# Characteristics of a Photodiode

## Spectral Response

The magnitude of the photocurrent generated by a photodiode is dependent upon the wavelength of the incident light. Silicon photodiodes exhibit a response from the ultraviolet through the visible and into the near infrared part of the spectrum. The spectral response peaks in the near infrared region between 800 nm and 950 nm. The shape of the spectral response curve, especially in the blue and UV part of the spectrum, can be altered by choosing among a number of manufacturing processes developed at PerkinElmer. An example of this is the “blue enhanced” photodiode whose sensitivity to light from the short wavelength part of the spectrum has been increased. Optical filters can also be added to change the spectral response.

There are several popular ways to characterize the spectral response, following are brief descriptions of the most common ones.

## Radiometric Sensitivity - $S_R$

Sr is the ratio of the short-circuit photocurrent generated by the photodiode (A-amps) divided by the energy of the incident light (W-watts). For photodiodes made with the VTS process, a typical radiometric sensitivity of 0.6 A/W can be expected at the peak spectral response wavelength of 925 nm. Curves of this measure of sensitivity are often plotted with the $S_R$ normalized in order to show relative spectral response.

$$S_R = I_{SC} / \Phi$$

where:

$S_R$ = radiometric sensitivity (A/W)

$I_{SC}$ = short circuit photocurrent (A)

$\Phi$ = radiant flux (W)

## Responsivity - Re

Re is a measure of sensitivity which takes into account the active area of the photodiode chip. This parameter is obtained by dividing the short-circuit light current (mA-microamps) by the energy of the light per unit area (µW/cm$^2$).

$$R_e = I_{SC}/E_e$$

where:

$R_e$ = responsivity (µA/[µW/cm$^2$])

$I_{SC}$ = short circuit photocurrent (µA)

$E_e$ = irradiance (µW/cm$^2$)

The VTP1188S has a typical responsivity of 0.15 µA/(µW/cm$^2$) @ 940 nm.

## Quantum Efficiency - Q.E.

If the photodiode operated at 100% efficiency each photon of light striking the detector would result in one electron being added to the photocurrent. The Q.E. relates, as a percentage, the energy per photon and the quantum yield, electrons per photon.

$$\text{Q.E.} = (124\ S_R)/\lambda$$

where:

Q.E. = quantum efficiency (%)

$S_R$ = radiometric sensitivity (A/W)

$\lambda$ = wavelength of light (micrometer)

The VTP process produces devices with a Q.E. of 75% @ 940 nm.

The responsivity of a silicon photodiode varies with temperature dependent upon the wavelength of the light. Curves in the data sheet section show plots of the responsivity temperature coefficient versus wavelength of light. The temperature coefficient is negative at the shorter wavelength of light and becomes positive in the infrared part of the spectrum. Of interest is the fact that for most diodes there is a range of wavelengths where the temperature coefficient is effectively zero.

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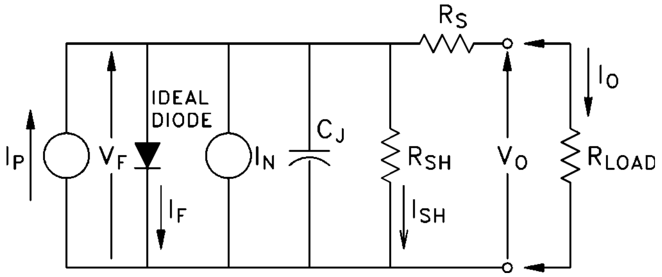
## Sensitivity

One of the standard methods used to specify the sensitivity of a photodiode is to state its short circuit photocurrent ($I_{SC}$) at a given light level from a well defined light source. The most commonly used source is an incandescent tungsten lamp running at a color temperature at 2850 K. At 100 fc, $I_{SC}$ can vary over a range from microamps to milliamps depending on chip size and package employed.

Photodiodes have unity internal gain. In order to increase their sensitivity to light one can either increase the active area of the photodiode chip itself or use lenses to increase the effective active area. The relationship between active area and sensitivity tends to be linear: doubling the active area doubles the output current.

## Linearity

Shown below is the equivalent circuit for a photodiode. Under zero applied reverse bias the photocurrent will divide between the internal junction or shunt resistance and the external load resistance.



where

$I_P$ = light generated photocurrent
$V_F$ = forward voltage drop across diode
$I_F$ = forward current through diode
$I_N$ = noise current
$C_J$ = junction capacitance
$R_{SH}$ = shunt resistance
$I_{SH}$ = shunt current
$R_S$ = series resistance
$V_O$ = output voltage
$I_O$ = output current

For an ideal photodiode, $R_S = 0$ and $R_{SH}$ = infinity.

$$I_O = I_P - I_F$$

If the external terminals are shorted together a short circuit photocurrent $I_{SC}$ will flow. When this happens, for the ideal case, $V_F = 0$.

