Physics and Technology

Emitters

Materials

Infrared emitting diodes (IREDs) can be produced from a range of different III-V compounds. Unlike the elemental semiconductor silicon, the compound III-V semiconductors consists of two different elements of group three (e.g. Al, Ga, In) and five (e.g. P, As) of the periodic table. The bandgap energies of these compounds vary between 0.18 eV and 3.4 eV. However, the IREDs considered here emit in the near infrared spectral range between 800 nm and 1000 nm, and, therefore, the selection of materials is limited to GaAs and the mixed crystal $Ga_{1-X}Al_XAs$, $0 \leq X < 0.8$, made from the pure compounds GaAs and AlAs.

Infrared radiation is produced by radiative recombination of electrons and holes from the conduction and valence bands. The emitted photon energy, therefore, corresponds closely to the bandgap energy E_g. The emission wavelength can be calculated according to the formula $\lambda(\mu m) = 1.240 / E_g(eV)$. The internal efficiency depends on the band structure, the doping material and the doping level. Direct bandgap materials offer high efficiencies, because no photons are needed for recombination of electrons and holes. GaAs is a direct gap material and $Ga_{1-X}Al_XAs$ is direct up to X = 0.44. The doping species Si provides the best efficiencies and shifts the emission wavelength below the bandgap energy into the infrared spectral range by about 50 nm typically.

Charge carriers are injected into the material via pn junctions. Junctions of high injection efficiency are readily formed in GaAs and $Ga_{1-X}Al_XAs$. P-type conductivity can be obtained with metals of valency two, such as Zn and Mg, n-type conductivity with elements of valency six, such as S, Se and Te. However, silicon of valency four can occupy sites of III-valence and V-valence atoms, and, therefore, acts as donor and as acceptor. The conductivity type depends primarily on the material growth temperature. By employing exact temperature control, pn junctions can be grown with the same doping species Si on both sides of the junction. Ge, on the other hand, also has a valency of four, but occupies group V sites at high temperatures i.e. p-type.

Only monocrystalline material is used for IRED production. In the mixed crystal system $Ga_{1-X}Al_XAs$, $0 \leq X < 0.8$, the lattice constant varies only by about 1.5×10^{-3}. Therefore, monocrystalline layered structures of different $Ga_{1-X}Al_XAs$ compositions can be produced with extremely high structural quality. These structures are useful because the bandgap can be shifted from 1.40 eV (GaAs) to values beyond 2.1 eV which enables transparent windows and heterogeneous structures to be fabricated. Transparent windows are another suitable means to increase efficiency, and heterogeneous structures can provide shorter switching times and higher efficiency. Such structures are termed double heterostructures (DH) and consist normally of two layers that confine a layer with a much smaller bandgap.

The best production method for all materials needed is liquid phase epitaxy (LPE). This method uses Ga-solutions containing As, sometimes Al, and the doping substance. The solution is saturated at high temperature, typically 900°C, and GaAs substrates are dipped into the liquid. The solubility of As and Al decreases with decreasing temperature. In this way epitaxial layers can be grown by slow cooling of the solution. Several layers differing in composition may be obtained using different solutions one after another, as needed e.g. for DHs.

In liquid phase epitaxial reactors, production quantities of up to 50 wafers, depending on the type of structure required, can be handled .

IRED Chips and Characteristics

At present, the most popular IRED chip is made only from GaAs. The structure of the chip is displayed in figure 62.

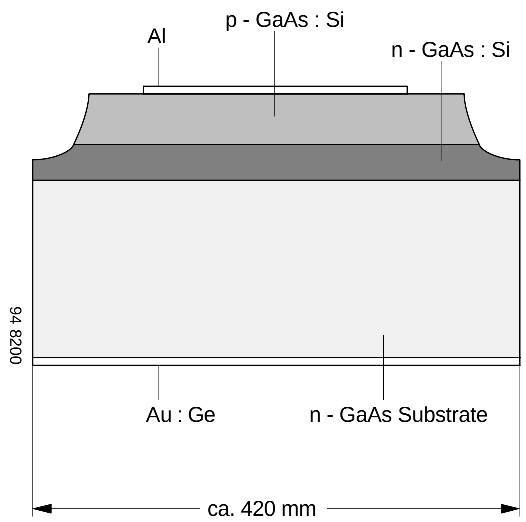


Figure 62.

On an n-type substrate, two Si-doped layers are grown by liquid phase epitaxy from the same solution. Growth starts as n-type at high temperature and becomes p-type below about 820°C. A structured Al-contact on the p-side and a large area Au:Ge contact on the back side provide a very low series resistance.

The angular distribution of the emitted radiation is displayed in figure 63.

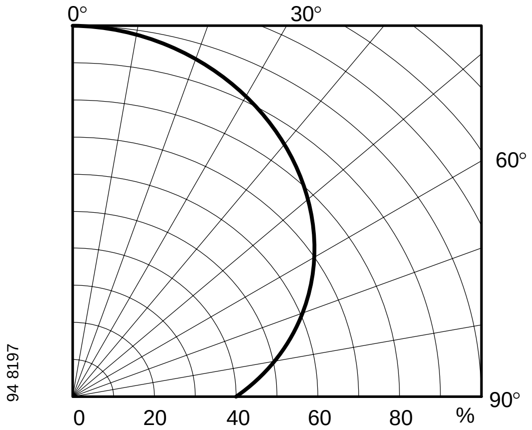


Figure 63.

The package of the chip has to provide good collection efficiency of the radiation emitted sideways, and has to diminish the refractive index step between the chip (n = 3.6) and the air (n = 1.0) with an epoxy of refractive index 1.55. In this way, the output power of the chip is increased by a factor of 3.5 for the assembled device.

The chip described is the most cost-efficient chip. The forward voltage at I_F = 1.5 A has the lowest possible value. The total series resistance is typically only 0.60 Ω. The output power and the linearity (defined as the optical output power increase, divided by the current increase between 0.1 and 1.5 A) are high. Relevant data on the chip and a typical assembled device are given in table 1.

