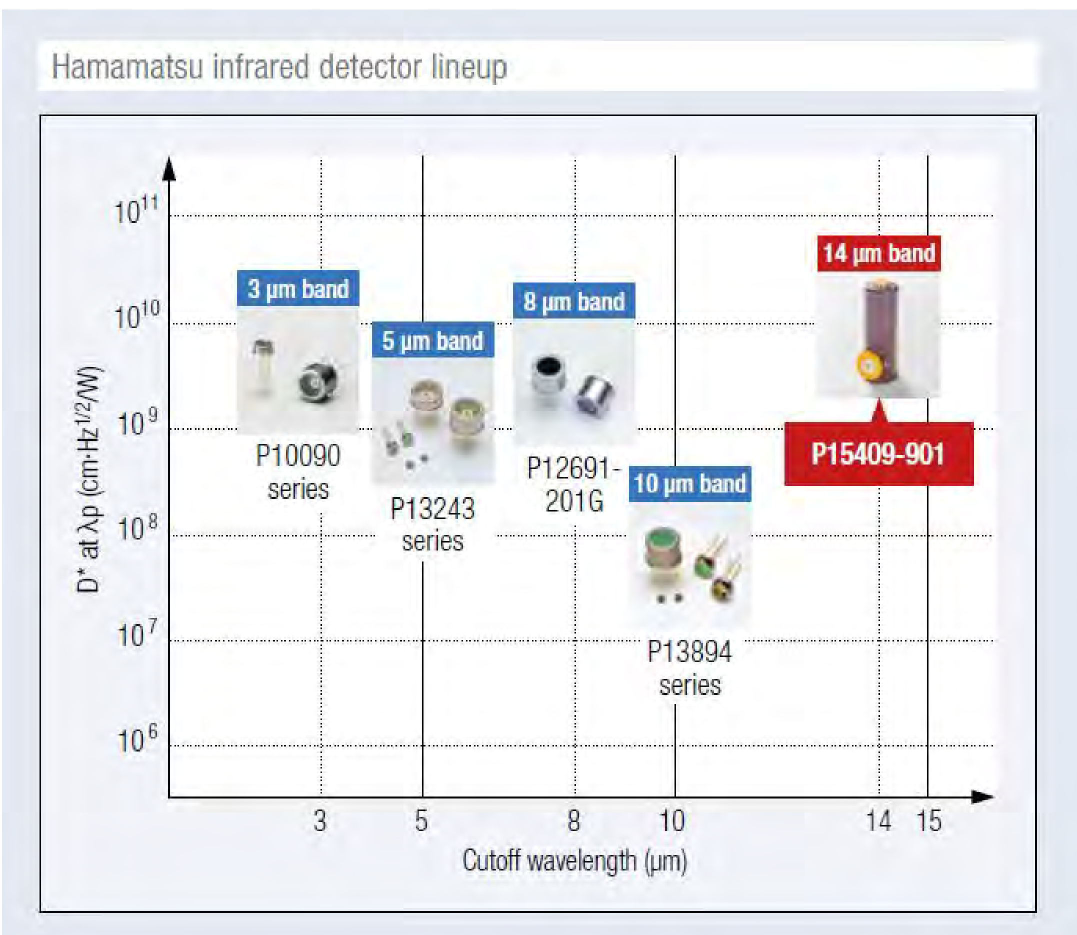
Compound semiconductor photosensors

Available from Boston Electronics - *shop.boselec.com*

Product name	Spectral response range (μm)	Features
InAs photovoltaic detectors	1 – 3.8	● Covers a spectral response range close to PbS but offers higher response speed
InSb photovoltaic detectors	1 – 5.5	● High sensitivity in so-called atmospheric window (3 to 5 μm) ● High-speed response
InSb photoconductive detectors	1 – 6.7	● Detects wavelengths up to around 6.5 μm, with high sensitivity over long periods of time by thermoelectric cooling
InAsSb photovoltaic detectors	1 – 11	● Infrared detector with cutoff wavelength of 5 μm, 8μm or 10 μm bands ● High-speed response and high reliability
Type Ⅱ superlattice infrared detector	1 – 14.5	● InAs and GaSb superlattice structure enables the detection up to around 14.5 μm



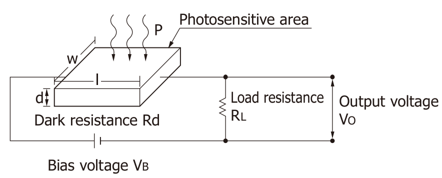
3. InSb photoconductive detectors

InSb photoconductive detectors are infrared detectors capable of detecting light up to approx. 6.5 µm. InSb photoconductive detectors are easy to handle since they are thermoelectrically cooled (liquid nitrogen not required).