$$I_{SC} = I_P \text{ (ideal case)}$$

For the real world case:

$$I_O = I_P - I_F - I_{SH}$$
$$I_{SC} = I_P - I_{SAT}\,(e^{qV_F/KT} - 1) - I_{SC}R_S / R_{SH}$$

where:

$$KT/q = 0.026 \text{ @ } 25°C$$

and since $V_O = 0$, thus: $V_F = I_{SC}\,R_S$

$$I_{SC} = I_P - I_{SAT}\,(e^{q(I_{SC}R_S)/KT} - 1) - (I_{SC}\,R_S)/\,R_{SH}$$

For the non ideal case the second and third term of the above equation limit the linearity. In order to achieve good linearity $R_S$ should be made as small as possible and $R_{SH}$ as large as possible.

Despite these shortcomings the short circuit light current is often quite linear over a wide range of light intensities. Excellent linearity over 6 to 9 decades of light intensity can be expected. As a consequence of this behavior photodiodes are often used in applications where absolute measurement of light intensity is required.

At low light levels linearity is limited by the dark (or shunt) resistance and the noise current. At high levels of irradiance linearity is limited by the internal series resistance of the photodiode.

## Dark Current ($I_D$)

The dark current is the leakage current that flows when the photodiode is in the dark and a reverse voltage is applied across the junction. This voltage is applied across the junction. This voltage may be as low as 10 mV or as high as 50 V and the dark currents may vary from pA to µA depending upon the junction area and the process used. Dark current is always specified at a particular value of reverse applied voltage.

The dark current is temperature dependent. The rule of thumb is that the dark current will approximately double for every 10°C increase in ambient temperature. However, specific diode types can vary considerably from this relationship.

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## Shunt Resistance ($R_{SH}$)

The shunt resistance, or dynamic junction resistance at zero voltage is determined by applying a small voltage to the photodiode, typically 10 mV, and measuring the resulting current. Values for the shunt resistance can vary from 100k to 100G ohms. The noise performance and the linearity of the short circuit photocurrent are directly related to the value of the shunt resistance. This parameter is voltage dependent but still is quite useful in calculating the offset gain ($G_{OS} = 1 + R_F / R_{SH}$) in transimpedance amplifier circuits.

The shunt resistance is dependent on the active area of the diode chip and on the type of processing used. It is also temperature dependent, decreasing with increasing temperature.

## Junction Capacitance ($C_J$)

A capacitance is associated with the depletion region which exists at the P-N junction. The response time of a photodiode is dependent to a large extent upon the product of the junction capacitance and the external load resistor.

The junction capacitance increases with increasing junction area of the photodiode chip. It is also a function of any reverse voltage applied across the photodiode. When a reverse voltage is applied the depletion layer will expand and the junction capacitance will decrease. The capacitance will continue to decrease with increasing reverse applied voltage until the depletion region expands to the back surface of the photodiode chip at which point the diode's capacitance becomes nearly constant.

## Reverse Breakdown Voltage ($V_{BR}$)

This is the maximum reverse voltage that can safely be applied across the photodiode before breakdown occurs at the junction. The breakdown voltage is determined by the process but is a screened parameter. The diode should never be exposed to $V_{BR}$ even for a short period of time since permanent damage can occur. Diodes normally intended for photovoltaic operation do not have this parameter specified. Typical values for $V_{BR}$ range from 5V to over 100V.

## Open Circuit Voltage ($V_{OC}$)

The open circuit voltage is the voltage generated by the photodiode when the photocurrent is equal to zero. $V_{OC}$ varies logarithmically with light. $V_{OC}$ is typically in the range of 300 mV to 450 mV @ 100 fc. Due to its large temperature coefficient $V_{OC}$ is not recommended as an accurate measure of light level.

## Response Time

A photodiode takes a certain amount of time to respond to a sudden change in light levels. It is common practice to express to response time in terms of the rise time ($t_R$) or the fall time ($t_F$) where:

$t_R$ = The time required for the output to rise from 10% to 90% of its final value.

$t_F$ = The time required for the output to fall from 90% to 10% of its on state value.

The response time of a photodiode depends upon many factors, including the wavelength of the light, the value of the applied voltage across the diode (since this has a major effect of the junction capacitance), and the load resistance.

Characteristic curves given with each process show that the non-saturated response time is largely dependent upon the product of the junction capacitance and load resistance. However, when this product is small, other effects become significant and limit the response time. For a more complete treatment of this subject the interested reader is referred to Application Note #3.

## Noise Current ($I_N$)

A photodiode will act as a source for electrical noise and generate a noise current ($I_N$). The noise current will limit the usefulness of the photodiode at very low light levels where the magnitude of the noise approached that of the signal photocurrent. The amount of noise generated is dependent upon the characteristics of the photodiode and the operating conditions.

