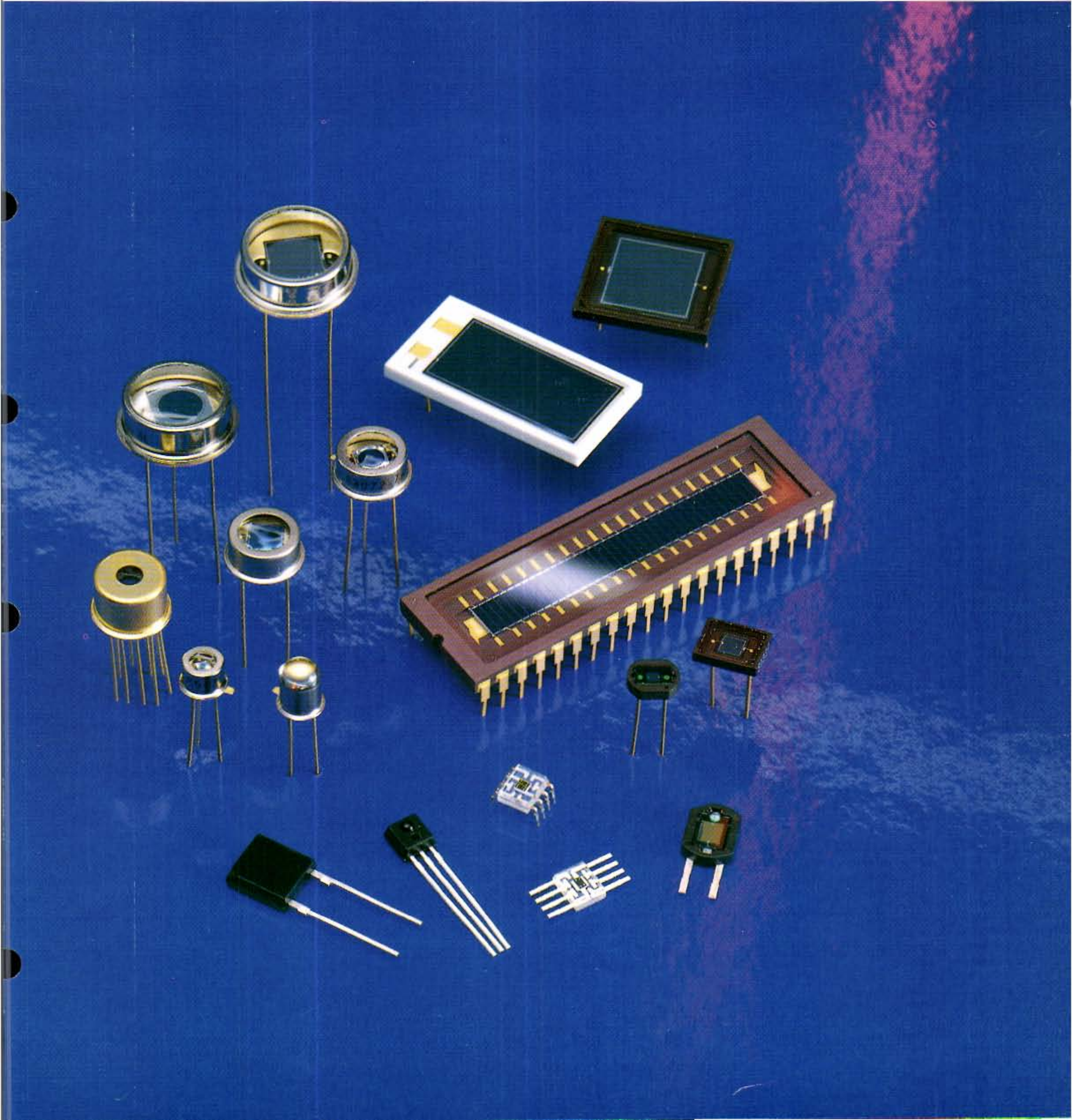
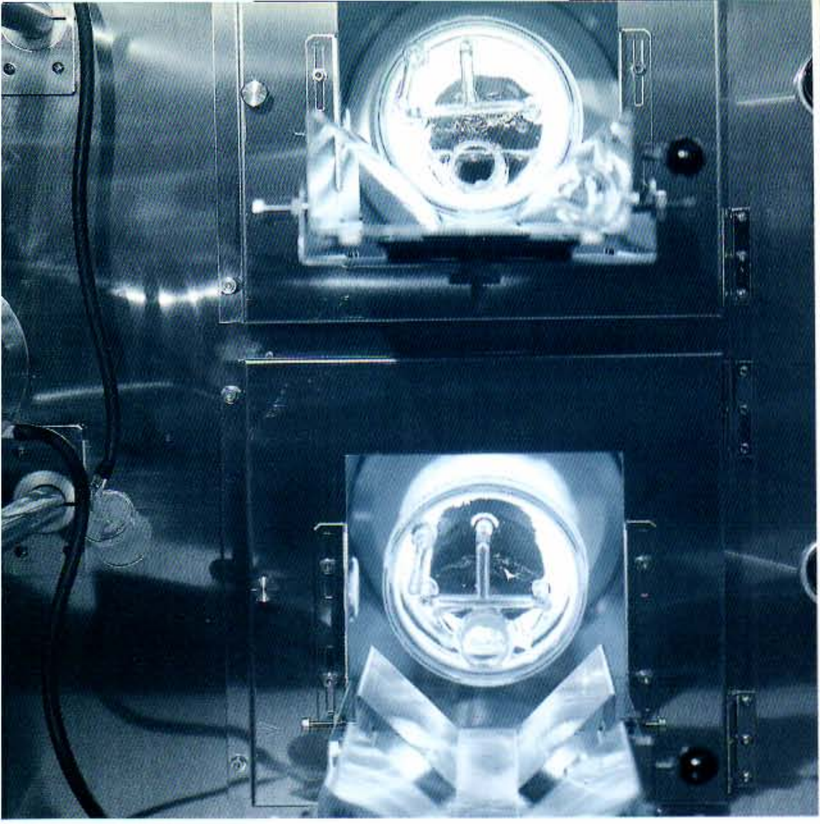
HAMAMATSU

Photodiodes

1989-90 CATALOG





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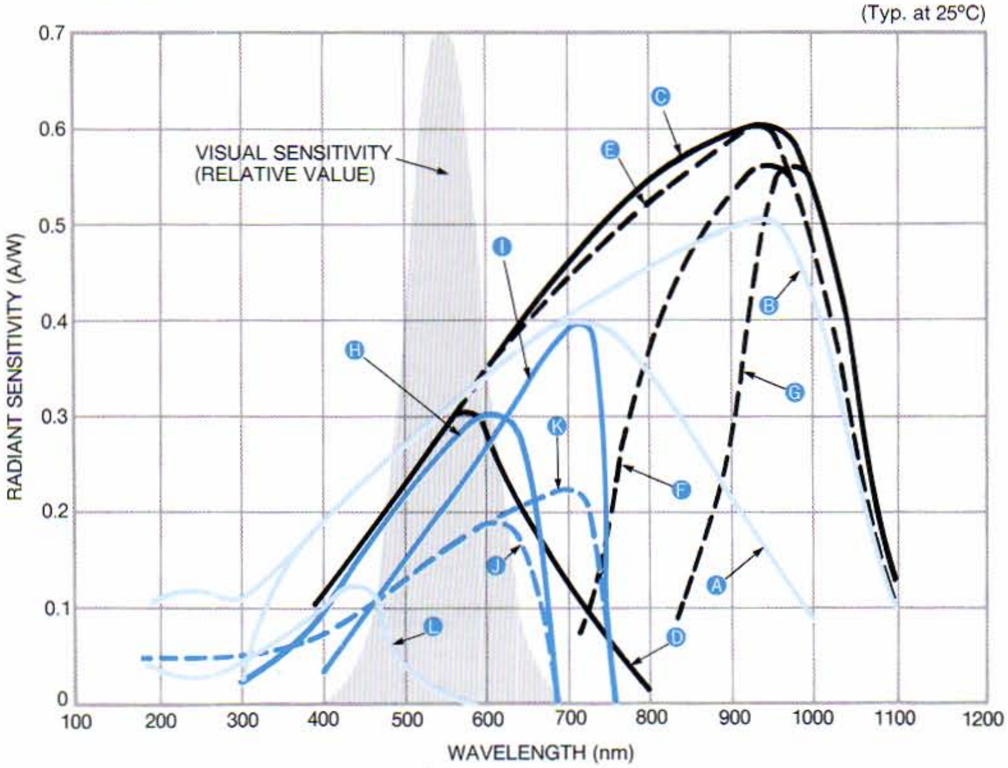


Type	Features	Spectral Response Characteristics			Type No.	Listed Page
		Range	Peak Wavelength	Mark		
Silicon Photodiodes	Ultraviolet to visible light, for precision photometry	190 ~ 1000	720	Ⓐ	S1226, S1227 Series	14·15
	Ultraviolet to infrared, for precision photometry	190 ~ 1100	960	Ⓑ	S1336, S1337 Series	16·17
	Visible light to infrared, for precision photometry	320 ~ 1100	960	Ⓒ	S2386, S2387 Series	18·19
	Visible light, for general-purpose photometry	320 ~ 730	560	Ⓓ	S1087, S1133, S2833 etc.	20·21
	Visible light to infrared, for general-purpose photometry	320 ~ 1100	960	–	S1087-01, S1133-01, etc.	
PIN Silicon Photodiodes	High-speed response, for optical communication optical fiber data link, etc.	320 ~ 1000	800	–	S2839, S2840	22 ~ 25
		320 ~ 1060	900	–	S2216, S1721, etc.	
		320 ~ 1100	960	Ⓔ	S1190, S1223, etc.	
	Visible light cutoff type	700 ~ 1100	960	Ⓕ	S2506	
		840 ~ 1100	980	Ⓖ	S2506-01	
	Large sensitive area, high ultraviolet sensitivity	190 ~ 1060	960	Ⓑ	S1723-05, etc.	
GaAsP Photodiodes (Diffusion Type)	For visible light	300 ~ 680	640	Ⓗ	G1115, G1116, G1117, etc.	26·27
	Extended red sensitivity	400 ~ 760	710	Ⓘ	G1735, G1736, G1737, etc.	
GaAsP Photodiodes (Schottky Type)	Ultraviolet to visible light	190 ~ 680	610	Ⓙ	G1125-02, G1126-02, etc.	28·29
	Extended red sensitivity	190 ~ 760	710	Ⓚ	G1745, G1746, G1747	
GaP Photodiodes	Ultraviolet to green light	190 ~ 550	440	Ⓛ	G1961, G1962, G1963	30·31
Silicon Avalanche Photodiodes (APD)	High-speed response and high gain	400 ~ 1000	800	–	S2381, S2382, S2383, S2384 S2385	32·33

Glossary of Terms Used in This Catalog

Spectral Response

The photocurrent produced by a given level of incident light varies with wavelength. This wavelength/response relationship is known as the spectral response characteristic and is expressed numerically in terms of radiant sensitivity, quantum efficiency, NEP, detectivity, etc.

Radiant Sensitivity

This measure of sensitivity is the ratio of radiant energy expressed in watts incident on the device to the photocurrent output expressed in amperes. It may be expressed as either an absolute sensitivity, i.e., the A/W ratio, or as a relative sensitivity, normalized with respect to the sensitivity at the wavelength of peak sensitivity, with the peak value usually taken as 100. For the purposes of this catalog, the spectral response range is taken to be the region within which the radiant sensitivity is within 5% of the peak value.

Quantum Efficiency (Q.E.)

This is the ratio of number of incident photons to resulting photoelectrons in the output current, without consideration given to the individual photon energy levels, resulting in a slightly different spectral response characteristic curve from that of the radiant sensitivity.

Short Circuit Current (I_{sh})

This value is measured using white light of 2856K distribution temperature from a standard tungsten lamp of 100 lux illuminance (100 lux for GaP photodiodes). The short circuit current is that current which flows when the load resistance is 0 and is proportional to the device photosensitive area.

Dark Current (I_d) and Shunt Resistance (R_{sh})

The dark current is the small current which flows when reverse voltage is applied to a photodiode under dark conditions. It is a source of noise for applications in which a reverse bias is applied to photodiodes as is typically the case with PIN photodiodes. To observe the dark current there are two methods—observation of the V/I ratio (termed shunt resistance) in the 0 V region (−10 mV for the data herein), or observation of the current at actual applied reverse bias conditions.

$$R_{sh} = \frac{10\ (\text{mV})}{\text{Dark Current at } V_R = 10\ \text{mV (A)}}$$

Junction Capacitance (C_j)

An effective capacitor is formed at the P-N junction of a photodiode. Its capacitance is termed the junction capacitance and is the major factor in determining the response speed of the photodiode. This is measured at 1 MHz for PIN types and 10 kHz for other types.

Time Response

1. Rise Time (t_r)

This is the measure of the photodiode response to a stepped light input. It is the time required for transition from 10% to 90% of the output level. The rise time depends on the wavelength of the incident light and load resistance. In this catalog, a GaAsP LED ($\lambda = 655$ nm) or GaP LED ($\lambda = 560$ nm) is used as a light source, and the load resistance is 1 kΩ.

2. Cutoff Frequency (f_c)

This is the measure of the high-speed phtodiode response to sinewave-modulated input light and used for PIN photodiodes and avalanche photodiodes. It is defined as the frequency at which the output of the photodiode decreases by 3 dB from the low frequency response. The light source used is a laser diode ($\lambda = 830$ nm) and the load resistance is 50Ω. f_c and t_r have the following relation;

$$t_r = \frac{0.35}{f_c}$$

NEP (Noise Equivalent Power)

This is the amount of light equivalent to the intrinsic noise level of the device. Stated differently, it is the light level required to obtain an S/N ratio of 1. The NEP is one means of expressing the spectral response. In this brochure, the NEP value at the wavelength of maximum response is used. Since the noise level is proportional to the square root of the bandwidth, the NEP is expressed in units of $W/Hz^{1/2}$.

$$\text{NEP} = \frac{\text{Noise Current } (A/Hz^{1/2})}{\text{Radiant Sensitivity at Peak (A/W)}}$$

Maximum Reverse Voltage (V_R max)

Applying reverse voltages to photodides can cause breakdown and severe deterioration of device performance. Therefore reverse voltage should be kept somewhat lower than the maximum rated value, $V_{R\ max}$, even for instantaneously applied reverse bias voltages.

Characteristics and Use of Photodiodes

INTRODUCTION

Photodiodes make use of the photovoltaic effect —the generation of a voltage across a P-N junction of a semiconductor when the junction is exposed to light. While the term photodiode can be broadly defined to include even solar batteries, it usually refers to sensors intended to detect the intensity of light. Photodiodes can be classified by function and construction as follows.

- **Photodiode Types**
  1) PN photodiodes
  2) PIN photodiodes
  3) Schottky type photodiodes
  4) Avalanche photodiodes

All of these types provide the following features and are widely used for the detection of the existence, intensity, position and color of light.

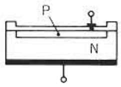
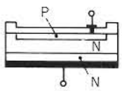
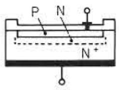
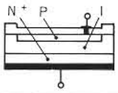
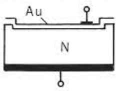
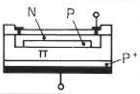
- **Features**
  1) Excellent linearity
  2) Low noise
  3) Wide spectral response
  4) Mechanical ruggedness
  5) Compact and lightweight
  6) Long life

This section will serve to introduce the construction characteristics, operation and use of photodiodes.

CONSTRUCTION

Hamamatsu photodiodes can be classified by manufacturing method and construction into five types of silicon photodiodes and two types each of GaAsP and GaP photodiodes.

Table 1: Photodiodes Types

Type	Construction	Features	Photodiode types
Planar diffusion type		Small dark current	Silicon photodiodes (eg, S2386, S2387 series, S1087, S1133 series) GaAsP photodiodes
Low C_j planar diffusion type		Small dark current Fast response High UV sensitivity High IR sensitivity	Silicon photodiodes (S1336 series, S1337 series)
PNN$^+$ type		Small dark current High UV sensitivity Suppressed IR sensitivity	Silicon photodiodes (S1226 series, S1227 series)
PIN type		Ultra-fast response	PIN silicon photodiodes
Schottky type		High ultraviolet sensitivity	GaAsP, GaP photodiodes
Avalanche type		Internal multiplying mechanism Ultra-fast response	Silicon avalanche photodiodes

- **Planar Diffusion Type**

An SiO_2 coating is applied to the P-N junction surface, yielding a photodiode with a low level dark current.

- **Low-Capacitance Planar Diffusion Type**

A high-speed version of the planar diffusion type photodiode. This type makes use of a highly pure, high-resistance N-type material to enlarge the depletion layer and thereby decrease the junction capacitance, thus lowering the response time to 1/10 the normal value. The P layer is made extra thin for high ultraviolet response.

- **PNN$^+$ Type**

A low-resistance N$^+$ material layer is made thick to bring the N-N$^+$ boundary close to the depletion layer. This somewhat lowers the sensitivity to infrared radiation, making this type of device useful for measurements of short wavelengths.

- **PIN Type**

An improved version of the low-capacitance planar diffusion device, this type makes use of an extra high-resistance I layer between the P- and N-layers to improve response time. This type of device exhibits even further improved response time when used with reversed bias and so is designed with high resistance to breakdown and low leakage for such applications.

- **Schottky Type**

A thin gold coating is sputtered onto the N material layer to form a Schottky Effect P-N junction. Since the distance from the outer surface to the junction is small, ultraviolet sensitivity is high.

- **Avalanche Type**

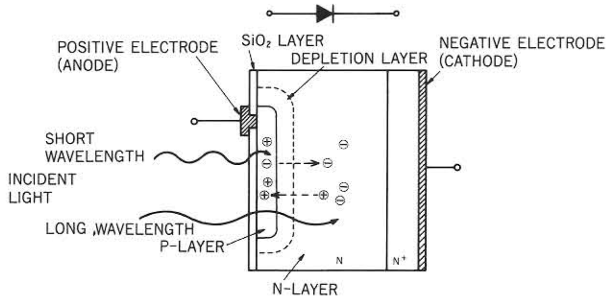
If a reverse bias is applied to a P-N junction and a high-field formed within the depletion layer, photon carriers will be accelerated by this field. They will collide with atoms in the field and secondary carriers are produced, this process occurring repeatedly. This is known as the avalanche effect and, since it results in the signal being amplified, this type of device is ideal for detecting extremely low level light.

THEORY OF OPERATION

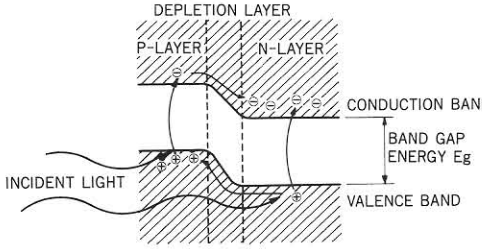
Figure 1 (a) shows a cross section of a photodiode. The P-layer material at the light sensitive surface and the N material at the substrate form a P-N junction which operates as a photoelectric converter. The usual P-layer for a silicon photodiode is formed by selective diffusion of boron to a thickness of approximately 1 μm and the neutral region at the junction between the P and N layers is known as the depletion layer. By varying and controlling the thickness of the outer P-layer, substrate N-layer and bottom N$^+$ layer as well as the doping concentration, the spectral response and frequency response can be controlled.

When light is allowed to strike a photodiode, the electrons within the crystal structure become stimulated. If the light energy is greater than the band gap energy E_g, the electrons are pulled up into the conduction band, leaving holes in their place in the valence band (see Figure 1 (b)). These electron-hole pairs occur throughout the P-layer, depletion layer and N-layer materials, and in the depletion layer the electric field accelerates the electrons towards the N-layer and the holes toward the P-layer. Of the electron-hole pairs that are generated in the N-layer, the electrons, along with electrons that have arrived from the P-layer, are left in the N-layer conduction band, while the holes diffuse through the N-layer up to the P-N junction while being accelerated, and collect in the P-layer valence band. In this manner, electron-hole pairs which are generated in proportion to the amount of incident light are collected in the N-layer and P-layer. This results in a positive charge in the P-layer and a negative charge in the N-layer. If an external circuit is connected between the P- and N-layers, electrons will flow away from the N-layer and holes from the P-layers towards the opposite electrode, respectively.

Figure 1 (a): Photodiode Cross-Section



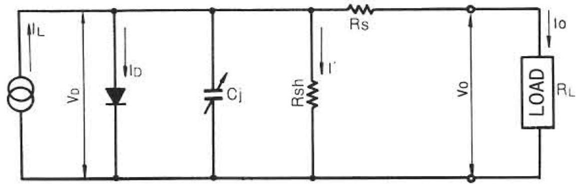
(b): Photodiode P-N Junction States



EQUIVALENT CIRCUIT

The photodiode equivalent circuit is shown in Figure 2.

Figure 2: Photodiode Equivalent Circuit



I_L: Current generated by the incident light (proportional to the amount of light)
I_D: Diode current
C_j: Junction capacitance
R_{sh}: Shunt resistance
R_s: Series resistance
I': Shunt resistance current
V_D: Voltage across the diode
I_O: Output current
V_O: Output voltage

Using the above equivalent circuit and solving for the output current, we have:

$$I_o = I_L - I_D - I' = I_L - I_s\,(exp\frac{eV_D}{kT} - 1) - I'$$

Where
I_s: photodiode reverse saturation current
e: Electron charge
k: Boltzmann's constant
T: Absolute temperature of the photodiode

The open circuit voltage V_{op} is the output voltage when I_o equals 0. Therefore, we have:

$$V_{op} = \frac{kT}{e}\,ln\left(\frac{I_L - I'}{I_s} + 1\right)$$

If we ignore I', since I_s increases logarithmically with respect to increasing ambient temperature, V_{op} is inversely proportional to ambient temperature and inversely proportional to the log of I_L. However, this relationship does not hold for very small amounts of incident light.

The short-circuit I_{sh} is the output current when the load resistance R_L equals 0 and V_O equals 0, yielding:

$$I_{sh} = I_L - I_s\left(exp\,\frac{e(I_{sh}\cdot R_s)}{kT} - 1\right) - \frac{I_{sh}\cdot R_s}{R_{sh}}$$

In the above relationship, the 2nd and 3rd terms limit I_{sh} linearity. However, if R_s is several ohms or lower and R_{sh} is 10^7 to 10^{11} ohms, these terms become negligible over quite a wide range.

V-I CHARACTERISTICS

When a voltage is applied to a photodiode in the dark state, the V-I characteristic curve observed is similar to the curve of a conventional rectifier diode as shown in Figure 3 ①. However when light strikes the photodiode, the curve at ① shifts to ② and, increasing the amount of incident light shifts the characteristic curve still further to position ③ in parallel with respect to incident light intensity. For the characteristics for ② and ③, if the photodiode terminals are shorted, a photocurrent I_{sh} or I_{sh}' proportional to the light intensity will flow in the direction from the anode to the cathode. If the circuit is open, an open circuit voltage V_{op} or V_{op}' will be generated with the positive polarity at the anode.