3 - 1 Operating principle

When infrared light enters an InSb photoconductive detector, the number of carriers increases, causing its resistance to lower. A circuit like that shown in Figure 3-1 is used to extract the signal as a voltage, and photosensitivity is expressed in units of V/W.

[Figure 3-1] Output signal measurement circuit for photoconductive detector



The output voltage (Vo) is expressed by equation (3-1).

$$V_O = \frac{R_L}{R_d + R_L} \cdot V_B \quad \cdots\cdots (3\text{-}1)$$

The change (ΔVo) in Vo, which occurs due to a change (ΔRd) in the dark resistance (Rd) when light enters the detector, is expressed by equation (3-2).

$$\Delta V_O = -\frac{R_L V_B}{(R_d + R_L)^2} \cdot \Delta R_d \quad \cdots\cdots (3\text{-}2)$$

ΔRd is then given by equation (3-3).

$$\Delta R_d = -R_d \frac{q(\mu_e + \mu_h)}{\sigma} \cdot \frac{\eta \tau \lambda P A}{l w d h c} \quad \cdots\cdots (3\text{-}3)$$

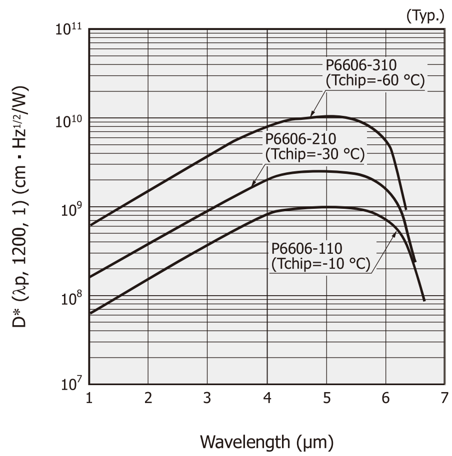
q : electron charge
μ_e: electron mobility
μ_h: hole mobility
σ : electric conductivity
η : quantum efficiency
τ : carrier lifetime
λ : wavelength
P : incident light level [W/cm²]
A : photosensitive area [cm²]
h : Planck's constant
c : speed of light in vacuum

3 - 2 Characteristics

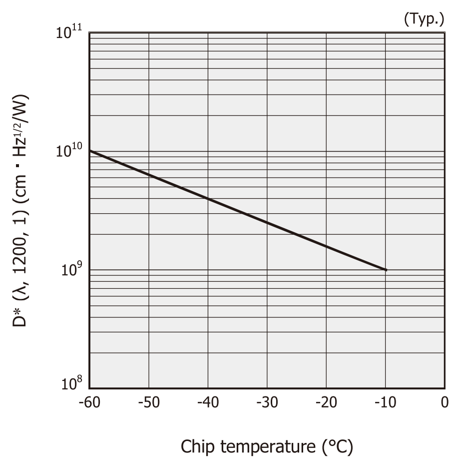
Spectral response

The band gap energy in InSb photoconductive detectors has a positive temperature coefficient, so cooling the detector shifts its cutoff wavelength to the short-wavelength side. This is the same for InSb photovoltaic detectors.

[Figure 3-2] Spectral response

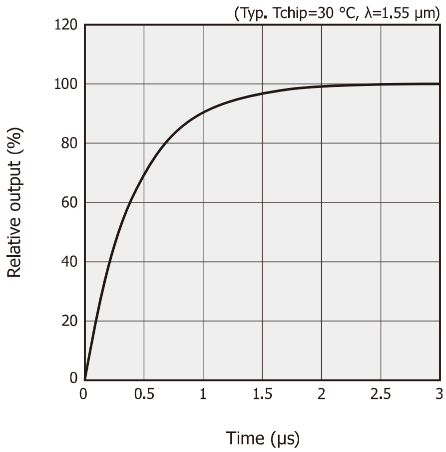


[Figure 3-3] D* vs. chip temperature (P6606-310)



Response characteristics

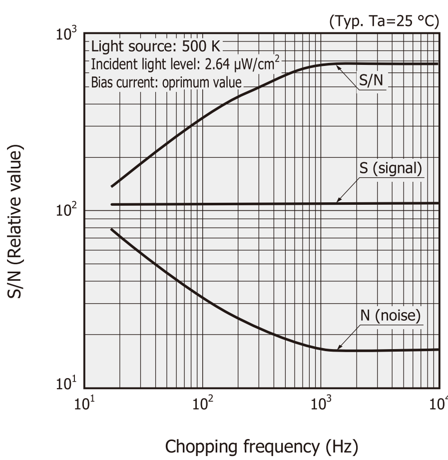
[Figure 3-4] Response characteristics (P6606-310)



Noise characteristics

Noise components in InSb photoconductive detectors include 1/f noise, g-r noise caused by electron-hole recombination, and Johnson noise. The 1/f noise is predominant at low frequencies below several hundred hertz, and the g-r noise is predominant at frequencies higher than that level. Figure 3-7 shows the relationship between the noise level and frequency for InSb photoconductive detectors. Narrowing the amplifier bandwidth will reduce the noise. Especially in low-light level measurement, the chopping frequency and bandwidth must be taken into account.

