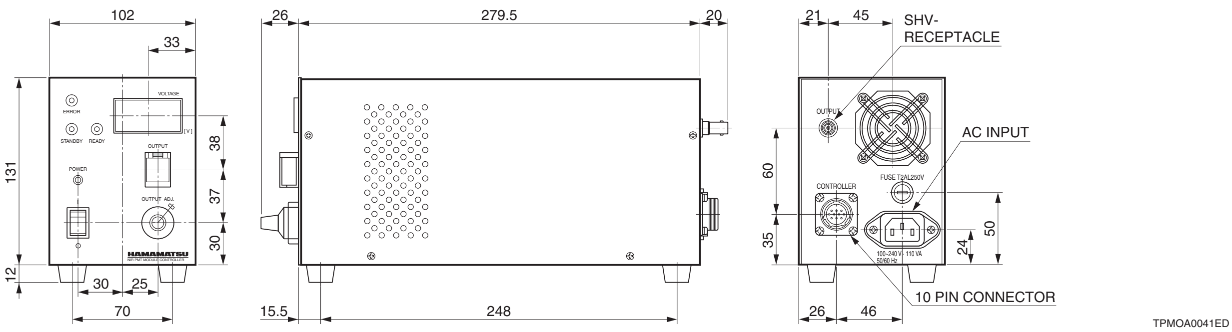


DIMENSIONAL OUTLINE (Unit: mm)

●NIR-PMT unit



●NIR-PMT unit controller



NIR-PMTs (near-infrared photomultiplier tubes)
(near-infrared: 1.4 μm / 1.7 μm)
R5509-43/-73

OVER VIEW

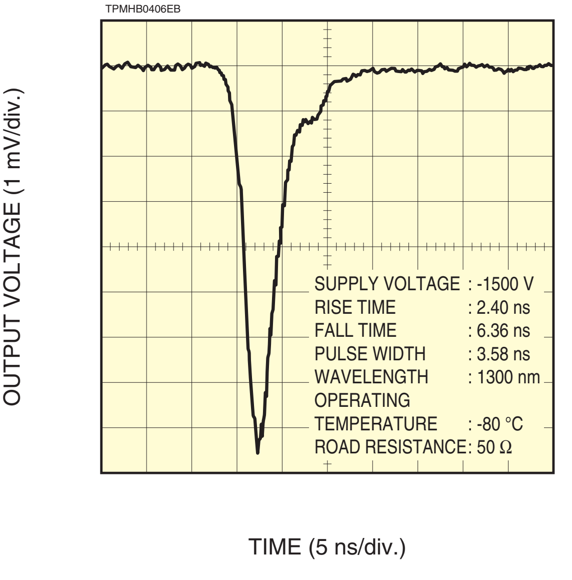
Hamamatsu near infrared photomultiplier tubes (NIR-PMT) R5509-43 and -73 have photocathodes with extended spectral response ranges to 1.4 μm or 1.7 μm where beyond 1.1 μm have been the limit of conventional photocathodes.
The R5509-43 is recommended for detection up to 1.35 μm, while the R5509-73 is up to 1.7 μm.
For operation, exclusive cooler C9940 series is necessary.

FEATURES

- **High sensitivity enables accurate PL (Photoluminescence) measurement with a low excitation power that could not be obtained with a strong excitation.**
  High gain and low noise improve the detection limit.
- **Flat response from visible to near IR minimizes spectral sensitivity correction.**
  The spectral response covers a wide range from 0.3 μm to 1.4 μm or 1.7 μm.
- **Photoluminescence from a room temperature sample can be measured.***
  High sensitivity enables weak light emission measurement.
- **Time resolved measurement in near IR is realized.**
  Fast time response (Rise time): 3 ns.

* Detection limit depends on the material and measurement condition.

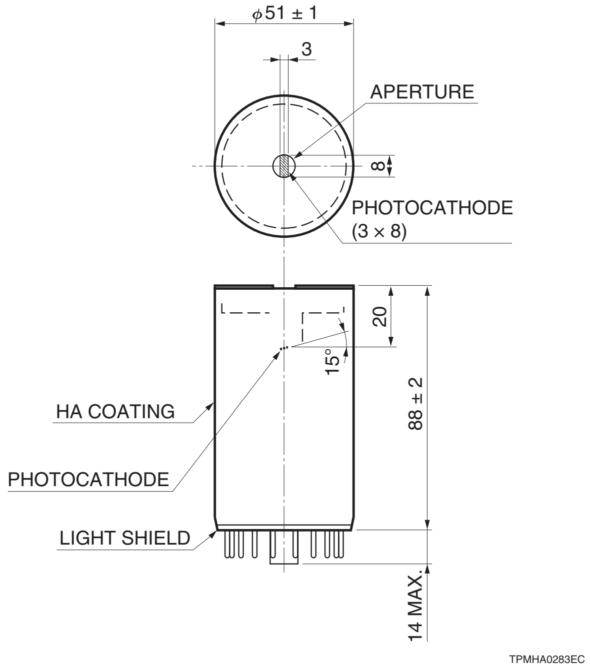
OUTPUT WAVEFORM (R5509-43)