# Characteristics of a Photodiode

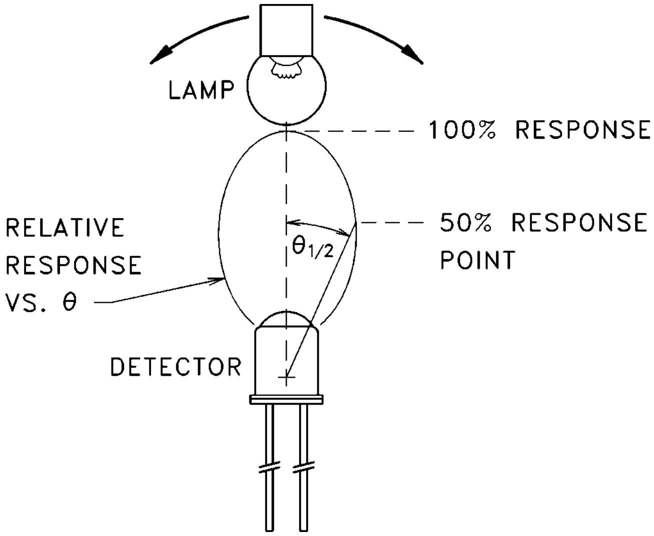
There are three main components which go into making up the total noise generated by the photodiode; thermal noise, shot noise, and flicker noise. Thermal (or Johnson noise) is inversely related to the value of the shunt resistance ($R_{SH}$) of the photodiode. Thermal noise tends to be the dominant noise component when the diode is operated under zero applied reverse bias conditions.

Shot noise is dependent upon the leakage or dark current ($I_D$) of the photodiode. It tends to dominate when the photodiode is used in the photoconductive mode where an external reverse bias is applied across the device.

Flicker noise is unlike thermal or shot noise in that it possesses a 1/f spectral density. Flicker noise may dominate when the bandwidth of interest contains frequencies less than 1 kHz. For a more detailed discussion of noise the reader may refer to Application Note #5.

## Angular Response

The angular response of a detector is basically a measure of its field of view. A photodiode in chip form would have a 180° field of view. A chip in a TO-18 package would have a narrower field of view due to the height of the wall of the package and any lensing caused by the window. Typically the output of the detector is at a maximum when the light source is directly overhead. As the light source is swung in an equal distance arc around the detector, an angle is reached where the signal from the detector is 1/2 of that when the light source was directly overhead. This point is defined as the 1/2 power angle ($\theta_{1/2}$).



## Package Style

Diodes presented in this catalog are mounted in several different types of packages or may be purchased unmounted. In general, the style of package chosen will have an influence on the electro-optical characteristics of the photodiode and the temperature range it can safely be exposed to.

Hermetic packages have glass to metal seals. The chips are typically mounted directly to the inside of the package. In special cases the chip might be isolated from the package in order to allow the metal package to be grounded, therefore reducing noise pickup in high gain circuits. Hermetic packages are quite rugged and are well suited for high humidity environments. However, some care must be used to prevent stress to the glass seals around the wires and lens.

Ceramic packages utilize an epoxy coating to protect the chip. In this type of packaging scheme the photodiode chip is placed down onto a metallized ceramic substrate which has leads exiting through the back surface. After bonding, the chip is coated with a clear epoxy. This represents a low cost approach to packaging large area chips.

Epoxy packages may be molded of cast. The photodiode chip is place down on a metal leadframe and then is completely encased in molded or cast epoxy. This is the lowest cost packaging scheme.

Unmounted cells in the VTS series are fragile, especially when the area is large. The front and back electrodes are solder coated and may be soldered using a 60/40 tin-lead solder. The flux should be active so that the joint may be made quickly to minimize heating. Whenever possible, it is recommended that soldering be done by PerkinElmer since excessive heat may degrade the device parameters. Avoid handling leadless cells with bare fingers.

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## Temperature Ratings

| Package Type | Storage | Operating |
|---|---|---|
| Hermetic | | |
| Chips < .040" x .040" | -55°C to 125°C | -40°C to 125°C |
| Chips > .040" x .040" | -40°C to 110°C | -40°C to 110°C |
| Ceramic or Metal Header “Blob Top” | -20°C to 75°C | -20°C to 75°C |
| Cast (Leadframe) Devices | -40°C to 100°C | -40°C to 100°C |
| Transfer Molded (Leadframe) Devices | -40°C to 85°C | -40°C to 85°C |
| Unmounted Photovoltaic Cells, Buss Wires or No Wires | -40°C to 150°C | -40°C to 125°C |
| Photovoltaic Cells with Insulated Flying Leads | -40°C to 105°C | -40°C to 105°C |
| Chip On-Board (Printed Circuit Boards) | -20°C to 85°C | -20°C to 85°C |