[Figure 3-7] S/N vs. chopping frequency

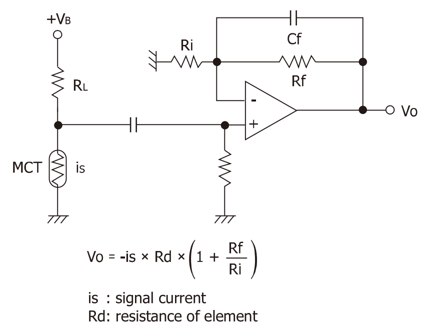


3 - 3 How to use

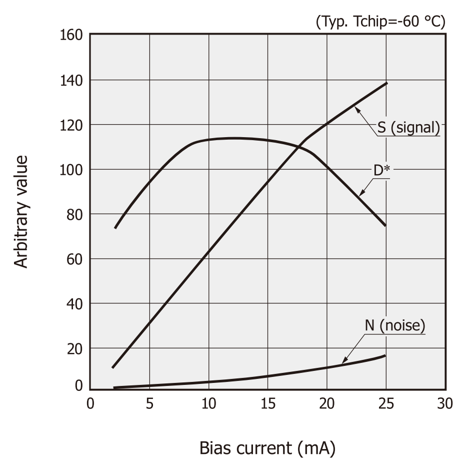
Operating circuit

Figure 3-5 shows a connection example for InSb photoconductive detectors. A power supply with low noise and ripple should be used. A load resistance (RL) of several kilohms is generally used to make it a constant current source. As the bias current is raised, both the signal and noise increase [Figure 3-6]. But the noise begins to increase sharply after reaching a particular value, so the bias current should be used in a range where the D* becomes constant. Raising the bias current more than necessary increases the chip temperature due to Joule heat and degrades the D*. This might possibly damage the detector so it should be avoided.

[Figure 3-5] Connection example



[Figure 3-6] Signal, noise, and D* vs. bias current (P6606-310)



Temperature compensation

Since the sensitivity and dark resistance of InSb photoconductive detectors drift according to the chip temperature, some measures must be taken to control

4. InAs/InAsSb/InSb photovoltaic detectors

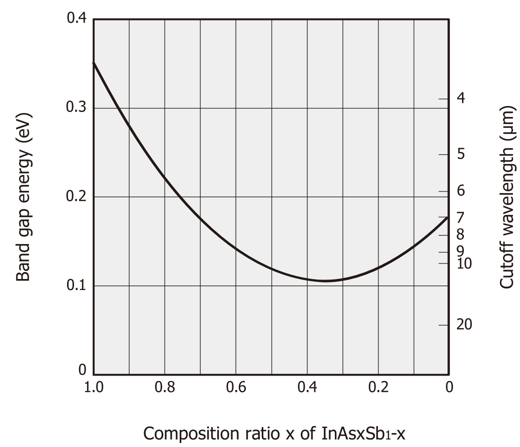
As with InGaAs PIN photodiodes, InAs/InAsSb/InSb photovoltaic detectors are infrared detectors having a PN junction. InAs photovoltaic detectors are sensitive around 3 µm, the same as PbS photoconductive detectors, while InSb photovoltaic detectors are sensitive to the 5 µm band, the same as PbSe photoconductive detectors. InAsSb photovoltaic detectors deliver high sensitivity in the 5 µm, 8 µm, or 10 µm band.

4 - 1 Characteristics

Spectral response

Controlling the composition of $InAs_xSb_{1-x}$, which is a III-V family compound semiconductor material, enables the fabrication of detectors whose cutoff wavelength at room temperature ranges from 3.3 µm (InAs) to 12 µm ($InAs_{0.38}Sb_{0.62}$).

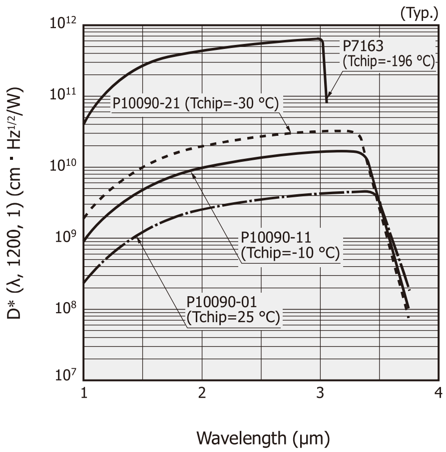
[Figure 4-1] Band gap energy and peak sensitivity wavelength vs. composition ratio x of $InAs_xSb_{1-x}$



InAs photovoltaic detectors include a non-cooled type, TE-cooled type (Tchip=-10 °C, -30 °C), and liquid nitrogen cooled type (Tchip=-196 °C) which are used for different applications. InAsSb photovoltaic detectors are available in non-cooled type and TE-cooled type (Tchip=-30 °C), and the non-cooled type includes a type with a band-pass filter and a two-element type that can detect two wavelengths. InSb photovoltaic detectors are only available as liquid nitrogen cooled types. Figure 4-2 shows spectral responses of InAs/InAsSb/InSb photovoltaic detectors. Cooling these detectors shifts their cutoff wavelengths to the shorter wavelength side.