SPECIFICATIONS

Type No.		R5509-43	R5509-73
Spectral response		300 nm to 1400 nm	300 nm to 1700 nm
Photocathode	Material	InP / InGaAsP	InP / InGaAs
	Minimum effective area	3 mm × 8 mm	
Recommended operating temperature		-80 °C	
Cathode sensitivity	Quantum efficiency	2 % Typ. (at 1300 nm: R5509-43, at 1500 nm: R5509-73)	
Gain		1×10^6	
Time response	Anode pulse rise time	3 ns	
	Anode pulse fall time	23 ns	
	Transit time spread (T.T.S.)	1.5 ns	

DIMENSIONAL OUTLINE (Unit: mm)



RELATED PRODUCTS

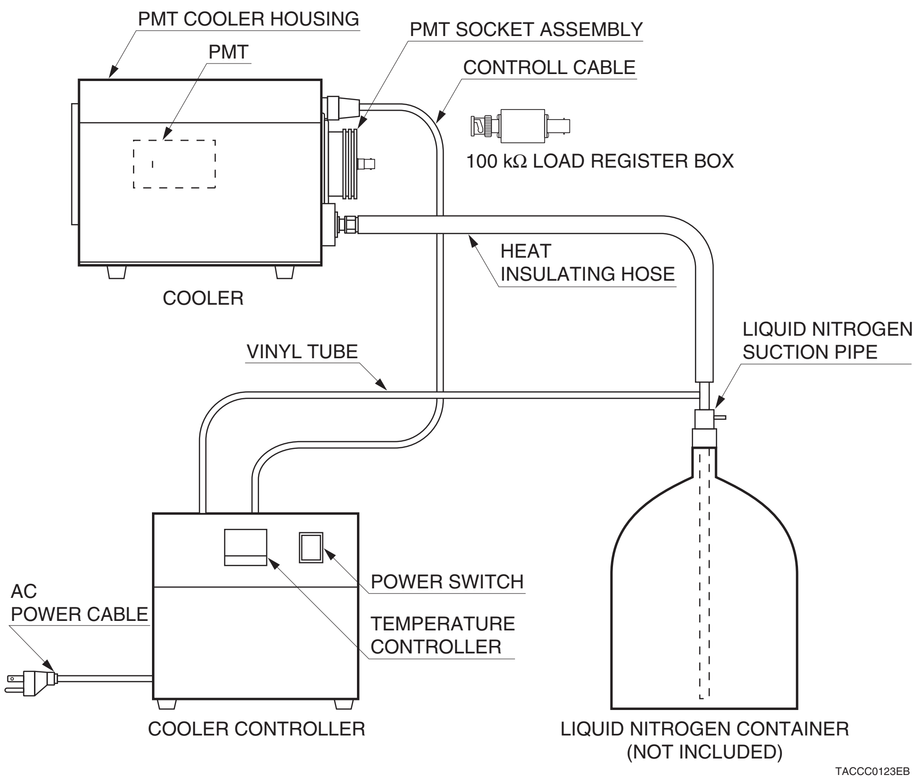
Exclusive coolers C9940-01/-02

The C9940-01/-02 are exclusive coolers for R5509 series photomultiplier tubes. To operate the R5509 series, it is necessary to cool it down to -70 °C to -90 °C range (recommended temperature: -80 °C). Cooling suppresses dark current and improves signal to noise ratio to make weak near infrared light measurements possible with high sensitivity.
Two types are available with different line voltage regulations, 100 V to 115 V (C9940-01) and 230 V (C9940-02) .

■FEATURES

- **Temperature range: -70 °C to -90 °C**
- **Voltage divider, Magnetic shield case included**
- **Alarm with output when liquid nitrogen is running out**
- **No external dry nitrogen is required**

■SYSTEM CONFIGURATION



■OTHER ACCESSORIES REQUIRED

- **Liquid nitrogen container**
  From 10 L to 25 L capacity
  The opening of the container should allow the 15 mm diameter liquid nitrogen suction pipe to be inserted.
- **High voltage power supply**
  Capable to provide stable output of -1500 V, 0.2 mA
  Recommended : C9525-02 (Supplied: High voltage cable E1168-17)
- **High voltage cable with an SHV-P connector**
  Recommended : E1168-17
- **Signal COAX cable with a BNC-P connector**
  Recommended : E1168-05

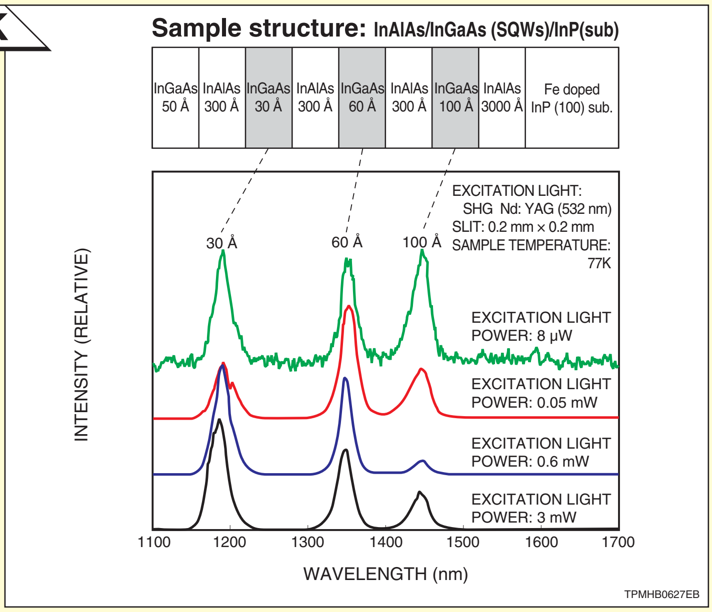
Photoluminescence measurement

Sample
InAlAs/InGaAs
single quantum wells

Photoluminescence spectra emitted from a sample with different InGaAs well widths.
This data proves that intensity distribution of the spectrum corresponding to each quantum well varies with the excitation light power.