Figure 3: V-I Characteristics

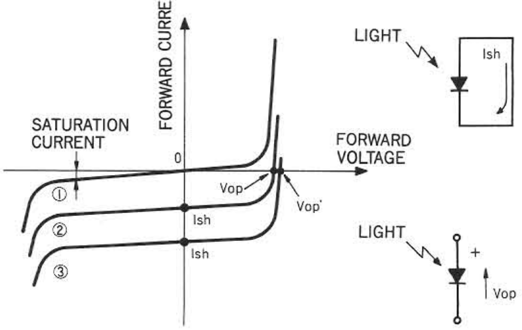
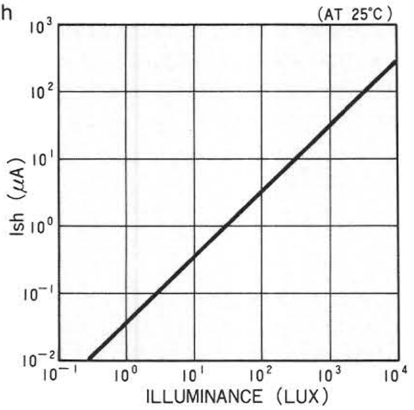
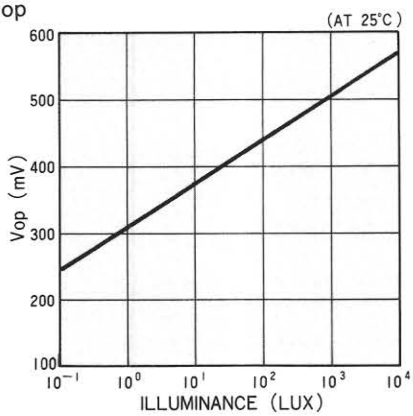


Figure 4: Output Signal vs. Incident Light Relationship (S2386-5K)

(a) I_{sh}



(b) V_{op}



The short circuit current I_{sh} is extremely linear with respect to the amount of incident light. When the incident light is within a range of 10^{-12} to 10^{-3}(W), the achievable range of linearity is 6 to 8 orders of magnitude, depending on the type of photodiode and circuit in which it is used. The lower limit of this linearity is determined by the NEP, while the upper limit depends on the load resistance and the reverse bias voltage, and is given by the following equation.

$$P_{MAX} = \frac{V_{Bi} + V_R}{(R_S + R_L) \cdot R\lambda} \; .... (1)$$

P_{MAX}: Input energy at upper limit of linearity (W)
V_{Bi} : Contact voltage (V)
V_R : Reverse bias voltage (V)
R_L : Load resistance (Ω)
R : Radiant sensitivity at wavelength λ
R_S : Series resistance

When laser light is condensed on an extremely small spot, however, the actual resistance increases, and linearity deteriorates.

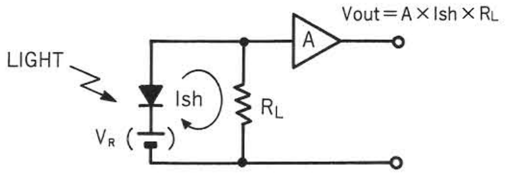
V_{OP} varies logarithmically with respect to a change of amount of light and is greatly affected by variations in temperature, making it unsuitable for light intensity measurements. Figure 4 shows the result of plotting I_{sh} and V_{OP} as a function of incident light illuminance.

Figure 5 (a) and (b) show methods of measuring light by measuring I_{sh}. In the circuit shown at (a), the voltage $(I_{sh} \times R_L)$ is amplified by an amplifier A and the use of the bias voltage V_R makes this circuit suitable for receiving high-speed pulse light, although the circuit has limitations with respect to linearity. This condition is shown in Figure 6. In the circuit of Figure 5 (b), an operational amplifier is used and the characteristics of the feedback circuit are such that the equivalent input resistance is several orders of magnitude smaller than R_f, enabling nearly ideal I_{sh} measurements. The value of R_f can be changed to enable I_{sh} measurements over a wide range.

If the zero region of Figure 3 ① is magnified, we see, as shown in Figure 7, that the dark current is linear over a voltage range of approximately ±10 mV. The slope in this region is termed the shunt resistance (R_{sh}) and this resistance is the cause of thermal noise currents described later. In this catalog, values of R_{sh} are given using a dark current of I_d with −10 mV applied.

Figure 5: Photodiode Operational Circuits

(a) Reverse Bias Circuit



(b) Op-Amp Circuit

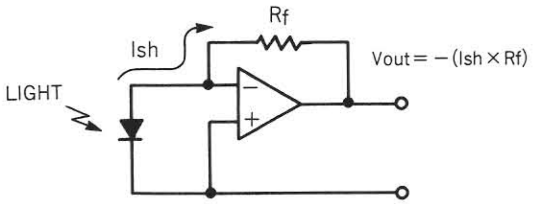


Figure 6: V-I Characteristics and Load Line

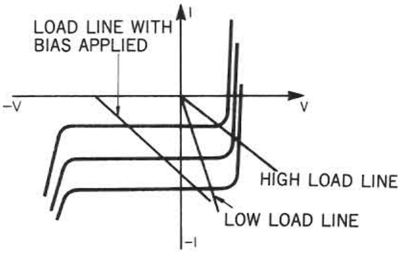
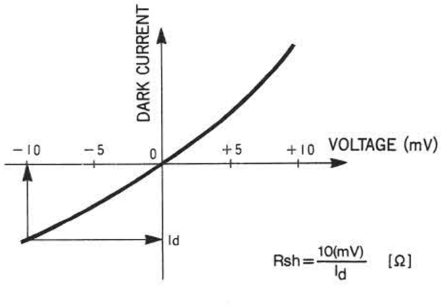


Figure 7: V-I Characteristics (Expanded Zero Region)



SPECTRAL RESPONSE CHARACTERISTICS

As explained in the section on principles of operation, when the energy of absorbed photons is lower than the band gap energy E_g, the photovoltaic effect does not occur The limiting wavelengths λ can be expressed in terms of E_g as follows.

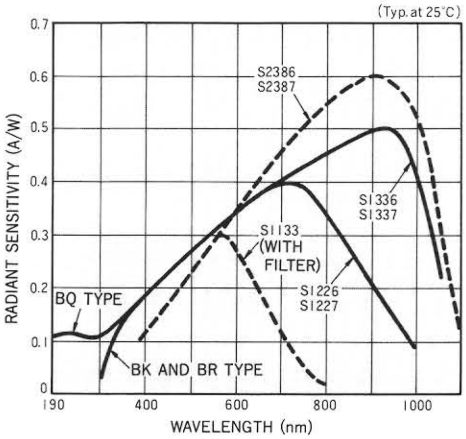
$$\lambda = \frac{1240}{Eg} \quad [\mathrm{nm}] \qquad (1)$$

At room temperatures, E_g is 1.12eV for silicon and 1.8eV for GaAsP, so that the limiting wavelengths are 1100nm and 700nm, respectively. For short wavelengths, however, the degree of light absorption within the diffusion layer becomes very high. Therefore, the thinner the diffusion layer is and the closer the P-N junction is to the surface, the higher the sensitivity will be (see Figure 1 (a)). For normal photodiodes the cutoff wavelength is 300 to 400nm, whereas for ultraviolet enhanced photodiodes (e.g. S1226 and S1336) it is below 190nm.

The cutoff wavelength is determined by the intrinsic material properties of the photodiode, but is also affected by the spectral transmittance of the window material. For borosilicate glass and plastic resin coating, wavelengths below approximately 300nm are absorbed. If these materials are used as the window, the short wavelength sensitivity will appear to be lost. For wavelengths below 300nm, photodiodes with fused silica windows are used. For measurements limited to the visible light region, a green filter is used as the light-receiving window.

Figure 8 shows the spectral response characteristics for various photodiode types. The BQ type shown uses a fused silica window, the BK type a borosilicate glass window and the BR type a resin coated window.

Figure 8: Spectral Response Characteristics



NOISE CHARACTERISTICS

Like other types of light sensors, the lower limits of light detection for photodiodes are determined by the noise characteristics of the device. The photodiode noise i_n is the sum of the thermal noise (or Johnson noise) i_j caused by the shunt resistance R_{sh} and the shot noise i_s resulting from the dark current and the photocurrent.

$$i_n = \sqrt{i_j^2 + i_s^2} \quad [A] \qquad (2)$$

When a photodiode is used in an operational amplifier circuit such as that shown in Figure 5 (b), since the applied voltage is the operational amplifier's input offset voltage only, the dark current may be ignored and i_n is given as follows.

$$i_n = i_j = \sqrt{\frac{4kTB}{R_{sh}}} \qquad (3)$$

Where

k: Boltzmann's constant
T: Absolute temperature of the photodiode
B: Noise bandwidth

When a bias voltage is applied as in Figure 5 (a), there is always a dark current. For a bias voltage of 1 to 2 V or greater, $i_s \gg i_j$, so that i_n is given as follows.

$$i_n = i_s = \sqrt{2qI_dB} \quad [A] \qquad (4)$$

Where

q: Electron charge
I_d: Dark current
B: Noise bandwidth

With the application of incident light, I_L exists and if $I_L \gg 0.026/R_{sh}$ or $I_L \gg I_d$, the above equations (3) and (4) are replaced by the following equation for shot noise.

$$i_n = i_s = \sqrt{2qI_LB} \qquad (5)$$

The amplitudes of these noise sources are each proportional to the square root of the measured bandwidth B, so that they are expressed in units of $(A/\sqrt{Hz})$.

The lower limit of light detection for a photodiode is usually expressed as the intensity of incident light required to generate a current equal to the noise current as expressed in equations (3) or (4). Essentially this is the noise equivalent power (NEP).

$$NEP = \frac{i_n}{S} \quad [W/\sqrt{Hz}] \qquad (6)$$

Where

i_n: noise
S: peak radiant sensitivity

Figure 9 shows the relationship between NEP and dark current, from which can be seen the agreement with the theoretical relationship. The light detection limit for DC coupling as shown in Figure 5(b) is influenced by the amplifier's thermal drift, low-frequency flicker noise and, as will be described later, gain peaking. Thus the limit is actually greater than the NEP.

If the incident light can be periodically switched ON and OFF by some means and detection performed in synchronization with this switching frequency, it is possible to eliminate the influence of noise outside this measurement bandwidth (refer to Figure 10). This techinique can allow the actual measured detection limit to approach the detector's theoretical NEP.

Figure 9: Relationship of NEP to Dark Current (S1226-5BK)

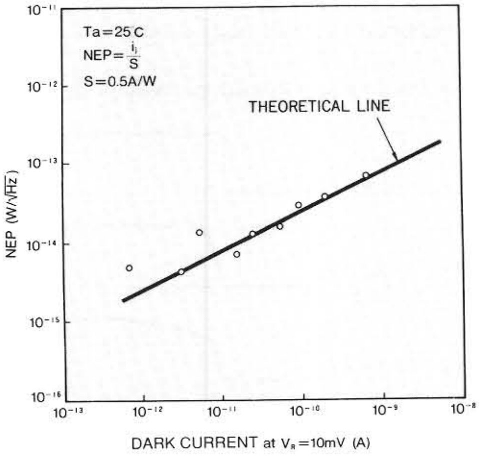
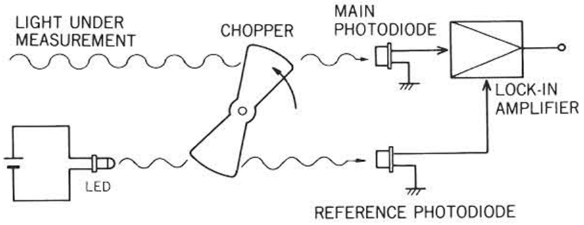


Figure 10: Synchronous Measurement Method



When compared with photodiodes not having an amplification mechanism, avalanche photodiodes exhibit additional excessive noise components caused by variations in the avalanche amplification process. Using the gain M and a light current I_L and excessive noise factor F when M = 1 in equation (4) above, we have the following expression.

$$i_n = \sqrt{2qI_LM^2FB}$$

In this expression, for M = 10 to 100, F may be approximated as follows.

$$F = M^x$$

The exponent *x* is known as the excessive noise index and is in the range of approximately 0.3 to 0.5. The advantage to using an avalanche photodiode is the ability to use a small load resistance and a small input resistance in the following stage in comparison with normal photodiodes. This enables not only an operating speed advantage, but a reduction in thermal noise generated by the noise resistance as well, thus enabling detection of extremely small signals. For details, refer to the separate data sheet.

REVERSE BIAS

Since photodiodes generate a voltage by virtue of the photovoltaic effect, they can operate without the need of an external power supply. However, speed of response and linearity can be improved by the use of such an external biasing source. It should be borne in mind that the signal current flowing in a photodiode circuit is determined by the number of photovoltaically generated electron-hole pairs and that the application of a bias voltage does not result in the loss of photoelectric conversion linearity.

Figure 11 shows an example of a reverse bias connection. Figures 12 and 13 show the effects of bias voltage on rise time and linearity limits, respectively. While application of a reverse bias to a photodiode is very useful in improving response speed and linearity, it has the accompanying disadvantage of increasing dark current and noise levels along with the danger of damaging the device by excessive applied reverse bias voltage. Thus, care is required to maintain the bias within the maximum ratings and to ensure that the cathode is maintained at a positive potential with respect to the anode.

For use in applications such as optical communications and remote control which require high response speed, the PIN photodiode provides not only good response speed but excellent dark current and voltage resistance characteristics with bias applied. Figure 14 shows an example of the actual connection shown in Figure 11 (b) with a load resistance 50 Ω. The ceramic capacitor C is used to enable a reduction of the bias supply impedance, while resistor R is used to protect the photodiode. This resistor is selected such that the voltage drop caused by the average photocurrent is sufficiently smaller than the bias voltage. Note that the photodiode and capacitor leads, coaxial cable and other wires carrying high-speed pulses should be kept as short as possible.

Figure 11: Reverse Bias Connection Example

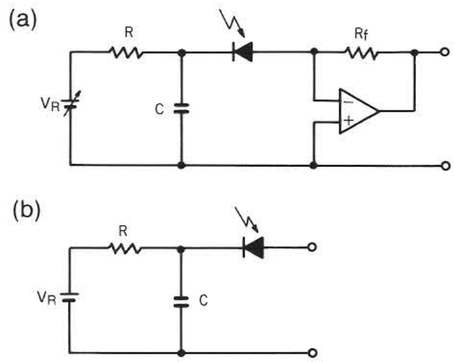


Figure 12: Rise Time vs. Bias Voltage

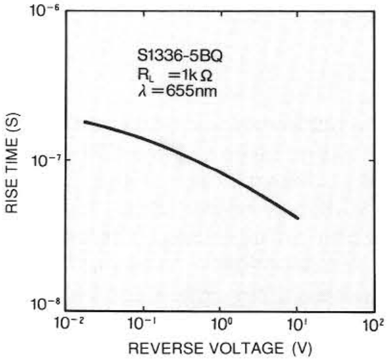


Figure 13: Linearity Limits

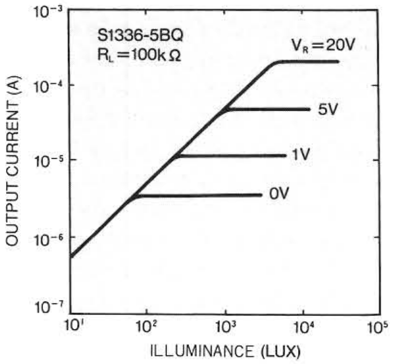
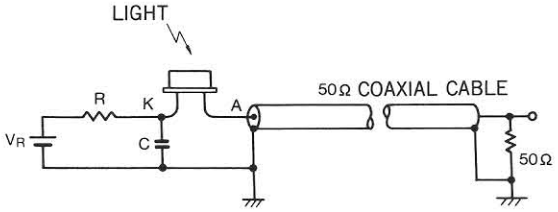


Figure 14: Connection to Coaxial Cable



RESPONSE SPEED

The response speed of a photodiode is a measure of the time required for the accumulated charge to become an external current and is generally expressed as the rise time t_r, fall time t_f or out off frequency f_c. t_r is the time required to rise from 10% to 90% of the normal output value and is determined by the following factors.

1) Time constant τ_1 determined by the terminal capacitance of the photodiode C_t and the load resistance R_L.
   (C_t is the sum of the package capacitance and the photodiode junction capacitance C_j)
2) Diffusion time τ_2 of carriers generated outside the depletion layer.

If the C_t x R_L time constant τ_1 is the governing factor, t_r is given as follows.

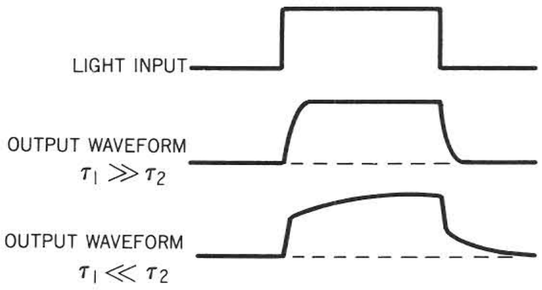
$$t_r = 2.2\tau_1 = 2.2C_t \times R_L$$

To shorten t_r, the design must be such that either C_t or R_L is made small. C_j is proportional to the light sensitive area A and inversely proportional to the second to third root of the resistivity ρ of the substrate material and reverse bias V_R.

$$C_j \propto A\,\{(V_R + 0.5) \times \rho\}^{-1/2 \sim -1/3}$$

Therefore, to achieve a fast response time, a photodiode with a small A and large ρ should be used with reverse bias applied. However, reverse bias also increases dark current so caution is necessary for low-light-level detection. The carriers generated outside the depletion layer occur when incident light misses the P-N junction and strikes the surrounding area of the photodiode chip and when this light is absorbed by the substrate section which is below the depletion area. The time τ_2 required for these carriers to diffuse may be greater than several µs. When the C_t x R_L time constant is small, it is the major factor that determines the response speed. Figure 15 shows an example of the response waveform of a photodiode and the frequency response of a PIN photodiode.

Figure 15 (a): Photodiode Response Waveform Example



In the case of a PIN or avalanche photodiode, C_t is particularly small. Also these types are designed for a low level of carrier generation outside the depletion region, thus suitable for high-speed light detection.

Figure 15 (b): S2386-18K Response Waveform
(V_R = 0V, R_L = 1 kΩ)

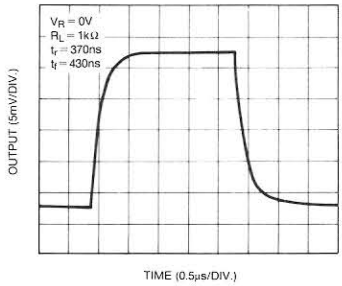


Figure 15 (c): S2840 Frequency Response (V_R=5V, R_L=50Ω)

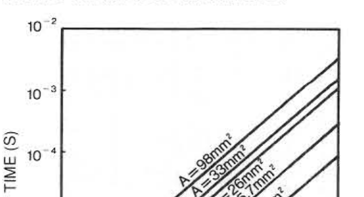
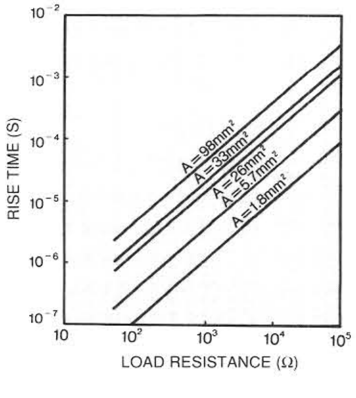


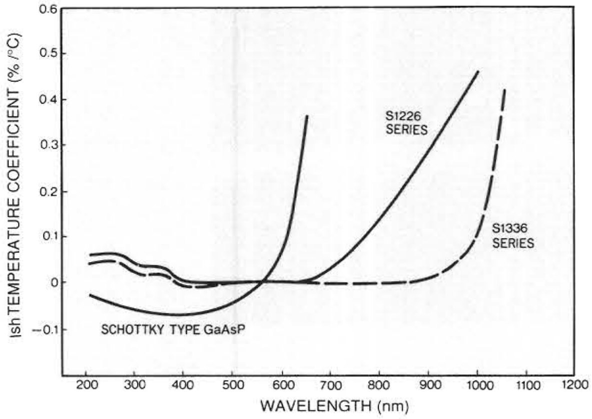
Figure 16: Rise Time vs. Load Resistance with Photosensitive Area as Parameter



TEMPERATURE CHARACTERISTICS

Ambient temperature variations greatly effect photodiode sensitivity and dark current. The cause of this is variation in the light absorption coefficient which is temperature related. For long wavelengths, sensitivity increases with increasing temperature and this increase become prominent at wavelengths longer than the peak wavelength. For short wavelengths, it decreases. Since ultraviolet enhanced photodiodes are designed to have low absorption in the short wavelength region, the temperature coefficient is extremely small at wavelengths shorter than the peak wavelength. Figure 17 shows examples of temperature coefficients of photodiodes sensitivity (I_{sh}) for a variety of photodiodes types.

Figure 17: Temperature Coefficient vs. Wavelength



The variation in dark current with respect to temperature occurs as a result of increasing temperatures causing electrons in the valence band to become excited, pulling them into the conduction band. A constant increase in dark current is shown with increasing temperature. Figure 18 indicates a two-fold increase in dark current for a temperature rise from 5°C to 10°C. This is equivalent to a reduction of the shunt resistance R_{sh} and a subsequent increase in thermal and shot noise. Figure 19 shows an example of the temperature charcteristics of open-circuit voltage V_{op}, indicating linearity with respect to temperature change.

Figure 18: Dark Current Temperature Dependence (S2387)

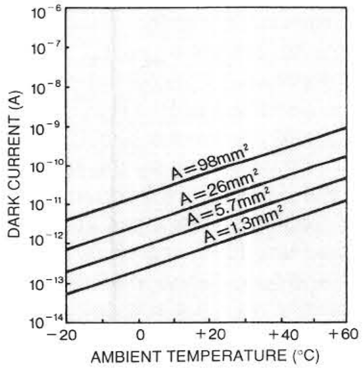
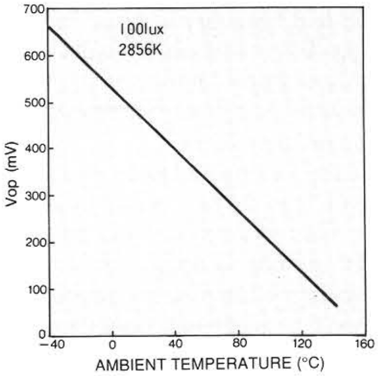


Figure 19: V_{op} Temperature Dependence (S2387)

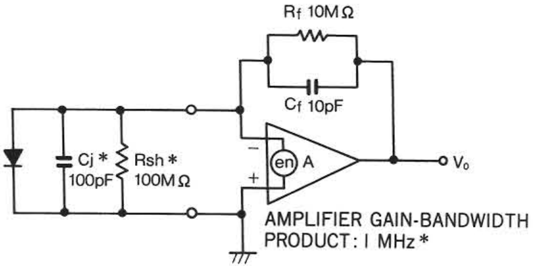


USE OF OPERATIONAL AMPLIFIERS

1) Transimpedance Circuit

Figure 20 shows a basic circuit connection of an operational amplifier and a photodiode. The output voltage V_o from DC through the low-frequency region is 180 degrees out of phase from the input short circuit current. The feedback resistance R_f is determined by I_{sh} and the required output voltage V_o. If, however, R_f is made greater than the photodiodes internal resistance R_{sh}, the operational amplifier's input noise voltage and offset voltage will be multiplied by ($R_f/R_{sh}+1$). This is superimposed on the output voltage, and the operational amplifier's bias current error (described later) will also increase. If there is an input capacitance, the feedback capacitance C_f prevents high-frequency oscillations and also forms a lowpass filter with a time constant C_f x R_f value. It should be chosen with regard to the desired transimpedance and bandwidth. If the input light is similar to a discharge spark, and it is desired to integrate the amount of light, R_f can be removed so that the operational amplifier and C_f act as an integrating circuit.