Table 7. Characteristic data of IRED chips

Technology	Typical Chip Data				Typical Device Data				
	Φe/mW at 0.1 A	λp/nm	Δλ/nm	Polarity	Φe/mW at 0.1 A	Φe/mW at 1.5 A	V_F/V at 0.1 A	V_F/V at 1.5 A	Φe(1.5A)/ Φe(0.1A)
GaAs on GaAs	4.3	950	50	pnp	15	140	1.3	2.1	9

UV, Visible, and Near IR Silicon Photodetectors

(adapted from ”Sensors, Vol 6, Optical Sensors, Chapt. 8, VCH – Verlag, Weinheim 1991)

Silicon Photodiodes (PN and PIN Diodes)

The physics of silicon detector diodes

The absorption of radiation is caused by the interaction of photons and the charge carriers inside a material. The different energy levels allowed and the band structure determine the likelihood of interaction and, therefore, the absorption characteristics of the semiconductors. The long wavelength cutoff of the absorption is given by the bandgap energy. The slope of the absorption curve depends on the physics of the interaction and is much weaker for silicon than for most other semiconducting materials. This results in the strong wavelength-dependent penetration depth which is shown in figure 64. (The penetration depth is defined as that depth where 1/e of the incident radiation is absorbed.)

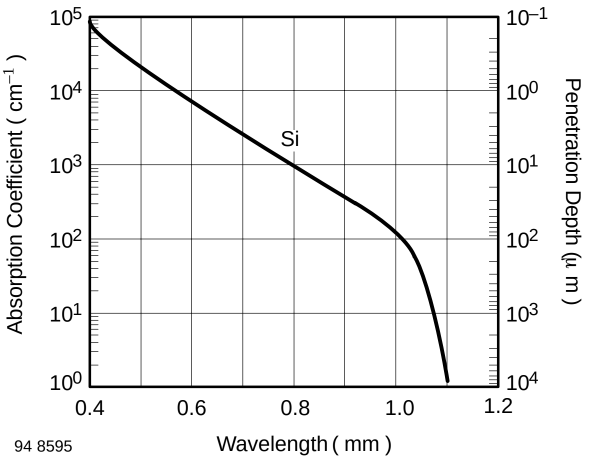


Figure 64. Absorption and penetration depth of optical radiation in silicon

Depending on the wavelength, the penetration depth varies from tenths of a micron at 400 nm (blue) to more than 100 µm at 1 µm (IR). For detectors to be effective, an interaction length of at least twice the penetration depth should be realized (equivalent to $1/e^2 = 86\%$ absorbed radiation). In the pn diode, the generated carriers are collected by the electrical field of the pn junction. The effects in the vicinity of a pn junction are shown in figure 65 for various types and operating modes of the pn diode. The incident radiation generates mobile minority carriers – electrons in the p-side, holes in the n-side. In the short circuit mode shown in figure 65 (top), the carriers drift under the field of the built-in potential of the pn junction. Other carriers diffuse inside the field-free semiconductor along a concentration gradient, which results in an electrical current through the applied load, or without load, in an external voltage, the open circuit voltage, V_{OC}, at the contact terminals. The bending of the energy bands near the surface is caused by surface states. An equilibrium is established between the generation, the recombination of carriers, and the current flow through the load.

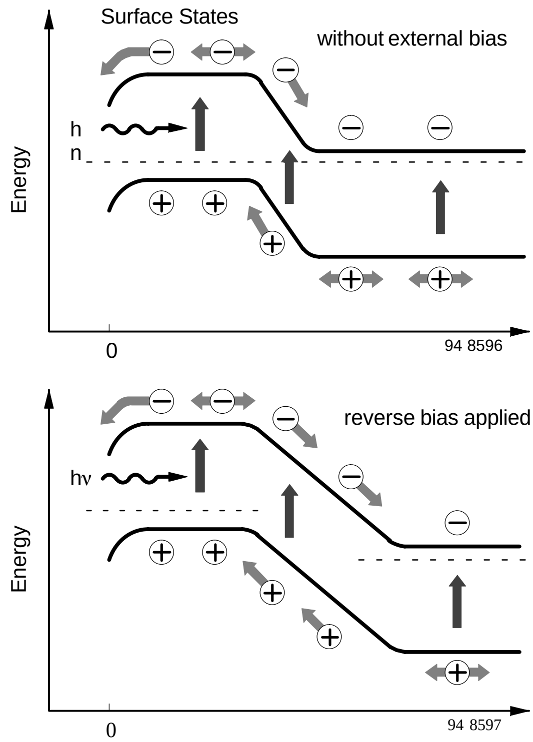


Figure 65. Generation-recombination effects in the vicinity of a pn junction. Top: Short circuit mode, bottom: reverse biased

The recombination takes place inside the bulk material with technology and process - dependent time constants which are very small near the contacts and the surfaces of the device. For short wavelengths with very small penetration depths, the carrier recombination is the efficiency limiting process. To achieve high efficiencies, as many carriers as possible should be separated by the electrical field inside the space charge region. This is a very fast process, much faster than the typical recombination times (for data, see chapter ’Operating modes and circuits’). The width, W, of the space charge is a function of the doping concentration N_B and the applied voltage V:

$$W = \sqrt{\frac{2 \times \epsilon_s \times \epsilon_o \times (V_{bi} + V)}{q \times N_B}} \qquad (1)$$

(for a one-sided abrupt junction), where V_{bi} is the built-in voltage, ε_S the dielectric constant of Si,

ε_o = vacuum dielectric constant and q the electronic charge. The diode's capacitance (which can be speed limiting) is also a function of space charge width and applied voltage. It is given by

$$C = \frac{\epsilon_s \times \epsilon_o \times A}{W} \qquad (2)$$

where A is the area of the diode. An externally applied bias will increase the space charge width (see figure 65) with the result that a larger number of carriers are generated inside this zone which can be flushed out very fast with high efficiency under the applied field. From equation (1), it is evident that the space charge width is a function of the doping concentration N_B.