SAMPLE TEMPERATURE

77K



Detector: NIR-PMT R5509-73

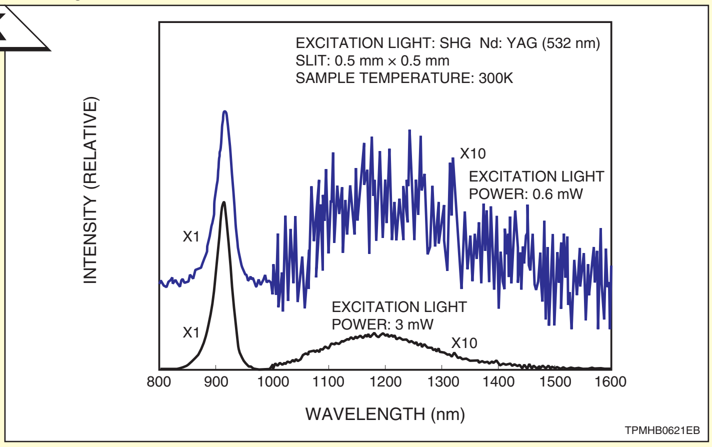
Sample
Undoped SI-InP

Emission from deep levels in a semi-insulating InP substrate at room temperature was clearly observed.

SAMPLE TEMPERATURE

300K

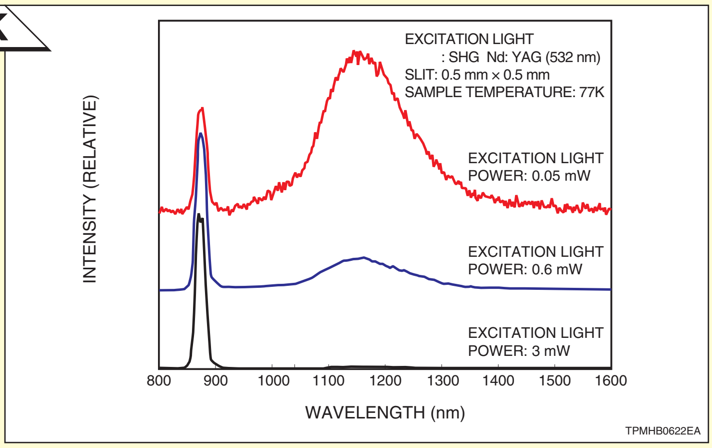
(room temperature)



Data shows that intensity distribution of the photoluminescence spectrum changes with excitation light power. Using a "low power excitation light" allows high-precision measurement not subject to variations in excitation light intensity. It is therefore essential to use "low power excitation light" in order to measure emission from deep levels and total band-to-band transition.

SAMPLE TEMPERATURE

77K



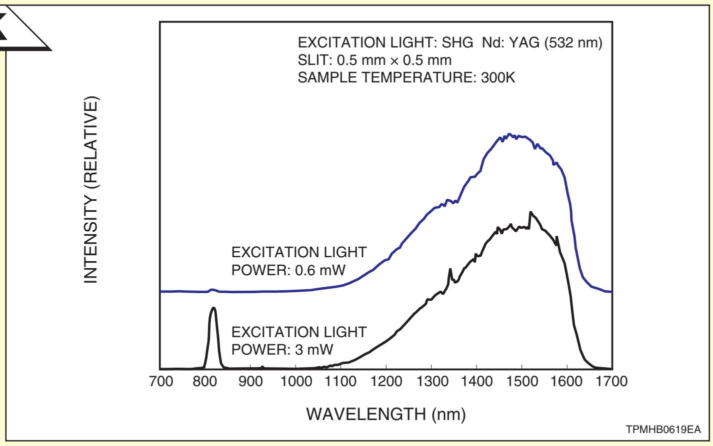
Detector: NIR-PMT R5509-73

Photoluminescence measurement

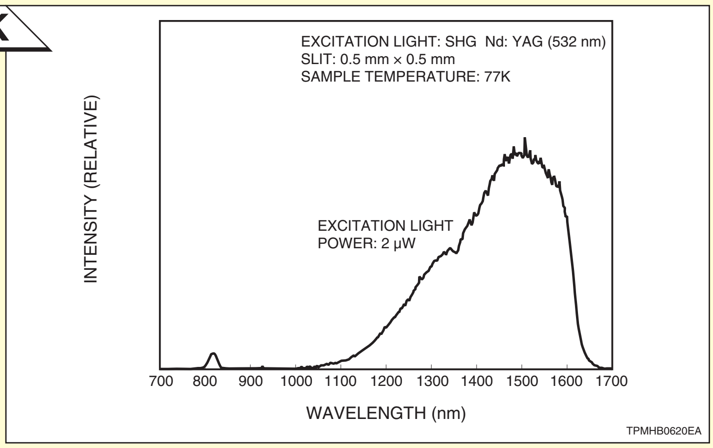
Sample
Undoped SI-GaAs

Emission from deep levels in a semi-insulating GaAs substrate at room temperatures was clearly observed.

