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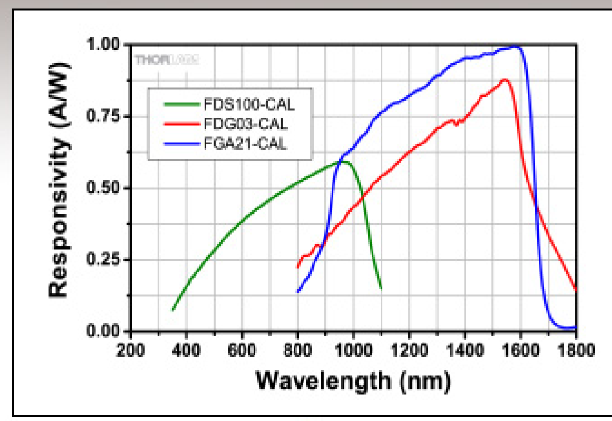
THORLABS

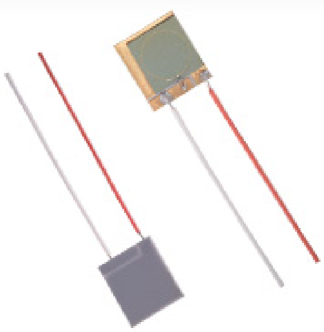
FDG05-CAL - August 31, 2016

Item # FDG05-CAL was discontinued on August 31, 2016. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

CALIBRATED PHOTODIODES

- ▶ **Si, Ge, and InGaAs Photodiodes Available**
- ▶ **NIST Traceable**
- ▶ **Photodiodes Shipped with Calibration Curves**





FDG05-CAL

FDG03-CAL

FGA21-CAL

OVERVIEW

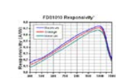
Thorlabs offers five photodiodes, with NIST traceable calibration, that ship from stock. These include one Indium Gallium Arsenide (InGaAs), two Silicon (Si), and two Germanium (Ge) photodiodes.

Calibration Features:

- Responsivity Measured Every 10 nm Over the Spectral Range of the Photodiode
- Measurement Uncertainty ±5%
- NIST Traceable

Each photodiode comes with its own data table and graph of the responsivity vs wavelength.

Mounted and Unmounted Detectors
Unmounted Photodiodes (150 - 2600 nm)
Calibrated Photodiodes (350 - 1800 nm)
Mounted Photodiodes (150 - 1800 nm)
Pigtailed Photodiodes (320 - 1000 nm)
Photoconductors (1 - 4.8 µm)



Click to Enlarge

The responsivity of a particular photodiode varies from lot to lot. Due to this, the photodiode you receive may have a slightly different response than what is represented in the graphs in the info icons below, but will include calibration data. To the right, a graph for the FDS1010 photodiode shows how significantly you can expect the response to vary. Data was collected from 104 photodiodes. Minimum, Average, and Maximum responsivity was calculated at each data point and has been plotted.

Please note that inhomogeneities at the edges of the active area of the detector can generate unwanted capacitance and resistance effects that distort the time-domain response of the photodiode output. Thorlabs therefore recommends that the incident light on the photodiode is well centered on the active area. This can be accomplished by placing a focusing lens or pinhole in front of the detector element.

Our photodiodes can be reverse voltage biased using the PBM42 DC Bias Module for higher optical power detection; for more information on voltage biasing as well as the noise floor, please see the *Lab Facts* tab.

Hide Photodiode Tutorial

PHOTODIODE TUTORIAL

Photodiode Tutorial

Theory of Operation

A junction photodiode is an intrinsic device that behaves similarly to an ordinary signal diode, but it generates a photocurrent when light is absorbed in the depleted region of the junction semiconductor. A photodiode is a fast, highly linear device that exhibits high quantum efficiency based upon the application and may be used in a variety of different applications.