[Figure 4-2] Spectral response

(a) InAs photovoltaic detectors



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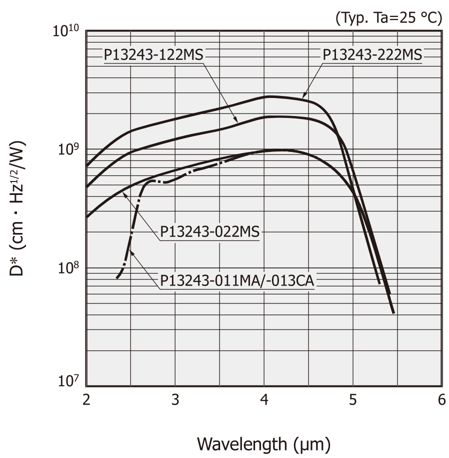
(b) InAsSb photovoltaic detectors (cutoff wavelength: 5 μm band)



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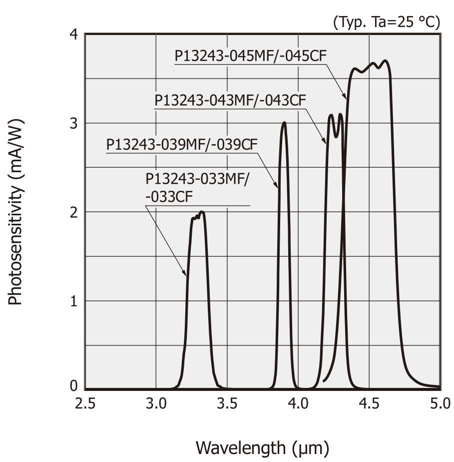
(c) InAsSb photovoltaic detectors with band-pass filter



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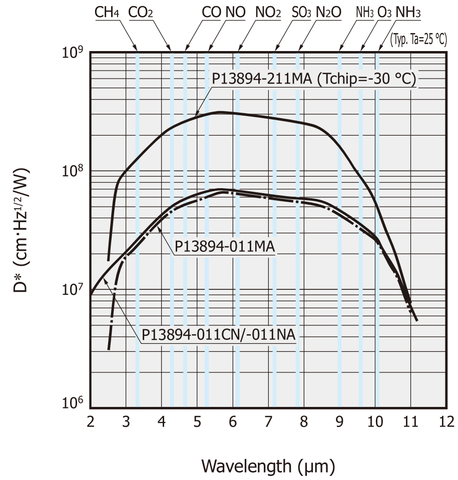
(d) InAsSb photovoltaic detectors (cutoff wavelength: 10 μm band)



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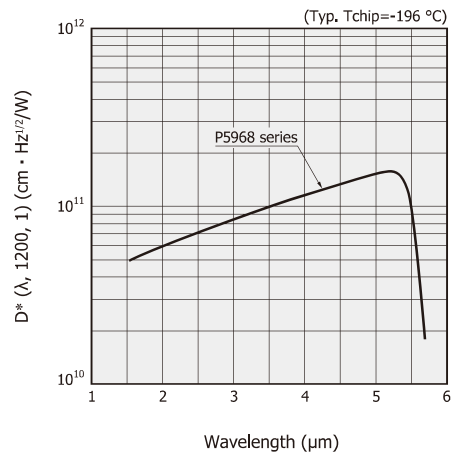
(e) InSb photovoltaic detectors



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Noise characteristics

InAs/InAsSb/InSb photovoltaic detector noise (i) results from Johnson noise (ij) and shot noise (isD) due to dark current (including photocurrent generated by background light). Each type of noise is expressed by the following equations:

$$i = \sqrt{ij^2 + isD^2} \quad \cdots\cdots\cdots\cdots\cdots (4\text{-}1)$$

$$ij = \sqrt{4k\ T\ B/Rsh} \quad \cdots\cdots\cdots\cdots (4\text{-}2)$$

$$isD = \sqrt{2q\ I_D\ B} \quad \cdots\cdots\cdots\cdots\cdots (4\text{-}3)$$

k : Boltzmann's constant
T : absolute temperature of element
B : noise bandwidth
Rsh: shunt resistance
q : electron charge
ID : dark current