SAMPLE TEMPERATURE
300K
(room temperature)



SAMPLE TEMPERATURE
77K

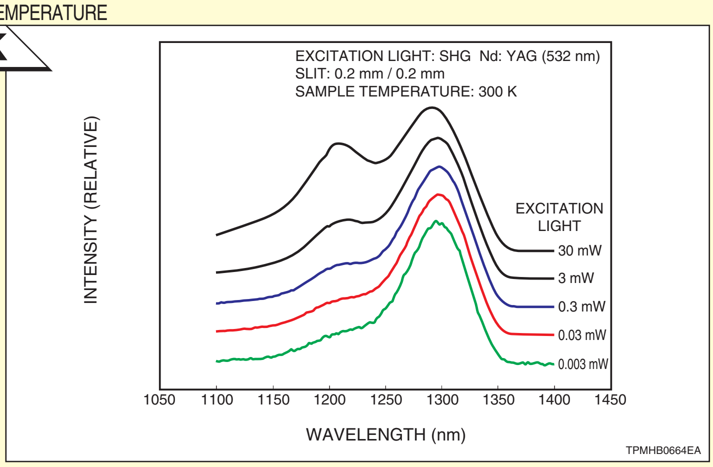


Detector: NIR-PMT R5509-73

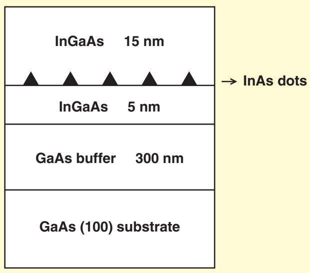
Sample
InAs/InGaAs
quantum dots structure

Figure shows PL spectrum at the room temperature from InAs quantum dots covered with InGaAs layer.
Size and uniformity of quantum dots can be estimated from the peak wavelength and the FWHM of PL spectrum. However, when excitation power is increased, luminescence of shorter wavelength (1200 nm) becomes strong, and the estimate of exact peak wavelength and the FWHM becomes impossible.
Therefore, it is important that excitation power must be kept as weak as possible for precise measurement.
For this reason, a high sensitivity detector is required.

SAMPLE TEMPERATURE
300K
(room temperature)



Basic structure



Detector: NIR-PMT R5509-43

APPLICATION EXAMPLES

Photoluminescence measurement

Sample

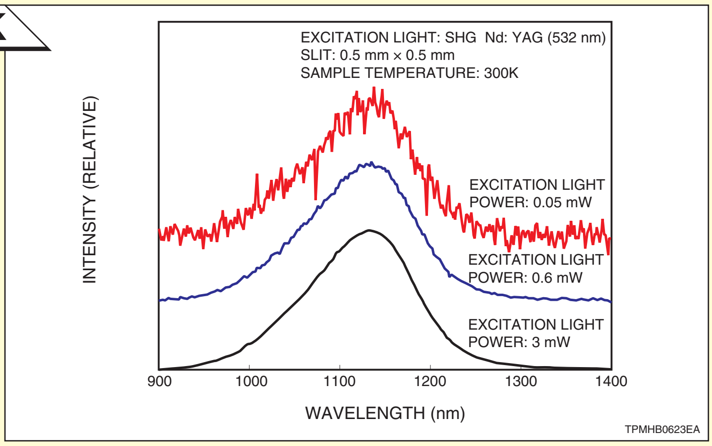
B-Dope Si (111)

low resistivity wafer ρ > 0.02 kΩ·cm

Silicon, the indirect bandgap semiconductor, has lower photoluminescence emission compared with direct bandgap semiconductors such as GaAs, InP, etc. However, the NIR-PMT has made it possible to observe a clear photoluminescence spectra from a room temperature silicon wafer even at low power excitation lights.

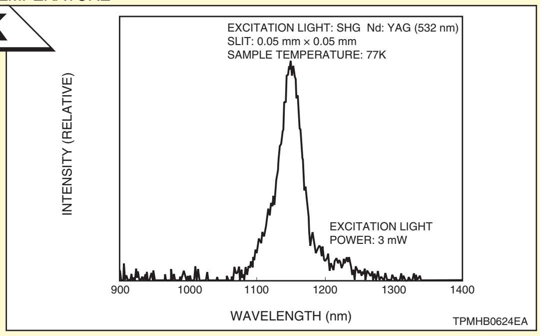
SAMPLE TEMPERATURE

300K (room temperature)