It is necessary to be able to correctly determine the level of the output current to expect and the responsivity based upon the incident light. Depicted in Figure 1 is a junction photodiode model with basic discrete components to help visualize the main characteristics and gain a better understanding of the operation of Thorlabs' photodiodes.

$$I_{OUT} = I_{DARK} + I_{PD}$$

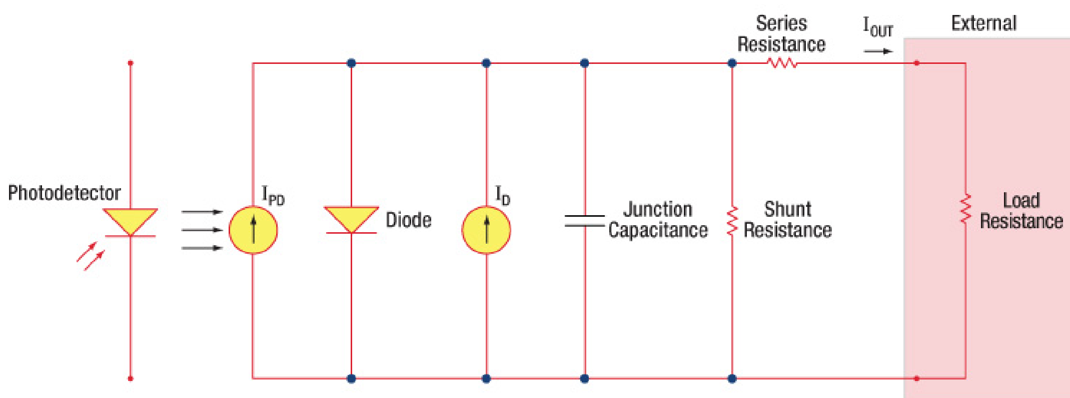


Figure 1: Photodiode Model

Photodiode Terminology

Responsivity

The responsivity of a photodiode can be defined as a ratio of generated photocurrent (I_{PD}) to the incident light power (P) at a given wavelength:

$$R(\lambda) = \frac{I_{PD}}{P}$$

Modes of Operation (Photoconductive vs. Photovoltaic)

A photodiode can be operated in one of two modes: photoconductive (reverse bias) or photovoltaic (zero-bias). Mode selection depends upon the application's speed requirements and the amount of tolerable dark current (leakage current).

Photoconductive

In photoconductive mode, an external reverse bias is applied, which is the basis for our DET series detectors. The current measured through the circuit indicates illumination of the device; the measured output current is linearly proportional to the input optical power. Applying a reverse bias increases the width of the depletion junction producing an increased responsivity with a decrease in junction capacitance and produces a very linear response. Operating under these conditions does tend to produce a larger dark current, but this can be limited based upon the photodiode material. (Note: Our DET detectors are reverse biased and cannot be operated under a forward bias.)

Photovoltaic

In photovoltaic mode the photodiode is zero biased. The flow of current out of the device is restricted and a voltage builds up. This mode of operation exploits the photovoltaic effect, which is the basis for solar cells. The amount of dark current is kept at a minimum when operating in photovoltaic mode.

Dark Current

Dark current is leakage current that flows when a bias voltage is applied to a photodiode. When operating in a photoconductive mode, there tends to be a higher dark current that varies directly with temperature. Dark current approximately doubles for every 10 °C increase in temperature, and shunt resistance tends to double for every 6 °C rise. Of course, applying a higher bias will decrease the junction capacitance but will increase the amount of dark current present.

The dark current present is also affected by the photodiode material and the size of the active area. Silicon devices generally produce low dark current compared to germanium devices which have high dark currents. The table below lists several photodiode materials and their relative dark currents, speeds, sensitivity, and costs.

Material	Dark Current	Speed	Spectral Range	Cost
Silicon (Si)	Low	High Speed	Visible to NIR	Low
Germanium (Ge)	High	Low Speed	NIR	Low
Gallium Phosphide (GaP)	Low	High Speed	UV to Visible	Moderate
Indium Gallium Arsenide (InGaAs)	Low	High Speed	NIR	Moderate
Indium Arsenide Antimonide (InAsSb)	High	Low Speed	NIR to MIR	High
Extended Range Indium Gallium Arsenide (InGaAs)	High	High Speed	NIR	High
Mercury Cadmium Telluride (MCT, HgCdTe)	High	Low Speed	NIR to MIR	High

Junction Capacitance

Junction capacitance (C_j) is an important property of a photodiode as this can have a profound impact on the photodiode's bandwidth and response. It should be noted that larger diode areas encompass a greater junction volume with increased charge capacity. In a reverse bias application, the depletion width of the junction is increased, thus effectively reducing the junction capacitance and increasing the response speed.