Figure 20: Basic Photodiode Connection Example



* Values commonly available.

However, a switch is required to discharge C_f before the next integration.

2) Bias Current

Since the actual input impedance of an operational amplifier is not infinite, there is some bias current that flows into or out of the input terminals. This may result in errors, depending upon the magnitude of the detected current. The bias current which flows in an FET input operational amplifier is sometimes lower than 0.1pA. Bipolar operational amplifiers, however, have bias currents in the order of several nA or even several hundred nA. However, the bias current of an FET operational amplifier generally increases two-fold for every increase of 10°C in temperature, whereas that of bipolar amplifiers decreases with increasing temperature. Therefore, the design of such circuits to operate at high temperatures should consider the use of bipolar amplifiers.

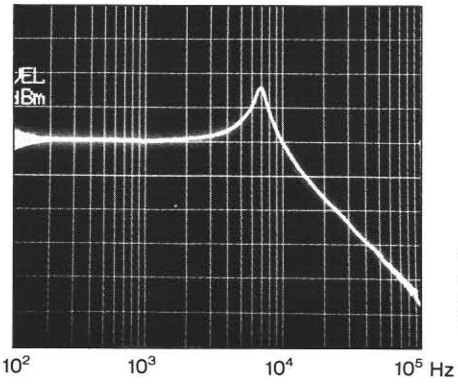
As is the case for offset voltage, the error voltages attributable to the bias current can be adjusted by means of a potentiometer connected to the offset adjustment terminals. Futhermore, leakage currents on the PC board used to house the circuit may be greater than the operational amplifier's bias current. Consideration must be given to the circuit pattern's design and its parts replacement. Additionally, the use of Teflon terminals and guarding may be required. However, the operational amplifier chosen is of utmost importance. A list of recommended FET and bipolar types is given on page 41.

3) Gain Peaking

The frequency response of a photodiode operational amplifier is determined by the time constant R_f x C_f. However, for large values of junction capacitance (i.e., input capacitance) a phenomenon known as gain peaking will occur. Figure 21 shows an example of such a frequency response, from which it can be seen that the output voltage increases sharply in the high frequency region, causing significant ringing in the output voltage response to pulsed light input. This gain operates in the same manner with respect to operational amplifier input noise and may result in abnormally high noise levels (see Photograph (c)). This occurs by virtue of the fact that the reactance of the input capacitance and that of the feedback capacitance on the operational amplifier circuit may jointly form an unstable amplifier with respect to input operational amplifier's noise. In such a case, loss of measurement accuracy may result.

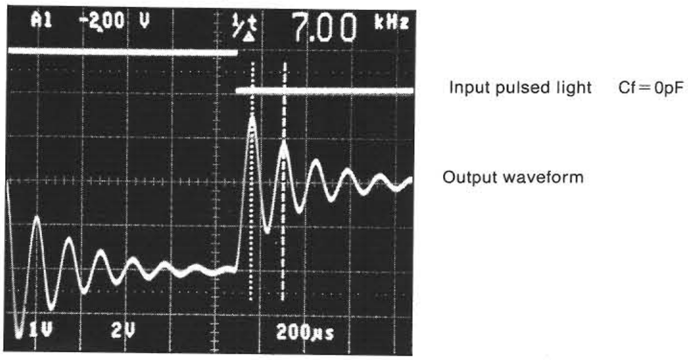
Figure 21: Gain Peaking

(a) Frequency Characteristic

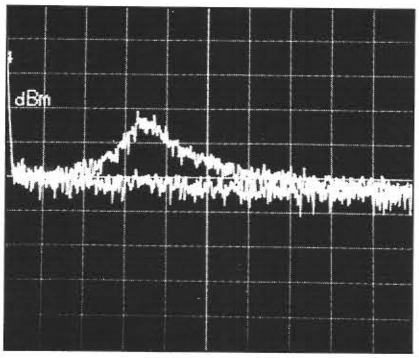


Circuit : Fig. 20
OP Amp : AD515JH
C_f : 0pF
Vertical axis: 20dB/Div

(b) Light Pulse Response



(c) Frequency Characteristic of Noise Output



Upper trace : C_f=0pF
Lower trace : C_f=10pF

Vertical axis : 20dB/Div
Horizontal axis : 2kHz/Div

4) Gain Peaking Analysis and Elimination

To achieve a wide frequency characteristic without gain peaking and ringing phenomena, it is necessary to select the optimum relationship between the photodiode, operational amplifier, and feedback element. With the photodiode, it is effective to reduce the junction capacitance C_j, explained in the section on response speed, in this case as well. With the operational amplifier, the higher the speed and the wider the bandwidth, the less the gain peaking occurs. However, if an adequate internal phase compensation is not provided, oscillation may be generated as a result. As feedback elements, not only the resistance, but also the capacitance should be connected in parallele, as explained previously, in order to avoid gain peaking. The gain peaking phenomena can be explained as follows, using the circuit shown in Figure 20. As shown in Figure 22, for the low-frequency region ①, the circuit gain of the operational amplifier is determined simply by the resistance ratio of Rsh to R_f.

Starting at the frequency $f_1=\frac{1}{2\pi C_j R_{sh}}$, gain increases with frequency as shown in region ②, but peaking will not occur under the condition of $R_f <$ Rsh. Next, at the frequency $f_2=\frac{1}{2\pi C_f R_f}$ and above, the circuit gain of the operational amplifier is determined by the ratio of C_j and C_f (region ③). At the point where frequency f_3 intersects the open-loop gain frequency response at rolloff (6dB/octave) of the operational amplifier, region ④ is entered. In this example, f_1, f_2, and f_3 correspond to 16Hz, 1.6kHz and 100kHz respectively. If C_f is made 1pF, f_2 shifts to f_2', and circuit gain increases further. What should be noted here is that, since the setting of circuit gain in region ② exceeds the open-loop gain curve, region ③ actually does not exist.

As a result, ringing occurs in the pulsed light response of the operational amplifier circuit and instability results (see Figure 21).

To summarize the above points:

a) When designing R_f and C_f, f_2 should be set to a value such that region ③ in Figure 22 exists.

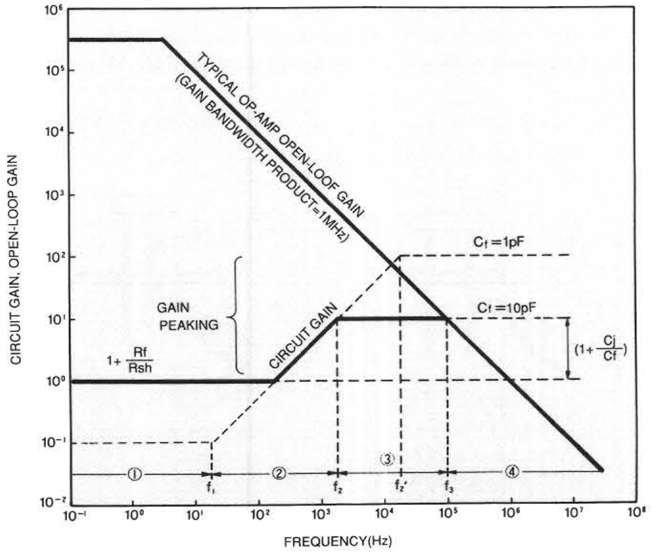
b) When f_2 is positioned to the right of the open-loop gain line of the operational amplifier, change the operational amplifier which has high frequency at which the gain becomes 1 (unity gain bandwidth), and set region ③.

The above measures should prevent ringing. However, in the high-frequency region ③, circuit gain exists, and the input noise of the operational amplifier and feedback resistance noise are not reduced, but rather, depending on the circumstances, may even be amplified and expressed as output. The following method can be used to prevent this situation.

c) Replace a photodiode with a small C_j value. In the example shown in the figure, the ratio of C_j to C_f should be close to 1.

Using the above procedures, the S/N deterioration caused by ringing and gain peaking can usually be solved. In a separate method, connecting from several hundreds pF to several nF or more of load capacitance to the output of the operational amplifier, for example by connecting a coaxial cable of several meters or more and capacitor, can generate oscillation in some types of operational amplifiers, so the capacitance load must be set as small as possible.

Figure 22: Graphical Representation of the Gain Peaking Phenomena



Reliability

If used within the specified operating ratings, photodiodes will exhibit virtually no loss of sensitivity. A loss of sensitivity can often be attributed to package, lead or filter failure. Package leakage at high temperatures and humidity, in particular, often causes a lowering of the shunt resistance. Therefore, ceramic case photodiodes have a somewhat limited temperature and humidity range. However, metallic case types feature excellent resistance to ambient humidity. Photodiodes with filters are greatly affected by the inherent resistance of the filter to environmental conditions (refer to Figure 23 and 24). These factors must be taken into consideration when using and storing photodiodes.

Hamamatsu photodiodes are subjected to reliability testing based on Japanese Industrial Standards (JIS), with consideration given to EIAJ (Japan Electronic Machinery Association), MIL (U.S. military) and IEC (International Electrical Standards Committee) standards as well. The basic applicable standards are listed below and in Table 2.

JIS-C7021	(Environmental testing methods and endurance testing methods for discrete semiconductor devices)
EIAJ-SD-121	(Environmental and life testing method for discrete semiconductor devices)
MIL-STD-750B	(Test methods for semiconductor devices)
IEC-Pub. 68	(Basic environmental testing procedures)

Table 2: Reliability Testing Table

Tested Item	Test Conditions	Criteria
Solder heat resistance	260°C for 10s	Deterioration in performance
Solderability	230°C for 5s	Application of solder
Thermal shock	100°C for 15s to 0°C for 5s (liquid), 5 cycles	Deterioration in performance
Temperature cycling	T_{stg} (Min.) to T_{stg} (Max.) (gas), 5 cycles	Deterioration in performance
Temperature /hymidity cycling	− 10°C to 65°C (90 to 98%), 10 cycles	Deterioration in performance
Hermetic sealing	Helium gas test for minute leaks and bubble test for large leaks	Hermetic sealing
Shock	100G for 6ms, XYZ directions, 3 times each	Mechanical and performance changes
Natural dropping	From 75cm onto wooden board, 3 times	Mechanical and performance changes
Vibration	100 to 2000Hz, 20G, XYZ directions	Mechanical and performance changes
Terminal strength	Pulling up to 0.5kg for 5s; twisting 3 times, bending 2 times	Terminal damage, etc.
Salt water spray	35°C, 5% solution for 24 hours	Case corrosion, lead rusting
Continuous operation	Room temperature and T_{opr} (Max.)	Deterioration in performance
Pressure cooker test	121°C (100%, 85%) and other conditions	Deterioration in performance
Anti-solvent	Isopropyl alcohol, trichloroethylene, acetone, etc.	Changes in marking and painting
High-temperature storage	T_{stg} (Max.)	Deterioration in performance
Resistance to humidity	40°C/95%, 60°C/95%, 85°C/85%	Deterioration in performance
Low-temperature storage	T_{stg} (Min.)	Deterioration in performance

Figure 23: High-Temperature/Humidity Storage Testing Example

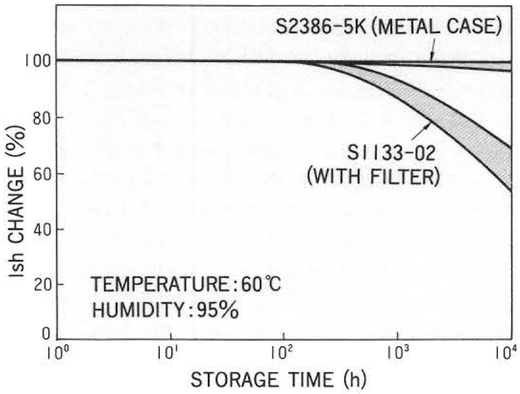
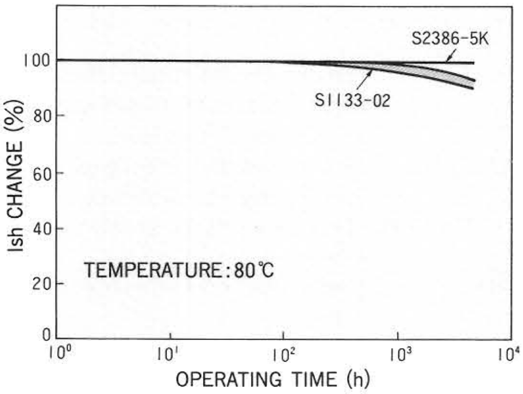


Figure 24: High-Temperature Operation Testing Example

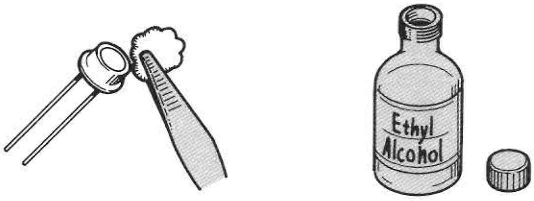


Precautions for Use

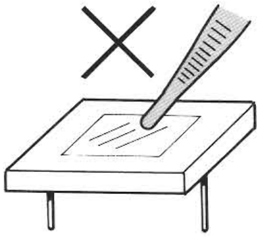
● Window

Care should be taken not to touch the window with the bare hands, especially in the case of UV detection since foreign materials on the window can seriously affect transmittance in the UV range.

Ethyl alcohol should be used to clean the light window. Other type cleansing agents could cause deterioration of the device's resin coating or filter and should be avoided.

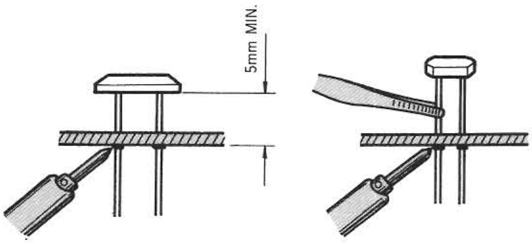


Lightly wipe dirt off the window using ethyl alcohol.



● Soldering

Since photodiodes are susceptible to damage from excess heat, care must be given to temperature and dwell time when soldering such devices. As a rule, metal case devices should be soldered at 260°C or below within 10 seconds and ceramic case devices at 260°C or below within 5 seconds. For soldering small devices, some form of heat sinking such as the use of a pair of tweezers to hold the device leads while soldering is also recommended.



Mount ceramic case types 5 mm minimum away from any surface and solder at 260°C maximum for 5 seconds maximum time.

Use tweezers, etc. as a heatsink when soldering small photodiodes.

Package	Maximum Soldering Temperature (°C)	Maximum Soldering Time (s)	Remarks
Metal Case	260	10	
Ceramic Case	260	5	5 mm or more removed
Plastic Case (Molded Package)	260	3	2 mm or more removed

- **Lead Handling**

Care should be taken to keep within the recommended mechanical limits: 0.5 kg pulling strain for 5 seconds maximum, two 90°C bends and three twists of the device leads at 6mm minimum away from the body.

Reference

● Physical Constants

Constant	Symbol	Value	Units
Electron Charge	e or q	1.602×10^{-19}	C
Speed of Light in Vacuum	c	2.998×10^{8}	m/s
Planck's Constant	h	6.626×10^{-34}	Js
Boltzmann's Constant	k	1.381×10^{-23}	J/K
Room Temperature Thermal Energy	–	0.0259	eV
1eV Energy	eV	1.602×10^{-19}	J
Wavelength in Vacuum Corresponding to 1eV	–	1240 (1.240)	nm (μm)
Dielectric Constant of Vacuum	ε_0	8.854×10^{-12}	F/m
Dielectric Constant of Silicon	ε_{si}	approx. 12	–
Dielectric Constant of Silicon Oxide	ε_{ox}	approx. 14	–
Energy Gap of Silicon	Eg	approx. 1.12 (Ta = 25 °C)	eV

● Unit Conversion Table for Illuminance

lux lx (lm/m^2)	photo ph (lm/m^2)	foot-candle fc (lm/ft^2)	watt per square centimeter* W/cm^2
1	1.000×10^{-4}	9.290×10^{-2}	5.0×10^{-6}
1.000×10^{4}	1	9.290×10^{2}	5.0×10^{-2}
1.076×10^{1}	1.076×10^{-3}	1	5.4×10^{-5}
2.0×10^{5}	2.0×10^{1}	1.9×10^{4}	1

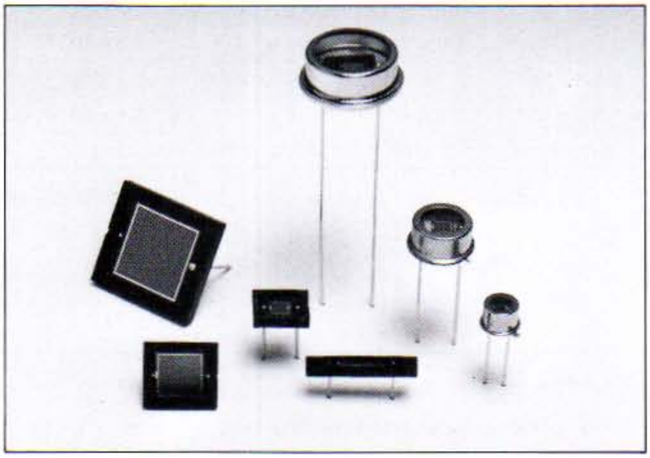
* Total irradiance (measured value) by the CIE standard light source "A".

Warranty

As a general rule Hamamatsu photodiodes are warranted for one year after delivery. The warranty is limited to replacement of the faulty device. It does not cover cases of operational failure caused by accident or misuse of the devices.

Silicon Photodiodes (UV to Visible Light, for Precision Photometr

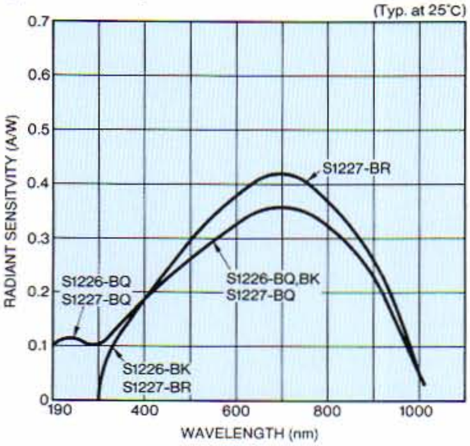
Type No. Ⓐ	Out-line Ⓑ	Package (mm)	Photosensitive Surface Size (mm)	Photosensitive Surface Effective Area (mm²)	Spectral Response Range (nm)	Spectral Response Peak Wave-length (nm)	Characteristics (25°C) Radiant Sensitivity (A/W) Peak Wave-length Typ.	200nm Min.	200nm Typ.	633nm He-Ne Laser Typ.	930nm GaAs LED Typ.	Short Circuit Current I_{sh}, 100 lux Min. (μA)	Short Circuit Current I_{sh}, 100 lux Typ. (μA)
S1226 Series (Metal Case)													
S1226-18BQ	①	TO-18	1.1×1.1	1.2	190~1000	720	0.35	0.08	0.1	0.33	0.17	0.5	0.65
-18BK					320~1000			–	–				
-5BQ	⑦	TO-5	2.4×2.4	5.7	190~1000			0.08	0.1			2.2	2.8
-5BK					320~1000			–	–				
-44BQ			3.6×3.6	13	190~1000			0.08	0.1			4.4	5.5
-44BK					320~1000			–	–				
-8BQ	⑩	TO-8	5.8×5.8	33	190~1000			0.08	0.1			12	15
-8BK					320~1000			–	–				
S1227 Series (Ceramic Case)													
S1227-16BQ	⑭	2.7×15	1.1×5.9	5.8	190~1000	720	0.35	0.08	0.1	0.33	0.17	2	2.5
-16BR	⑮				320~1000		0.42	–	–	0.39	0.20	2.2	2.8
-33BQ	⑯	6×7.6	2.4×2.4	5.7	190~1000		0.35	0.08	0.1	0.33	0.17	2	2.5
-33BR	⑰				320~1000		0.42	–	–	0.39	0.20	2.2	2.8
-66BQ	⑱	8.9×10.1	5.8×5.8	33	190~1000		0.35	0.08	0.1	0.33	0.17	11	14
-66BR	⑲				320~1000		0.42	–	–	0.39	0.20	13	16
-1010BQ	⑳	15×16.5	10×10	100	190~1000		0.35	0.08	0.1	0.33	0.17	32	40
-1010BR	㉑				320~1000		0.42	–	–	0.39	0.20	36	45



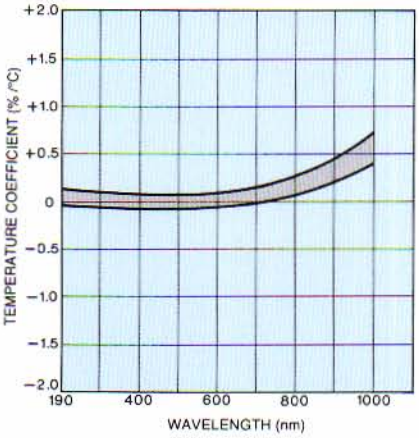
Ⓐ Window materials are
K: Borosilicate glass
Q: Fused silica
R: Resin coating

Ⓑ See pages 34 to 37 .

