LOW-LIGHT-LEVEL MEASUREMENT IN THE NIR

NIR (NEAR INFRARED:1.4µm/1.7µm) PHOTOMULTIPLIER TUBES R5509-42/R5509-72

with EXCLUSIVE COOLERS

APPLICATION EXAMPLE: Photoluminescence measurement

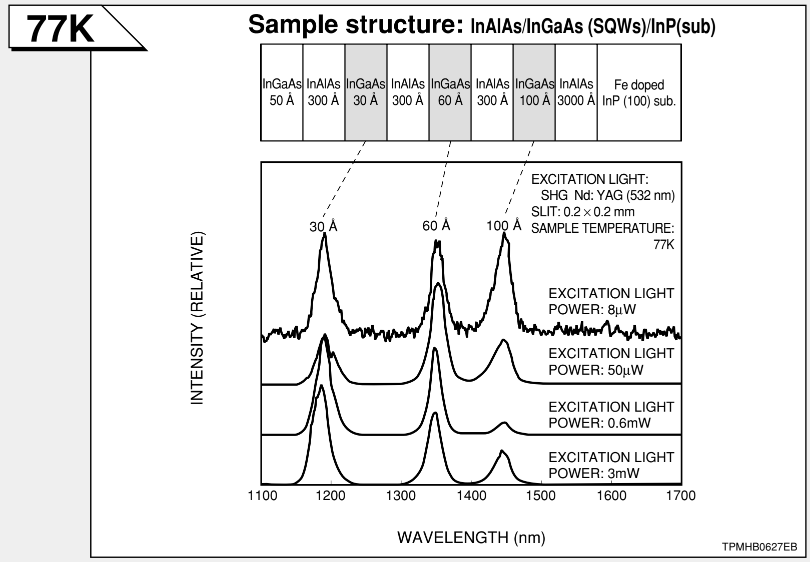
Sample 1

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



OVER VIEW

Hamamatsu near infrared photomultiplier tubes (NIR-PMT) R5509-42 and -72 have newly developed 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. NIR-PMTs the R5509-42 and -72 not only have these new spectral response ranges, but also have good features of conventional photomultiplier tubes for fast time response and photon counting performance, which allow weak light detection in the near infrared region. They can solve the problems of low sensitivity and slow time response in other conventional near infrared detectors like a germanium diode which is so far commonly used in this range.

TPMHF0435

FEATURES

- **Using a "low power excitation light" allows high-precision measurement not affected by strong excitation light.**
  High gain and low noise improve the detection limit.

- **Flat response from visible to near IR minimize spectral sensitivity correction.**
  The spectral response covers a wide range from 300 nm 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).

HAMAMATSU

APPLICATION EXAMPLES

Photoluminescence measurement

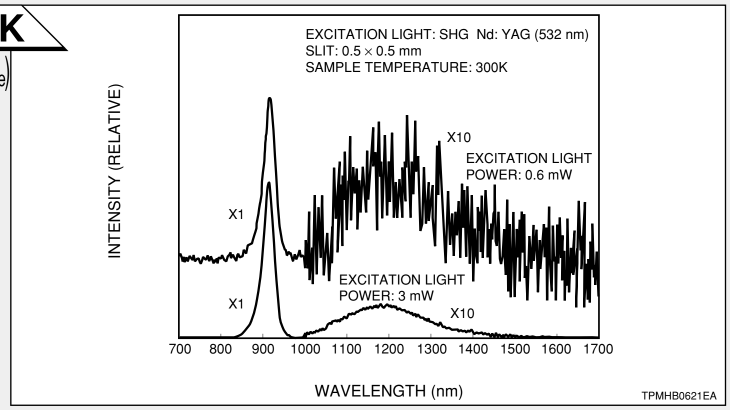
Sample 2

Undoped SI-InP

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

SAMPLE TEMPERATURE

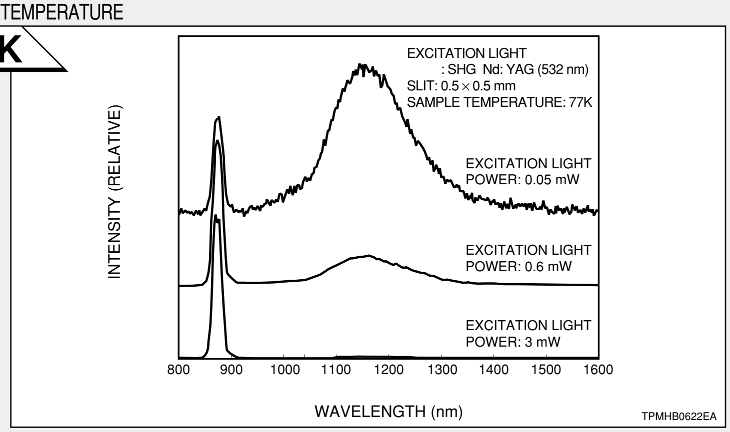
300K (room temperature)



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



Data was measured with a near infrared measurement system described later.

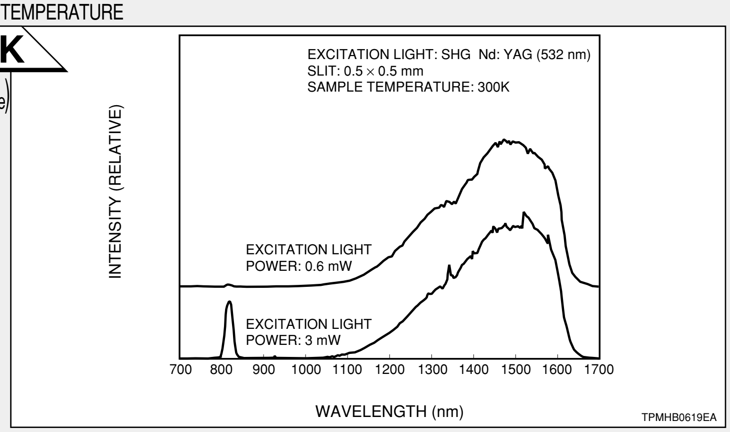
Sample 3

Undoped SI-GaAs

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

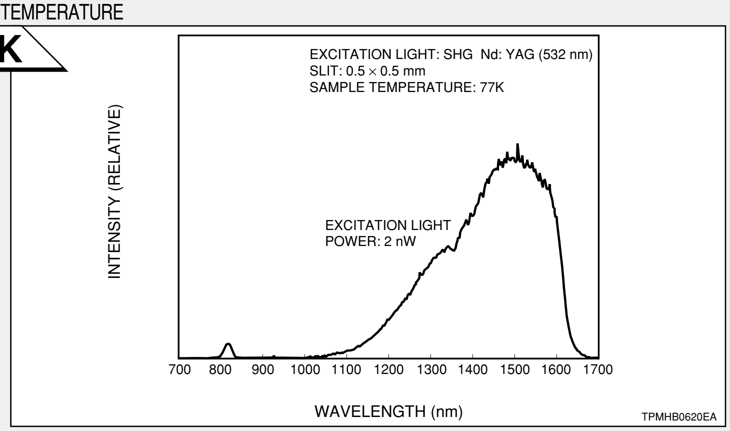
SAMPLE TEMPERATURE

300K (room temperature)



SAMPLE TEMPERATURE

77K



Data was measured with a near infrared measurement system described later.