Bandwidth and Response

A load resistor will react with the photodetector junction capacitance to limit the bandwidth. For best frequency response, a 50 Ω terminator should be used in conjunction with a 50 Ω coaxial cable. The bandwidth (f_{BW}) and the rise time response (t_r) can be approximated using the junction capacitance (C_j) and the load resistance (R_{LOAD}):

$$f_{BW} = 1 / (2 * \pi * R_{LOAD} * C_j)$$
$$t_r = 0.35 / f_{BW}$$

Noise Equivalent Power

The noise equivalent power (NEP) is the generated RMS signal voltage generated when the signal to noise ratio is equal to one. This is useful, as the NEP determines the ability of the detector to detect low level light. In general, the NEP increases with the active area of the detector and is given by the following equation:

$$NEP = \frac{Incident\ Energy * Area}{\frac{S}{N} * \sqrt{\Delta f}}$$

Here, S/N is the Signal to Noise Ratio, Δf is the Noise Bandwidth, and Incident Energy has units of W/cm^2. For more information on NEP, please see Thorlabs' Noise Equivalent Power White Paper.

Terminating Resistance

A load resistance is used to convert the generated photocurrent into a voltage (V_{OUT}) for viewing on an oscilloscope:

$$V_{OUT} = I_{OUT} * R_{LOAD}$$

Depending on the type of the photodiode, load resistance can affect the response speed. For maximum bandwidth, we recommend using a 50 Ω coaxial cable with a 50 Ω terminating resistor at the opposite end of the cable. This will minimize ringing by matching the cable with its characteristic impedance. If bandwidth is not important, you may increase the amount of voltage for a given light level by increasing R_{LOAD}. In an unmatched termination, the length of the coaxial cable can have a profound impact on the response, so it is recommended to keep the cable as short as possible.

Shunt Resistance
Shunt resistance represents the resistance of the zero-biased photodiode junction. An ideal photodiode will have an infinite shunt resistance, but actual values may range from the order of ten Ω to thousands of MΩ and is dependent on the photodiode material. For example, and InGaAs detector has a shunt resistance on the order of 10 MΩ while a Ge detector is in the kΩ range. This can significantly impact the noise current on the photodiode. For most applications, however, the high resistance produces little effect and can be ignored.

Series Resistance
Series resistance is the resistance of the semiconductor material, and this low resistance can generally be ignored. The series resistance arises from the contacts and the wire bonds of the photodiode and is used to mainly determine the linearity of the photodiode under zero bias conditions.