Diodes with a so-called pin structure are show according to equation (1) a wide space charge width where i stands for intrinsic, very low doped. This zone is also sometimes nominated as ν or p rather than low doped n, n^- or p, p^-zone indicating the very low doping.

Per equation (2), the junction capacitance C, is low due the large space charge region of the pin diode.

These photodiodes are mostly used in applications requiring high speeds.

Figure 66, shows the cross section of pin diodes and pn diodes. The space charge width of the pin diode (bottom) with a doping level ($n=N_B$) as low as $N_B = 5 \times 10^{11}\ cm^{-3}$ is about 80 µm wide for a 2.5 V bias in comparison with a pn diode with a doping (n) of $N_B = 5 \times 10^{15}\ cm^{-3}$ with only 0.8 µm.

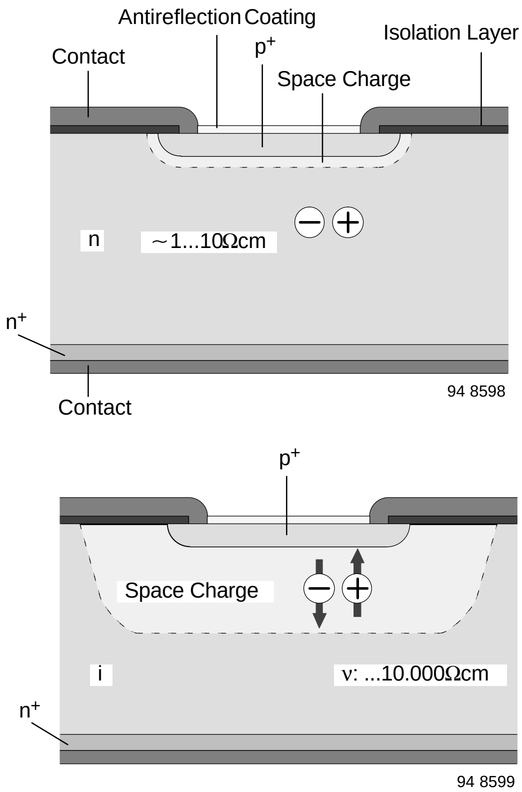


Figure 66. Comparison of pn diode (top) and pin diode (bottom)

Properties of Silicon Photodiodes

I-V Characteristics of illuminated pn junction

The cross section and the I-V-characteristics of a photodiode are shown in figure 72. The characteristic of the non illuminated diode is identical to the characteristic of a standard rectifier diode. The relationship between current, I, and voltage, V, is given by

$$I = I_S \times (\exp V/V_T - 1)$$

with $V_T = kT/q$
$k = 1.38 \times 10^{-23}\ JK^{-1}$, Boltzmann constant
$q = 1.6 \times 10^{-19}$ As, electronic charge.

I_S, the dark-reverse saturation current, is a material and technology-dependent quantity. The value is influenced by the doping concentrations at the pn junction, by the carrier lifetime, and especially by the temperature. It shows a strongly exponential temperature dependence and doubles every 8°C.

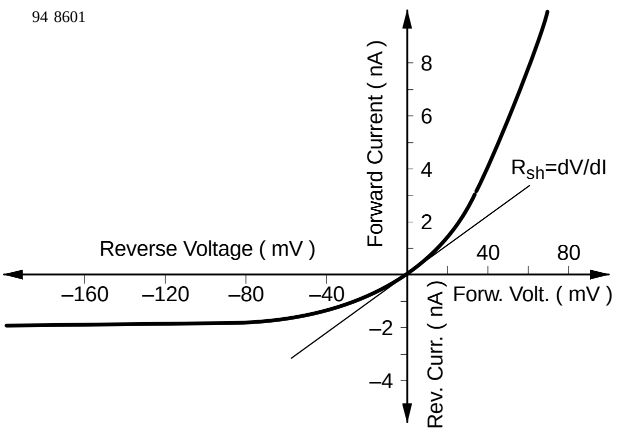


Figure 67. Measured I-V-characteristics of an Si photodiode in the vicinity of the origin

Typical dark currents of Si photodiodes are dependent on size and technology and range from less than picoamps up to tens of nanoamps at room temperature conditions. As noise generators, the dark current I_{r0} and the shunt resistance R_{sh} (defined and measured at a voltage of 10 mV forward or reverse, or peak-to-peak) are limiting quantities when detecting very small signals.

The photodiode exposed to optical radiation generates a photocurrent I_r exactly proportional to the incident radiant power Φ_e.

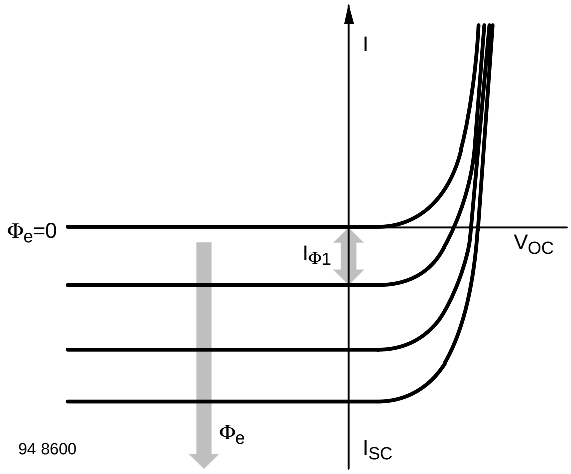


Figure 68. I-V-Characteristics of an Si photodiode under illumination. Parameter: Incident radiant flux