Sample 4

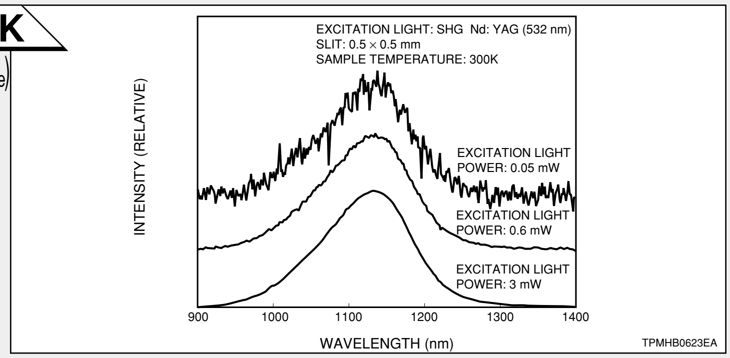
B-Doped Si (111)

low resistivity wafer ρ > 0.02 kΩcm

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.

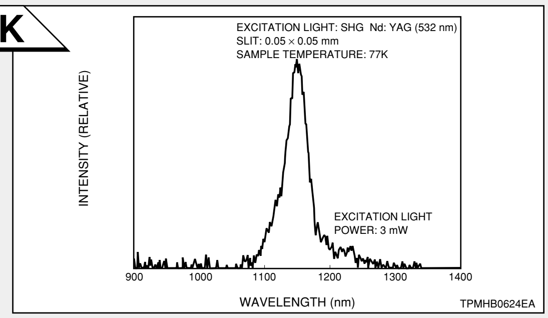
SAMPLE TEMPERATURE

300K (room temperature)



SAMPLE TEMPERATURE

77K

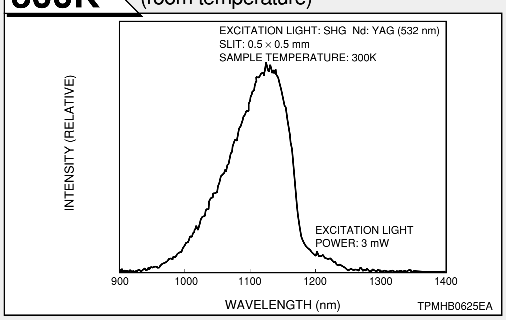


high resistivity wafer ρ > 5 kΩcm

Clear photoluminescence spectra can be observed at room temperature, even in faint emission from a high resistivity silicon wafer.

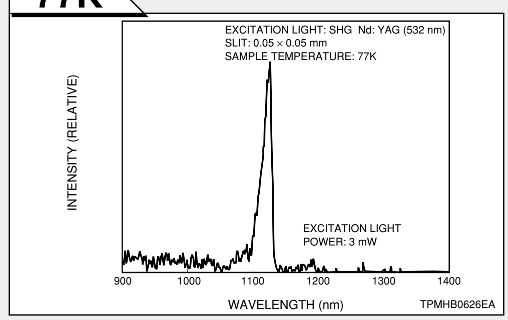
SAMPLE TEMPERATURE

300K (room temperature)



SAMPLE TEMPERATURE

77K



Data was measured with a near infrared measurement system described later.

Sample 5

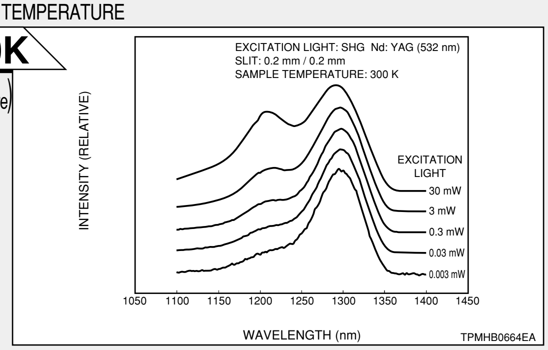
InAs/InGaAs

quantum dots structure

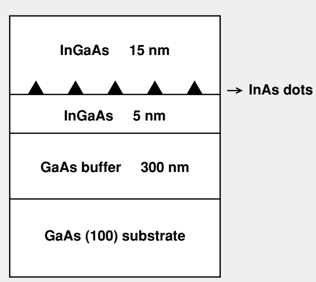
Figure shows PL spectrum at the room temperature from InAs quantum dots covered with InGaAs layer.
Size and uniformity of quantum dots can be estimated from the peak wavelength and the FWHM of PL spectrum.
However, when excitation power is increased, luminescence of shorter wavelength (1200 nm) becomes 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



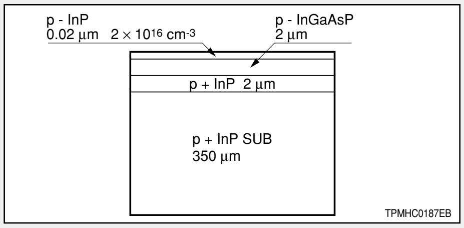
Data was measured with a near infrared measurement system described later.

APPLICATION EXAMPLES

Photoluminescence measurement

Sample 6

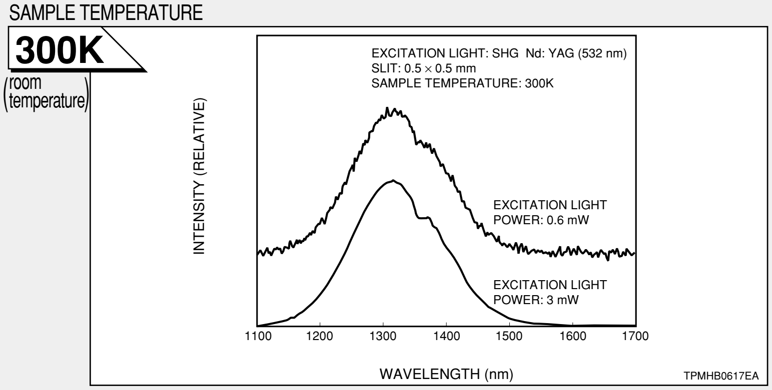
InGaAsP/InP

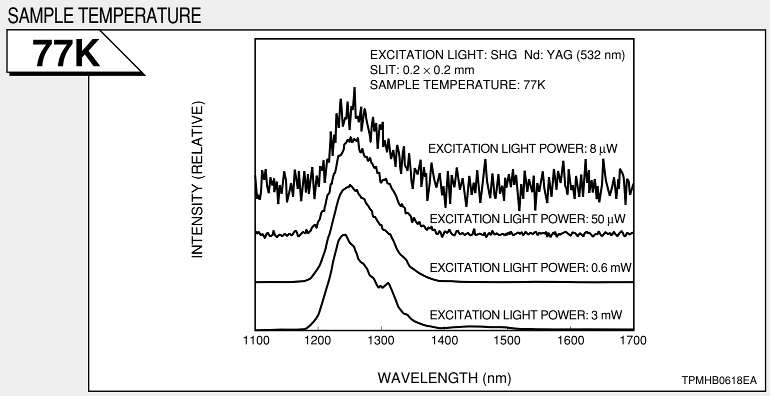


An epitaxial wafer at the room temperature can be evaluated.