Common Operating Circuits

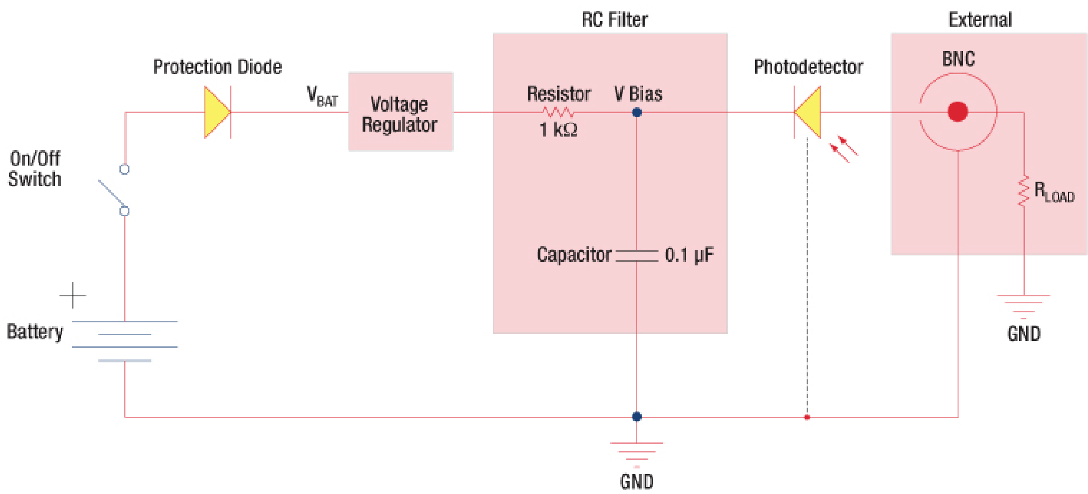


Figure 2: Reverse-Biased Circuit (DET Series Detectors)

The DET series detectors are modeled with the circuit depicted above. The detector is reverse biased to produce a linear response to the applied input light. The amount of photocurrent generated is based upon the incident light and wavelength and can be viewed on an oscilloscope by attaching a load resistance on the output. The function of the RC filter is to filter any high-frequency noise from the input supply that may contribute to a noisy output.

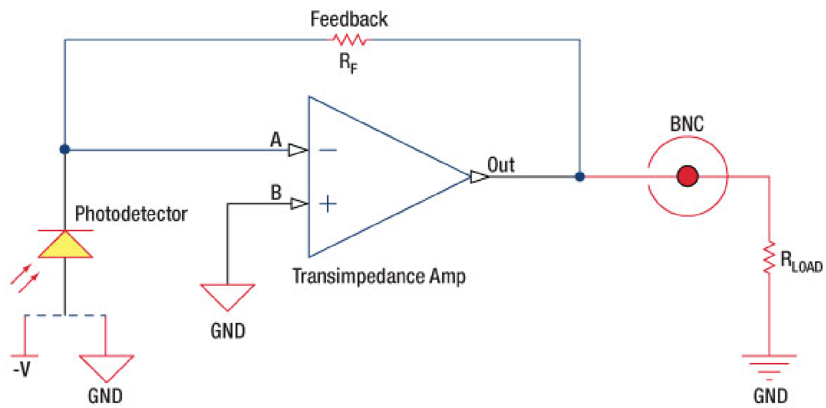


Figure 3: Amplified Detector Circuit

One can also use a photodetector with an amplifier for the purpose of achieving high gain. The user can choose whether to operate in Photovoltaic of Photoconductive modes. There are a few benefits of choosing this active circuit:

- Photovoltaic mode: The circuit is held at zero volts across the photodiode, since point A is held at the same potential as point B by the operational amplifier. This eliminates the possibility of dark current.
- Photoconductive mode: The photodiode is reversed biased, thus improving the bandwidth while lowering the junction capacitance. The gain of the detector is dependent on the feedback element (R_f). The bandwidth of the detector can be calculated using the following:

$$f(-3dB) = \sqrt{\frac{GBP}{4\pi * R_f * C_D}}$$

where GBP is the amplifier gain bandwidth product and C_D is the sum of the junction capacitance and amplifier capacitance.

Effects of Chopping Frequency

The photoconductor signal will remain constant up to the time constant response limit. Many detectors, including PbS, PbSe, HgCdTe (MCT), and InAsSb, have a typical 1/f noise spectrum (i.e., the noise decreases as chopping frequency increases), which has a profound impact on the time constant at lower frequencies.

The detector will exhibit lower responsivity at lower chopping frequencies. Frequency response and detectivity are maximized for

$$f_c = \frac{1}{2\pi\tau_r}$$

LAB FACTS

Thorlabs Lab Fact: Photodiode Saturation Limit and Noise Floor

We present laboratory measurements of the saturation limit and noise floor of a Thorlabs silicon photodiode. While all photodiodes function similarly, there are a number of parameters that affect the noise floor and saturation limit of a photodiode including the sensor temperature, resistivity, reverse bias voltage, responsivity, and system bandwidth. Here we investigated the effect of reverse bias voltage and load resistance within a silicon-based photodiode detection system. Increasing the reverse bias increased the saturation limit and had minimal effect on the noise floor. Decreasing the load resistance decreased the noise floor until reaching the noise of the measurement system, but also decreased the saturation limit. These results demonstrate some of the considerations necessary for choosing the reverse bias voltage and load resistance, and emphasize that noise sources within all of the components must be considered when creating a detection system.