- **Spectral Response**

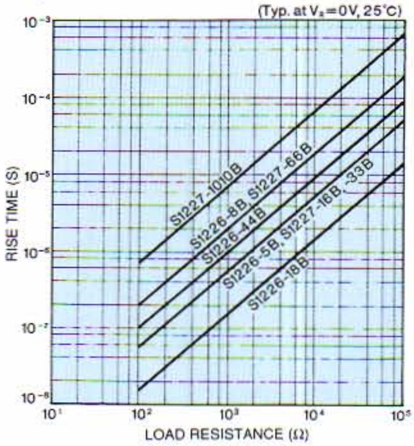


- **Temperature Characteristic of Ish**

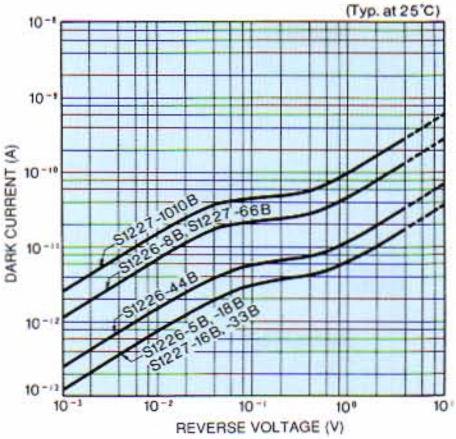


Characteristics (at 25°C)							Absolute Maximum Ratings			Type No.
Dark Current Id V_R = 10mV Max. (pA)	Temperature Dependence of Id Typ. (Times/°C)	Shunt Resistance, Rsh V_R = 10mV Min. (GΩ)	Shunt Resistance, Rsh V_R = 10mV Typ. (GΩ)	Junction Capacitance, Cj V_R = 0V Typ. (pF)	Rise Time t_r V_R = 0V R_L = 1kΩ Typ. (μs)	NEP Typ. (W/Hz$^{1/2}$)	Reverse Voltage $V_R$max (V)	Temperature Range Operating (°C)	Temperature Range Storage (°C)	
15	1.09	0.7	10	50	0.15	3.7×10^{-15}	5	−20〜+60	−55〜+80	S1226-18BQ
									−55〜+100	-18BK
20		0.5	10	200	0.5	3.7×10^{-15}			−55〜+80	-5BQ
									−55〜+100	-5BK
50		0.2	5	400	1	5.2×10^{-15}			−55〜+80	-44BQ
									−55〜+100	-44BK
100		0.1	1	1000	2	1.2×10^{-14}			−55〜+80	-8BQ
									−55〜+100	-8BK
20	1.09	0.5	5	200	0.5	5.2×10^{-15}	5	−20〜+60	−20〜+80	S1227-16BQ
									−20〜+70	-16BR
20		0.5	10	200	0.5	3.7×10^{-15}			−20〜+80	-33BQ
									−20〜+70	-33BR
100		0.1	1	1000	2	1.2×10^{-14}			−20〜+80	-66BQ
									−20〜+70	-66BR
300		0.03	0.5	3200	7	1.6×10^{-14}			−20〜+80	-1010BQ
									−20〜+70	-1010BR

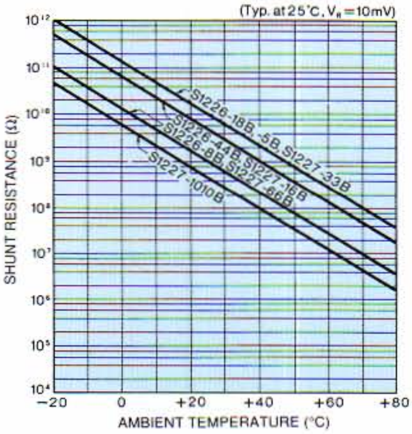
- **Response Time vs. Load Resistance**



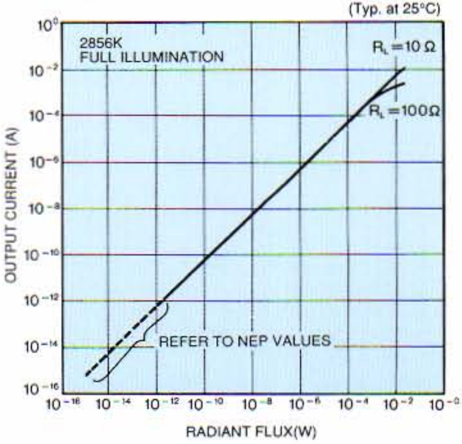
- **Dark Current vs. Reverse Voltage**



- **Shunt Resistance vs. Temperature**

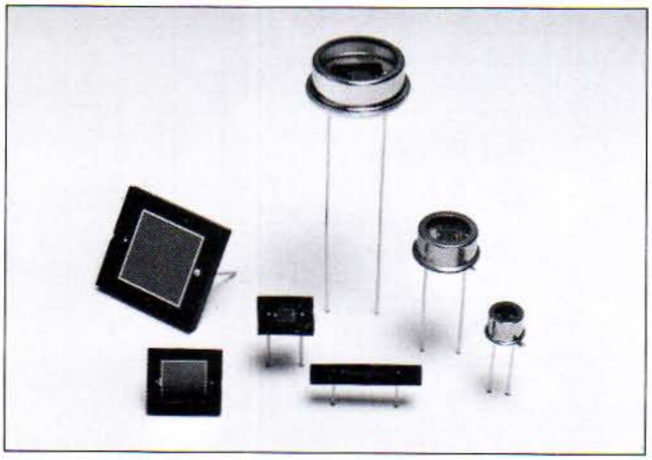


- **Linearity**



Silicon Photodiodes (UV to IR, for Precision Photometry)

Ⓐ Type No.	Ⓑ Out-line	Package (mm)	Photosensitive Surface		Spectral Response		Characteristics (25°C)						
			Size (mm)	Effective Area (mm²)	Range (nm)	Peak Wave-length (nm)	Radiant Sensitivity (A/W)					Short Circuit Current I_{sh}, 100 lux	
							Peak Wave-length Typ.	200nm		633nm He-Ne Laser Typ.	930nm GaAs LED Typ.	Min. (μA)	Typ. (μA)
								Min.	Typ.				
S1336 Series (Metal Case)													
S1336-18BQ	❶	TO-18	1.1×1.1	1.2	190~1100	960	0.5	0.08	0.1	0.33	0.5	1	1.2
-18BK					320~1100			–	–				
-5BQ	❼	TO-5	2.4×2.4	5.7	190~1100			0.08	0.1			4	5
-5BK					320~1100			–	–				
-44BQ			3.6×3.6	13	190~1100			0.08	0.1			8	10
-44BK					320~1100			–	–				
-8BQ	❿	TO-8	5.8×5.8	33	190~1100			0.08	0.1			22	28
-8BK					320~1100			–	–				
S1337 Series (Ceramic Case)													
S1337-16BQ	⓮	2.7×15	1.1×5.9	5.8	190~1100	960	0.5	0.08	0.1	0.33	0.5	4	5
-16BR	⓯				320~1100		0.62	–	–	0.4	0.6	4.4	5.5
-33BQ	⓰	6×7.6	2.4×2.4	5.7	190~1100		0.5	0.08	0.1	0.33	0.5	4	5
-33BR	⓱				320~1100		0.62	–	–	0.4	0.6	4.4	5.5
-66BQ	⓲	8.9×10.1	5.8×5.8	33	190~1100		0.5	0.08	0.1	0.33	0.5	20	25
-66BR	⓳				320~1100		0.62	–	–	0.4	0.6	22	28
-1010BQ	⓴	15×16.5	10×10	100	190~1100		0.5	0.08	0.1	0.33	0.5	65	80
-1010BR	㉑				320~1100		0.62	–	–	0.4	0.6	70	85

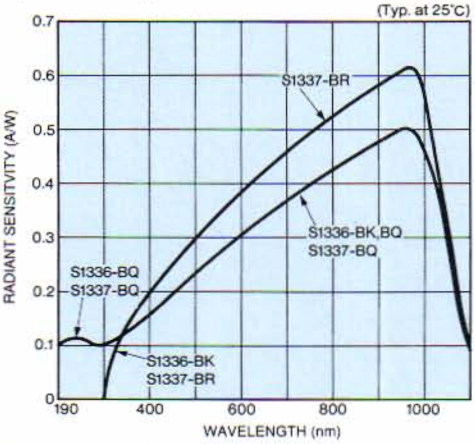


Ⓐ Window materials are

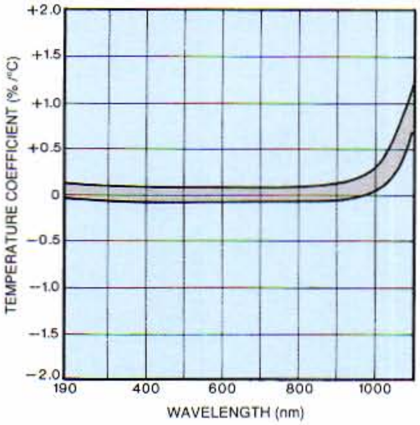
K: Borosilicate glass
Q: Fused silica
R: Resin coating

Ⓑ See pages 34 to 37 .

- **Spectral Response**

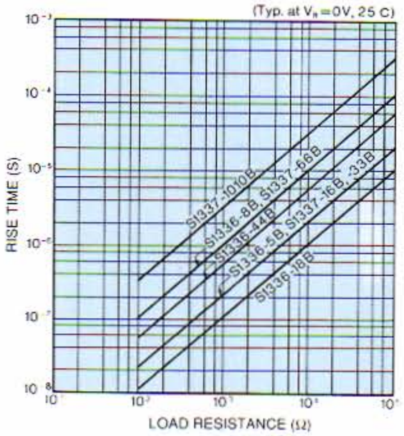


- **Temperature Characteristic of Ish**

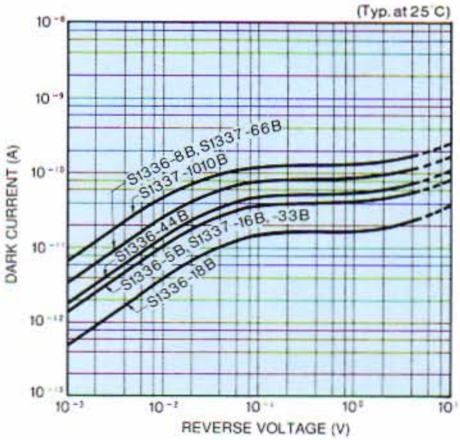


Characteristics (at 25°C)							Absolute Maximum Ratings			Type No.
Dark Current I_d V_R = 10mV Max. (pA)	Temperature Dependence of Id Typ. (Times/°C)	Shunt Resistance, R_{sh} V_R = 10mV		Junction Capacitance, Cj V_R = 0V Typ. (pF)	Rise Time t_r V_R = 0V R_L = 1kΩ Typ. (μs)	NEP Typ. (W/Hz$^{1/2}$)	Reverse Voltage $V_R$max (V)	Temperature Range		
		Min. (GΩ)	Typ. (GΩ)					Operating (°C)	Storage (°C)	
20	1.15	0.5	2	20	0.1	5.8×10^{-15}	5	−20∼+60	−55∼+80	**S1336-18BQ**
									−55∼+100	**-18BK**
25		0.4	1	65	0.2	8.1×10^{-15}			−55∼+80	**-5BQ**
									−55∼+100	**-5BK**
60		0.17	0.6	160	0.5	1.1×10^{-14}			−55∼+80	**-44BQ**
									−55∼+100	**-44BK**
150		0.06	0.4	370	1	1.3×10^{-14}			−55∼+80	**-8BQ**
									−55∼+100	**-8BK**
25	1.15	0.4	1	65	0.2	8.1×10^{-15}	5	−20∼+60	−20∼+80	**S1337-16BQ**
									−20∼+70	**-16BR**
25		0.4	1	65	0.2	8.1×10^{-15}			−20∼+80	**-33BQ**
									−20∼+70	**-33BR**
150		0.06	0.4	370	1	1.3×10^{-14}			−20∼+80	**-66BQ**
									−20∼+70	**-66BR**
500		0.02	0.2	1100	3	1.8×10^{-14}			−20∼+80	**-1010BQ**
									−20∼+70	**-1010BR**

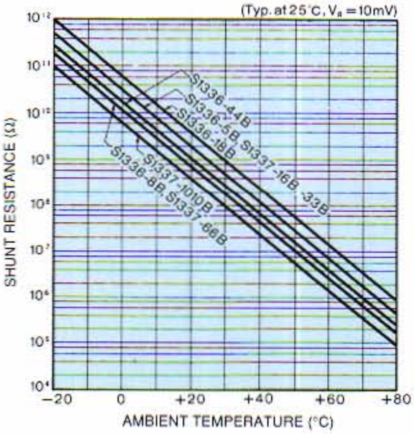
• Response Time vs. Load Resistance



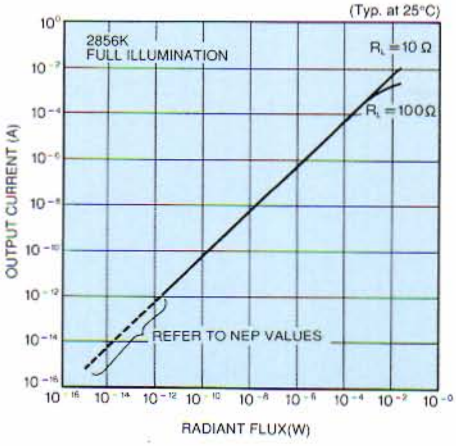
• Dark Current vs. Reverse Voltage



• Shunt Resistance vs. Temperature

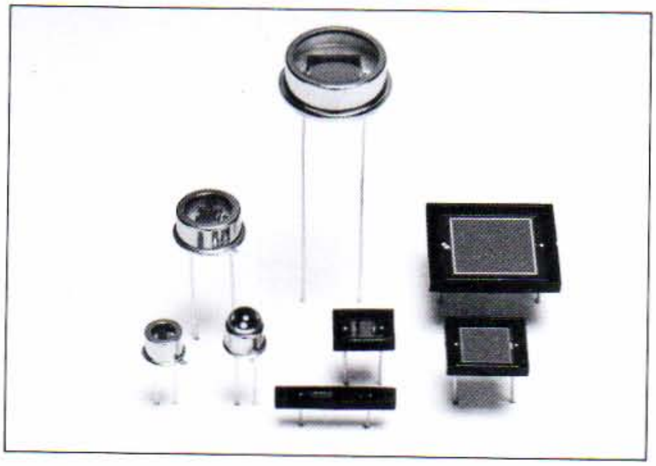


• Linearity



Silicon Photodiodes (Visible Light to IR, for Precision Photometry)

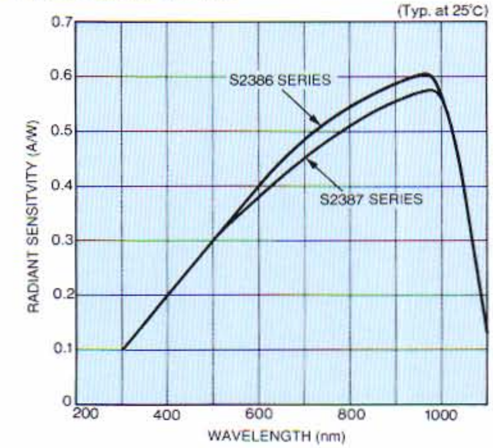
Ⓐ Type No.	Ⓑ Out-line	Package (mm)	Photosensitive Surface		Spectral Response		Characteristics (25°C)					
							Typical Radian Sensitivity (A/W)				Short Circuit Current Ish. 100 lux	
			Size (mm)	Effective Area (mm²)	Range (nm)	Peak Wave-length (nm)	Peak Wave-length	560nm GaP LED	633nm He-Ne Laser	930nm GaAs LED	Min. (μA)	Typ. (μA)
S2386 Series (Metal Case)												
S2386-18K	①	TO-18	1.1×1.1	1.2	320~1100	960	0.6	0.38	0.43	0.58	1	1.2
-18L	②										3.2	4.0
-5K	⑦	TO-5	2.4×2.4	5.7							4.4	5.8
-44K			3.6×3.6	13							9.6	12
-45K			3.9×4.6	17.9							12	15
-8K	⑩	TO-8	5.8×5.8	33							26	33
S2387 Series (Ceramic Case)												
S2387-16R	⑮	2.7×15	1.1×5.9	5.8	320~1100	960	0.58	0.34	0.38	0.58	4.4	5.5
-33R	⑰	6×7.6	2.4×2.4	5.7							4.4	5.5
-66R	⑲	8.9×10.1	5.8×5.8	33							24	30
-1010R	㉑	15×16.5	10×10	100							68	85



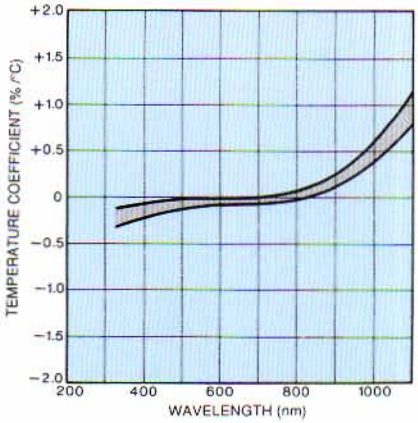
Ⓐ Window materials are
- K: Borosilicate glass
- L: Lens type borosilicate glass
- R: Resin coating

Ⓑ See pages 34 to 37 .

- **Spectral Response**

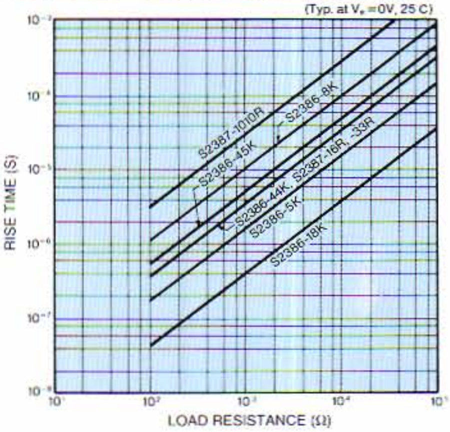


- **Temperature Characteristic of Ish**

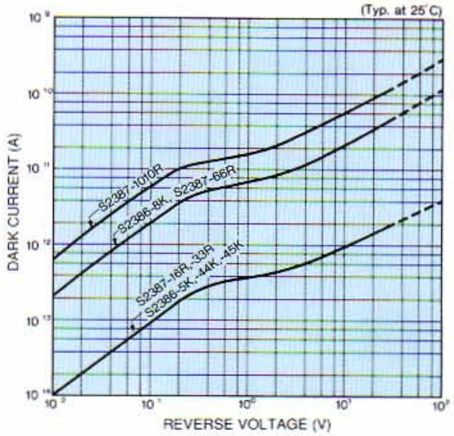


Characteristics (at 25°C)							Absolute Maximum Ratings			
Dark Current I_d V_R = 10mV Max. (pA)	Temperature Dependence of Id Typ. (Times/°C)	Shunt Resistance, R_{sh} V_R = 10mV Min. (GΩ)	Shunt Resistance, R_{sh} V_R = 10mV Typ. (GΩ)	Junction Capacitance, Cj V_R = 0V Typ. (pF)	Rise Time t_r V_R = 0V R_L = 1kΩ Typ. (μs)	NEP Typ. (W/Hz$^{1/2}$)	Reverse Voltage $V_R$max (V)	Temperature Range Operating (°C)	Temperature Range Storage (°C)	Type No.
2	1.12	5	100	170	0.4	6.8×10^{-16}	30	−20〜+80	−55〜+100	**S2386-18K**
										-18L
5		2	50	800	1.8	9.6×10^{-16}				**-5K**
20		0.5	15	1700	3.6	1.8×10^{-15}				**-44K**
30		0.3	25	2500	5.5	1.36×10^{-15}				**-45K**
50		0.2	10	4400	10	2.1×10^{-15}				**-8K**
5	1.12	2	50	800	1.8	9.9×10^{-16}	30	−20〜+60	−20〜+80	**S2387-16R**
										-33R
50		0.2	10	4400	10	2.2×10^{-15}				**-66R**
200		0.05	5	15000	33	3.1×10^{-15}				**-1010R**

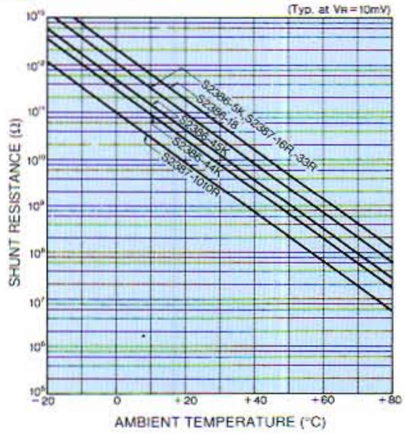
- **Response Time vs. Load Resistance**



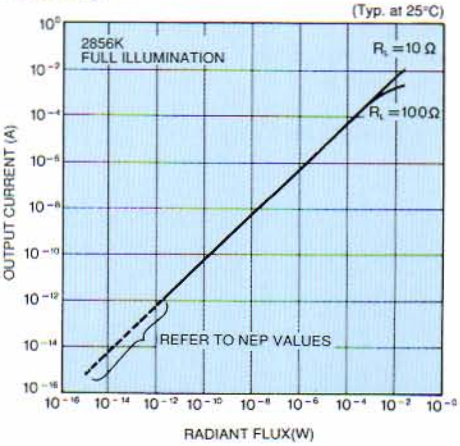
- **Dark Current vs. Reverse Voltage**



- **Shunt Resistance vs. Temperature**

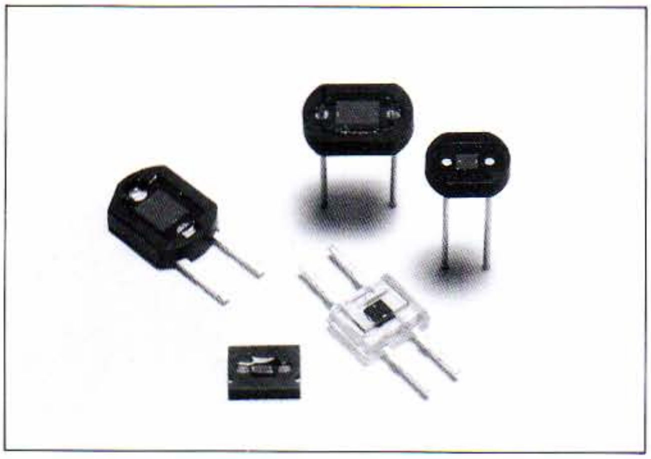


- **Linearity**



Silicon Photodiodes (Visible Light/Visible Light to IR Photometry)

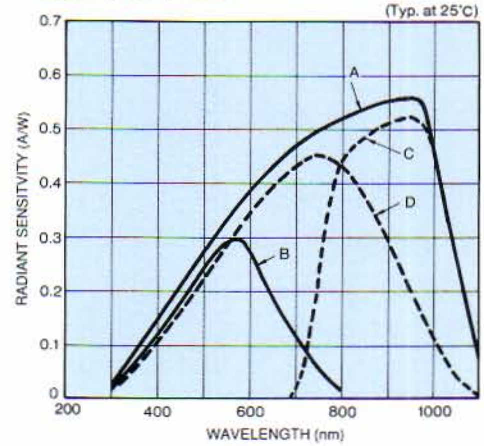
Type No.	Features	Ⓐ Outlines / Window Materials	Photosensitive surface		Spectral Response		Characteristics (25°C)			
							Typical Radiant Sensitivity (A/W)			
			Size (mm)	Effective Area (mm²)	Range Mark (nm)	Peak Wave-length (nm)	Peak Wave-length	560nm GaP LED	633nm He-Ne Laser	930nm GaAs LED
S1087-01	For visible light to near IR	㉒/R	1.3×1.3	1.6	320~1100/A	960	0.58	0.35	0.42	0.57
S1087	For visible light	㉓/V			320~730/B	560	0.3	0.3	0.2	–
S1087-03	For visible light, fast response									
S2164	Chip carrier type, for visible light to near IR	㉗/R	1.3×1.3	1.6	320~1100/A	960	0.58	0.35	0.42	0.55
S2164-01	Chip carrier type,visible light cutoff type	㉗/F			700~1100/C	960	0.55	–	–	0.55
S1133-01	For visible light to near IR	㉔/R	2.4×2.8	6.6	320~1100/A	960	0.58	0.35	0.42	0.57
S1133-11	For visible light to near IR, fast response									
S1133	For visible light	㉕/V			320~730/B	560	0.3	0.3	0.2	–
S1133-03	For visible light, fast response									
S1133-02	For visible light, high sensitivity				320~840/B					
S1133-12	For visible light, high sensitivity, high speed									
S1133-14	For visible light to near IR, high speed, low IR sensitivity	㉔/R			320~1060/D	720	0.4	0.35	0.38	0.20
S1133-05	For visible light, high-speed , low IR ratio	㉕/V			320~730/B	560	0.3	0.3	0.2	–
S1787-08	For visible light to near IR, SIP case	㉖/R	2.4×2.8	6.6	320~1100/A	960	0.58	0.35	0.42	0.57
S1787-04	For visible light to near IR, SIP case	㉖/V			320~730/B	560	0.3	0.3	0.2	–
S1787-06	For visible light, fast response, SIP case									
S1787-05	For visible light, SIP case				320~840/B					
S1787-07	For visible light, high speed, high sensitivity, SIP case									
★ S4011	For visible light, compact epoxy mold 4-pin DIP	㉙/V	1.3×1.3	1.6	320~730/B	560	0.3	0.3	0.2	–
S2833	For visible light, epoxy mold 4-pin DIP	㉚/V	2.4×2.8	6.6						



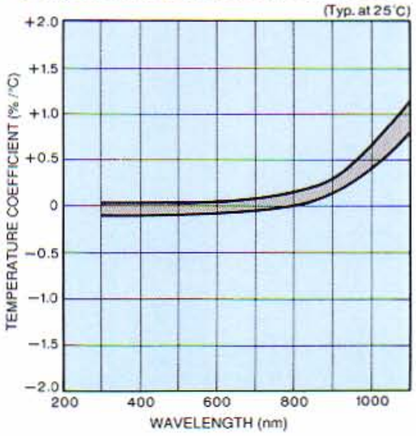
Ⓐ See pages 34 to 37 for outlines.
Window materials are
- R: Resin coating
- V: Visible compensating filter
- F: Visible light cutoff filter

★ mark indicates newly listed products.