The quotient of both is the spectral responsivity $s(\lambda)$,

$$s(\lambda) = I_r/\phi_e\ [A/W]$$

The characteristic of the irradiated photodiode is then given by

$$I = I_S \times (\exp V/V_T - 1) - s(\lambda) \times \phi_e$$

and in the case $V \approx 0$, zero or reverse bias we find,

$$I = -I_s - s(\lambda) \times \phi_e$$

Dependent on load resistance, R_L, and applied bias, different operating modes can be distinguished. The unbiased diode operates in the photovoltaic mode. Under short circuit conditions (load $R_L = 0\,\Omega$), the short circuit current, I_{SC} flows into the load. When R_L increases to infinity, the output voltage of the diode rises to the open circuit voltage, V_{OC}, given by

$$V_{OC} = V_T \times \ln(s(\lambda) \times \phi_e/I_s + 1)$$

Because of this logarithmic behavior, the open circuit voltage is sometimes used for optical lightmeters in photographic applications. The open circuit voltage shows a strong temperature dependence with a negative temperature coefficient. The reason for this is the exponential temperature coefficient of the dark reverse saturation current I_S. For precise light measurement, a temperature control of the photodiode is employed. Precise linear optical power measurements require small voltages at the load typically smaller than about 5% of the corresponding open circuit voltage. For less precise measurements, an output voltage of half the open circuit voltage can be allowed. The most important disadvantage of operating in the photovoltaic mode is the relatively large response time. For faster response, it is necessary to implement an additional voltage source reverse biasing the photodiode. This mode of operation is termed the photoconductive mode. In this mode, the lowest detectable power is limited by the shot noise of the dark current, I_s, while in the photovoltaic mode, the thermal (Johnson) noise of the shunt resistance, R_{sh}, is the limiting quantity.

Spectral responsivity

Efficiency of Si photodiodes:

The spectral responsivity, s_λ, is given as the number of generated charge carriers ($\eta \times N$) per incident photons N of energy $h \times \nu$ (η is the percent efficiency, h is Plancks constant, and ν is the frequency of radiation). Each photon will generate one charge carrier at the most . The photocurrent I_{re} is then given as

$$I_{re} = \eta \times N \times q$$

$$s_\lambda = I_{re}/\phi_e$$

$$= \eta \times N \times q/(h \times \nu \times N) = \eta \times q/(h \times \nu)$$

$$s_\lambda = \frac{\lambda(\mu m)}{1.24} \; [A/W]$$

At fixed efficiency, a linear relationship between wavelength and spectral responsivity is valid.

Figure 69 shows that semiconductors absorb radiation similar to a cut-off filter. At wavelengths smaller than the cut-off wavelength the incident radiation is absorbed. At larger wavelengths the radiation passes through the material without interaction. The cut-off wavelength corresponds to the bandgap of the material. As long as the energy of the photon is larger than the bandgap, carriers can be generated by absorption of photons, provided that the material is thick enough to propagate photon-carrier interaction. Bearing in mind that the energy of photons decreases with increasing wavelength, it can be understood, that the curve of the spectral responsivity vs. wavelength in the ideal case (100% efficiency) will have a triangular shape (see figure 69). For silicon photodetectors, the cut-off wavelength is near 1100 nm.

In most applications, it is not necessary to detect radiation with wavelengths larger than 1000 nm. Therefore, designers use a typical chip thickness of 200 µm to 300 µm, which results in reduced sensitivity at wavelengths larger than 950 nm . With a typical chip thickness of 250 µm, an efficiency of about 35% at 1060 nm is achieved. At shorter wavelengths (blue-near UV, 500 nm to 300 nm) the sensitivity is limited by recombination effects near the surface of the semiconductor. The reduction in the efficiency starts near 500 nm and increases with decreasing wavelength. Standard detectors designed for visible and near IR radiation may have only poor UV/blue sensitivity and poor UV stability. Well designed sensors for wavelengths of 300 to 400 nm can operate with fairly high efficiencies. At smaller wavelengths (< 300 nm), the efficiency decreases strongly.

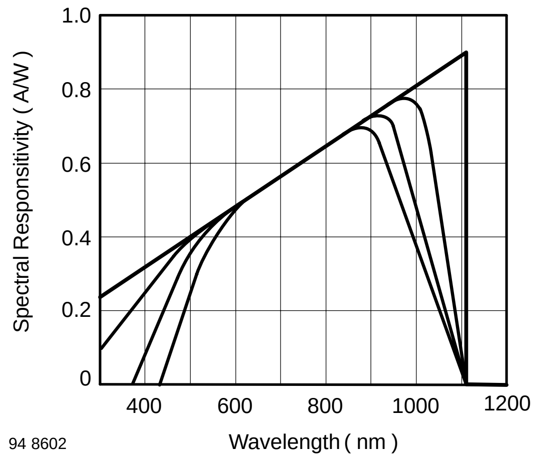


Figure 69. Spectral responsivity as a function of wavelength of a Si photodetector diode, ideal and typical values

Temperature dependence of spectral responsivity

The efficiency of carrier generation by absorption and the loss of carriers by recombination are the factors which influence the spectral responsivity. The absorption coefficient increases with temperature. Radiation of long wavelength is therefore more efficiently absorbed inside the bulk, and results in increased response. For shorter wavelengths (< 600 nm), reduced efficiency is observed with increasing temperature because of increased recombination rates near the surface. These effects are strongly dependent on technological parameters and therefore cannot be generalized to the behavior at longer wavelengths.

Uniformity of spectral responsivity

Inside the technologically defined active area of photodiodes, the spectral responsivity shows a variation of the sensitivity in the order of < 1%. Outside the defined active area, especially at the lateral edges of the chips, the local spectral response is sensitive to the applied reverse voltage. Additionally, this effect depends on the wavelength. Therefore, the relation between power (Watt) related spectral responsivity, s_λ (A/W), and power density (Watt/cm^2) related spectral responsivity, s_λ [A/(W/cm^2)] is not a constant. This relation is a function of wavelength and reverse bias.

Stability of spectral responsivity

Si detectors for wavelengths between 500 nm and 800 nm appear to be stable over very long periods of time. In the literature concerned here, remarks can be found on instabilities of detectors in the blue, UV, and near IR under certain conditions. Thermal cycling reversed the degradation effects.
Surface effects and contamination are possible causes but are technologically well controlled.

Angular dependence of responsivity

The angular response of Si photodiodes is given by the optical laws of reflection. The angular response of a detector is shown in figure 70.