SAMPLE TEMPERATURE

77K

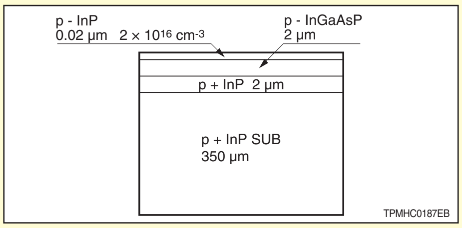


Detector: NIR-PMT R5509-73

Sample

InGaAsP/InP

Basic structure

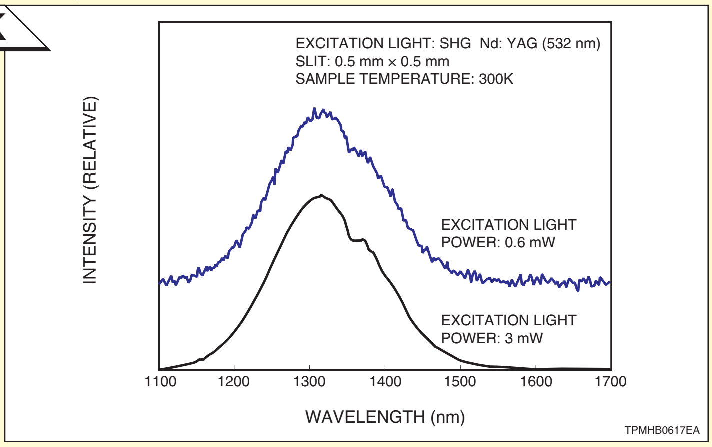


An epitaxial wafer at the room temperature can be evaluated.

Photoluminescence measurement in 77 K sample is possible at low power excitation lights from a few to tens of micro-watts.

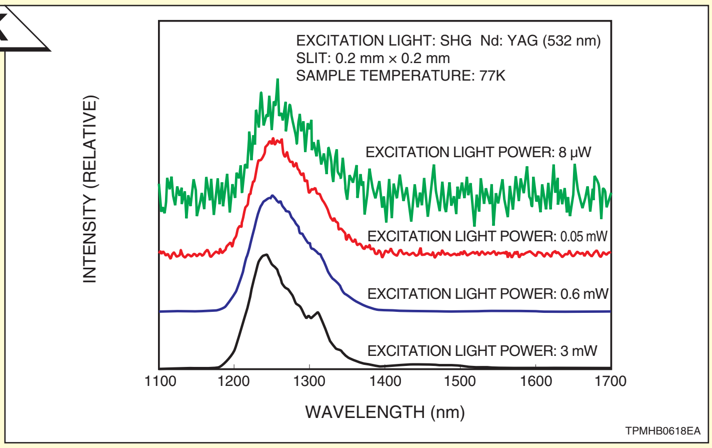
SAMPLE TEMPERATURE

300K (room temperature)



SAMPLE TEMPERATURE

77K



Detector: NIR-PMT R5509-43

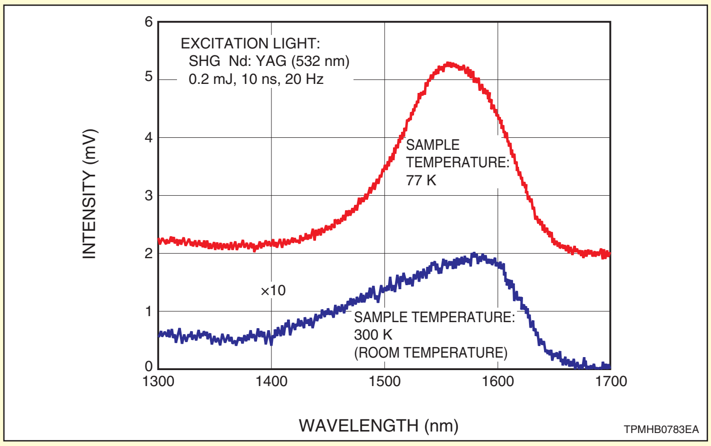
Photoluminescence measurement

Sample

β-$FeSi_2$

The NIR-PMT measures the photoluminescence of β-$FeSi_2$ currently being studied for use as an environmentally-friendly semiconductor material.
This β-$FeSi_2$ sample is a silicide thin film grown by Fe-irradiation onto a silicon (111) substrate kept at a high temperature.
As can be seen from the graph on the right, the photoluminescence intensity at a sample temperature of 77 K is at least 30 times higher than at 300 K. The peak wavelength of the 77 K sample occurs at 1562 nm while that of the 300 K sample shifts slightly to 1585 nm.
(The longer wavelength side is limited by the photomultiplier tube sensitivity.)