- **Spectral Response**

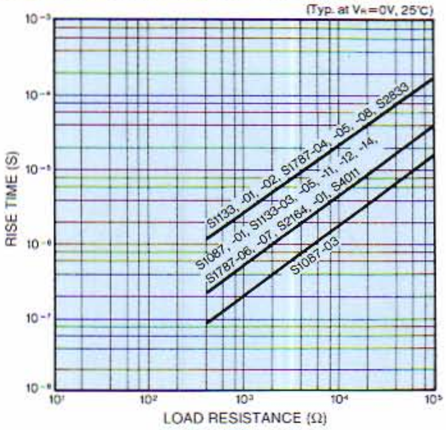


- **Temperature Characteristic of Ish**

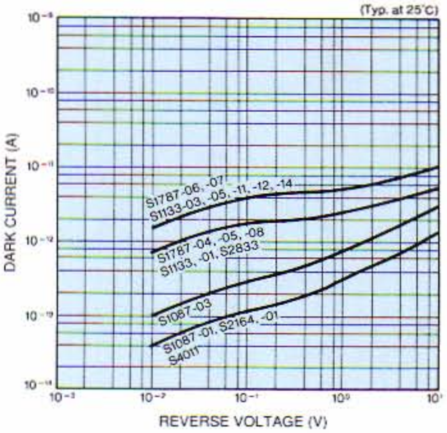


Characteristics (at 25°C)									Absolute Maximum Ratings			Type No.
Infrared Sensitivity Ratio Typ. (%)	Short Circuit Current, I_{sh} 100 lux Typ. (μA)	Temperature Dependence of I_{sh} Typ. (%/°C)	Dark Current I_d $V_R = 1V$ Max. (pA)	Temperature Dependence of I_d Typ. (Times/°C)	Shunt Resistance, R_{sh} V_R = 10mV		Junction Capacitance, Cj $V_R = 0V$ Typ. (pF)	Rise Time t_r $V_R = 0V$ $R_L = 1k\Omega$ Typ. (μs)	Reverse Voltage $V_R$max (V)	Temperature Range		
					Min. (GΩ)	Typ. (GΩ)				Operating (°C)	Storage (°C)	
–	1.5	+0.1	10	1.12	4	30	200	0.5	10	−10∼+60	−20∼+70	S1087-01
10	0.13	−0.01										S1087
		−0.02	20		2	10	60	0.2				S1087-03
–	1.5	+0.1	10	1.12	4	30	200	0.5	10	−10∼+60	−20∼+70	S2164
	1.0											S2164-01
–	5.5	+0.1	10	1.12	4	30	700	2.5	10	−10∼+60	−20∼+70	S1133-01
			20		2	10	200	0.5				S1133-11
10	0.54	−0.01	10		4	30	700	2.5				S1133
	0.50		20		2	10	200	0.5				S1133-03
20	0.85	−0.02	10		4	30	700	2.5				S1133-02
	0.78	−0.01	20		2	10	200	0.5				S1133-12
–	3.2	+0.1										S1133-14
8	0.50	−0.02										S1133-05
–	5.5	+0.1	10	1.12	4	30	700	2.5	10	−10∼+60	−20∼+70	S1787-08
10	0.54	−0.01										S1787-04
	0.50	−0.02	20		2	10	200	0.5				S1787-06
20	0.85	−0.01	10		4	30	700	2.5				S1787-05
	0.78	−0.02	20		2	10	200	0.5				S1787-07
10	0.25	−0.01	10	1.12	4	30	200	0.5	10	−10∼+60	−20∼+70	S4011
	1.0						700	2.5				S2833

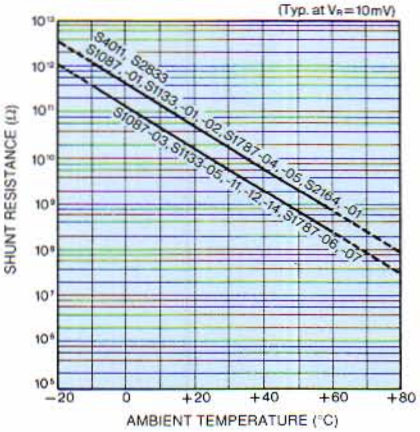
• Response Time vs. Load Resistance



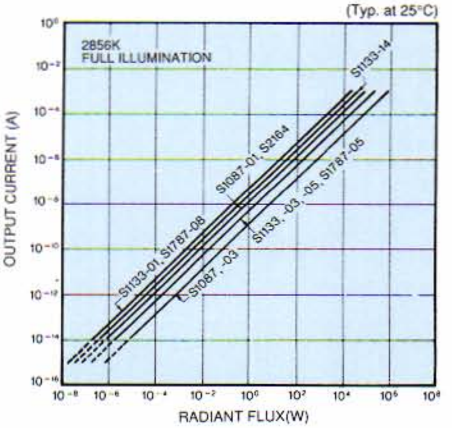
• Dark Current vs. Reverse Voltage



• Shunt Resistance vs. Temperature



• Linearity (Representative Example)



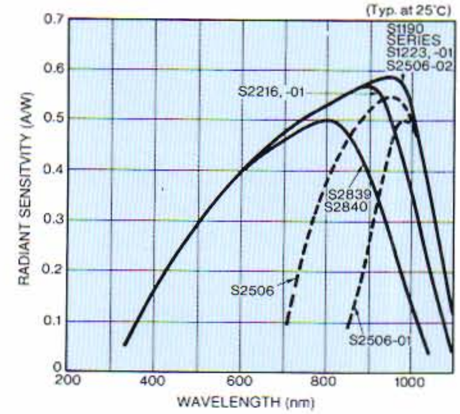
PIN Silicon Photodiodes (1)

Type No.	Features	Ⓐ Outlines / Window Materials	Package	Photosensitive Surface		Spectral Response		Characteristics (at 25°C)				
				Size (mm)	Effective Area (mm²)	Range (nm)	Peak Wavelength (nm)	Radiant Sensitivity Typ. (A/W)			Short Circuit Current Ish, 100 lux	
								Peak Wavelength	633nm He-Ne Laser	930nm GaAs LED	Min. (μA)	Typ. (μA)
S2216-01	Ultra-high speed response, low bias type	④/K	TO-18 (3 pin)	ϕ 0.8	0.5	320~1060	900	0.57	0.42	0.55	0.4	0.5
S2216-02				ϕ 0.4	0.12						0.1	0.14
S2839				ϕ 0.4	0.12	320~1000	800	0.5	0.42	0.32	0.08	0.1
S2840				ϕ 0.8	0.5						0.30	0.38
S1190	High-speed response	①/K	TO-18	1.1×1.1	1.2	320~1100	960	0.57	0.42	0.57	0.8	1.1
S1190-01	High-speed response, lens window	③/L									6	8
S1190-03	High-speed response	④/K	TO-18 (3 pin)								0.8	1.1
S1190-04	Low capacitance, lens window	③/L	TO-18								6	8
★ S1190-13	S1190-04 3-pin case	⑤/L	TO-18 (3 pin)									
S1223	2.4 x 2.8mm sensitive area	⑦/K	TO-5	2.4×2.8	6.6	320~1100	960	0.6	0.42	0.6	4	6.3
S1223-01	3.6 x 3.6mm sensitive area			3.6×3.6	13						8	13
S2506	Visible light cutoff epoxy mold	㉘/M	Epoxy mold	2.77×2.77	7.7	700~1100	960	0.55	–	0.5	4.0	5.5
S2506-01	High immunity to ambient fluorescent lighting					840~1100	980	0.5		0.4	2.2	3.0
S2506-02	Clear epoxy mold					320~1100	960	0.6	0.4	0.6	6.3	7.0

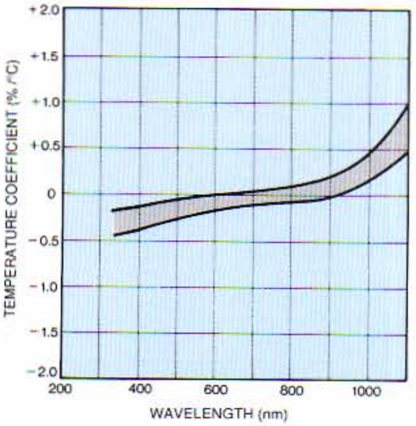
Ⓐ See page 34 to 37 for outlines.
Window materials are
- K: Borosilicate glass
- L: Lens type borosilicate glass
- F: Visible light cutoff filter
- M: Epoxy mold

★ mark indicates newly listed products.

• Spectral Response (Representative Example)

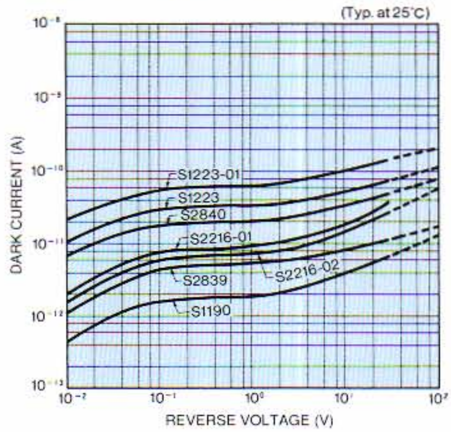


• Temperature Characteristic of Ish

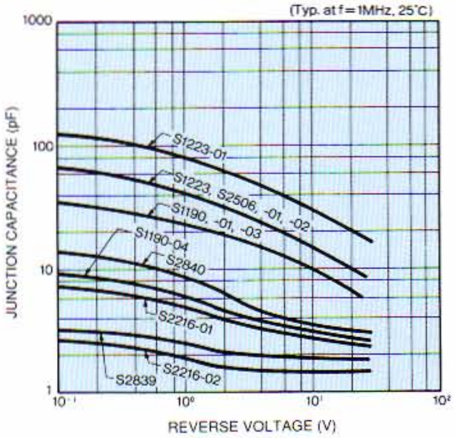


Characteristics (at 25°C)					Maximum Ratings				Type No.
Dark Current I_d Max. (nA)	Temperature Dependence of I_d Typ. (Times/°C)	Junction Capacitance, Cj Typ. (pF)	Cutoff Frequency fc Typ. (MHz)	NEP Typ. ($W/Hz^{1/2}$)	Reverse Voltage $V_R$max. (V)	Power Dissipation P max. (mW)	Temperature Range		
							Operating (°C)	Storage (°C)	
1 (V_R = 5 V)	1.15	3 (V_R = 5 V)	40 (V_R = 5 V)	5.0×10^{-15} (V_R = 5 V)	30	50	−20～+80	−55～+100	**S2216-01**
0.5 (V_R = 5 V)		1.5 (V_R = 5 V)	50 (V_R = 5 V)	4.0×10^{-15} (V_R = 5 V)					**S2216-02**
0.15 (V_R = 5 V)		2 (V_R = 5 V)	150 (V_R = 5 V)	3.6×10^{-15} (V_R = 5 V)					**S2839**
0.3 (V_R = 5 V)		4 (V_R = 5 V)	150 (V_R = 5 V)	7.2×10^{-15} (V_R = 5 V)					**S2840**
2 (V_R = 10 V)	1.15	10 (V_R = 10 V)	25 (V_R = 10 V)	2.0×10^{-15} (V_R = 10 V)	20	50	−20～+80	−55～+100	**S1190**
									S1190-01
									S1190-03
3 (V_R = 10 V)		3 (V_R = 10 V)	20 (V_R = 10 V)	9.9×10^{-15} (V_R = 10 V)	30				**S1190-04**
									S1190-13
10 (V_R = 20 V)	1.15	10 (V_R = 20 V)	30 (V_R = 20 V)	8.9×10^{-15} (V_R = 20 V)	30	100	−20～+80	−55～+100	**S1223**
20 (V_R = 20 V)		20 (V_R = 20 V)	20 (V_R = 20 V)	1.2×10^{-14} (V_R = 20 V)					**S1223-01**
10 (V_R = 12 V)	1.15	16 (V_R = 12 V)	25 (V_R = 12 V)	1×10^{-13} (V_R = 12 V)	35	150	−25～+80	−40～+100	**S2506**
								−40～+80	**S2506-01**
								−40～+100	**S2506-02**

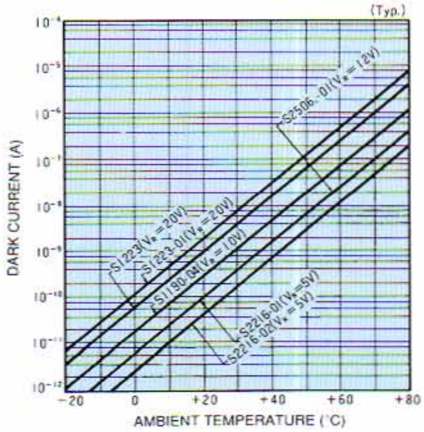
- **Dark Current vs. Reverse Voltage**



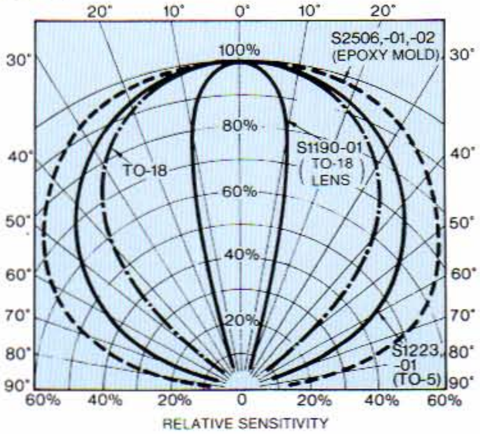
- **Junction Capacitance vs. Reverse Voltage**



- **Dark Current vs. Temperature**



- **Directivity**



PIN Silicon Photodiodes (2)

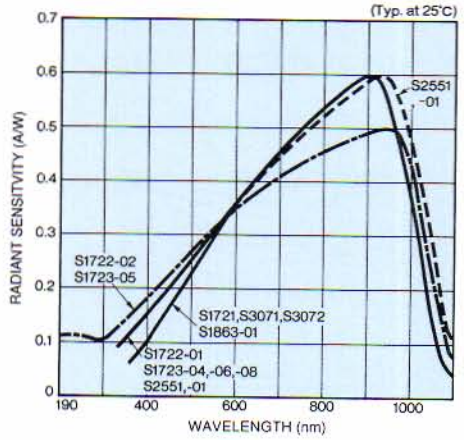
Type No.	Features	Ⓐ Outlines / Window Materials	Package	Photosensitive Surface		Spectral Response		Characteristics (at 25°C)				
				Size (mm)	Effective Area (mm²)	Range (nm)	Peak Wave-length (nm)	Radiant Sensitivity Typ. (A/W)			Short Circuit Current I_{sh}, 100 lux	
								Peak Wave-length	633nm He-Ne Laser	930nm GaAs LED	Min. (μA)	Typ. (μA)
S1721	2.54mm dia. sensitive area, for visible to IR	⑧/K	TO-5	ϕ 2.54	5.1	320~1060	920	0.6	0.4	0.6	3.6	4.5
★ S3072	3mm dia. sensitive area, for visible to IR	⑧/K	TO-5	ϕ 3.0	7.0	320~1060	920	0.6	0.44	0.6	5.0	6.3
S1722-01	4.1mm dia. sensitive area, for visible to IR	⑪/K	TO-8	ϕ 4.1	13.2	320~1060	920	0.6	0.4	0.6	12	15
S1722-02	Fused silica window, high UV sensitivity	⑪/Q				190~1100	960	0.5	0.38	0.5		
★ S3071	5.0mm dia. sensitive area, for visible to IR	⑪/K	TO-8	ϕ 5.0	19.6	320~1060	920	0.6	0.44	0.6	14	17
S1863-01		⑫/K	ϕ14mmTO-8						0.4			
S1723-04	10 x 10mm sensitive area, for visible to IR	㉑/R	Ceramic	10×10	100	320~1060	920	0.6	0.4	0.6	65	80
S1723-08	White substrate version of S1723-04											
S1723-06	Low dark current version of S1723-08											
S1723-05	Fused silica window, high UV sensitivity	⑳/Q				190~1100	960	0.5	0.38	0.5		
S2551	For CT application, etc.	㉛/R	Ceramic	1.2×29.1	35	320~1060	920	0.6	0.4	0.6	24	32
S2551-01	High-voltage withstand type											

※ Other PIN photodiodes with various sensitive area sizes (10x20, 18x18, 28x28 mm etc.) are also available.

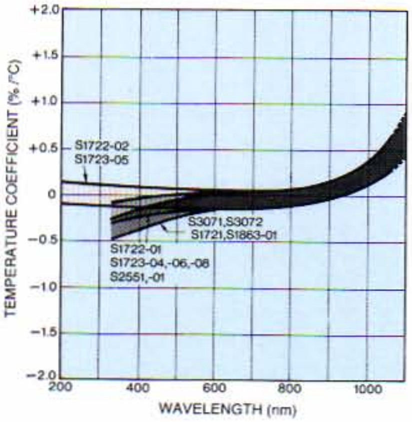
Ⓐ See pages 34 to 37 for outlines.
Window materials are
K: Borosilicate glass
Q: Fused silica
R: Resin coating

★ mark indicates newly listed products.

- **Spectral Response**

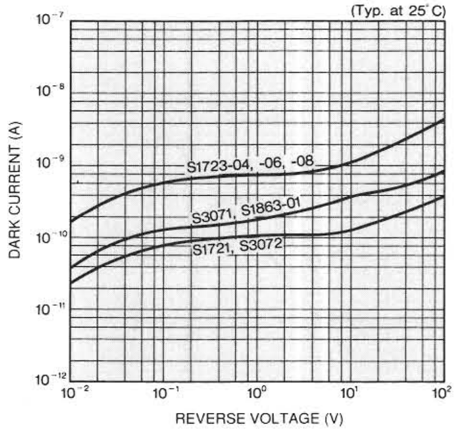


- **Temperature Characteristic of Ish**

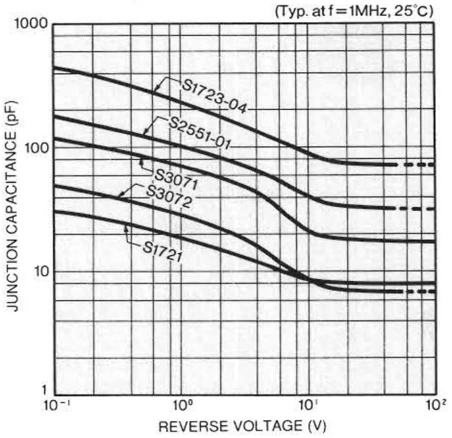


Characteristics (at 25°C)					Maximum Ratings				
Dark Current I_d Max. (nA)	Temperature Dependence of I_d Typ. (Times/°C)	Junction Capacitance, Cj Typ. (pF)	Cutoff Frequency fc Typ. (MHz)	NEP Typ. (W/Hz$^{1/2}$)	Reverse Voltage $V_R$max. (V)	Power Dissipation P max. (mW)	Temperature Range Operating (°C)	Temperature Range Storage (°C)	Type No.
10 (V_R = 30 V)	1.15	8 (V_R = 30 V)	50 (V_R = 30 V)	1.3×10^{-14} (V_R = 30 V)	100	50	−20~+60	−55~+100	S1721
10 (V_R = 24 V)	1.15	7 (V_R = 24 V)	45 (V_R = 24 V)	1.6×10^{-14} (V_R = 24 V)	60	50	−20~+60	−55~+100	S3072
30 (V_R = 100 V)	1.15	12 (V_R = 100 V)	150 (V_R = 100 V)	7.3×10^{-14} (V_R = 100 V)	200	50	−20~+60	−55~+100	S1722-01
		10 (V_R = 100 V)	60 (V_R = 100 V)						S1722-02
30 (V_R = 50 V)	1.15	17 (V_R = 50 V)	60 (V_R = 50 V)	2.7×10^{-14} (V_R = 50 V)	100	50	−20~+60	−55~+100	S3071
50 (V_R = 50 V)									S1863-01
10 (V_R = 30 V)	1.15	70 (V_R = 30 V)	30 (V_R = 30 V)	3.8×10^{-14} (V_R = 30 V)	50	100	−20~+60	−20~+80	S1723-04
									S1723-08
5 (V_R = 30 V)				3.0×10^{-14} (V_R = 30 V)					S1723-06
10 (V_R = 30 V)		100 (V_R = 30 V)	15 (V_R = 30 V)	3.6×10^{-14} (V_R = 30 V)					S1723-05
1 (V_R = 10 mV)	1.15	250 (V_R = 0 V)	3 (V_R=0V, R_L=1kΩ)	3.9×10^{-14} (V_R = 10 mV)	5	50	−20~+60	−20~+80	S2551
30 (V_R = 30 V)		35 (V_R = 30 V)	60 (V_R = 30 V)	5.2×10^{-14} (V_R = 30 V)	50				S2551-01

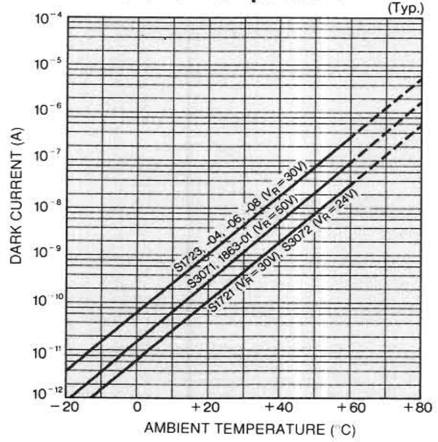
● Dark Current vs. Reverse Voltage



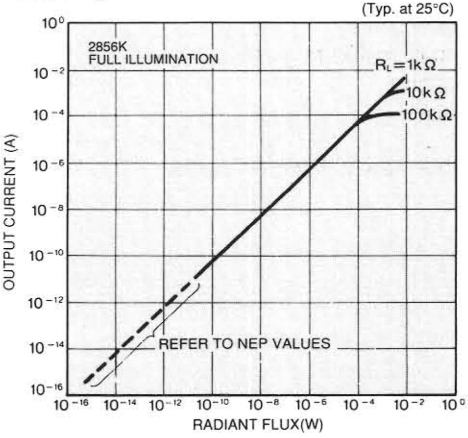
● Junction Capacitance vs. Reverse Voltage