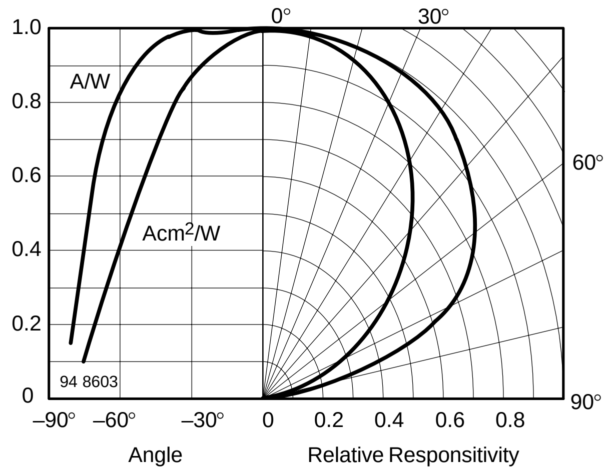


Figure 70. Responsivity of Si photodiodes as a function of the angle of incidence

The semiconductor surfaces are covered with quarter wavelength anti-reflection coatings. The encapsulation is performed with uncoated glass or sapphire windows.

The bare silicon response can be altered by optical imaging devices such as lenses. In this way, nearly every arbitrary angular response can be achieved.

Dynamic Properties of Si Photodiodes

Si photodiodes are available in many different variations. The design of the diodes can be tailored to meet special needs. Si photodiodes may be designed for maximum efficiency at given wavelengths, for very low leakage currents, or for high speed. The design of a photodiode is nearly always a compromise between various aspects of a specification.

Inside the absorbing material of the diode, photons can be absorbed in different regions. For example at the top of a p^+n^{-} -diode there is a highly doped layer of p^+ -Si. Radiation of shorter wavelengths will be effectively absorbed, but for larger wavelengths only a small amount is absorbed. In the vicinity of the pn junction, is the space charge region, where most of the photons should generate carriers. An electric field accelerates the generated carrier in this part of the detector to a high drift velocity. The carriers which are not absorbed in these regions penetrate into the field-free region where the motion of the generated carriers fluctuates by the slow diffusion process.

The dynamic response of the detector is composed of the different processes which transport the carriers to the contacts. The dynamic response of photodiodes is influenced by three fundamental effects:

- Drift of carriers in an electric field
- Diffusion of carriers
- Capacitance × load resistance

The carrier drift in the space charge region occurs rapidly with very small time constants. Typically, the transit times in an electric field of 0.6 V/µm are in the order of 16 ps/µm and 50 ps/µm for electrons and holes, respectively. At the (maximum) saturation velocity, transit time is in the order of 10 ps/µm for electrons in p-material. With a 10 µm drift region, travelling times of 100 ps can be expected. The response time is a function of the distribution of the generated carriers and is therefore dependent on the wavelength.
The diffusion of carriers is a very slow process. The time constants are in the order of some µs.
The typical pulse response of detectors is dominated by these two processes. Obviously, carriers should be absorbed in large space charge regions with high internal electrical fields. This requires material with an adequate low doping level.

Furthermore, a reverse bias of rather large voltage is useful. Radiation of shorter wavelength is absorbed in smaller penetration depths. At wavelengths shorter than 600 nm, decreasing wavelength leads to an absorption in the diffused top layer. The movement of carriers in this region is also diffusion limited. Because of small carrier lifetimes, the time constants are not as large as in homogeneous substrate material.
Finally, the capacitive loading of the output in combination with the load resistance limits the frequency response.

Properties of Silicon Phototransistors

The phototransistor is equivalent to a photodiode in conjunction with a bipolar transistor amplifier (figure 71). Typically, current amplification, B, is between 100 and 1000 depending on the type and application. The active area of the phototransistor is usually about $0.5 \times 0.5\ mm^2$. Data of spectral responsivity are equivalent to those of photodiodes, but must be multiplied by the factor of the current amplification, B.

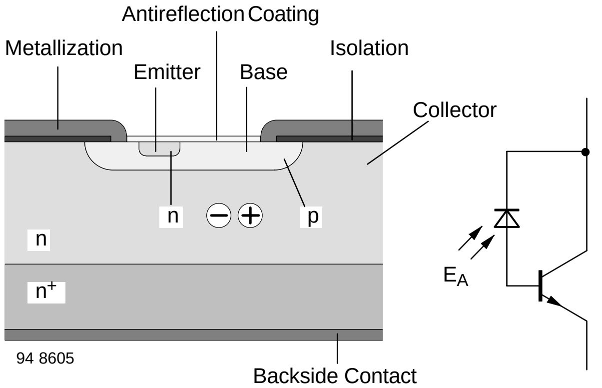


Figure 71. Phototransistor, cross section and equivalent circuit

The switching times of phototransistors are dependent on the current amplification and load resistance and are between 30 µs and 1 µs. The resulting cut-off frequencies are a few hundred kHz.

The transit times, t_r and t_f, are given by

$$t_{r,f} = \sqrt{(1/2f_t^2)^2 + b(RC_B V)^2}$$

f_t: Transit frequency
R: Load resistance1.6
C_B: Base-collector capacitance, b= 4...5
V: Amplification

Phototransistors are most frequently applied in transmissive and reflective optical sensors.

Measurement Techniques

Introduction

The characteristics of optoelectronics devices given in the data sheets are verified either by 100% production tests followed by statistic evaluation or by sample tests on typical specimens. These tests can be divided into the following categories:

- Dark measurements
- Light measurements
- Measurements of switching characteristics, cut-off frequency and capacitance
- Angular distribution measurements
- Spectral distribution measurements
- Thermal measurements.

The dark and light measurements are 100% measurements. All other values are typical. The basic circuits used for these measurements are shown in the following sections. The circuits may be modified slightly to cater for special measurement requirements.

Most of the test circuits may be simplified by use of a Source Measure Unit (SMU), which allows either to source voltage and measure current or to source current and measure voltage.