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

Data was measured with a near infrared measurement system described later.





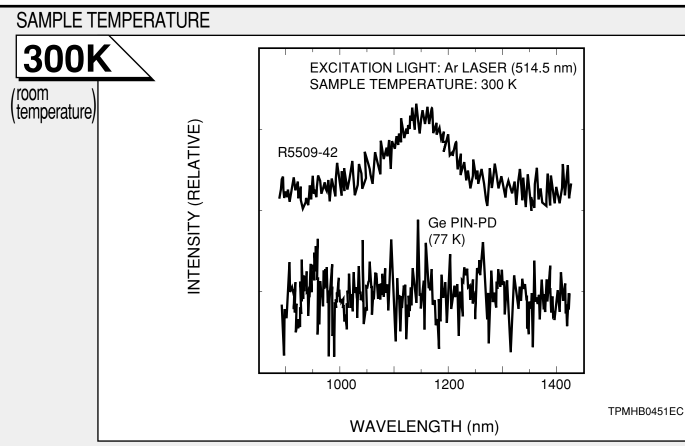
●Comparison with Ge PIN photodiode

Sample 7

B-Doped Si (111)

low resistivity wafer 0.005-0.2 Ωcm

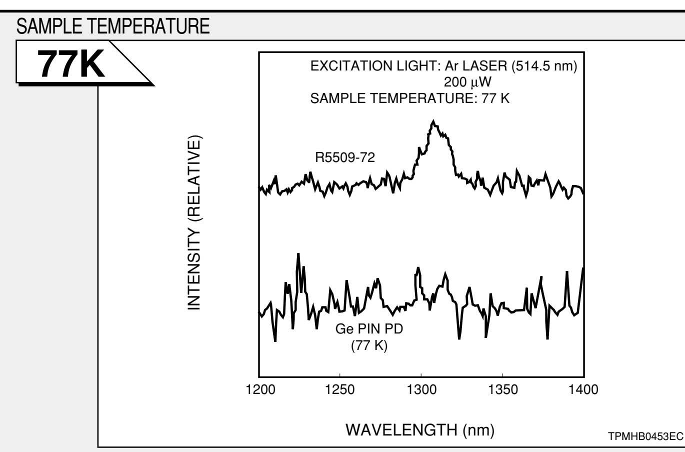
The R5509-42 PMT provides high detection efficiency that allows detecting a distinct photoluminescent peak with a high S/N ratio from a room temperature sample.
The data were taken with a relatively weak excitation in order to compare with a germanium detector (Ge PIN PD) which did not show a clear peak.



Sample 8

InGaAsP/InP

InGaAs/InP photoluminescence measurements were performed under weak excitation conditions in order to compare the detection limit between the R5509-72 and a Ge PIN photodiode. The result proves that the R5509-72 allows to detect a peak output in the vicinity of 1.3 μm which is undetectable with the Ge PIN photodiode.
In addition to the improvement in the detection limit at low light levels in the NIR region, the R5509-72 provides excellent time response, therefore, time-resolved photometry in the NIR region is now possible.



Measurement of Raman spectroscopy

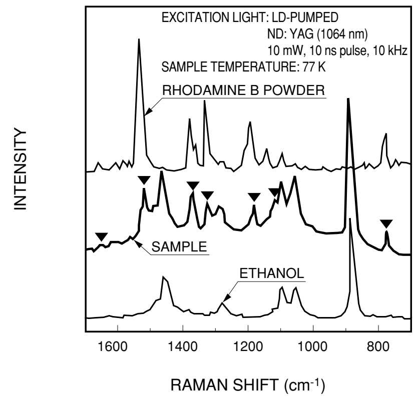
Sample 9

Rhodamine B in Ethanol Solution (2 × 10^{-2} mol/L)

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.

SAMPLE TEMPERATURE

300K (room temperature)



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Cathodoluminescence (CL) measurement

Sample 10

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 R5509-42 photomultiplier tube shows clear, sharp CL images with a high S/N ratio. The R5509-42 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

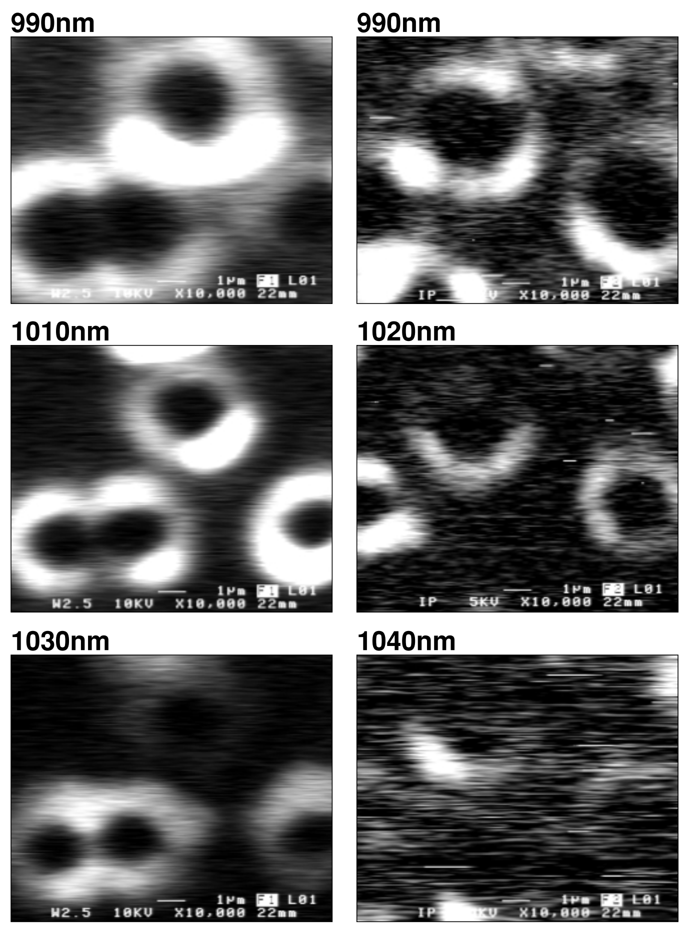
Electron	Accelerating Voltage	5 kV
Probe	Current	10 nA