● Dark Current vs. Temperature

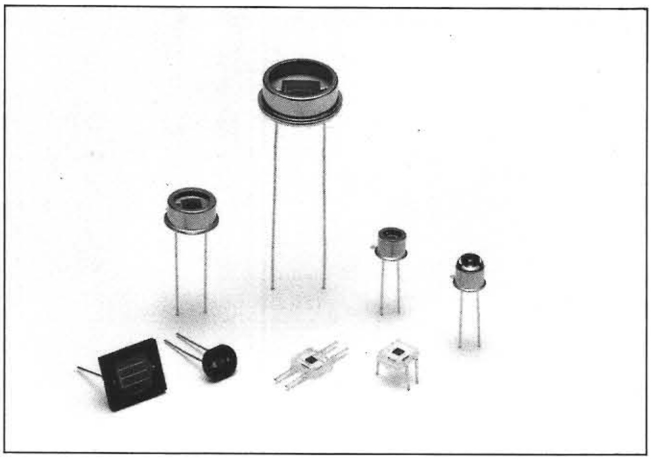


● Linearity



GaAsP Photodiodes

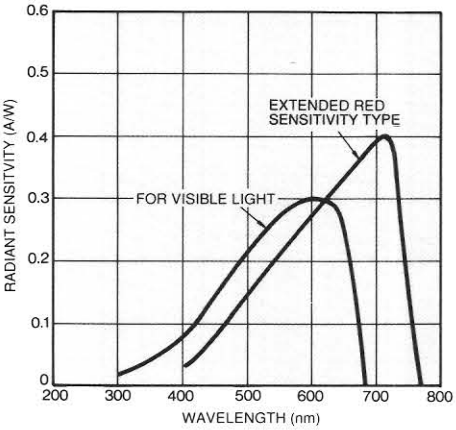
Type No.	Ⓐ Outlines / Window Materials	Package (mm)	Photosensitive Surface Size (mm)	Photosensitive Surface Effective Area (mm²)	Spectral Response Range (nm)	Spectral Response Peak Wave-length (nm)	Characteristics (25°C) Typical Radiant Sensitivity (A/W) Peak Wave-length	Characteristics (25°C) Typical Radiant Sensitivity (A/W) 560nm GaP LED	Characteristics (25°C) Typical Radiant Sensitivity (A/W) 633nm He-Ne Laser	Short Circuit Current Ish, 100 lux Min. (μA)	Short Circuit Current Ish, 100 lux Typ. (μA)
Diffusion Type (for Visible Light)											
G1115	❶/K	TO-18	1.3×1.3	1.66	300~680	640	0.3	0.29	0.29	0.12	0.15
G1116	❼/K	TO-5	2.7×2.7	7.26						0.45	0.6
G1117	❿/K	TO-8	5.6×5.6	29.3						2	2.5
G1118	㉒/R	5×6	1.3×1.3	1.66						0.12	0.15
G1120	⓳/R	8.9×10.1	5.6×5.6	29.3						2	2.5
★ G3067	❸/L	TO-18	1.3×1.3	1.66						0.75	0.95
G2711	㉚/M	Epoxy mold	1.3×1.3	1.66						0.15	0.18
Diffusion Type (Extended Red Sensitivity Type)											
G1735	❶/K	TO-18	1.3×1.3	1.66	400~760	710	0.4	0.22	0.29	0.2	0.25
G1736	❼/K	TO-5	2.7×2.7	7.26						0.8	1.1
G1737	❿/K	TO-8	5.6×5.6	29.3						3.5	4.5
G1738	㉒/R	5×6	1.3×1.3	1.66						0.2	0.25
G1740	⓳/R	8.9×10.1	5.6×5.6	29.3						3.5	4.5
★ G3297	❸/L	TO-18	1.3×1.3	1.66						1.5	1.8



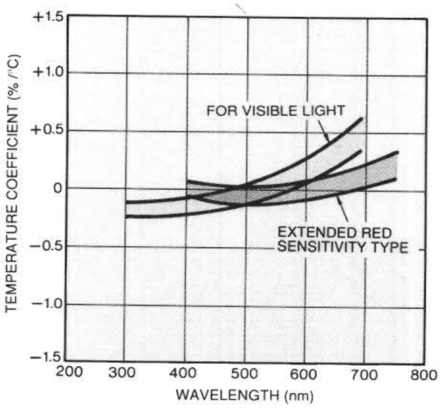
Ⓐ See pages 34 to 37 for outlines.
Window materials are
K: Borosilicate glass
L: Lens type borosilicate glass
R: Resin coating
M: Epoxy mold

★ mark indicates newly listed products.

- **Spectral Response**



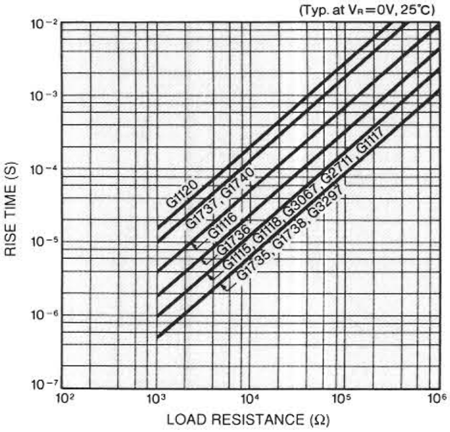
- **Temperature Characteristic of Ish**



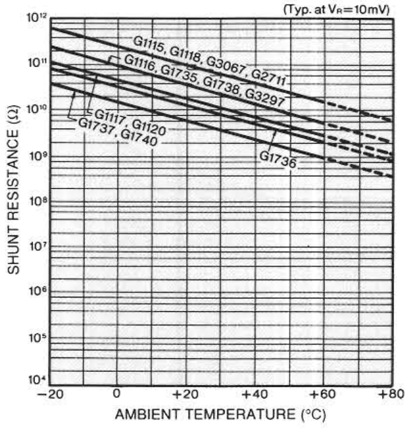
Characteristics (25°C)								Absolute Maximum Ratings			Type No.
Dark Current, Id Max.		Temperature Dependence of Id Typ.	Shunt Resistance, R_{sh} V_R = 10mV		Junction Capacitance, Cj V_R = 0V Typ.	Rise Time t_r V_R = 0V R_L = 1k Ω Typ.	NEP Typ.	Reverse Voltage $V_R$max	Temperature Range		
V_R = 10mV (pA)	V_R = 1V (pA)	(Times/°C)	Min. (G Ω)	Typ. (G Ω)	(pF)	(μs)	(W/Hz$^{1/2}$)	(V)	Operating (°C)	Storage (°C)	
1	10	1.07	10	80	300	1	1.5×10^{-15}	5	−10～+60	−20～+80	G1115
2.5	25		4	30	1400	4	2.5×10^{-15}				G1116
5	50		2	15	6000	15	3.5×10^{-15}				G1117
1	10		10	80	300	1	1.5×10^{-15}			−20～+70	G1118
5	50		2	15	6000	15	3.5×10^{-15}				G1120
1	10		10	80	300	1	1.5×10^{-15}			−20～+80	G3067
1	10		10	80	300	1	1.5×10^{-15}		−20～+70	−30～+80	G2711

Dark Current V_R = 10mV (pA)	Dark Current V_R = 1V (pA)	Temperature Dependence (Times/°C)	Rsh Min. (G Ω)	Rsh Typ. (G Ω)	Cj (pF)	tr (μs)	NEP (W/Hz$^{1/2}$)	$V_R$max (V)	Operating (°C)	Storage (°C)	Type No.
2	20	1.07	5	25	250	0.5	2.0×10^{-15}	5	−10～+60	−20～+80	G1735
5	50		2	10	1200	1.8	3.2×10^{-15}				G1736
10	100		1	5	4500	10	4.5×10^{-15}				G1737
2	20		5	25	250	0.5	2.0×10^{-15}			−20～+70	G1738
10	100		1	5	4500	10	4.5×10^{-15}				G1740
2	20		5	25	250	0.5	2.0×10^{-15}			−20～+80	G3297

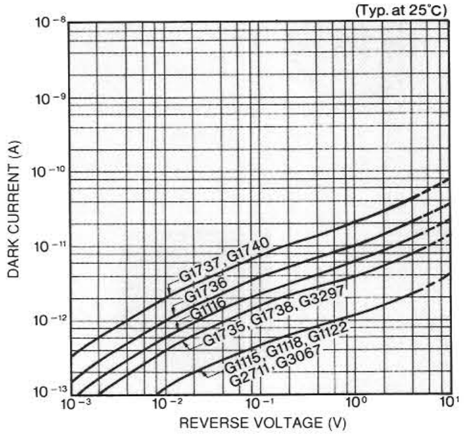
- **Response Time vs. Load Resistance**



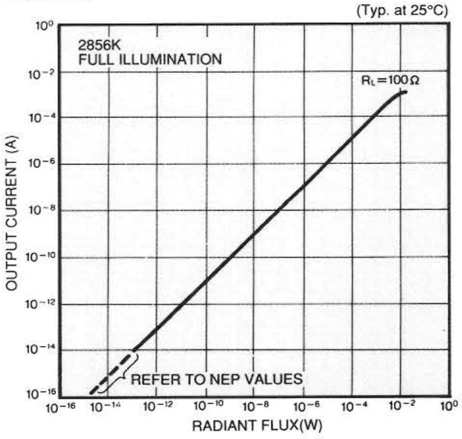
- **Shunt Resistance vs. Temperature**



- **Dark Current vs. Reverse Voltage**

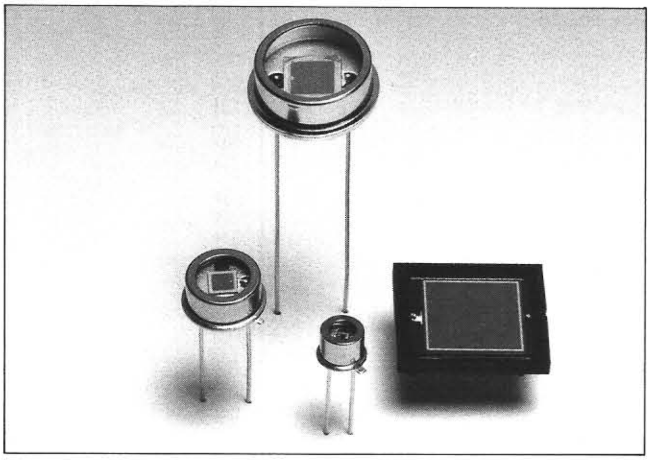


- **Linearity**



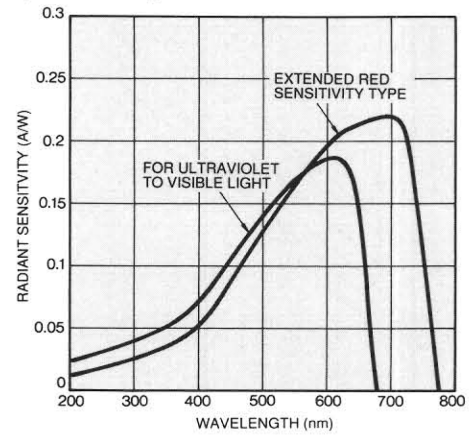
GaAsP Photodiodes

Type No.	Ⓐ Outlines / Window Materials	Package (mm)	Photosensitive Surface		Spectral Response		Characteristics (25°C)					
							Typical Radiant Sensitivity (A/W)				Short Circuit Current I_{sh}, 100 lux	
			Size (mm)	Effective Area (mm²)	Range (nm)	Peak Wavelength (nm)	Peak Wavelength	254nm Hg-Line	560nm GaP LED	633nm He-Ne Laser	Min (µA)	Typ. (µA)
Schottky Type (for Ultraviolet to Visible Light)												
G1125-02	❶/Q	TO-18	1.1×1.1	1.0	190~680	610	0.18	0.035	0.17	0.17	0.05	0.07
G1126-02	❼/Q	TO-5	2.3×2.3	5.2							0.25	0.3
G1127-02	❿/Q	TO-8	4.6×4.6	21							0.9	1.2
G2119	⓴/Q	15×16.5	10.1×10.1	98							5	6
Schottky Type (Extended Red Sensitivity Type)												
G1745	❶/Q	TO-18	1.1×1.1	1.0	190~760	710	0.22	0.02	0.18	0.2	0.1	0.15
G1746	❼/Q	TO-5	2.3×2.3	5.2							0.5	0.65
G1747	❿/Q	TO-8	4.6×4.6	21							1.8	2.4

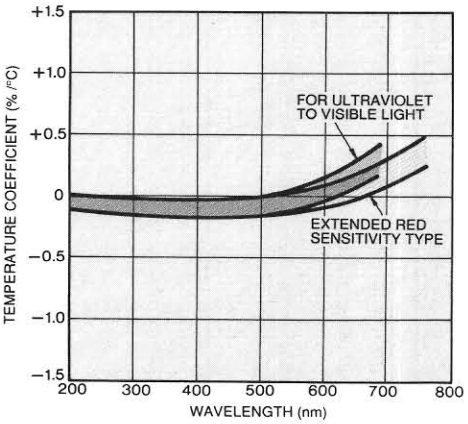


Ⓐ See pages 34 to 37 for outlines.
Window material is
Q: Fused silica

- **Spectral Response**

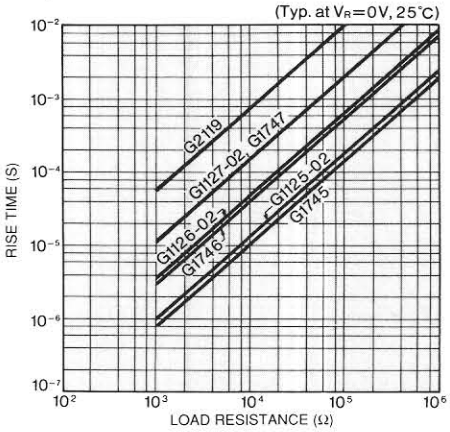


- **Temperature Characteristic of Ish**

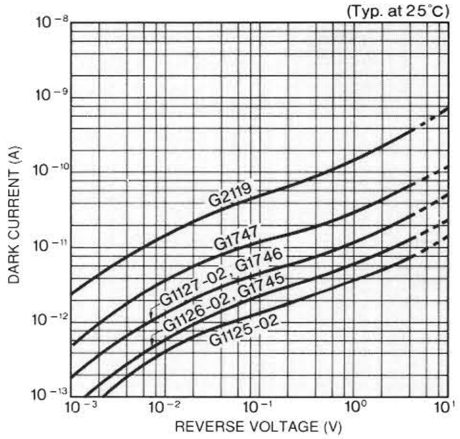


Characteristics (25°C)								Absolute Maximum Ratings			Type No.
Dark Current, I_d Max.		Temperature Dependence of I_d Typ.	Shunt Resistance, R_{sh} V_R = 10mV		Junction Capacitance, Cj V_R = 0V Typ.	Rise Time t_r V_R = 0V R_L = 1k Ω Typ.	NEP Typ.	Reverse Voltage $V_R$max	Temperature Range		
V_R = 10mV (pA)	V_R = 1V (pA)	(Times/°C)	Min. (G Ω)	Typ. (G Ω)	(pF)	(μs)	(W/Hz$^{1/2}$)	(V)	Operating (°C)	Storage (°C)	
2.5	25	1.07	4	25	450	1	4.5×10^{-15}	5	−10～+60	−20～+70	G1125-02
5	50		2	15	1800	3.5	5.8×10^{-15}				G1126-02
10	100		1	8	7000	12	8.0×10^{-15}				G1127-02
100	1000		0.1	0.7	25000	55	2.7×10^{-14}				G2119
5	50	1.07	2	15	400	0.8	4.8×10^{-15}	5	−10～+60	−20～+70	G1745
10	100		1	8	1600	3	6.5×10^{-15}				G1746
20	200		0.5	2.5	6000	12	1.2×10^{-14}				G1747

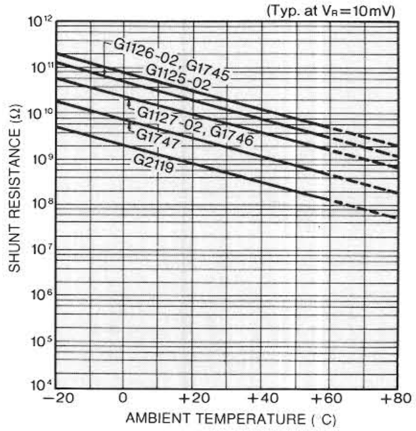
- **Response Time vs. Load Resistance**



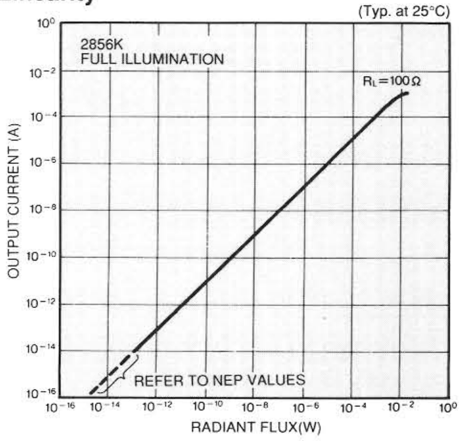
- **Dark Current vs. Reverse Voltage**



- **Shunt Resistance vs. Temperature**

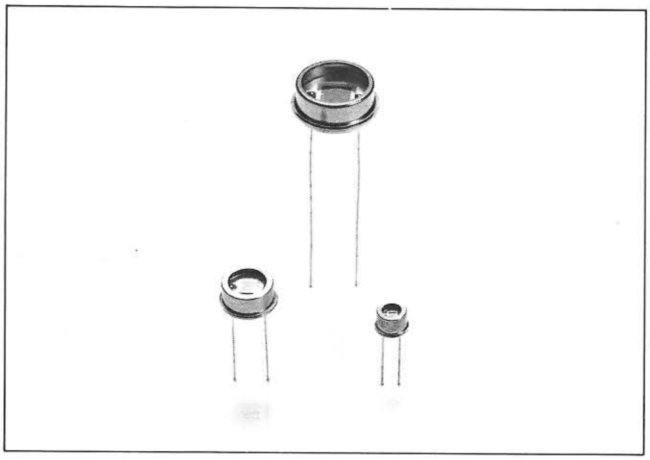


- **Linearity**



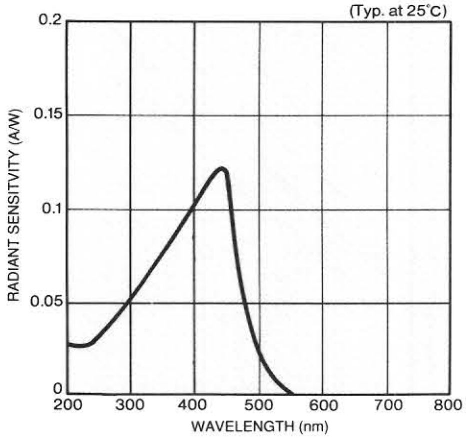
GaP Photodiodes

Type No.	Ⓐ Outlines / Window Materials	Package (mm)	Photosensitive Surface		Spectral Response		Characteristics (25°C)				
			Size (mm)	Effective Area (mm²)	Range (nm)	Peak Wavelength (nm)	Typical Radiant Sensitivity (A/W)			Short Circuit Current Ish, 1000 lux	
							Peak Wavelength	254nm Hg-Line	400nm	Min. (µA)	Typ. (µA)
Schottky Type											
G1961	❶/Q	TO-18	1.1×1.1	1.0	190〜550	440	0.12	0.03	0.1	0.04	0.05
G1962	❻/Q	TO-5	2.3×2.3	5.2						0.23	0.3
G1963	❿/Q	TO-8	4.6×4.6	21						0.75	0.9

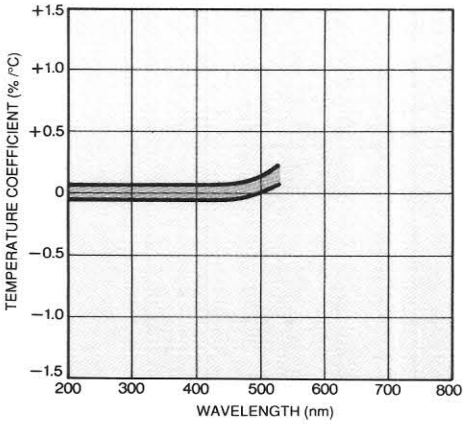


Ⓐ See pages 34 to 37 for outlines.
Window material is
Q: Fused silica

- **Spectral Response**

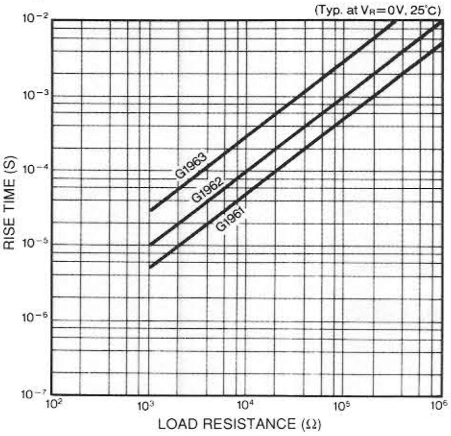


- **Temperature Characteristic of Ish**

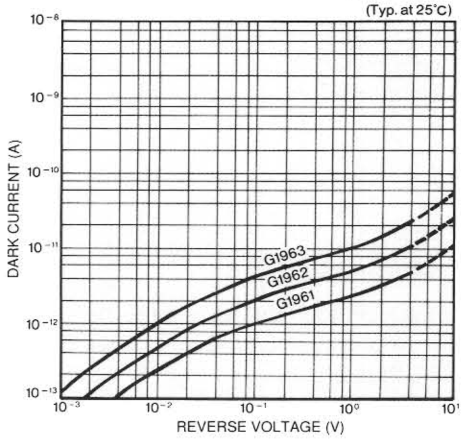


Characteristics (25°C)								Absolute Maximum Ratings			Type No.
Dark Current, I_d Max.		Temperature Dependence of I_d Typ.	Shunt Resistance, R_{sh} V_R = 10mV		Junction Capacitance, Cj V_R = 0V Typ.	Rise Time t_r V_R = 0V R_L = 1k Ω Typ.	NEP Typ.	Reverse Voltage $V_R$max	Temperature Range		
V_R = 10mV (pA)	V_R = 1V (pA)	(Times/°C)	Min. (G Ω)	Typ. (G Ω)	(pF)	(μs)	(W/Hz$^{1/2}$)	(V)	Operating (°C)	Storage (°C)	
2.5	25	1.07	4	40	600	5	5.4×10^{-15}	5	−10～+60	−20～+70	G1961
5	50		2	20	3000	10	7.6×10^{-15}				G1962
10	100		1	10	12000	30	1.1×10^{-14}				G1963

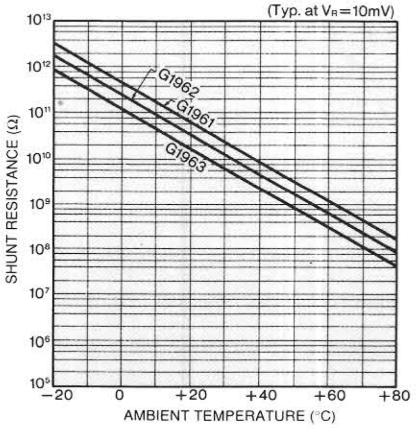
- **Response Time vs. Load Resistance**



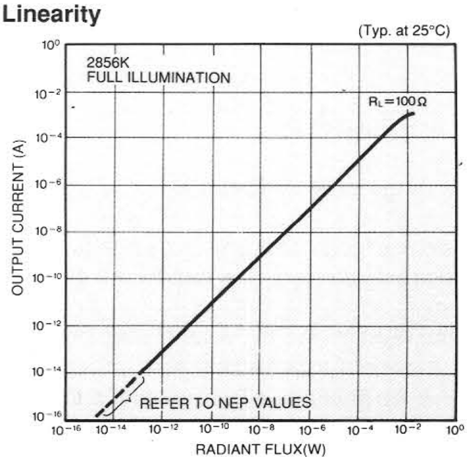
- **Dark Current vs. Reverse Voltage**



- **Shunt Resistance vs. Temperature**

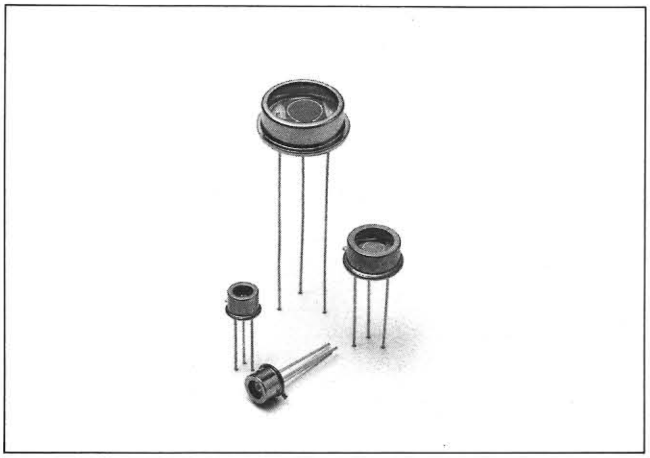


- **Linearity**



Silicon Avalanche Photodiodes (APD)

Type No.	Ⓐ Outlines / Window Materials	Package (mm)	Photosensitive Surface		Spectral Response		Characteristics (at 25°C)				
			Size (mm dia.)	Effective Area (mm²)	Range (nm)	Peak Wave-length (nm)	Quantum Efficiency Typ.		Breakdown Voltage, V_B I_d = 100μA		Breakdown Voltage Temperature Coefficient Typ. (V/°C)
							at 540nm M = 1 (%)	at 800nm M =1 (%)	Typ. (V)	Max. (V)	
S2381	❻/K	TO-18	ϕ0.2	0.03	400~1000	800	50	70	150	300	0.5
S2382		TO-18	ϕ0.5	0.19							
S2383		TO-18	ϕ1.0	0.78							
S2384	❾/K	TO-5	ϕ3.0	7.0							
S2385	⓭/K	TO-8	ϕ5.0	19.6							



Ⓐ See pages 34 to 37 for outlines.
Window material is
K: Borosilicate glass

Ⓑ Measured at the gain indicated in the characteristics table.