Dark and Light Measurements

Emitter Devices

IR diodes (GaAs)

The forward voltage, V_F, is measured either on a curve tracer or statically using the circuit shown in figure 72. A specified forward current (from a constant current source) is passed through the device and the voltage developed across it is measured on a high-impedance voltmeter.

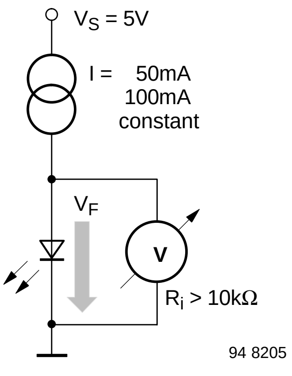


Figure 72.

To measure the reverse voltage, V_R, a 10 µA or 100 µA reverse current from a constant current source is impressed through the diode (figure 73) and the voltage developed across it is measured on a voltmeter of high input impedance ($\geq$10MΩ).

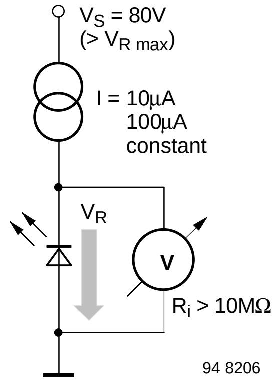


Figure 73.

For most devices, V_R is specified at 10 µA reverse current. In this case either a high impedance voltmeter has to be used, or the current consumption of the DVM has to be calculated and added to the specified current. A second measurement step will then give correct readings.

In the case of GaAs IR diodes, the total radiant output power, Φ_e, is usually measured. This is done with a calibrated large-area photovoltaic cell fitted in a conical reflector with a bore which accepts the test item – see figure 74. An alternative test set uses a silicon photodiode attached to an integrating sphere. A constant dc or pulsating forward current of specified magnitude is passed through the IR diode. The advantage of pulse-current measurements at room temperature (25°C) is that the results can be reproduced exactly.

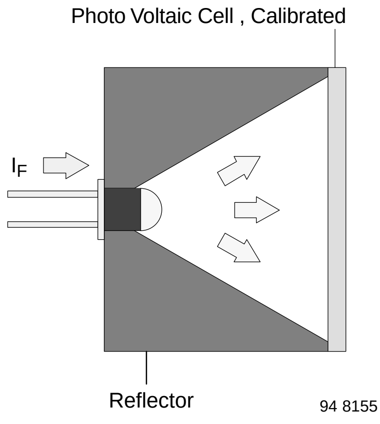


Figure 74.

If, for reasons of measurement economy, only dc measurements (figure 75) are to be made, then the energizing time should be kept short (below 1 s) and of uniform duration, to minimize any fall-off in light output due to internal heating

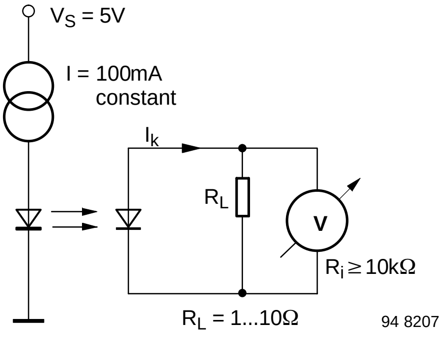


Figure 75.

To ensure that the relationship between irradiance and photocurrent is linear, the photodiode should operate near short-circuit configuration. This can be achieved by using a low resistance load ($\leq 10\ \Omega$) of such a value that the voltage dropped across it is very much lower than the open circuit voltage produced under identical illumination conditions ($R_{meas} \ll R_i$).The voltage across the load should be measured with a sensitive DVM.

Knowledge of the radiant intensity, I_e, produced by an IR emitter enables customers to assess the range of IR light barriers. The measurement procedure for this is more or less the same as that used for measuring the radiant power. The only difference is that in this case the photodiode is used without a reflector and is mounted at a specified distance from, and on the optical axis of, the IR diode (figure 76) so that only radiant power of a narrow axial beam is considered. The radiant power within a solid angle of $\Omega = 0.01$ steradian (sr) is measured at a distance of 100 mm. The radiant intensity is then obtained by using this measured value for calculating the radiant intensity for a solid angle of $\Omega = 1$ sr.

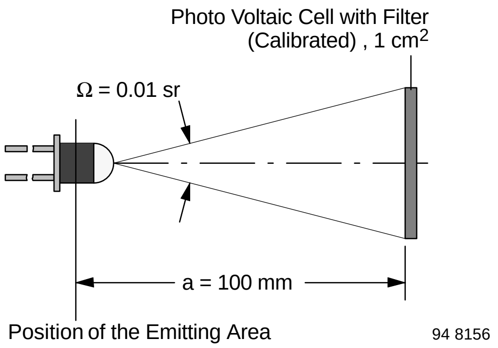


Figure 76.

Detector Devices

Photovoltaic cells, photodiodes

- Dark measurements

The reverse voltage characteristic, V_R, is measured either on a curve tracer or statically using the circuit shown in figure 77. A high-impedance voltmeter, which draws only an insignificant fraction of the device's reverse current must be used.

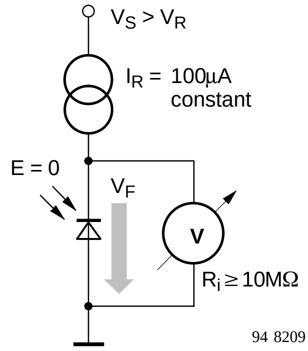


Figure 77.

Dark reverse current measurements, I_{ro}, must be carried out in complete darkness – the reverse currents of silicon photodiodes are of the order of nanoamperes only, and an illumination of a few lux is quite sufficient to falsify the test result. If a highly sensitive DVM is to be used, then a current sampling resistor of such a value that the voltage dropped across it is small in comparison with the supply voltage must be connected in series with the test item (figure 78). Under these conditions, any reverse voltage variations of the test samples can be ignored. Shunt resistance (dark resistance) is determined by applying very slight voltage to the photodiode and then measuring the dark current. In the case of 10 mV or less, forward and reverse polarity will result in similar readings.