SAMPLE TEMPERATURE

10K

R5509-42

Ge PIN-PD
77K



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

Measurement of singlet oxygen

Sample 11

Singlet oxygen

Rose Bengal in pure water

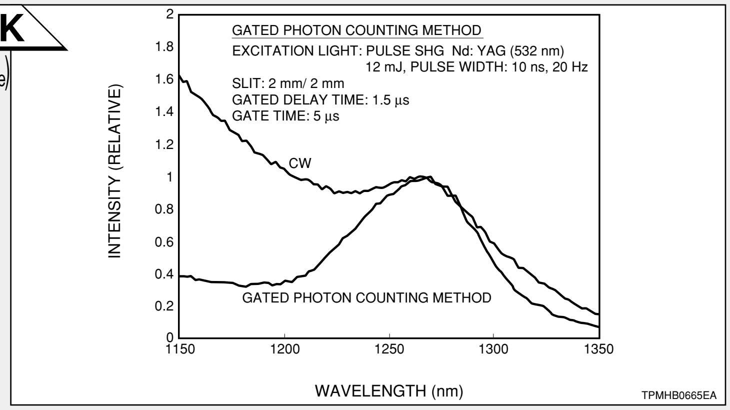
Using the R5509-42 and a pulsed laser, singlet oxygen emission with a peak at 1270 nm were efficiently detected by signal processing with a gated pulse counter, reducing effects of fluorescence.
(Data obtained by CW YAG laser excitation is also shown in the same graph for comparison.)

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

Data was measured with a near infrared measurement system described later.

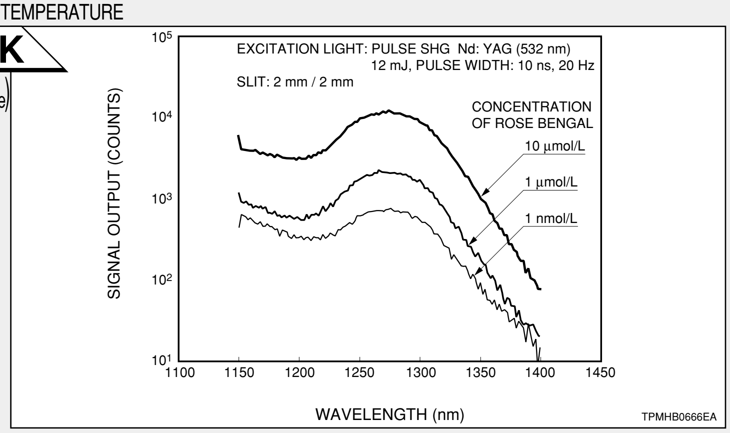
SAMPLE TEMPERATURE

300K (room temperature)



SAMPLE TEMPERATURE

300K (room temperature)



Sample 12

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.

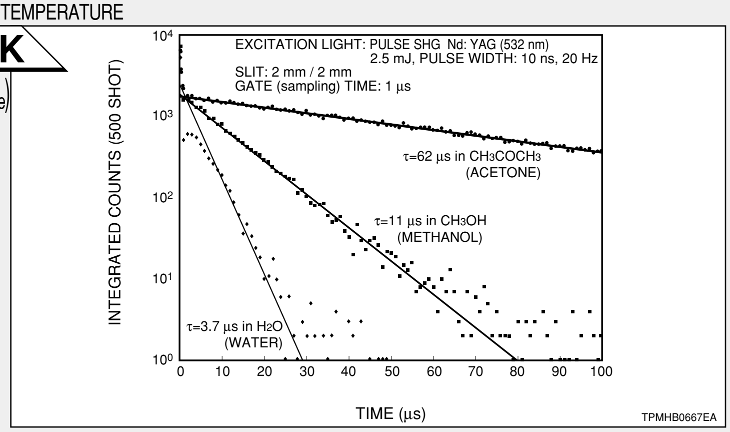
Singlet oxygen lifetime can be measured with high accuracy, by using gated photon counting techniques that utilize high-speed response of a near infrared PMT and allow continuous scan of signal pulses obtained in a short gate time (sampling time).

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.

Data was measured with a near infrared measurement system described later.

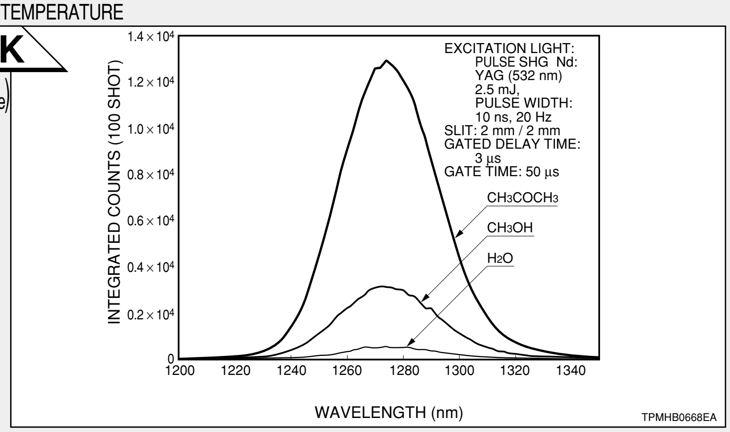
SAMPLE TEMPERATURE

300K (room temperature)



SAMPLE TEMPERATURE

300K (room temperature)



The samples 2 to 6 , 11 and 12 were measured with the measurement system shown below:

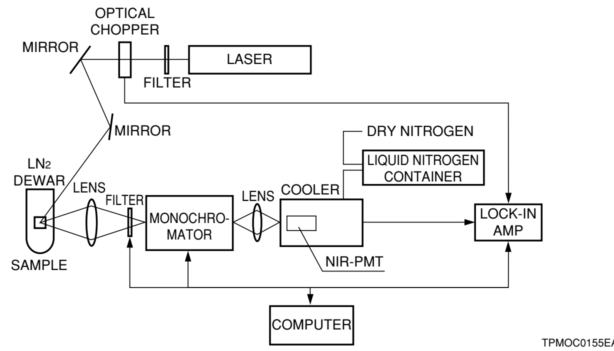
Measurement System

Most of the application data in this sheet were measured with the following system using an R5509 series PMT.
Time resolved measurement and gated measurement were performed with a pulsed YAG laser and a photon counter in place of CW laser and lock-in amplifier.