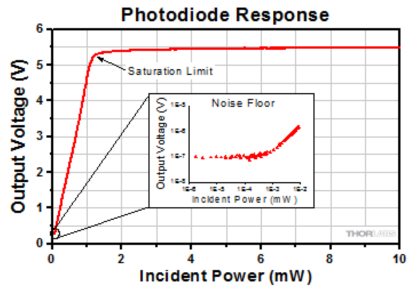


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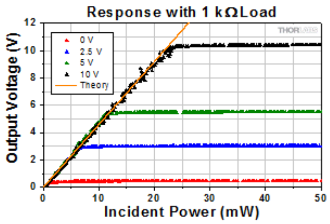
Figure 1. Overview of the Photodiode's Response Curve, Highlighting the Saturation Limit and the Noise Floor

For our experiment we used the FDS100 Si Photodiode as the photodiode under investigation. The collimated output of a fiber-pigtailed laser diode was used as the light source with output power from 0 to 50 mW. The collimated beam was incident upon a beamsplitter that transmitted the majority of the light to the photodiode under investigation and reflected the rest towards a reference power sensor. The photodiode response was then evaluated under various resistive loads and with different reverse bias voltages.

Lab Facts

Click for full Lab Facts summary

The plots to the right and below summarize the measured results for the various tested configurations. From these graphs the changes to the photodiode's linear response, noise floor, and saturation limit can be observed under different reverse voltage biases and load resistances. Figure 1 provides an overview of the photodiode response with a reverse voltage bias of 5 V and resistive load of 10 kΩ. The photodiode saturated at the upper limit of the response when the output photovoltage approached the reverse bias voltage. The noise floor at the lower limit of the response was a result of dark current and the thermal noise from the resistive load (Johnson noise). Figure 2 summarizes the results obtained using the photodiode with a 1 kΩ resistive load and various reverse bias voltages. It illustrates that the saturation limit can be raised by increasing the reverse bias voltage (within specification). Figure 3 summarizes the results from using the photodiode with a 5 V reverse bias voltage and various resistive loads. It illustrates that the slope of the photovoltage response increased as the load resistance was increased. Figure 4 summarizes the noise floor results obtained using a 0 V reverse bias voltage and various resistive loads. The noise floor increased when larger load resistances were used. It is important to note that the 1 kΩ data was measured above the theoretical Johnson noise due to the voltage noise within the measurement system. Minimal change in the overall noise floor was seen when using a 5 V reverse bias voltage. For details on the experimental setup employed and these summarized results, please click here.



Click to Enlarge
Figure 2. Photovoltage Dependence on Reverse Bias Voltage

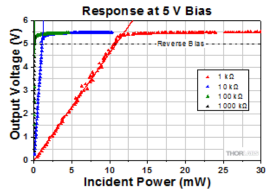


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Figure 3. Response with Various Resistive Loads

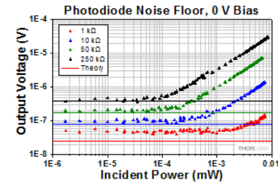

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Figure 4. Noise Floor with Various Resistive Loads

Hide Si Photodiodes with NIST Traceable Calibration

Si Photodiodes with NIST Traceable Calibration

Two NIST traceable calibrated Si photodiodes are available from stock. Si photodiodes are sensitive across the visible and into the near infrared spectrum. The FDS100-CAL and FDS1010-CAL are both large area Si photodiodes and are packaged in a can and on a square ceramic substrate respectively. For detailed information about their specifications and to view responsivity, dark current, and capacitance graphs, please click on the info icons in the table below.