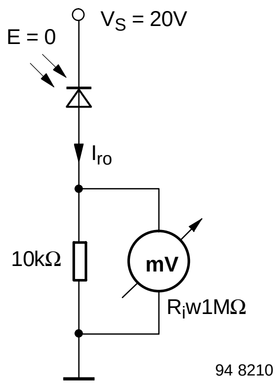


Figure 78.

- Light measurements

The same circuit used in the dark measurement can be used to carry out light reverse current, I_{ra}, measurements on photodiodes. The only difference is that the diode is now irradiated and a current sampling resistor of lower value must be used (figure 79), because of the higher currents involved.

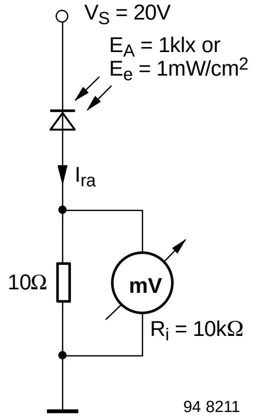


Figure 79.

The open circuit voltage, V_o, and short circuit current, I_k, of photovoltaic cells and photodiodes are measured by means of the test circuit shown in figure 80. The value of the load resistor used for the I_k measurement should be chosen so that the voltage dropped across it is low in comparison with the open circuit voltage produced under conditions of identical irradiation.

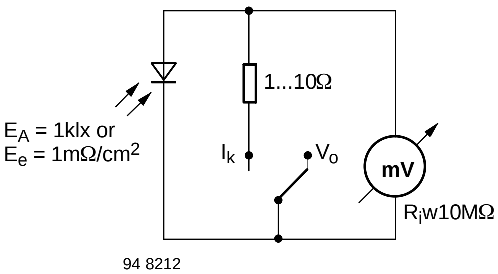


Figure 80.

The light source used for light measurements is a calibrated incandescent tungsten lamp with no filters. The filament current is adjusted for a color temperature of 2856 K (standard illuminant A to DIN 5033 sheet 7), and the specified illumination, E_v, (usually 100 or 1000 lux) is produced by adjusting the distance, a, between the lamp and the detector on an optical bench. E_v can be measured on a V(λ)-corrected luxmeter, or, if the luminous intensity, I_v, of the lamp is known, E_v can be calculated using the formula: $E_v = I_v/a^2$.

It should be noted that this inverse square law is only strictly accurate for point light sources, that is for sources where the dimensions of the source (the filament) are small ($\leq$10%) in comparison with the distance between source and detector.

Since lux is a measure for visible light only, near infrared radiation (800 to 1100 nanometers) where silicon detectors have their peak sensitivity, is not taken into account. Unfortunately, near infrared emission of filament lamps of various construction varies widely. As a result, light current measurements carried out with different lamps (but the same lux and color temperature calibration) may result in readings that differ up to 20%.

The simplest way to overcome this problem is to calibrate (measure the light current) some items of a photodetector type with a standard lamp (OSRAM WI 41 / G) and then use these devices for adjustment of the lamp used for field measurements.

An IR diode is used as a radiation source (instead of the tungsten incandescent lamp), to measure detector devices being used mainly in IR transmission systems together with IR emitters (e.g. IR remote control, IR headphone). Operation is possible both with dc or pulsed current.

The adjustment of irradiance, E_e, is similar to the above mentioned adjustment of illuminance, E_v. To achieve a high stability similar to the filament lamps, consideration should be given to the following two points:

- The IR emitter should be connected to a good heat sink to provide sufficient temperature stability.
- dc or pulse-current levels as well as pulse duration have great influence on the self-heating of IR diodes and should be chosen carefully.
- The radiant intensity, I_e, of the device is permanently controlled by a calibrated detector.

Phototransistors, photodarlington transistors

The collector emitter voltage, V_{CEO}, is measured either on a transistor curve tracer or statically using the circuit shown in figure 81. Normal bench illumination does not change the measured result.

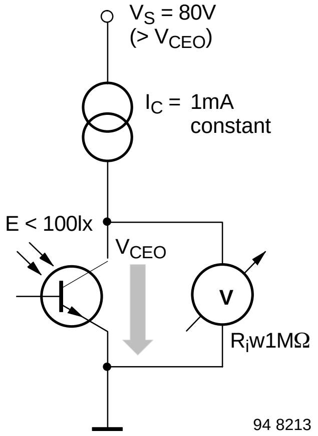


Figure 81.

In contrast, however, the collector dark current, I_{CEO} or I_{co}, must be measured in complete darkness (figure 82). Even ordinary daylight illumination of the wire fed-through glass seals would falsify the measurement result.

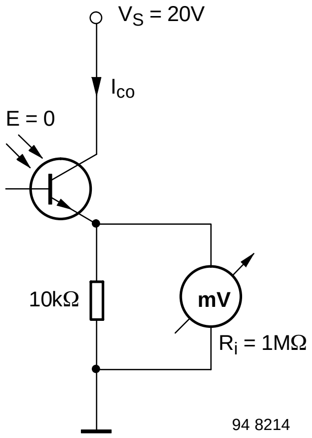


Figure 82.

The same circuit is used for collector light current, I_{ca}, measurements (figure 83), the device being positioned so that its optical axis points towards an incandescent tungsten lamp with no filters, producing a standard-A illuminance of 100 or 1000 lx with a color temperature of T_f = 2856 K. Alternatively an IR irradiance by a GaAs diode is used (refer to the photovoltaic cells and photodiodes section). Note that a lower value sampling resistor is used, in keeping with the higher current involved.