■STRUCTURE

Excitation light: LD-pumped Nd: (SHG) YAG laser,
λ=532 nm, maximum output=50 mW
or
Pulsed Nd: (SHG) YAG laser,
λ=532 nm, pulse energy more than 12 mJ,
repetition rate=20 Hz, pulse with=5 ns to 7 ns
Monochromator: Czerny-Turner type
Aperture ratio: F=3, Focal length: 100 mm,
Diffraction grating: grooves/mm=600,
Brazed wavelength=1 µm, Wavelength resolution: 2 nm
Detector: NIR PMT R5509-42 or R5509-72
Exclusive cooler PC176TSCE005 [Cooling Temperature: -80 °C]
Sample cell: LN_2 dewar or without
Signal processing: Lock-in amplifier or photon counter

■SYSTEM CONFIGURATION WITH CW LASER + LOCK-IN AMPLIFIER



●REFERENCE

Photocathode and Photomultiplier tubes

1. M. Niigaki, T. Hirohata, T. Suzuki, N. Oishi, S. Furuta, H. Kan and T. Hiruma, "Near Infrared Photomultiplier with Transferred Electron Photocathode", Bulletin of the Research Institute of Electronics, Shizuoka Univ. 30-3, 189 (1995)
2. M. Niigaki, T. Hirohata, T. Suzuki, H. Kan and T. Hiruma, "Field-assisted photoemission from InP/InGaAsP photocathode with p/n junction", Appl. Phys. Lett., 71, 2493 (1997)

Photoluminescence

3. S. Furuta, K. Kuroyanagi, M. Niigaki, T. Hirohata, H. Kan and T. Hiruma, "Characterization of Doped-Si and SiGe Quantum Well Using Near-Infrared Photomultiplier Tube", Bulletin of the Research Institute of Electronics, Shizuoka Univ. 30-3, 233 (1995).
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6. S. Fukatsu, Y. Mera, M. Inoue, K. Maeda, H. Akiyama and H. Sakaki, "Time-resolved D-band luminescence in strain-relieved SiGe/Si", Appl. Phys. Lett., 68, 1889 (1996)
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10. Takashi Suemasu, Yoichiro Negishi, Kenichiro Takakuma and Fumio Hasegawa, "Room Temperature 1 µm Electroluminescence from a Si-Based Light Emitting Diode with β-$FeSi_2$ Active Region", Jpn. J. Appl. Phys., 39, L1013 (2000)
11. Shigero Ibuka and Michio Tajima, "Characteristics of Silicon-on-Insulator Wafers by Photoluminescence Decay Lifetime Measurement", Jpn. J. Appl. Phys., 39, L1124 (2000)

Singlet oxygen

12. O. Shimizu, J. Watanabe, K. Imakubo and S. Naito, "Formation of Singlet Oxygen Photosensitized by Aromaic Amino Acids in Aqueous Solutions", Chemistry Lett., 19, 203 (1997)
13. O. Shimizu, J. Watanabe and K. Imakubo, "Photon-Counting Technique Facilitates both Time-and Spectra-Resolved Measurements of Near-IR Emission of Singlet Oxygen $O_2(^1\Delta_g)$ in Aqueous Solution", J. Phys. Soc. Jpn., 66, 268 (1997)

SPECIFICATIONS

●GENERAL

Parameter		R5509-42	R5509-72	Unit
Spectral Response		300 to 1400	300 to 1700	nm
Photocathode	Material	InP/InGaAsP	InP/InGaAs	—
	Minimum Effective Area	3 × 8		mm
Window	Material	Borosilicate glass		—
Dynode	Secondary Emitting Surface	Cu-BeO		—
	Structure	Line focused		—
	Number of Stage	10		—
Base		21-pin base		—
Recommended Operating Ambient Temperature		-80		°C

●MAXIMUM RATING (Absolute maximum values)

Parameter		Value	Unit
Supply Voltage	Between Anode and Cathode	1750	V dc
	Between Anode and Last Dynode	250	V dc
Average Anode Current		2	µA
Storage Ambient Temperature		-90 to +50	°C
Operating Ambient Temperature		-90 to -70	°C

●CHARACTERISTICS (at -80 °C, Supply voltage: -1500 V dc)

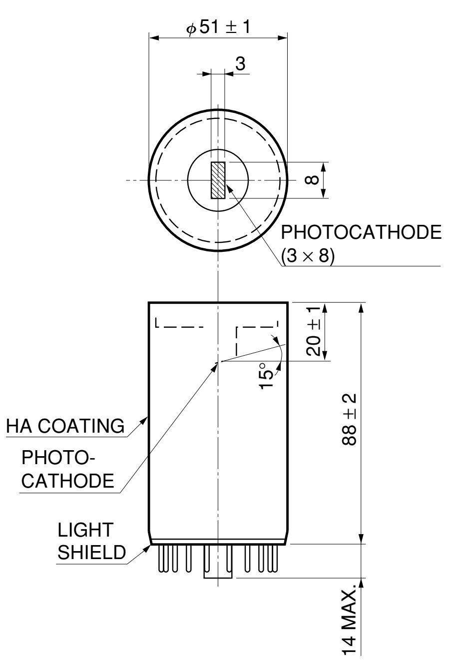
Parameter		R5509-42			R5509-72			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
Cathode Sensitivity	Quantum Efficiency ⓐ	0.48	—	—	0.29	—	—	%
	Radiant ⓐ	5	—	—	3.5	—	—	mA/W
Anode Sensitivity	Radiant ⓐ	1000	—	—	700	—	—	A/W
Gain		2×10^5	1×10^6	—	2×10^5	1×10^6	—	—
Anode Dark Current ⓑ		—	5	10	—	50	100	nA
Anode Dark Counts ⓑ		—	2×10^4	—	—	2×10^5	—	s^{-1}
Time Response	Anode Pulse Rise Time	—	3	—	—	3	—	ns
	Electron Transit Time	—	23	—	—	23	—	ns
	Transit Time Spread	—	1.5	—	—	1.5	—	ns

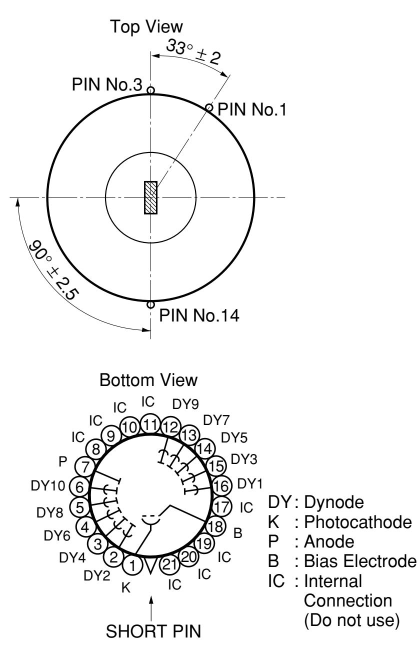
NOTE: ⓐat 1300 nm (R5509-42), at 1500 nm (R5509-72) ⓑAfter 30 minutes' storage in darkness

The dedicated coolers PC176TSCE005 and PC176TSCE006 are shipped after adjusting the voltage divider circuit to provide the optimum voltage distribution ratio that best matches the PMT.