Item #	Info	Wavelength	Active Area	Rise/Fall Time[a]	NEP ($W/Hz^{1/2}$)	Dark Current	Capacitance	Package	$V_{bias,max}$	Compatible Sockets
FDS100-CAL		350 - 1100 nm	13 mm^2	10 ns @ 20 V	1.2×10^{-14} @ 900 nm, 20 V	1.0 nA @ 20 V (Typ.)	24 pF @ 20 V (Typ.)	TO-5 Can (Ø0.36")	25 V	STO5S STO5P
FDS1010-CAL		350 - 1100 nm	100 mm^2	65 ns @ 5 V	2.07×10^{-13} @ 970 nm, 5 V	600 nA @ 5 V (Max)	375 pF @ 5 V (Typ.)	0.45" x 0.52" Ceramic Wafer	25 V	Not Available

a. R_L = 50 Ω. Specified at peak responsivity wavelength of 980 nm for FDS100-CAL and 970 nm for FDS1010-CAL; rise time may vary with wavelength.

Part Number	Description	Price	Availability
FDS100-CAL	**Calibrated Si Photodiode, 350 - 1100 nm, 3.6 x 3.6 mm Active Area**	**$151.00**	**Today**
FDS1010-CAL	**Calibrated Si Photodiode, 350 - 1100 nm, 10 x 10 mm Active Area**	**$182.00**	**Today**

Ge Photodiodes with NIST Traceable Calibration

Two NIST traceable calibrated Ge photodiodes are available from stock. Ge photodiodes are sensitive in the near infrared spectrum from 800 - 1800 nm. The FDG03-CAL and FDG05-CAL are AR Coated for 1300 to 1550 nm and are packaged in a can and on a square ceramic substrate respectively. For detailed information about their specifications and to view responsivity, dark current, and capacitance graphs, please click on the info icons in the table below.

Item #	Info	Wavelength	Active Area	Rise/Fall Time[a]	NEP ($W/Hz^{1/2}$)	Dark Current	Capacitance	Package	$V_{bias,max}$	Compatible Sockets
FDG03-CAL		800 - 1800 nm	7.1 mm^2	500 ns @ 3 V	1.0×10^{-12} @ 1500 nm	1.0 µA @ 1 V (Typ.)	3250 pF @ 1 V (Typ.)	TO-5 Can (Ø0.36")	3 V	STO5S STO5P
					4.0×10^{-12}	10 µA		0.275" x		

FDG05-CAL		800 - 1800 nm	19.6 mm^2	220 ns @ 5 V	@ 1550 nm	@ 5 V (Typ.)	3000 pF @ 5 V (Typ.)	0.310" Ceramic Wafer	5 V	Not Available

a. R_L = 50 Ω. Specified at peak responsivity wavelength of 1550 nm; rise time may vary with wavelength.

Part Number	Description	Price	Availability
FDG03-CAL	Calibrated Ge Photodiode, 800 - 1800 nm, Ø3.0 mm Active Area	$279.00	Today
FDG05-CAL	Calibrated Ge Photodiode, 800 - 1800 nm, Ø5.0 mm Active Area	$385.00	Lead Time