S/N RATIO CONSIDERATION

The silicon avalanche photodiode has an internal gain mechanism. It can amplify a small signal to over the thermal noise level, thus producing a high S/N ratio. However, when the signal is amplified, the inherent excess noise caused by current fluctuation in the multiplication process is also generated. This noise current of an avalanche photodiode can be represented by the following equation;

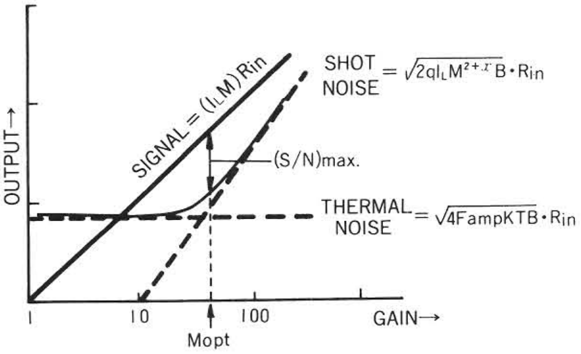
$$\text{Noise current} = \sqrt{2qI_OM^2FB}$$

($F = M^x$ in the range of M = 10 to 100)

Where F is excess noise factor, M is gain, I_O is photocurrent at M = 1, q is electronic charge, B is bandwidth and x is excess noise index.

The figure at the right shows the relationship between output and gain. It is clear that the optimum gain exists in the region where the shot noise is equal to the thermal noise.

• Output vs. Gain

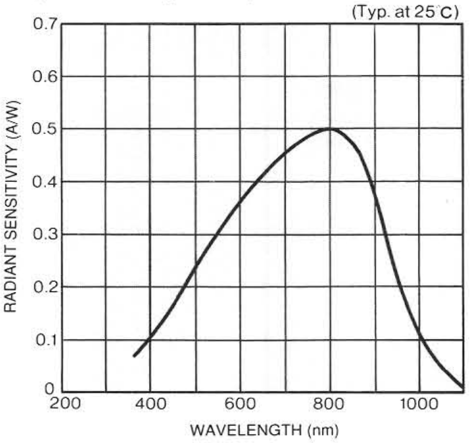


F_{amp} : Noise index of next-stage amplifier
R_{in} : Input resistance for next-stage amplifier
K : Boltzmann's constant
T : Absolute temperature

Characteristics (25°C)							Maximum Ratings		Type No.
Dark Current, I_d Ⓑ		Junction Ⓑ Capacitance Cj Typ. (pF)	Cutoff Ⓑ Frequency fc R_L=50Ω Typ. (MHz)	Excess Noise Index χ		Gain M λ=800 Typ.	Ambient Operating Temperature (°C)	Storage Temperature Range (°C)	
Typ. (nA)	Max. (nA)			Typ.	Max.				
0.1	1	2	1200	0.30	0.42	100	−20～+60	−55～+100	S2381
0.3	3	3	900						S2382
0.6	6	7	700						S2383
1	10	40	120			60			S2384
3	30	95	40			40			S2385

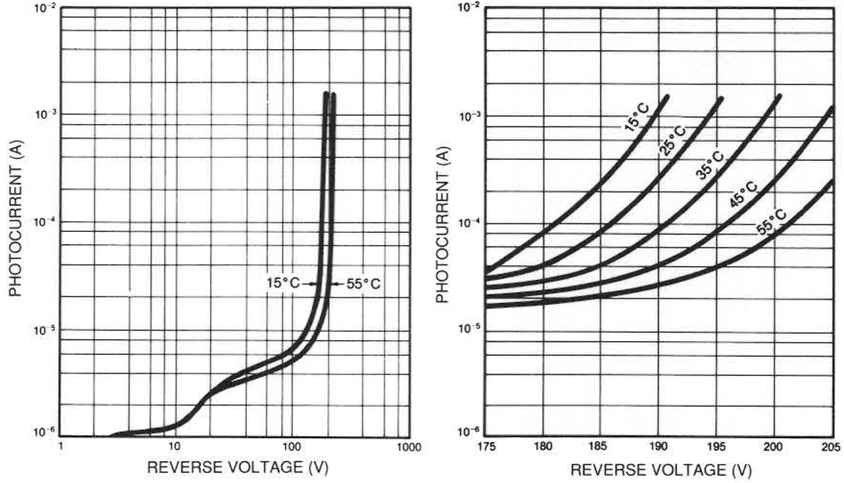
- **Spectral Response (S2381, M=1)**

(Typ. at 25°C)

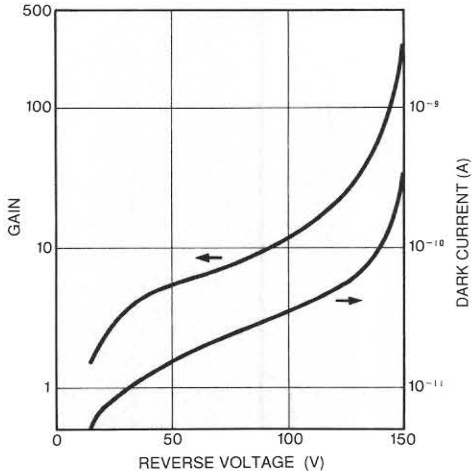


- **Photocurrent vs. Reverse Voltage (S2381)**

(Enlarged Graph)

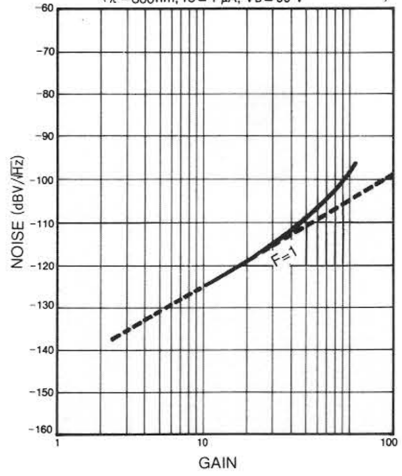


- **Gain/Dark Current vs. Reverse Voltage (S2381)**



- **Noise vs. Gain (S2381)**

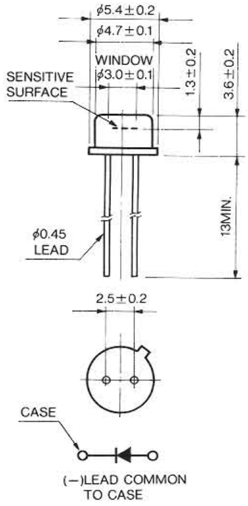
(at 25°C, f = 10 kHz, R_L = 100 kΩ, B = 363 Hz
λ = 800nm, I_O = 1 μA, V_B = 90 V)



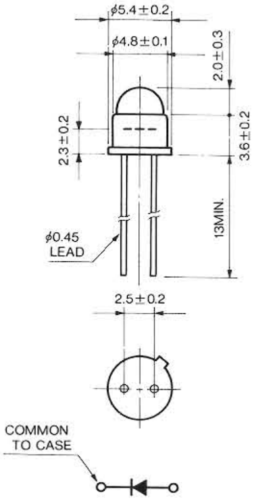
Dimensional Outlines

Unit: mm

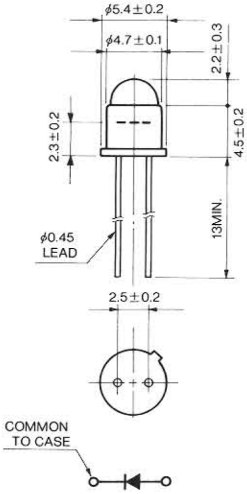
❶ S1226-18BQ etc.



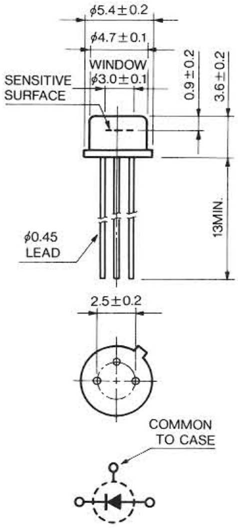
❷ S2386-18L etc.



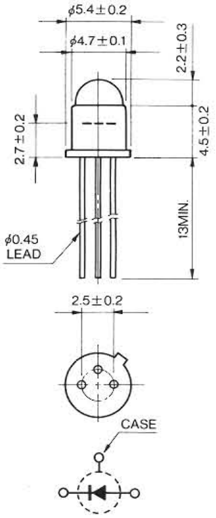
❸ S1190-01



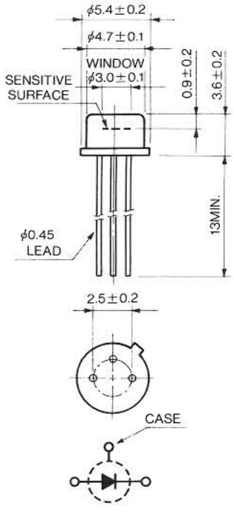
❹ S2216-01 etc.



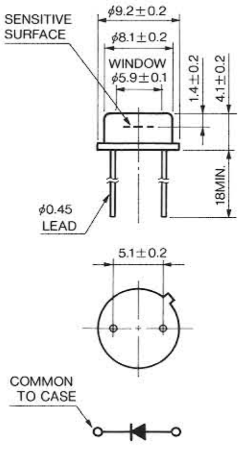
❺ S1190-13



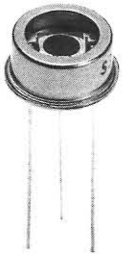
❻ S2381,S2382,S2383

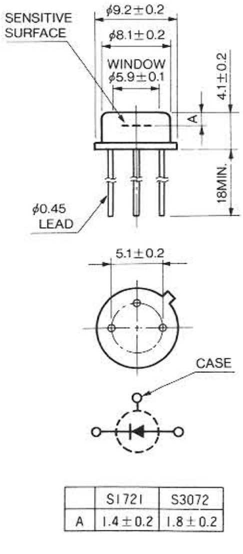


❼ S1226-5BQ etc.



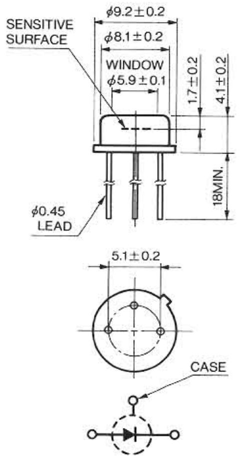
❽ S1721,S3072





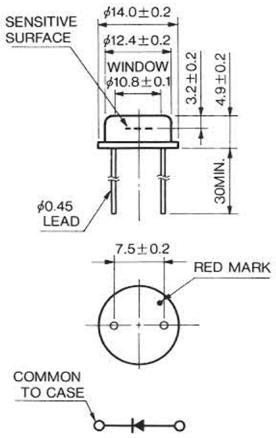
	S1721	S3072
A	1.4±0.2	1.8±0.2

❾ S2384

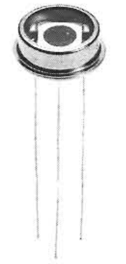


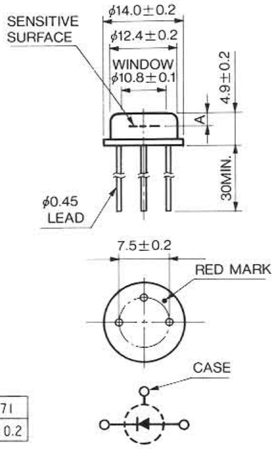
Unit: mm

⑩ S1226-8BQ etc.



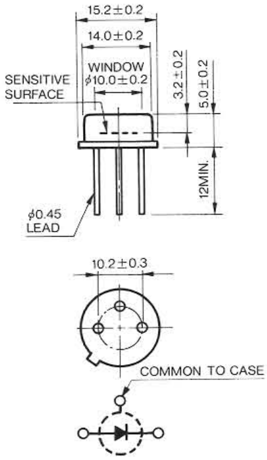
⑪ S1722, S3071etc.



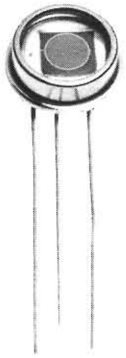


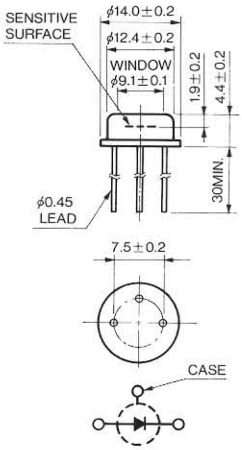
	S1722	S3071
A	2.5 ± 0.2	2.2 ± 0.2

⑫ S1863-01

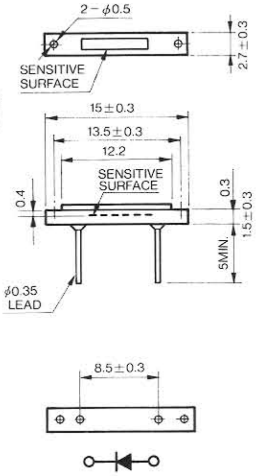


⑬ S2385

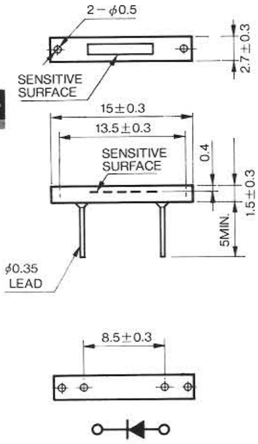




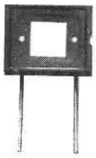
⑭ S1227-16BQ etc.

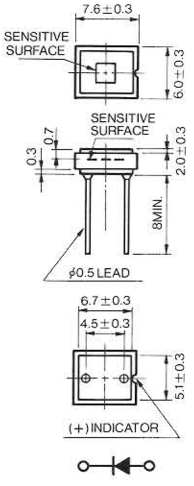


⑮ S1227-16BR etc.

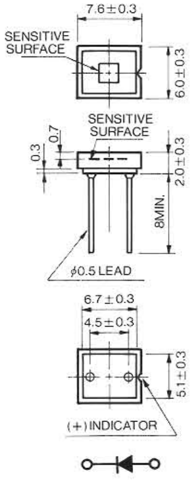


⑯ S1227-33BQ etc.

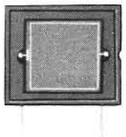


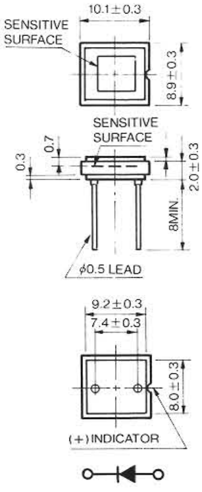


⑰ S1227-33BR etc.

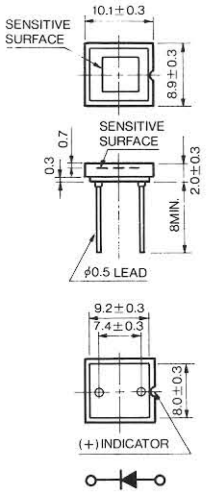


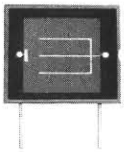
⑱ S1227-66BQ etc.





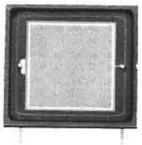
⑲ S1227-66BR etc.

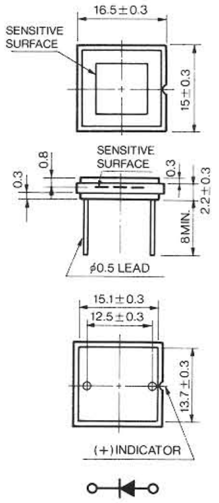




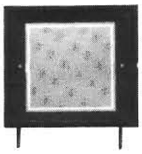
G1120
G1740

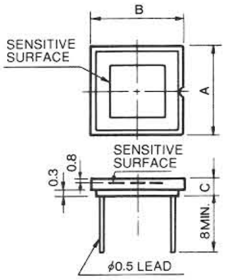
⑳ S1227-1010BQ etc.



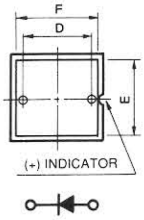


㉑ S1227-1010BR etc.

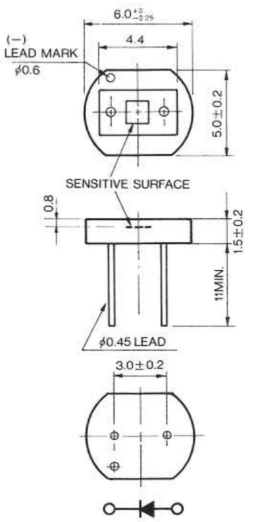




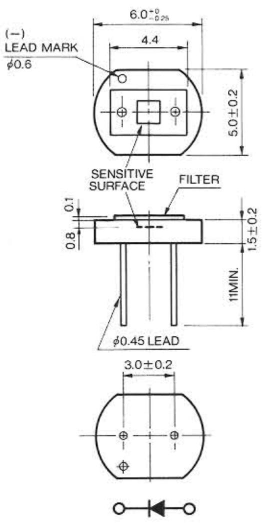
	S1723-06,-08	S1227-1010BR
A	14.5±0.3	15±0.3
B	16±0.3	16.5±0.3
C	2.1±0.3	2.2±0.3
D	12.1±0.3	12.5±0.3
E	13.1±0.3	13.7±0.3
F	14.6±0.3	15.1±0.3



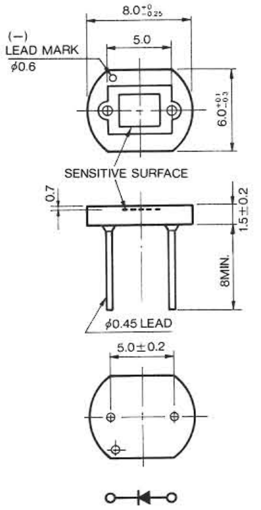
㉒ S1087-01, G1118, G1738



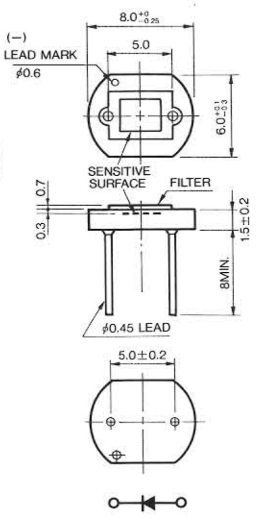
㉓ S1087, S1087-03



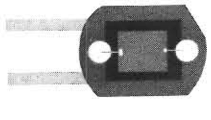
㉔ S1133-01, S1133-11 etc.

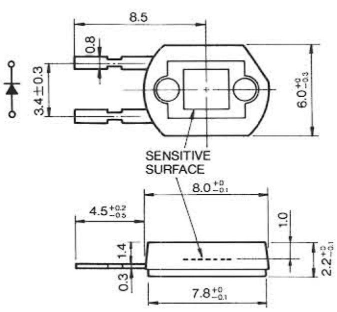


㉕ S1133, S1133-03 etc.