DIMENSIONAL OUTLINE AND BASING DIAGRAM

(Unit: mm)





[Cautions for operation]

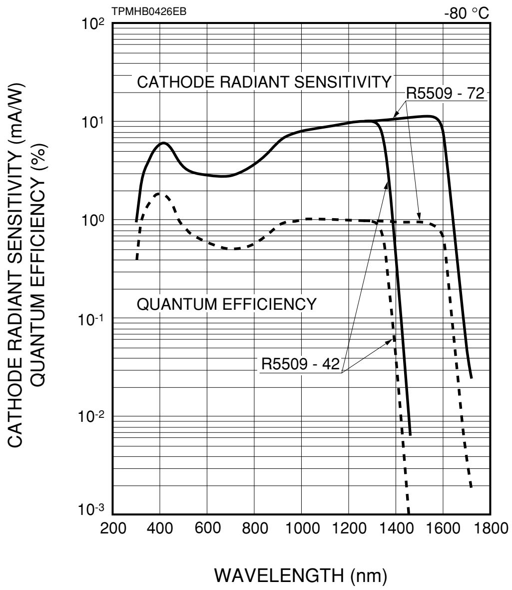
- ●Operate the tube at the anode current less than 2 µA while the entire photocathode is illuminated in order to avoid the photocathode damage due to excessive cathode current.
- ●In order to protect the photocathode, the high voltage should be increased or decreased gradually.
- ●When the R5509-42 or -72 shall to be operated, do not supply the high voltage before the tube is cooled down to -70 °C at least.
- ●Use the exclusive cooler **PC176TSCE005** or **PC176TSCE006** for cooling.

[Warranty]

- ●A cooler other than specified may cause a trouble in the tube like loss of performance or a mechanical damage. Any trouble caused in association with a cooler other than specified shall not be subject to warranty.
- ●Hamamatsu photomultiplier tubes are warranted to the original purchase for a period of 12 months following the date of shipment. The warranty is limited to repair or replacement of any defective material due to defects in workmanship or materials used in manufacture.

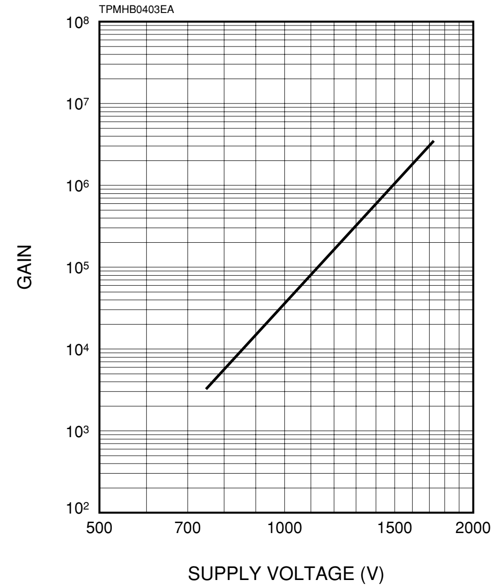
CHARACTERISTICS FIGURES

●Spectral Response

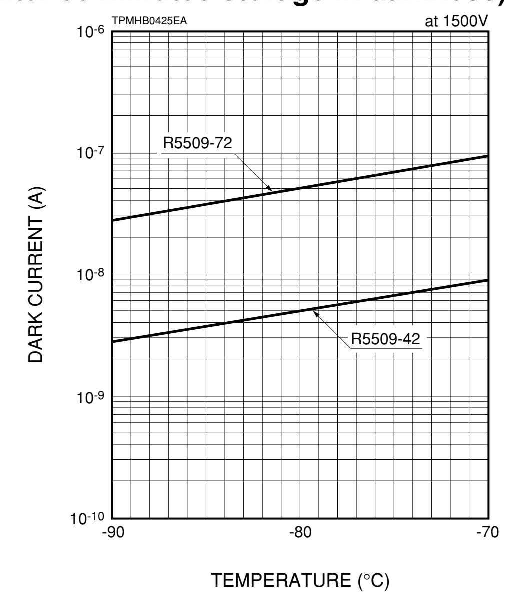


* Spectral response characteristics when used with the dedicated cooler

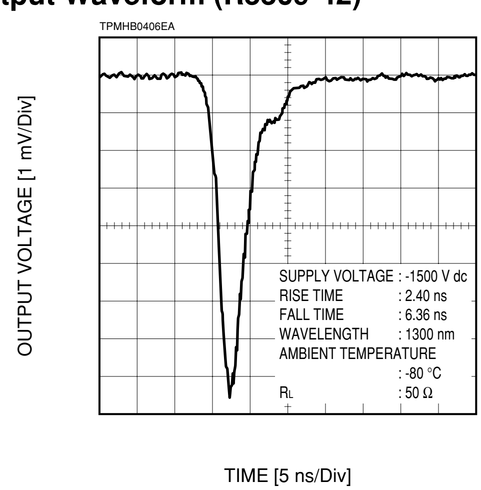
●Typical Gain (R5509-42, -72)



●Temperature Characteristics of Dark Current (After 30 minutes storage in darkness)

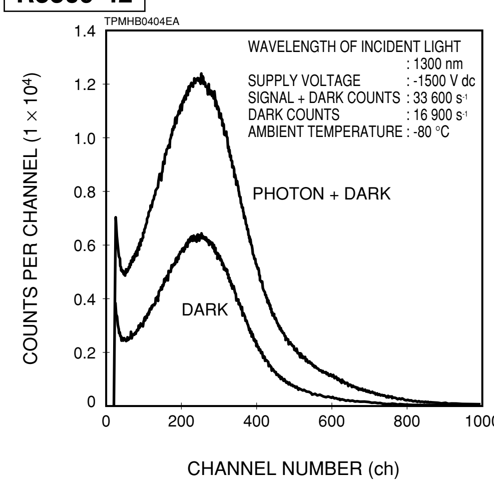


●Output Waveform (R5509-42)

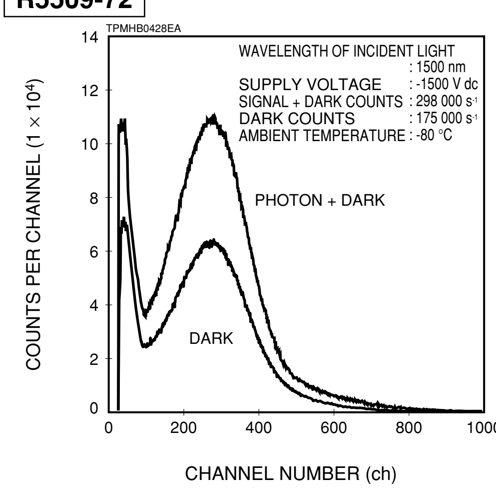


●Single Photoelectron Pulse Height Distribution (PHD)