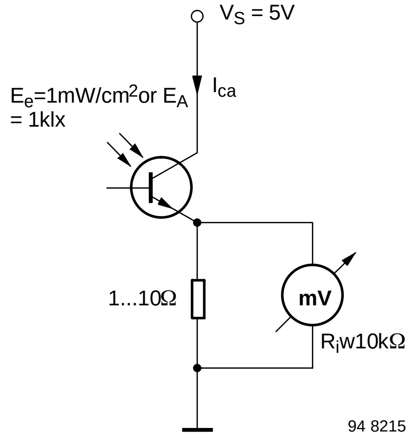


Figure 83.

To measure the collector emitter saturation voltage, V_{CEsat}, the device is illuminated and a constant collector current passed through it. The magnitude of this current is adjusted so that it is less than the minimum light current, $I_{ca\,min}$, for the same illuminance (figure 84). The saturation voltage of the phototransistor or Darlington stage (approximately 100 mV or 600 mV, respectively) is then measured on a high impedance voltmeter.

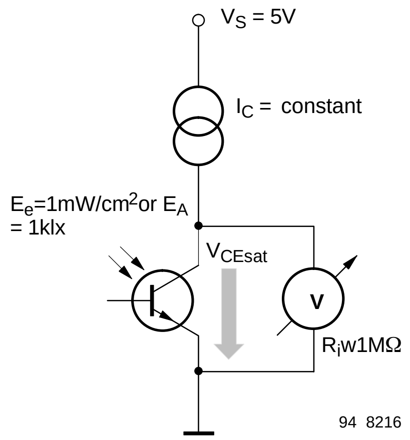


Figure 84.

Switching Characteristics

Definition

Each electronic device generates a certain delay between input and output signals as well as a certain amount of amplitude distortion. A simplified circuit (figure 85) shows how the input and output signals of optoelectronic devices can be displayed on a dual-trace oscilloscope.

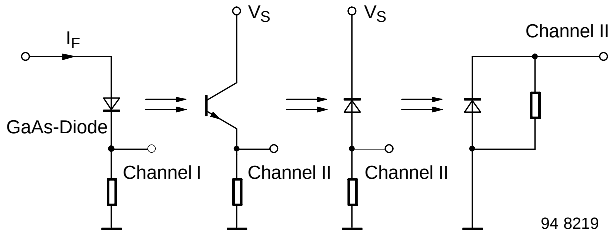
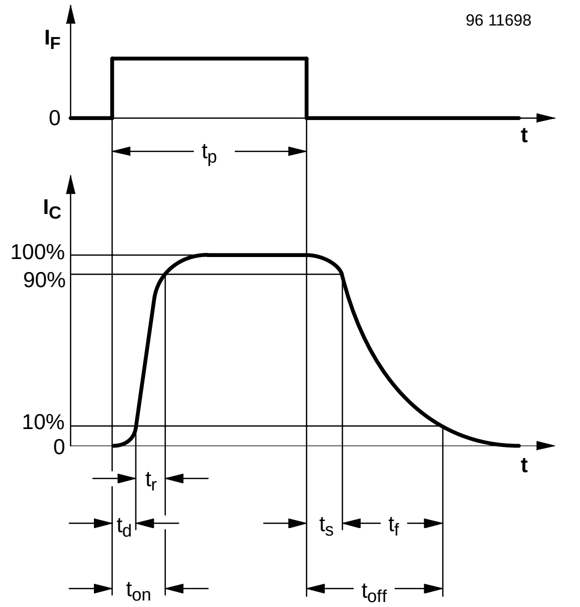


Figure 85.

The switching characteristics can be determined by comparing the timing of the output current waveform with that of the input current waveform (figure 86).



t_p	pulse duration	t_s	storage time
t_d	delay time	t_f	fall time
t_r	rise time	t_{off} (= t_s + t_f)	turn-off time
t_{on} (= t_d + t_r)	turn-on time		

Figure 86.

These time parameters also include the delay that exists in a luminescence diode between the forward current (I_F) and the radiant power (Φ_e).

Notes Concerning the Test Set-up

The circuits used for testing IR emitting, emitting sensitive and optically coupled isolator devices are basically the same (figure 85), the only difference being the way in which the test item is connected in the circuit.

It is assumed that the rise and fall times associated with the signal source (pulse generator) and the dual trace oscilloscope are insignificant, and that the switching characteristics of any radiant sensitive device used in the set-up are considerably shorter than those of the test item. The switching characteristics of IR emitters, for example ($t_r \approx$ 10 to 1000 ns) are measured with the aid of a pin photodiode as a detector ($t_r \approx$ ns).
Photo – and darlington transistors and photo – and solar cells ($t_r \approx$ 0.5 to 50 μs) are, as a rule, measured by use of fast IR diodes (t_r < 30 ns) as emitters.

Red light-emitting diodes are used as light sources only for devices which cannot be measured with IR diodes because of their spectral sensitivity (e.g. BPW21R). This is because these diodes emit only 1/10 of the radiant power of IR diodes and consequently generate only very low signal levels.

Switching Characteristic Improvements on Phototransistors and Darlington Phototransistors

As in any ordinary transistor, switching times are reduced if the drive signal level, and hence the collector current, is increased. Another time reduction (especially in fall time t_f) can be achieved by use of a suitable base resistor, assuming there is an external base connection, although this can only be done at the expense of sensitivity.

Technical Description – Assembly

Emitter

Emitters are manufactured using the most modern Liquid Phase Epitaxy (LPE) process. By using this technology, the number of undesirable flaws in the crystal is reduced. This results in a higher quantum efficiency and thus higher radiation power. Distortions in the crystal are prevented by using mesa technology which leads to lower degradation. A further advantage of the mesa technology is that each individual chip can be tested optically and electrically even on the wafer.

Detector

Vishay Semiconductor detectors have been developed so that they match perfectly to the emitter. They have low capacitance values, high photosensitivity and are designed for an extremely low saturation voltage.

Silicon nitride passivation protects the surface against possible impurities.

Assembly

The components are fitted onto lead frames by fully automatic equipment using conductive epoxy adhesive. Contacts are established automatically with digital pattern recognition using the well-proven thermosonic technique. In addition to optical and mechanical checks, all components are measured at a temperature of 100°C on a short/open test equipment.