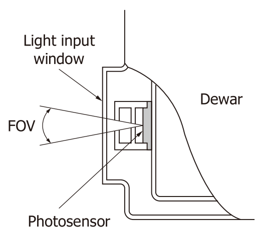
When considering the spectral response range of InSb photovoltaic detectors, background light fluctuations (background radiation noise) from the surrounding areas cannot be ignored. The D* of photovoltaic detectors is given by equation (4-4) assuming that the background radiation noise is the only noise source.

$$D^* = \frac{\lambda\sqrt{\eta}}{h\,c\sqrt{2Q}}\ [\mathrm{cm\cdot Hz^{1/2}/W}] \cdots\cdots (4\text{-}4)$$

λ : wavelength
η : quantum efficiency
h : Planck's constant
c : speed of light
Q: background photon flux [photons/cm^2·s]

To reduce background radiation noise, the detector's field of view (FOV) must be limited by using a cold shield or unwanted wavelengths must be eliminated by using a cooled band-pass filter. Figure 4-4 shows how the D* relates to the field of view.

[Figure 4-3] Field of view (FOV)



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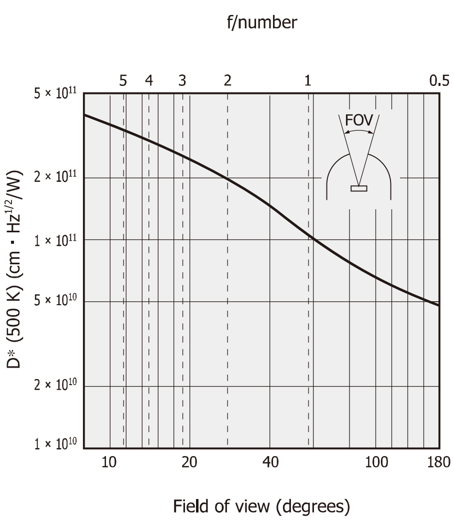
[Figure 4-4] D* vs. field of view (P5968-060, typical example)



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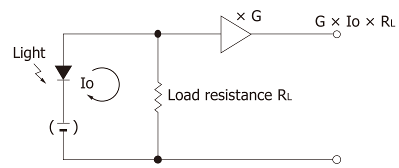
4 - 2 How to use

Operating circuit

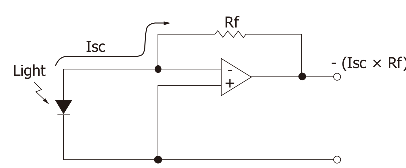
Figure 4-5 shows connection examples for InAs/InAsSb/InSb photovoltaic detectors. The photocurrent is extracted as a voltage using a load resistor or op amp. When connecting an op amp to an InAs/InAsSb photovoltaic detector with low shunt resistance, we recommend the use of an op amp with low voltage noise.

[Figure 4-5] Connection examples

(a) When load resistor is connected



(b) When op amp is connected



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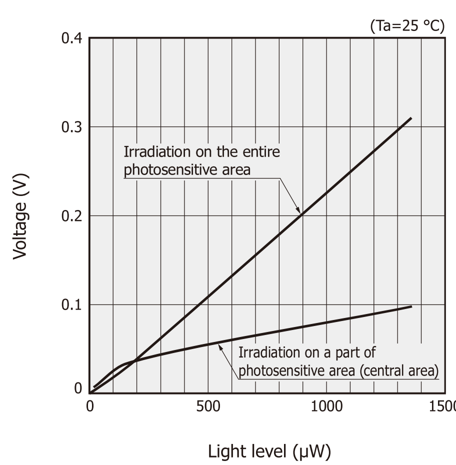
Light incidence

The P12691-201G has a lens built in the product, so it uses collimated light for light incidence. Focusing light in front of the detector may reduce the output.
When using the P13243 series or P13894 series, it is necessary to irradiate the entire photosensitive area uniformly. If you irradiate only a part of the photosensitive area, the output signal may become smaller and linearity may deteriorate [Figure 4-6].

[Figure 4-6] Linearity (P13243 series, typical example)



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Resistance measurement

Measuring the resistance of InAs/InAsSb/InSb photovoltaic detectors with a multimeter might damage the detectors. This risk is even higher at room temperature, so always cool the detector when making this measurement. In this case, the bias voltage applied to the device must be less than the value of the absolute maximum ratings.

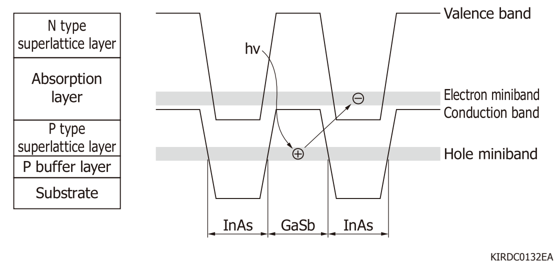
5. Type Ⅱ superlattice infrared detector

Type Ⅱ superlattice infrared detector is a photovoltaic detector with sensitivity expanded to the 14 μm band using Hamamatsu unique crystal growth technology and process technology. This product is an environmentally friendly infrared detector and does not use mercury or cadmium, which are substances restricted by the RoHS Directive. It is a replacement for conventional products that contain these substances.