R5509-42



R5509-72



RELATED PRODUCTS

Exclusive cooler PC176TSCE005 and PC176TSCE006 for R5509-42, -72

PC176TSCE005 and PC176TSCE006 are exclusively designed coolers for R5509-42 and -72 using liquid nitrogen. The dark current of R5509-42 and -72 will be reduced drastically by cooling so that the PMT will be able to detect very weak light.
The cooler housing is magnetically and electrostatically shielded excluding external noises to provide very stable and high S/N ratio measurement.
Hamamatsu also provides the PC176TSCE006 cooler suitable for a selfpressurized liquid nitrogen container.

■FEATURES

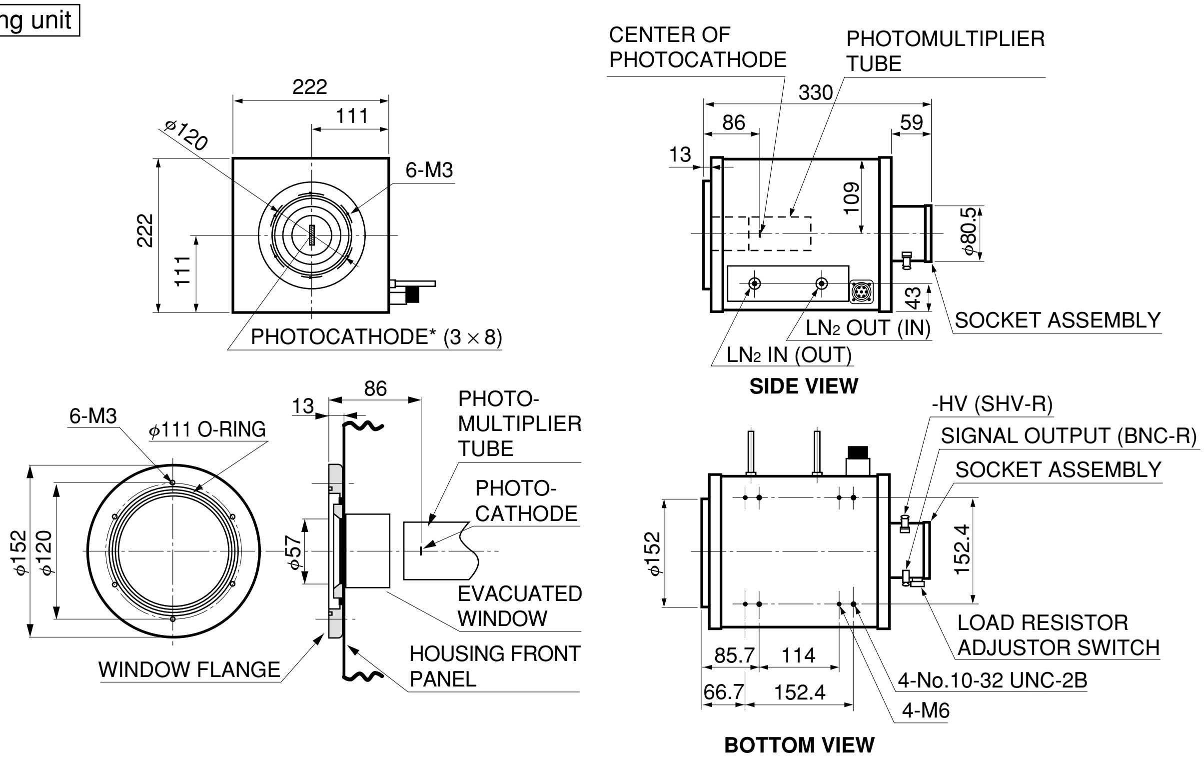
- **Temperature controllable range: 0 to -100 °C**
  (R5509-42, -72 operating range shall be: -70 to -90 °C)
- **Exclusive socket assembly with load resistor selectable circuit**
- **Built-in magnetic electrostatic shield**
- **Built-in warning buzzer for liquid nitrogen supply shortage**

■SPECIFICATIONS

Parameter		PC176TSCE005	PC176TSCE006
Coolant medium		Liquid Nitrogen Vaporization	
Temperature Controllable Range		0 °C to -100 °C (continuously adjustable)	
Cool-down Time		Approx. 2 h (-80 °C setting)	
Liquid Nitrogen Consumption rate (Max.)		0.75 L/h (-100 °C setting)	
Dry Nitrogen	Gas Pressure	35 kPa	—
	Consumption rate	47 L (14.7 MPa)/100 h	—
Socket Assembly	Voltage Divider Current	158 µA (PMT Supply Voltage: -1750 V)	
	-HV Connector	SHV-R	
	Signal Connector	BNC-R	
	Load Resistor	50 Ω/ 1 kΩ/ 100 kΩ/ 10 MΩ/ Open	
AC Input Voltage		100 V to 120 V, 220 V to 240 V (50/60 Hz)	
Power Consumption		15 VA	
Operating Ambient Temperature		Less than +30 °C	
Weight	Cooling Unit	Approx. 6 kg	
	Controller and others	Approx. 11 kg	Approx. 11 kg
Components		Cooling Unit, Controller, Solenoid Control Cable, Solenoid Valve, 3/8" OD Rubber Tube, Insulated Transfer Hose, LN_2 Transfer Head for 35 mm to 40 mm Neck OD LN_2 Dewar	Cooling unit, Controller, Solenoid Control Cable, Flow Limit Valve, Solenoid Valve, Insulated Transfer Hose, Control Solenoid with Connecting Hose with 3/4-16UNF or PT 1/4 Screws in End

■DIMENSIONAL OUTLINE (Unit: mm)

Cooling unit



* The socket assembly can be rotated by 90 degrees in order to match the shape of the input light.