Detector: NIR-PMT R5509-73



Cathodeluminescence (CL) measurement

Sample

InAs/InP

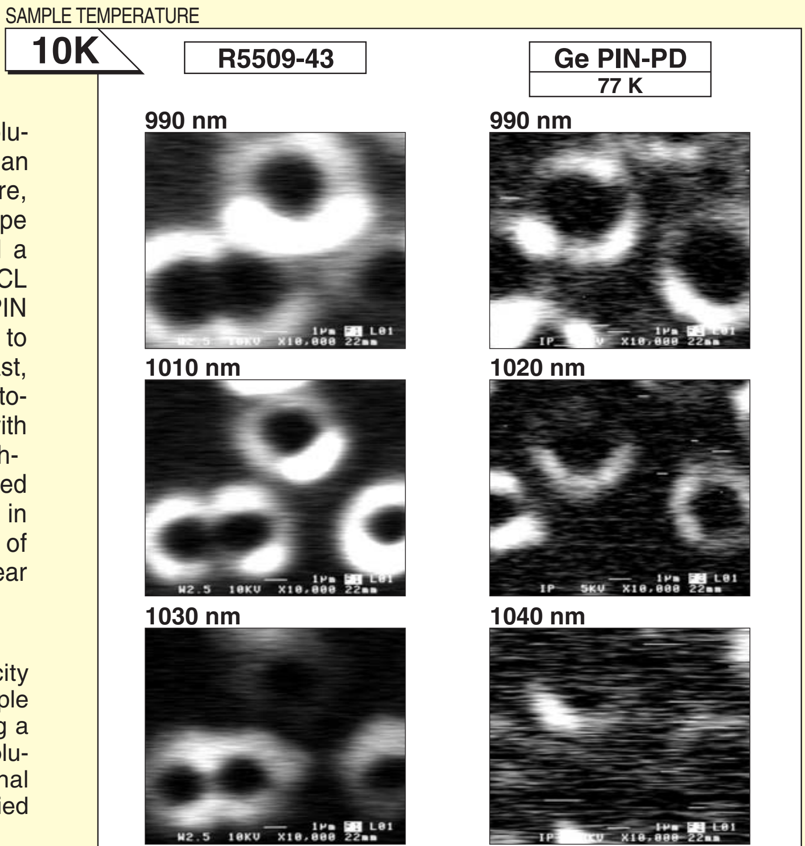
The data on the right show images of cathodoluminescence (CL) emitted from InAs islands in an InAs/InP multiple quantum well structure, observed with a scanning electron microscope (SEM) to which a light collection system and a monochromator were installed. The right-hand CL images were taken with the SEM using a Ge PIN photodiode. These images are not clear due to external noise such as cosmic rays. In contrast, the left-hand data taken with an R5509-43 photomultiplier tube shows clear, sharp CL images with a high S/N ratio. The R5509-43 allows high-sensitivity CL measurements in the near infrared region, which are expected to prove useful in optical evaluations of samples, analysis of inorganic or organic substances, and other near infrared spectroscopy.

Cathodoluminescence (CL) measurement
When a sample is irradiated by high-velocity electron beams, electron-hole pairs in the sample are excited and then recombine while producing a characteristic luminescence known as cathodoluminescence (CL). Information on the internal electron structures of the sample can be studied by measuring this luminescence.

Condition

Electron probe	Accelerating voltage	5 kV
	Current	10 nA

Detector: NIR-PMT R5509-43



Photos: By courtesy of Prof. Y. Takeda, Dept. of Materials Science and Engineering, Graduate School of Engineering, Nagoya University;
Prof. A. Nakamura, Center for Integrated Research in Science and Engineering, Nagoya University

APPLICATION EXAMPLES

Fluorescence lifetime measurement

Sample

InAs Quantum Dots

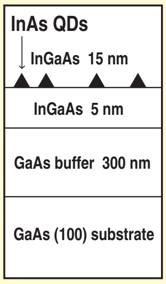
SAMPLE TEMPERATURE

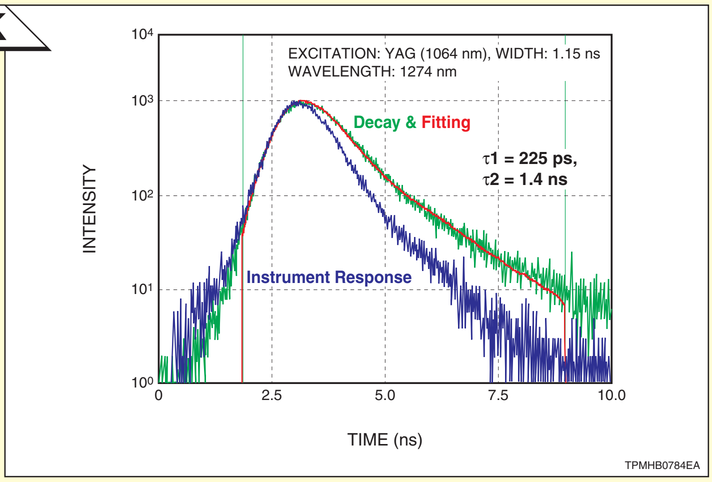
300K

(room temperature)

Data shown here is photoluminescence lifetime from InAs quantum dots grown on an InGaAs substrate, measured with time-correlated single photon counting (TCSPC) technique.