5 - 1 Structure

By stacking thin films of InAs and GaSb alternately, energy bands (minibands) which are not found in bulk crystals are formed. The position of the miniband can be controlled by changing its thickness and composition.

[Figure 5-1] Cross-sectional structure and energy levels

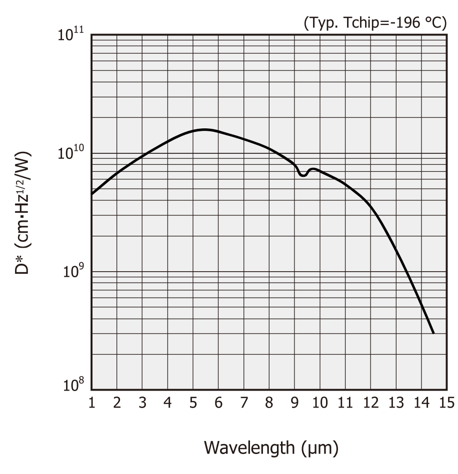


5 - 2 Characteristics

Spectral response

Type Ⅱ superlattice infrared detector is liquid nitrogen cooled type. Figure 5-2 shows spectral response.

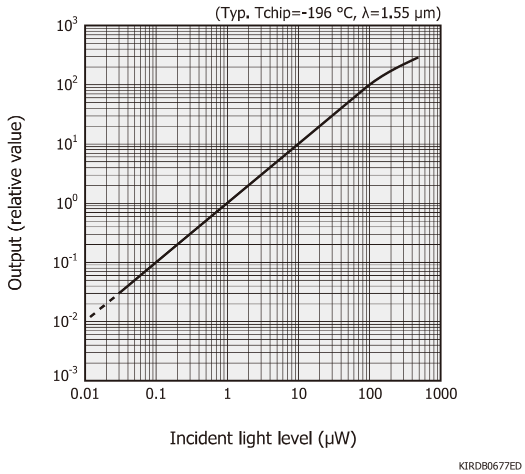
[Figure 5-2] Spectral response



Linearity

The linearity of type II superlattice infrared detectors is about two orders of magnitude better than a conventional MCT photoconductive detector.

[Figure 5-3] Linearity



5 - 3 How to use

Operating circuit

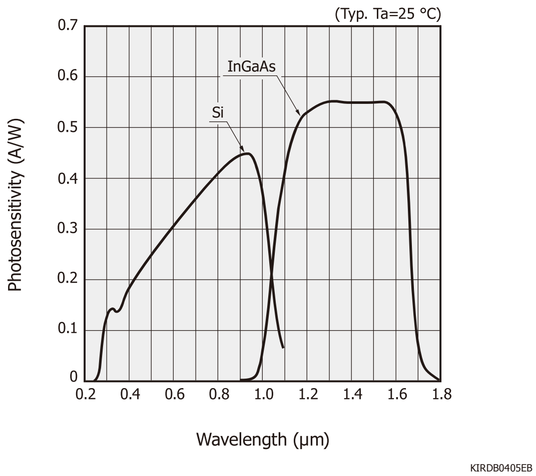
Using an op amp, the photocurrent is converted into voltage and then the converted voltage is output. For details, see "1. InGaAs PIN photodiodes | 1-2 How to use (P.8)".

Background radiation

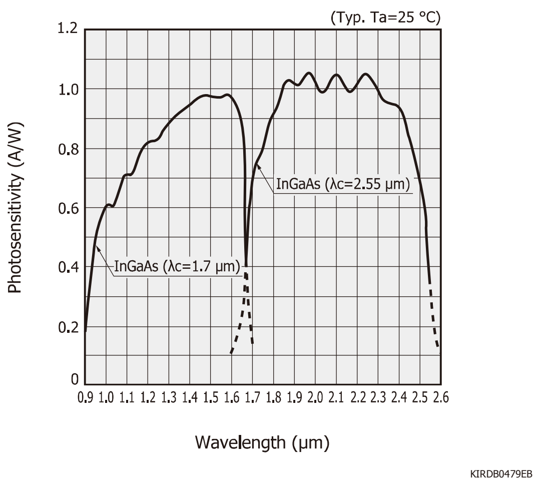
In infrared measurement, background radiation that is not the signal light affects the measurement. Use a cold shield to set the proper FOV, so as to avoid detecting background radiation.