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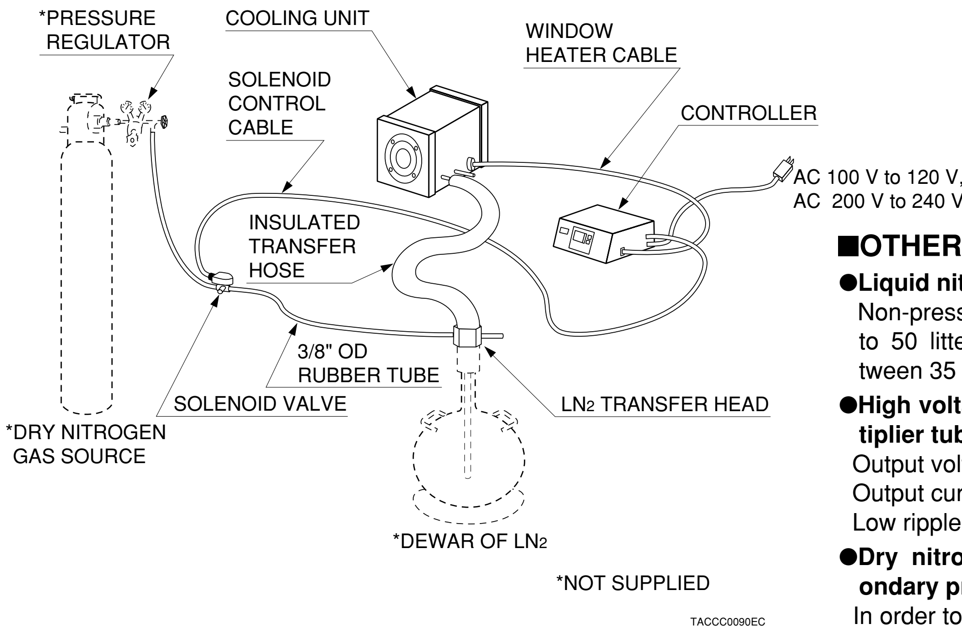
■CONNECTION DIAGRAM

●PC176TSCE005



■OTHER ACCESSORIES REQUIRED

●Liquid nitrogen dewar

Non-pressurized dewar having a capacity of 10 to 50 litters, and the neck outer diameter between 35 and 40 mm.

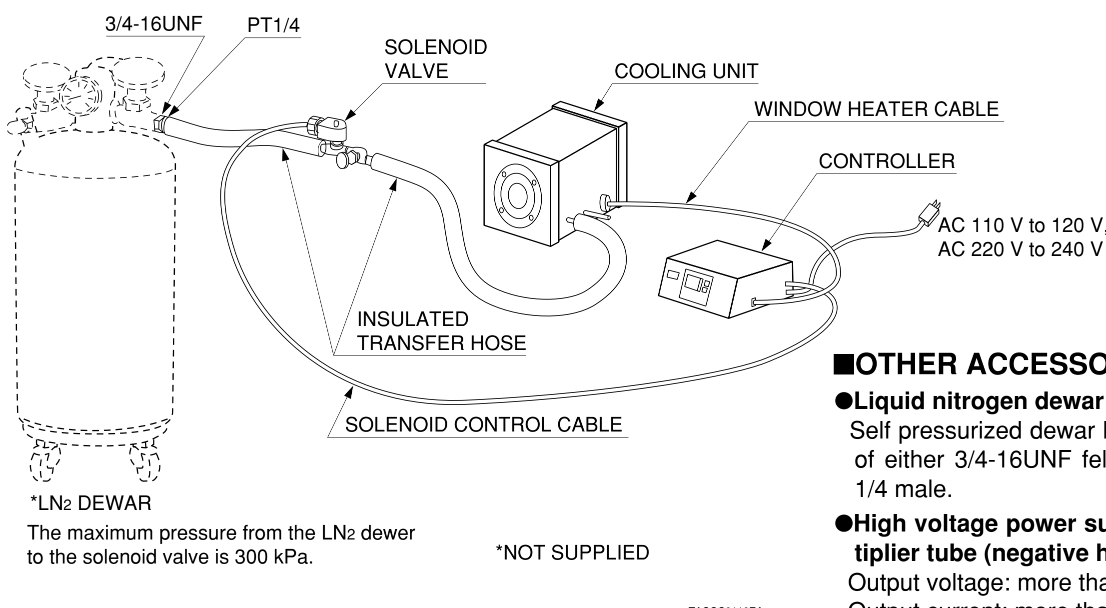
●High voltage power supply for the photomultiplier tube (negative high voltage)

Output voltage: more than -1750 V
Output current: more than 0.2 mA
Low ripple, High stability

●Dry nitrogen gas, pressure regulator (secondary pressure 35 kPa), pressure gauge

In order to supply a proper amount of liquid nitrogen to the cooling unit, an external pressure needs to be added to the dewar. A pressure regulator capable of reducing a secondary pressure to 35 kPa is necessary when used with a dry nitrogen gas container. Connect the 3/8" rubber tube to the exit of the pressure regulator.

●PC176TSCE006



■OTHER ACCESSORIES REQUIRED

●Liquid nitrogen dewar

Self pressurized dewar having a matching screw of either 3/4-16UNF felmale (removable) or PT 1/4 male.

●High voltage power supply for the photomultiplier tube (negative high voltage)

Output voltage: more than -1750 V
Output current: more than 0.2 mA
Low ripple, High stability

RELATED PRODUCTS

Peripheral devices and options

●**Relay optics**

The relay optics is designed for efficient light collection from the exit slit of a monochromator to the PMT photocathode. Optical axis adjustment can also be made precisely.
A mechanical shutler is mounted.
For more information, please contact our sales office.

●**Input window with condenser lens**

The input window of the PC176TSCE005 and PC176TSCE006 are also available with a condenser lens mounted on its inner side. This window efficiently collects the incoming collimated light onto the PMT photocathode and can be easily replaced with the standard window.

●**High-voltage power supply C3350**

Output voltage (DC): 0 V to ±3000 V, Output current: 10 mA, Bench-top high-voltage power supply with high stability and low ripple.

Related Products for Photon Counting

●**Preamplifiers**

It is recommended that a fast preamplifier is used in front of the photon counting unit C3866 or C6465.
C6438 (DC to 50 MHz) Gain: 20 dB
C5594 (50 kHz to 1.5 GHz) Gain: 36 dB

●**Photon counting units**

C3866 high-speed type (maximum count rate: up to 10^7 s^{-1}) with built-in prescaler
C6465 standard type (maximum count rate: up to 10^6 s^{-1})
These photon counting units convert photoelectron pulses from the R5509 series PMT into a 5 V digital signal. Photon counting with a high S/N ratio can be performed by connecting the output to a pulse counter. We recommend using these photon counting units in conjunction with a C6438 or C5594 series preamplifiers.

●**Photon counting board M7824, M8503**

The M7824 photon counting board is designed for direct plug-in to the ISA bus slot in a PC. The M7824 has a pulse counter that counts photoelectron pulses converted into logic (TTL) signals by a photon counting unit, and transfers them to the PC. The built-in gate function with 50 µs (Min.) internal gate facilitates photon counting with a wide dynamic range.
The M8503 has fast internal gating of 50 ns (minimum) enabling fast time resolved measurement in highly repetitive (1 MHz Max.) phenomena like fluorescence.

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