SILICON PHOTODIODES - MODES OF OPERATION AND CHARACTERISTICS

EQUIVALENT CIRCUIT FOR PIN PHOTODIODE

The equivalent electrical circuit for a P on N photodiode is shown in figure 1. Fundamentally a photodiode is a current generator when illuminated. This current is distributed between the internal shunt resistance, internal series resistance and the external load resistance. As a voltage is created across these resistors, a forward bias is created across the diode, which begins to shunt the current available to the load. When operated with a reverse voltage bias across the photodiode, the internal effect of the diode bias is nullified resulting in an ideal current source.
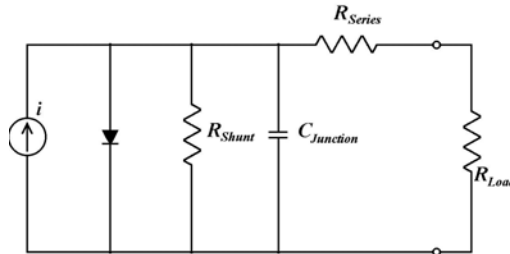

Figure 1   Detector equivalent circuit

PHOTOVOLTAIC AND PHOTOCONDUCTIVE OPERATION

When a photodiode is operated in a photovoltaic mode, the photodiode is unbiased. During the time that the photodiode operates with a reverse bias voltage, the operating mode is considered photoconductive. Figure 2 shows a typical I-V curve for a silicon photodiode. This graph indicates the increase in relative current to the increase in illumination at V=0 (short circuit current). The illumination curves are linear to input light intensity until the photodiode becomes forward biased, at this point the generated current starts to flow through the diode. Photodiode open circuit voltage is where I=0 on the illumination curve (diode is forward biased) and varies as the logarithm of the illumination level. Both the photovoltaic load (PV) and the photoconductive (PC) load lines are indicated in figure 2 as well. As shown, the PV load line indicates a linear current vs. illumination is generated for illuminations L=1 and L=2; while the PV load line indicates a non-linear current vs. illumination for L=3 and L=4 as the diode becomes forward biased. The PC load line will maintain a linear current vs. illumination for all illumination levels.
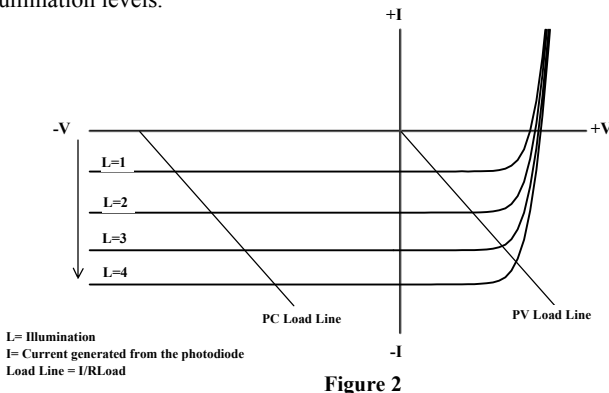
Figures 3a and 3b are typical for photovoltaic operation. Photovoltaic applications are designed for low noise (reduced dark currents) and the frequency response of figure 3a will be dependant on load resistance and the shunting impedance of the photodiode junction capacitance $[1/(2\pi FC)]$. The circuit shown in figure 3b illustrates a transimpedance amplifier. This amplifier will clamp the photodiode voltage bias to zero volts. The resultant effective impedance seen by the junction capacitance will be very low yielding excellent frequency response.
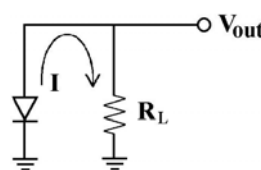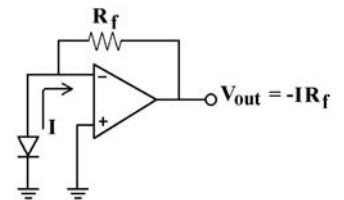