[Figure 6-2] Spectral response

(a) Si + InGaAs



(b) Standard type InGaAs + long wavelength type InGaAs

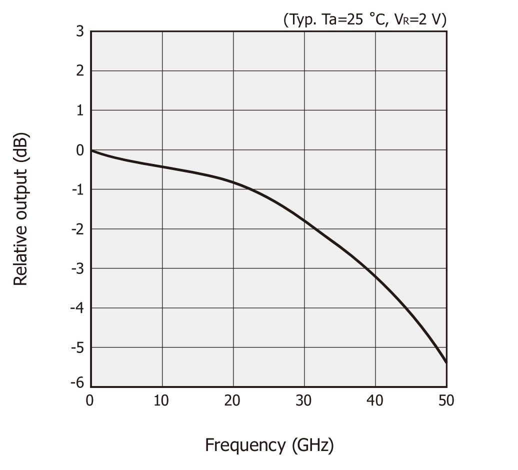


7. New approaches

7 - 1 Ultra high-speed InGaAs PIN photodiodes

As ultra high-speed response photosensors, the product demand for higher-speed photodiodes is on the rise in addition to 25 Gbps and 50 Gbps photodiodes. In this case, it is essential to keep the cost of the system itself from rising, so low power consumption and ease of assembling are required. To ensure the S/N, reduction in sensitivity from previous products is not acceptable. The photodiodes must maintain the present photosensitivity as much as possible and operate at high speed under a low reverse voltage. At the same time, the manufacturing process must integrate optical techniques to guide as much light as possible into a small photosensitive area. We have produced an ultra high-speed InGaAs PIN photodiode that operates from a low reverse voltage and verified its operation on transmission bands up to 64 Gbps at V_R=2 V in combination with an optimum preamp. We are currently working to achieve even higher speeds.

[Figure 7-1] Frequency characteristics



9 - 5 Radiation thermometers

Any object higher than absolute zero degrees radiates infrared light matching its own temperature. The quantity of infrared light actually emitted from an object is not directly determined just by the object temperature but must be corrected according to the object's emissivity (e).
Figure 9-5 shows the radiant energy from a black body. The black body is e=1. Figure 9-6 shows the emissivity of various objects. The emissivity varies depending on temperature and wavelength.
The noise equivalent temperature difference (NEΔT) is used as one measure for indicating the temperature resolution. NEΔT is defined in equation (9-1).

$$\mathrm{NE\Delta T} = \frac{L_N}{\left.\frac{dL}{dT}\right|_{T=T_1}} \quad \cdots\cdots\cdots (9\text{-}1)$$

L_N: noise equivalent luminance
T_1: temperature of object

Noise equivalent luminance (L_N) relates to the detector NEP as shown in equation (9-2).

$$\mathrm{NEP} = T_o \, L_N \, \Omega \, A_o / \gamma \quad \cdots\cdots\cdots (9\text{-}2)$$

T_o : optical system loss
Ω : solid angle from optical system toward measurement area
A_o: aperture area of optical system
γ : circuit system loss

$\left.\frac{dL}{dT}\right|_{T=T_1}$ in equation (9-1) represents the temperature coefficient of radiant luminance (L) from an object at temperature T_1. The radiant luminance can be obtained by integrating the spectral radiant exitance over the wavelength range (λ_1 to λ_2) being observed.

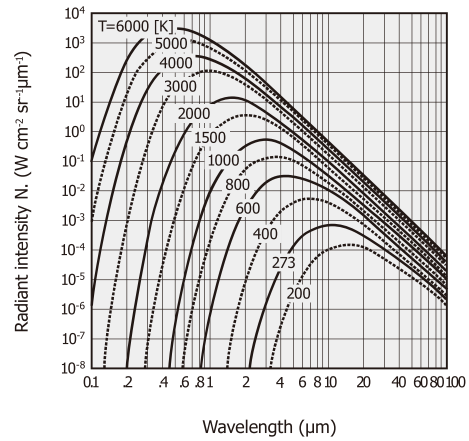
$$L = \int_{\lambda_1}^{\lambda_2} \frac{1}{\pi} M_\lambda \, d\lambda \quad \cdots\cdots\cdots (9\text{-}3)$$

M_λ: spectral radiant exitance

Radiation thermometers offer the following features compared to other temperature measurement methods.