Hide InGaAs Photodiode with NIST Traceable Calibration

InGaAs Photodiode with NIST Traceable Calibration

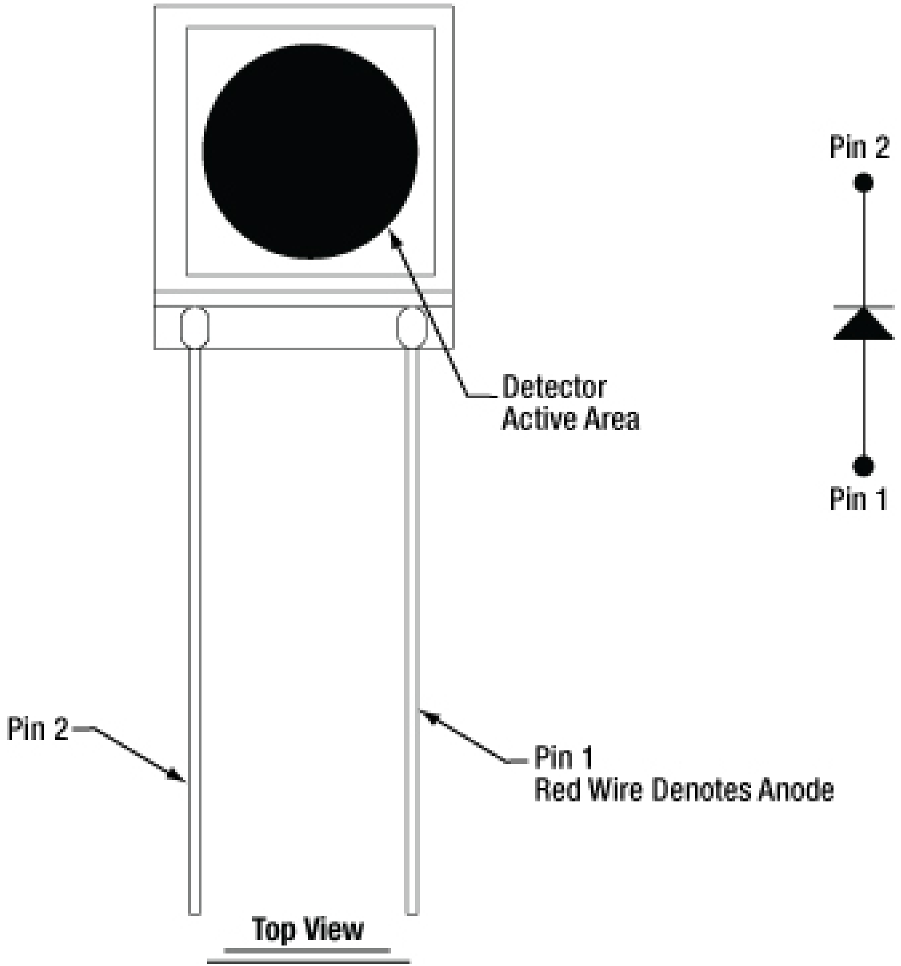
One NIST traceable calibrated InGaAs photodiode is available from stock. InGaAs photodiodes are sensitive in the near infrared spectrum from 800 to 1700 nm. The FGA21-CAL has a PIN structure that results in fast zero bias Rise / Fall times. For detailed information about its specifications and to view responsivity, dark current, and capacitance graphs, please click on the info icon in the table below.

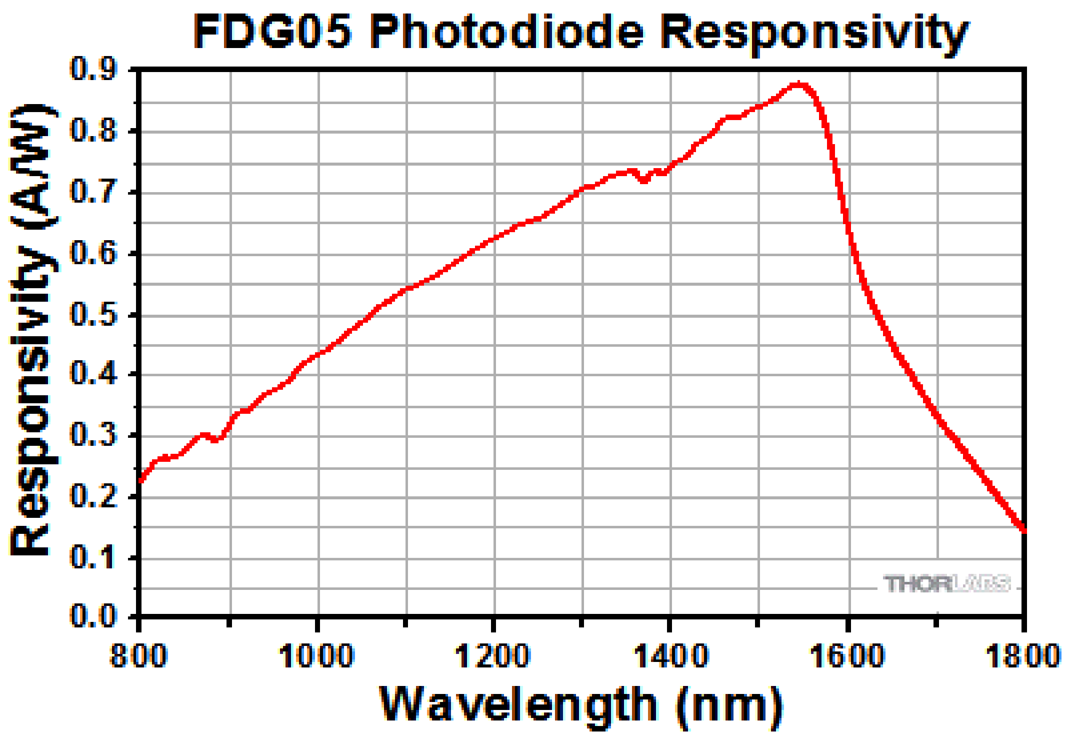
Item #	Info	Wavelength	Active Area	Rise/Fall Time[a]	NEP ($W/Hz^{1/2}$)	Dark Current	Capacitance	Package	$V_{bias,max}$	Compatible Sockets
FGA21-CAL		800 - 1700 nm	3.1 mm^2	14 ns @ 3 V	3.0×10^{-14} @ 1550 nm	50 nA @ 1 V (Typ.) 200 nA @ 1 V (Max)	100 pF @ 3 V (Typ.) 150 pF @ 3 V (Max)	TO-5 Can (Ø0.36")	3 V	STO5S STO5P