Figure 3a

Figure 3b

Figures 4a and 4b illustrate circuits typical for photoconductive applications. A photoconductive mode of operation will enhance the photodiode speed requirements as the junction capacitance is reduced with increase in reverse bias. The reverse bias will generate a dark current proportional to the bias voltage and should be evaluated for the particular application. The circuits in Figure 4 are similar to the Figure 3 above, except the photodiodes are operated with a reverse bias.
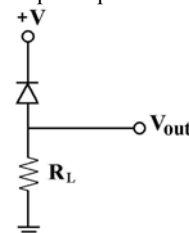

Figure 2

L= Illumination
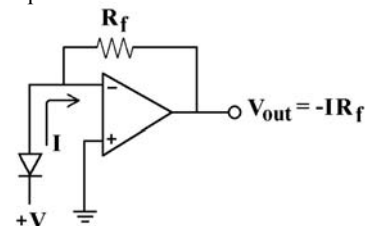I= Current generated from the photodiode
Load Line = I/RLoad

Figure 4a

Figure 4b

PHOTODIODE SERIES

Quantum Devices offers two basic photodiode constructions, they are PV for photovoltaic applications, and PC for photoconductive applications. It is important to understand that these two series can be used in both photovoltaic and photoconductive modes. Basically the PV series provides excellent dark current while designed to minimize the internal series resistance to enhance the linearity of illumination levels well into the forward biased operating point. The PC series is designed to provide a low junction capacitance while providing reliable dark current parameters. The PC series also provide improved far-red spectral response.

GLOSSARY OF TERMS

Breakdown Voltage (Vb) is the voltage at which the semiconductor fails to withstand the applied voltage and begins to act as a conductor. This parameter is usually taken as the reverse voltage required to cause the dark current to exceed a predetermined value.

Responsivity (R) is the fraction of incident power resulting in an electric current that flows through an external load. It is defined as the ratio of the photo current to the power of the incident light; R (responsivity) =I (amperes) / L (watts). The typical responsivity (bias = 0 volts) is shown below for both the PV and PC series:

Absolute Spectral Response (typ.)
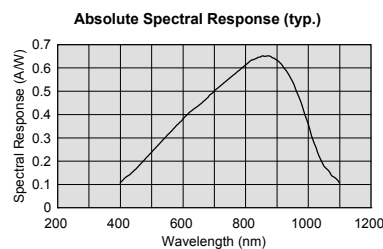
Dark Current (Id) is the current that flows through the photodiode under reverse bias in the absence of light. The dark current is the combination of surface and bulk leakage currents. Increasing reverse bias across the photodiode will increase the dark current. Dark current is also a function of junction area.

Junction Capacitance (Cj) is similar to the capacitance of a parallel plate capacitor. The junction capacitance increases with the active area and decreases with increasingly reverse bias voltage. Compared to zero bias, the capacitance typically is reduced to 40% at a bias of –3volts, to 29% at –5volts, and 23% at –15volts.

Quantum Efficiency (QE) is the measure of the effectiveness of the incident photons to the electrical current conversion process within the silicon cell and consequently has a direct relationship to responsivity. Quantum efficiency is expressed as a percentage and can be calculated by the formula:

$$\text{Q.E. (\%)} = \frac{1.24 \times R(A/W)}{\lambda(\mu m)}$$

The following table references the ideal responsivities at a quantum efficiency of 100% of an ideal photodiode over the 200-1100nm wavelength range. Silicon becomes transparent to radiation longer than 1100nm and is not suitable for wavelengths beyond this.

Wavelength (nm)	100% Q.E. (A/W)
200	.161
300	.242
400	.323
500	.403
600	.484
700	.565
800	.645
900	.726
1000	.806
1100	.887

For more information contact...
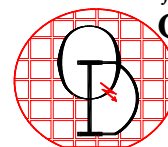
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