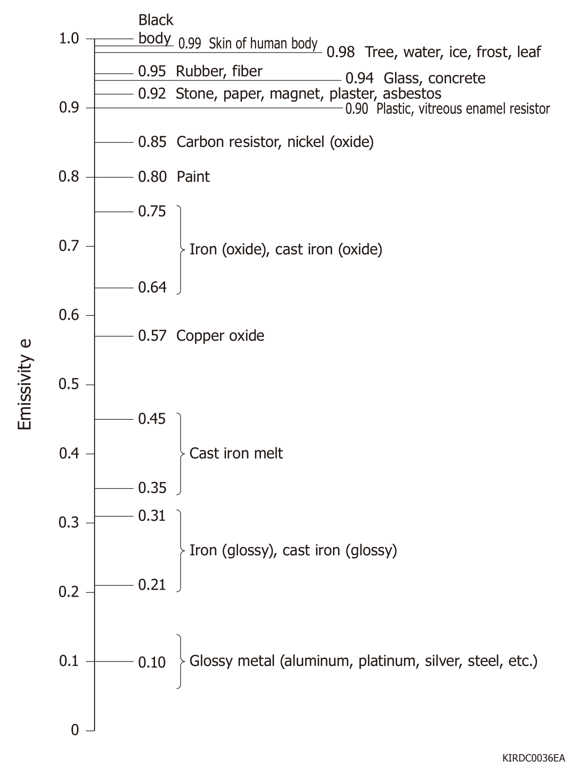
· Non-contact measurement avoids direct contact with object.
· High-speed response
· Easy to make pattern measurements

[Figure 9-5] Black body radiation law (Planck's law)



Infrared detectors for radiation thermometers should be selected according to the temperature and material of the object to be measured. For example, peak emissivity wavelength occurs at around 5 μm in glass materials and around 3.4 μm or 8 μm in plastic films, so a detector sensitive to these wavelength regions must be selected.
Infrared detectors combined with an infrared fiber now make it possible to measure the temperature of objects in hazardous locations such as complex internal structures, and objects in a hot, vacuum, or in high-pressure gases.

[Figure 9-6] Emissivity of various objects



9 - 12 FTIR

The FTIR (Fourier transform infrared spectrometer) is an instrument that acquires a light spectrum by Fourier-transforming interference signals obtained with a double-beam interferometer. It has the following features:

· High power of light due to non-dispersive method (simultaneous measurement of multiple spectral elements yields high S/N)
· High wavelength accuracy

The following specifications are required for infrared detectors that form the core of the FTIR.

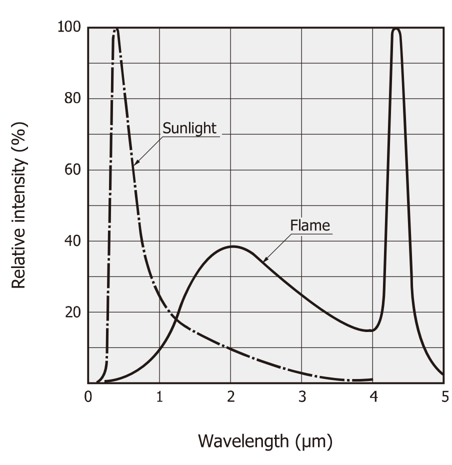
· Wide spectral response range
· High sensitivity
· Photosensitive area size matching the optical system
· Wide frequency bandwidth
· Excellent linearity versus incident light level

Thermal type detectors are generally used over a wide spectral range from 2.5 µm to 25 µm. Quantum type detectors such as InAs, InAsSb, and InSb are used in high-sensitivity and high-speed measurements.

9 - 7 Flame eyes (flame monitors)

Flame eyes detect light emitted from flames to monitor the flame burning state. Radiant wavelengths from flames cover a broad spectrum from the ultraviolet to infrared region as shown in Figure 9-9. Flame detection methods include detecting a wide spectrum of light from ultraviolet to infrared using a two-color detector, and detecting near infrared region or light with 4.3 µm wavelength using an InAsSb photovoltaic detector.

[Figure 9-9] Radiant spectrum from flame



9 - 9 Gas analyzers

Gas analyzers measure gas concentrations by making use of the fact that gases absorb specific wavelengths of light in the infrared region. Gas analyzers basically utilize two methods: a dispersive method and a non-dispersive method. The dispersive method disperses infrared light from a light source into a spectrum and measures the absorption amount at each wavelength to determine the constituents and quantities of the sample. The non-dispersive method measures the absorption amounts only at particular wavelengths. The non-dispersive method is currently the method mainly used for gas analysis. Non-dispersive method gas analyzers are used for measuring automobile exhaust gases (CO, CH, CO_2) and exhaled respiratory gas components (CO_2), as well as for regulating fuel exhaust gases (COx, SOx, NOx) and detecting fuel leaks (CH_4, C_2H_6). Further applications include CO_2 (4.3 µm) measurements in carbonated beverages (soft drinks, beer, etc.) and sugar content (3.9 µm) measurement. Figure 9-10 shows absorption spectra of various gases.
Hamamatsu provides InGaAs, InAs, InAsSb, InSb, and the like. as sensors to measure the various light wavelengths. Quantum cascade lasers (QCL; middle infrared semiconductor lasers) are also available for use in gas analyzers. There is a lineup of products with specific oscillation wavelength in the middle infrared region (4 to 10 µm).

[Figure 9-10] Gas absorption spectra