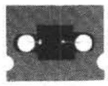


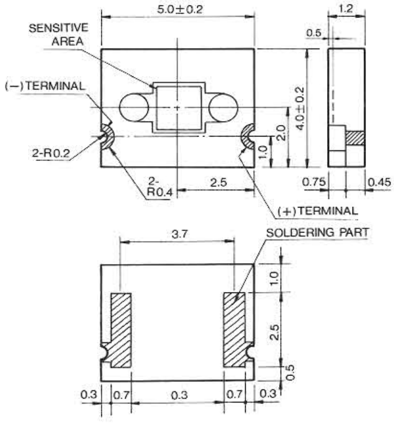
㉖ S1787 Series





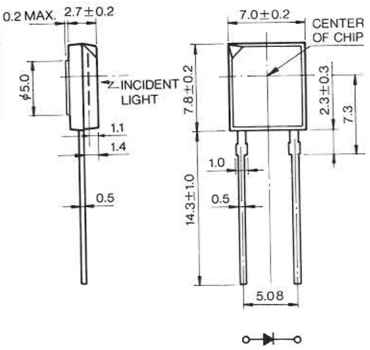
㉗ S2164, S2164-01



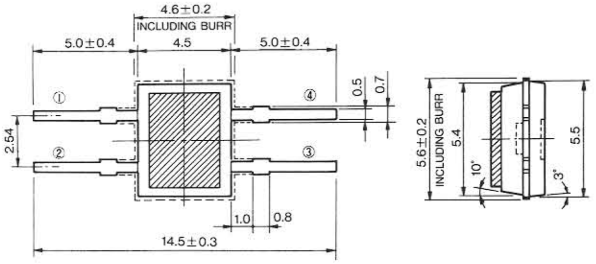


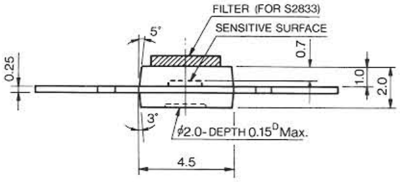
Unit: mm

㉘ S2506 Series



㉙ S4011





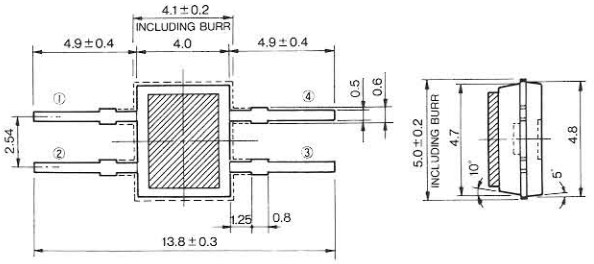
PIN CONNECTION

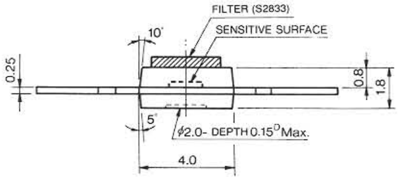
①	NC
②	CATHODE
③	ANODE
④	CATHODE

㉚ S2833, G2711

S2833

G2711

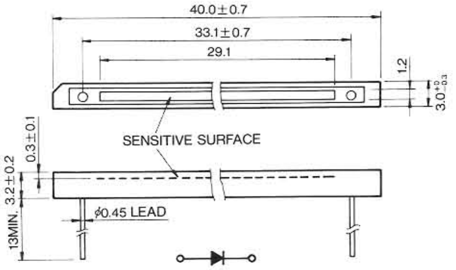




PIN CONNECTION

①	NC
②	CATHODE
③	ANODE
④	CATHODE

㉛ S2551, S2551-01



∗ The spacings of the leads in the figures are indicated as center-to-center dimensions. The photograph shows a typical type.

Specially Designed Photodiodes and Related Devices

In addition to the many devices described in this catalog, Hamamatsu is able to produce a variety of special devices such as photodiodes with operational amplifiers, thermoelectrically-cooled photodiodes, and linear or area arrays with specifications and configurations to match your specific requirements. Please contact us about such requirements. The following devices show examples of our capability.

●Multi-Element Photodiodes

Type No.	Sensitive Area (mm)	No. of Elements	Spectral Response (nm)	Package	Main Use
S1446	2.54 dia.	2	190 ~ 1100	3-pin TO-8	Double beam spectral photometer
S2841			190 ~ 1000		
G1964 (GaAsP)			190 ~ 680		
S994-13	1.45 x 1.45	2 x 2	320 ~ 1000	10-pin TO-5	Position detection
S1557	1 dia. (quadrant)	4	320 ~ 1060	5-pin TO-18	CD and optical disk, position detection
S1557-01	1 dia. (quadrant)	4	320 ~ 1060	Ceramic case (5-pin)	
S1651	0.30 x 0.60	2 x 2	320 ~ 1060	5-pin TO-18	
S1651-01	0.30 x 0.60	2 x 2	320 ~ 1060	Ceramic case (5-pin)	
S1671	1.7 x 2.8	2 x 2	320 ~ 1060	5-pin TO-18	Position detection
S2856	4 segmented	4	320 ~ 1060	Epoxy mold, 8-pin DIP type	For CD and optical disk
S2802	6 segmented	6	320 ~ 1060	Epoxy mold, 8-pin DIP type	

●Photodiode/Op-amp Devices

Type No.	Sensitive Area (mm)	Spectral Response (nm)	Peak Wavelength	Package
S1406-03	2.4 x 2.4	190 ~ 1100	960	10-pin TO-5 (Input window : 3mm dia.)
S1406-04	2.4 x 2.4	320 ~ 1100	960	
S1406-05	2.4 x 2.4	190 ~ 1000	720	
S1406-06	2.4 x 2.4	320 ~ 1000	720	
G1957	2.7 x 2.7	300 ~ 680	610	

●PIN Photodiode/Pre-amp Devices

Type No.	Sensitive Area (mm)	Response Wavelength Range (nm)	Response at 820 nm (mV/μV)	Cut-off Frequency (MHz)	Package
S2858	0.8 dia.	320 ~ 1060	16.5	15	3-pin TO-18
S2858-01				25	

●Thermoelectrically-Cooled Photodiodes

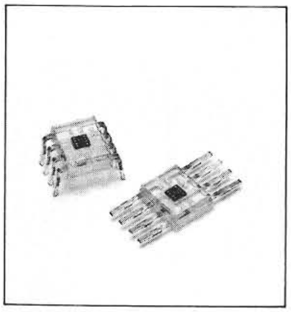
Type No.	Sensitive Area (mm)	Spectral Response (nm)	Peak Wavelength (nm)	Cooling Temperature ΔT (°C)	Package
S3477-01	2.4 x 2.4	190 ~ 1000	720	35	TO-66
S2592-01					TO-8
S3477-03	2.4 x 2.4	190 ~ 1100	960	35	TO-66
S2592-03					TO-8

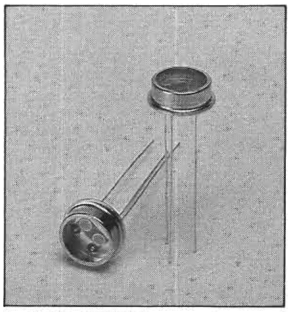
●Photodiodes with BNC Connectors

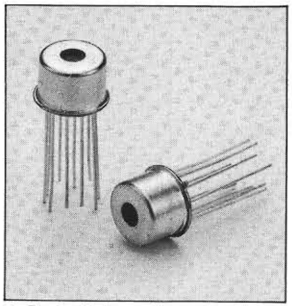
Type No.	Sensitive Area (mm)	Response Wavelength Range (nm)	Peak Wavelength (nm)	Package
S2281	11.3 dia.	190 ~ 1100	960	Metal case with BNC connector
S2281-01	11.3 dia.	190 ~ 1000	720	

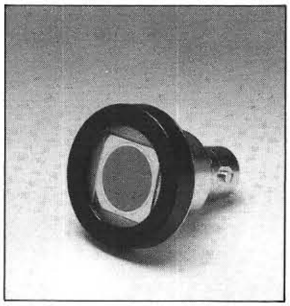
●Monochromatic Photodiodes

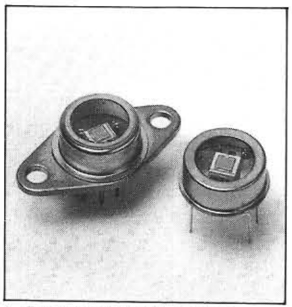
Type No.	Peak Response Wavelength (nm)	Spectral Response width FWHM (nm)
S2684 Series	340, 405, 500, 520, 560, 650, 700	10 ± 2

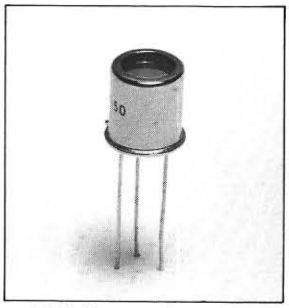

▲ S2856, S2802 (for optical disks)


▲ S1446, S2841 (for spectroscopy)


▲ Photodiodes with op-amps


▲ S2281 (with BNC connector)


▲ Photodiodes with coolers



▲ S2684 (for monochromatic light)

35, 38 and 46 ELEMENT PHOTODIODE ARRAYS

Hamamatsu offers linear photodiode arrays designed for multichannel spectrophotometers. These photodiode arrays feature wide spectral response from ultraviolet to near infrared and low cross-talk between elements. The following 6 series are available, depending on the sensitivity and operation mode. Each series is provided with 35, 38 and 46 element arrays with 1.0 mm pitch. Driver/amplifier circuits are also available.

Operation Mode	Type No.	Features
With reverse bias applied (Charge integration readout)	S2311 Series	High IR sensitivity, low dark current
	S2312 Series	Low IR sensitivity, low dark current
	S2313 Series	Low C_j, suppressed IR sensitivity
Zero bias (Real time readout)	S2317 Series	High IR sensitivity, low dark current
	S2318 Series	Low IR sensitivity, low dark current
	S2319 Series	Low C_j, suppressed IR sensitivity

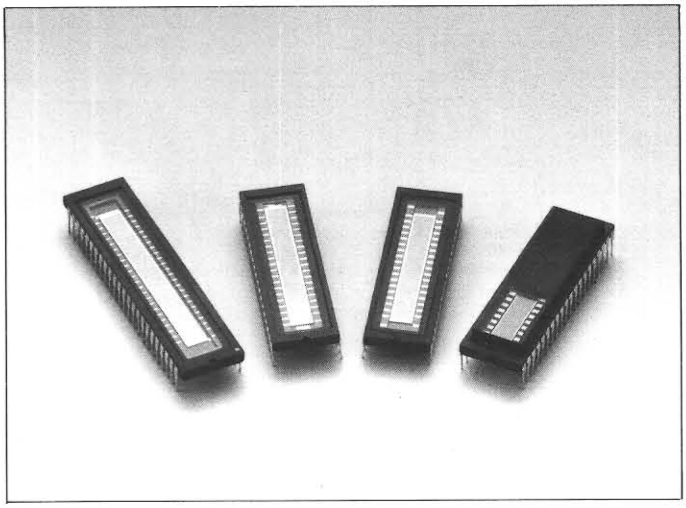
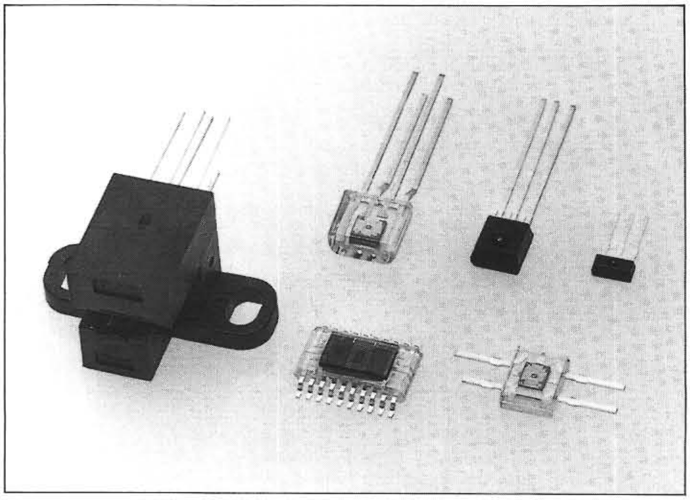


PHOTO ICs (Intelligent Light Sensors)

Photo ICs are intelligent light sensors consisting of a photodiode, a signal processing circuit and a signal output circuit, all integrated in a single chip. Photo ICs allow the user to design and manufacture compact devices with fewer production processes at a low cost. Proximity sensors, color sensors, and position sensors are just some for example of the Photo ICs available from Hamamatsu.

Type No.	Product Name	Features
S2827 S2828	Photo IC sensors	Amplifier and Schmitt trigger circuit are included. Digital output, TTL compatible
S3599	Light modulation phto IC	Optical synchronous detection is easily performed as oscillator and LED driver are included. Digital output, TTL compatible
H3911	Linear encoder module	Incremental 2-phase digital output using moire stripes of slits
H3833	Photo IC color sensor	No output gain adjustment required, good color temperature discrimination for fluorescent lamps



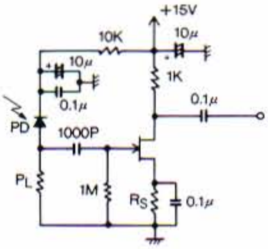
PHOTOSENSOR AMPLIFIER C2719

The C2719 Photosensor Amplifier is a current-to-voltage conversion amplifier used to amplify very-low photoelectric currents from a photodiode with very little noise. There are three sensitivity ranges (H/M/L) to match the photodiode signal. A 10-turn potentiometer is used to zero the amplifier, so fine adjustment is possible with good resolution.

As the C2719 is operated by dry batteries, it can easily be used anywhere. An external power input connector is also provided at the rear panel for a long, continuous operation.

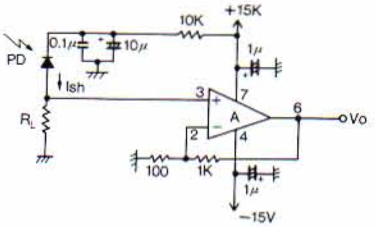
Application Examples

① Low noise light-sensitive pre-amplifier



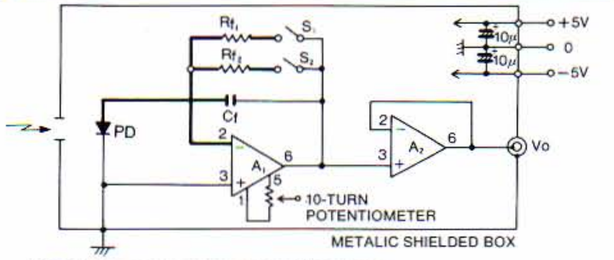
PD: PIN photodiodes, e.g. S1721, S2506, S2216
R_L: Determined by sensitivity and time constant of C_j of photodiode
R_S: Determined by operating point of FET
FET: 2SK19, 2SK152, 2SK316, etc.

② High speed light sensor



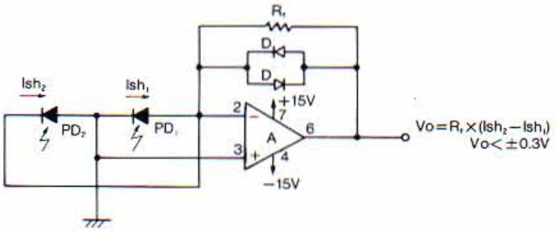
PD: PIN photodiodes, e.g. S1721, S2506, S2216
R_L: Determined by sensitivity and time constant of C_j of photodiode
A: HA2625, HA5162, LF357, etc.
V_O: $I_{sh} \times R_L \times 11$ (V)

③ Low level light sensor head



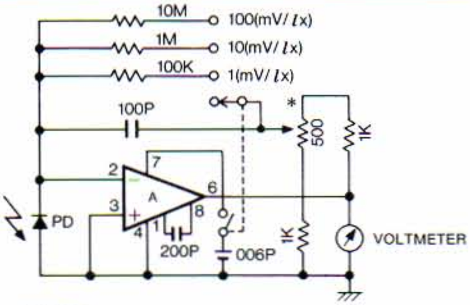
Bold lines require guarded or teflon wiring
A_1: AD515, OPA111, OPA128, etc.
A_2: OP-07
C_f: 10 to 10 pF polystyrene capacitor
R_f: Metal glaze resistor (up to 10 GΩ)
S: Low leakage reed relay
PD: S1226, S1336, S2386, etc.

④ Light balance detection circuit



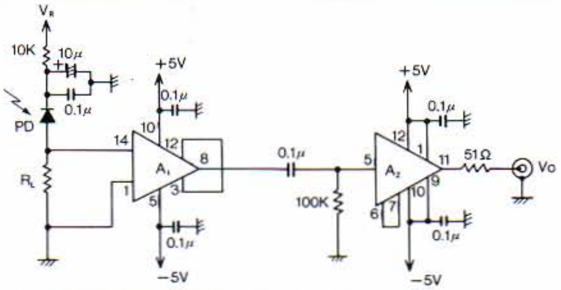
When equal light enters photodiodes, V_O is 0. In unbalanced state, V_O = ± 0.3 ~ 0.5V. Filter can be used for detection of specific wavelengths.

⑤ Illuminance meter



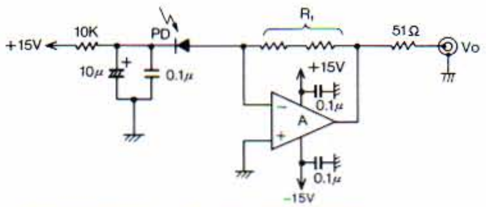
OP-Amp: CA3130
PD: S1133 (0.5 μA/100 lux)
*: Meter calibration V.R.

⑥ High speed light sensor using video amplifier



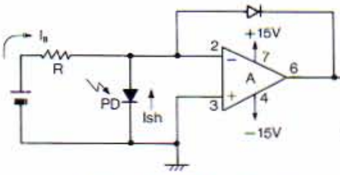
PD: PIN photodiodes, e.g. S1721, S2506, S2216
R_L: Determined by sensitivity and time constant of C_j of photodiode
A_1: LM733 (Under the conditions shown in the figure, G=20, B=90 MHz)
A_2: LH0033

⑦ Light sensor using high speed operational amplifier



PD: PIN photodiodes, e.g. S1721, S2506, S2216
R_f: Several resistors connected in series to eliminate parallel capacitance
A: LH0032

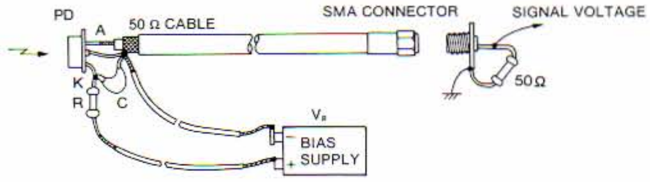
⑧ Light-to-logarithmic voltage conversion circuit



$$V_O \fallingdotseq -0.06 \log\left(\frac{I_{sh}+I_B}{I_0}+1\right) \text{(V)}$$

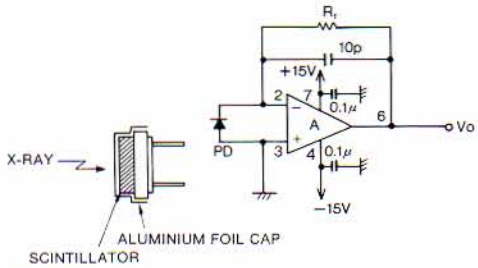
D_1: Logdiodes, S1853, ZU490 (Ferranti), etc.
I_B: Current source for setting operating point, $I_B \ll I_{sh}$
R: $10^9 \sim 10^{10}\Omega$
I_0: D_1 saturation voltage, $10^{-15} \sim 10^{-12}$ (A)
A: FET-input opamp

9 Ultra-high speed light detection using PIN photodiode



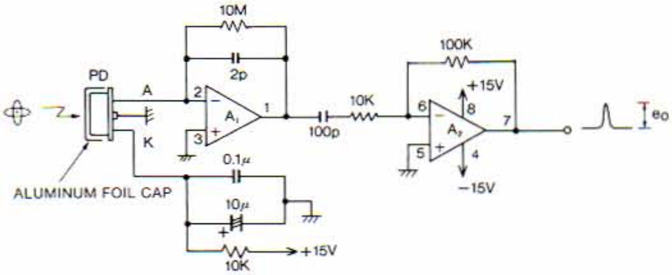
PD: PIN photodiodes, e.g. S1721, S2506, S2216
R: 10kΩ, Voltage drop by average photocurrent should be sufficiently smaller than V_R
C: 10000pF ceramic capacitors (3 pcs)
PD, C: Coaxial cable should be as short as possible

10 CT scanner, X-ray monitor



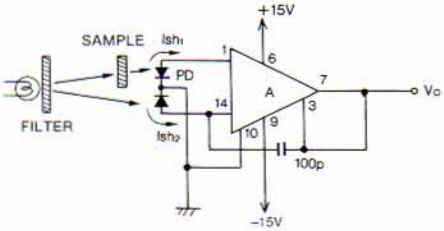
PD: S1337 series
R_f: 10 ~ 100MΩ
A: OPA111 etc.
Scintillator, CdWO, BGO, etc. adhered to photodiode

11 Gamma-ray, X-ray detector



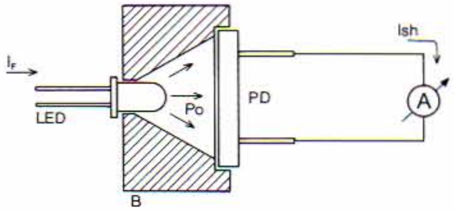
PD: S1722
A_1, A_2: LF442
e0: Several mV or tens of mV for cobalt 60

12 Light absorption meter



PD: S2841, S1446
A: LOG100 (Burr Brown)
Filter: Bandpass filter etc., when needed
V_{out} = log (I_{sh1}/I_{sh2}) [V]
Notes: When I_{sh1} is equal to I_{sh2} without the sample, absorbance A of the sample is a direct measure of V_{out}, i.e., A = $-V_{out}$

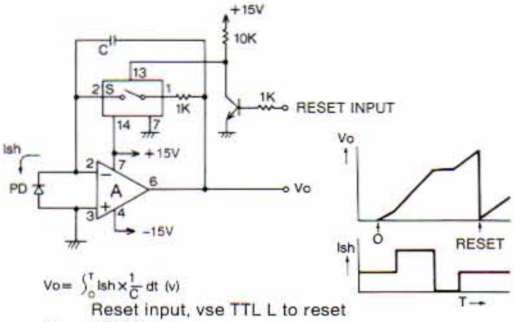
13 LED total light emission measurement



A: Ammeter, 1~10mA
PD: S2387-1010BR
B: Aluminnm block, inner metal plating
Po: Total light emission (W)
Refer to spectral response features chart for PD radiant sensitivity
Example: 0.6 A/W at 930 nm

P_o=Ish/R

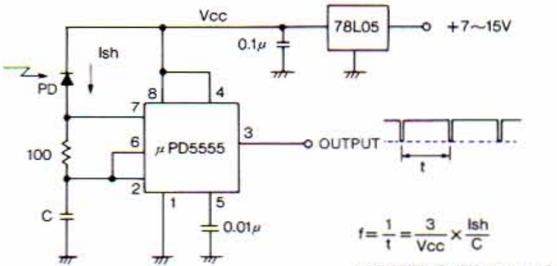
14 Light integration circuit



$Vo= \int_0^T Ish \times \frac{1}{C} dt$ (v)

Reset input, vse TTL L to reset
A: LF356 etc.
S: COMS 4066
PD: S1226, S1336, S2386 etc.
C: Polycarbonate capacitor

15 Light-to-frequency conversion circuit



$f = \frac{1}{t} = \frac{3}{Vcc} \times \frac{Ish}{C}$

μPD5555, CμOS timer IC

The operational amplifiers used in these circuit examples will differ in such factors as operating ambient temperature range, bias current, phase compensation, offset adjustment method, depending on the type used.
Typical Operational Amplifiers, Video and Buffer Amplifiers
Analog Devices AD515
Burr-Brown OPA111, OPA128
National Semiconductor LF357, LF356, LH0032, LH0033 LF442, LM733
Harris HA2625, HA5162
RCA CA3130, PMI OP-07 etc.

HAMAMATSU

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Main Products

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- PIN Silicon Photodiodes
- Silicon Avalanche Photodiodes
- GaAsP Photodiodes
- Photo IC
- PCD Linear Image Sensors
- Position-Sensitive Detectors
- Phototransistors
- Infrared Detectors
- CdS Photoconductive Cells
- Optoisolators
- Opto-Hybrid IC
- Infrared Emitters

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- Imaging Tubes
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