Basic structure





Detector: Detector equivalent to the H10330C-45 NIR-PMT unit
System: Near-infrared lifetime measurement system

Fluorescence lifetime measurement

Sample

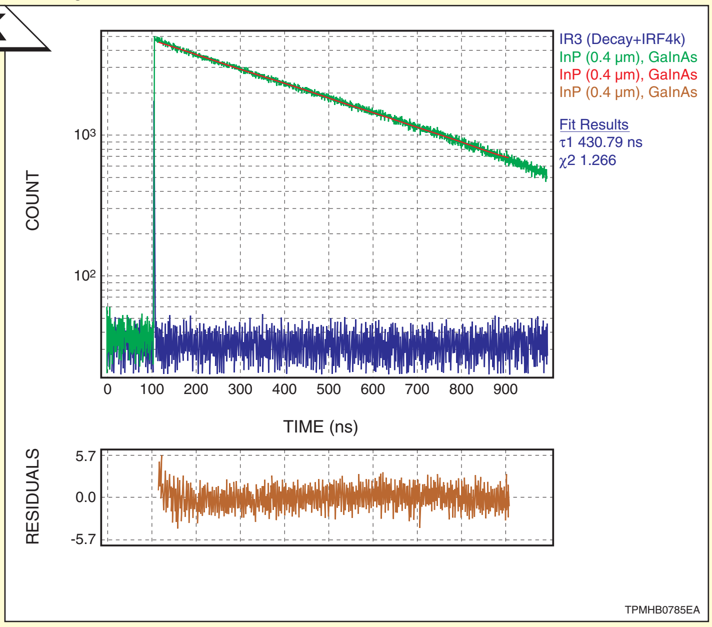
InGaAsP

SAMPLE TEMPERATURE

300K

(room temperature)

NIR-PMTs allow making fluorescence lifetime measurements in the near infrared region. Up till now this has been difficult to measure with conventional detectors.
This measurement shows the fluorescence lifetime of a compound semiconductor (at room temperature).



EXCITATION: Nd: YAG (1064 nm)
FLUORESCENT WAVELENGTH: 1347 nm
SAMPLE TEMPERATURE: 300 K

τ=430.79 ns was obtained after deconvolution by the software.

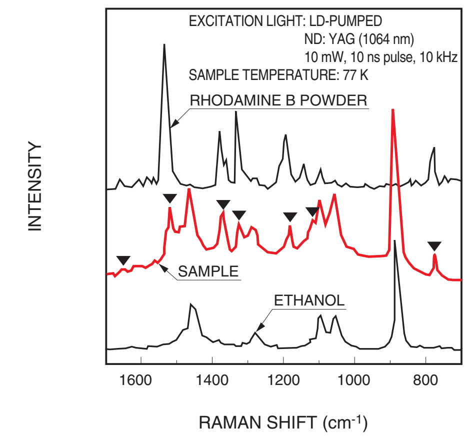
Detector: Detector equivalent to the H10330C-75 NIR-PMT unit
System: Near-infrared life time measurement system

Measurement of Raman spectroscopy

Sample

Rhodamine B in Ethanol Solution (20 μmol/L)

SAMPLE TEMPERATURE
300K
(room temperature)



Raman spectroscopy is effective in studying the structure of molecules in a solution. In particular, near infrared Raman spectroscopy enables measurement of samples which were previously impossible with conventional methods using visible light excitation because of the influence of fluorescence. In this application, clear Raman spectra of solute rhodamine B (marked by ▼) are measured, as well as a Raman spectrum of ethanol solution. This data was obtained with weak excitation light averaging 10 mW output using pulsed excitation light and gate detection method under fluorescent room lighting conditions.

Detector: Detector equivalent to the H10330C-45 NIR-PMT unit

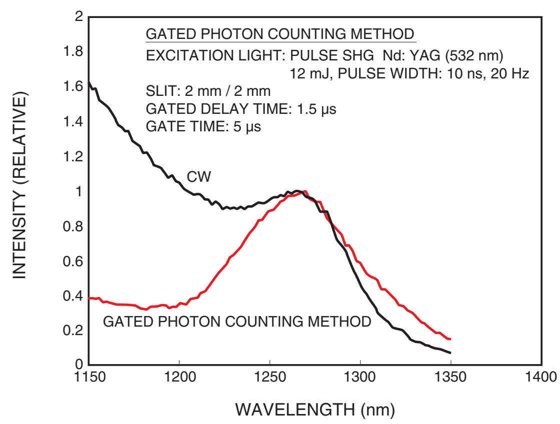
Measurement of singlet oxygen

Sample

Singlet oxygen

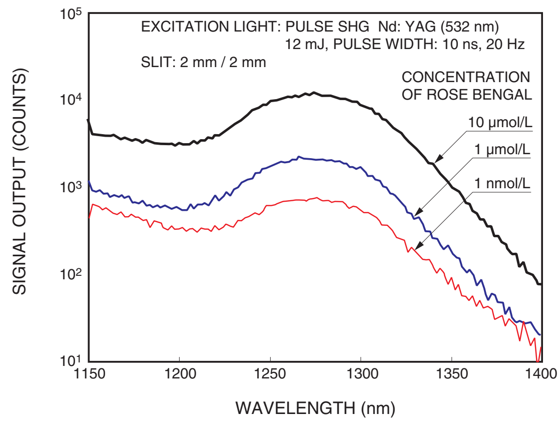
Rose Bengal in pure water

SAMPLE TEMPERATURE
300K
(room temperature)



Using the R5509-43 and a pulsed laser, singlet oxygen emission with a peak at 1270 nm were efficiently detected by signal processing with a gated pulse counter, reducing effects of fluorescence.
(Data obtained by CW YAG laser excitation is also shown in the same graph for comparison.)

SAMPLE TEMPERATURE
300K
(room temperature)



The graph on the right shows detection limits evaluated by changing the concentration of the photosensitizer Rose Bengal. This proves that emissions from singlet oxygen of low concentration, even only 1 nmol/L, can be detected.

Detector: NIR-PMT R5509-43

Measurement of singlet oxygen

Sample

Singlet oxygen

Rose Bengal in acetone, methanol and water

Lifetime characteristics and emission spectrum of the singlet oxygen when the photosensitizer Rose Bengal was dissolved in acetone, methanol and water were measured.

Singlet oxygen lifetime can be measured with high accuracy, by using gated photon counting techniques that utilize high-speed response of a near infrared PMT and allow continuous scan of signal pulses obtained in a short gate time (sampling time).

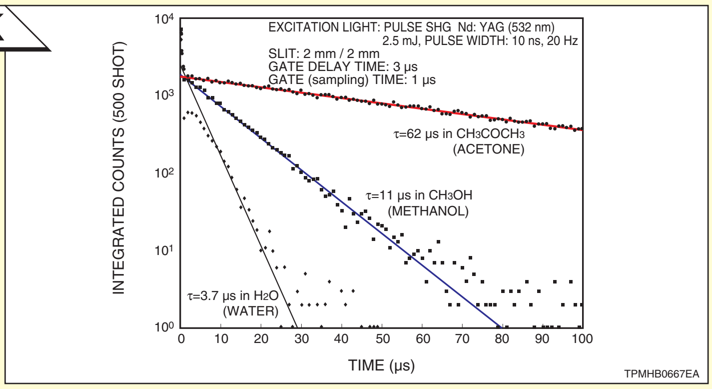
In solvents which singlet oxygen has a long life, there is little singlet oxygen that thermally disappears so more singlet oxygen disappears during the emission process. This results in an increase in the entire emission level.

Detector: NIR-PMT R5509-43

SAMPLE TEMPERATURE

300K

(room temperature)



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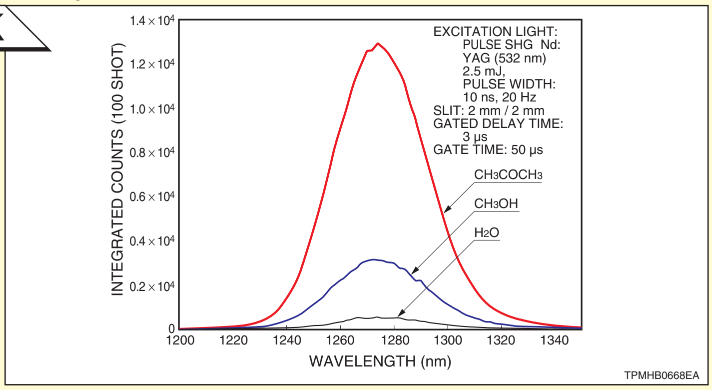
SAMPLE TEMPERATURE

300K

(room temperature)



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Sample

5-ALA (Photosensitizer)

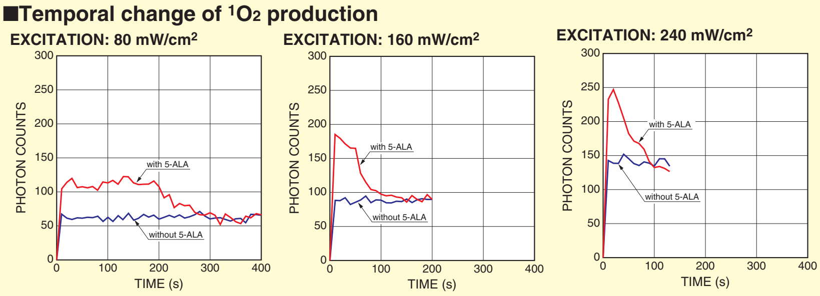
In photodynamic therapy (PDT), singlet oxygen plays an important role in killing tumor cells. Changes in the amount of generated singlet oxygen can be observed at the cellular level. This implies that monitoring the singlet oxygen is the key to setting optimal PDT laser irradiation conditions. Accurate measurements can be made since NIR-PMT units can directly capture weak singlet-oxygen emissions (1270 nm) from cells.

Experimental conditions

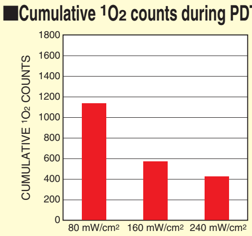
Photosensitizer: 5-ALA
Cancer cells: Rat brain tumor cells 9L
Excitation light: 635 nm

Detector: Detector equivalent to the H10330C-45 NIR-PMT unit

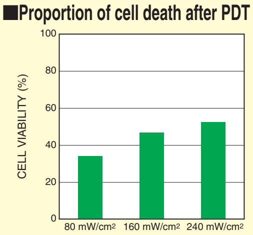
■Temporal change of $^1O_2$ production



■Cumulative $^1O_2$ counts during PDT at each fluence rate



■Proportion of cell death after PDT at each fluence rate



TPMHB0786EA

Data courtesy of:
Junkoh Yamamoto, Department of Neurosurgery, University of Occupational and Environmental Health, Japan
Toru Hirano, Photon Medical Research Center, Hamamatsu University School of Medicine, Japan

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