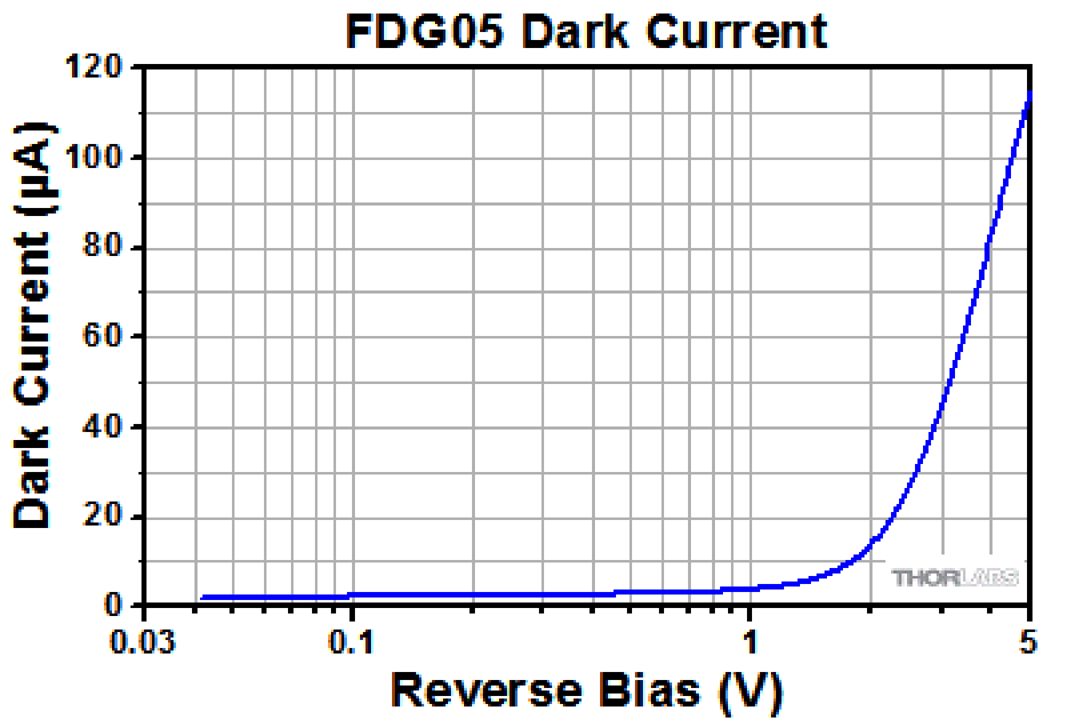
a. R_L = 50 Ω. Specified at peak responsivity wavelength of 1500 nm; rise time may vary with wavelength.

Part Number	Description	Price	Availability
FGA21-CAL	Calibrated InGaAs Photodiode, 800 - 1700 nm, Ø2.0 mm Active Area	$367.00	Lead Time

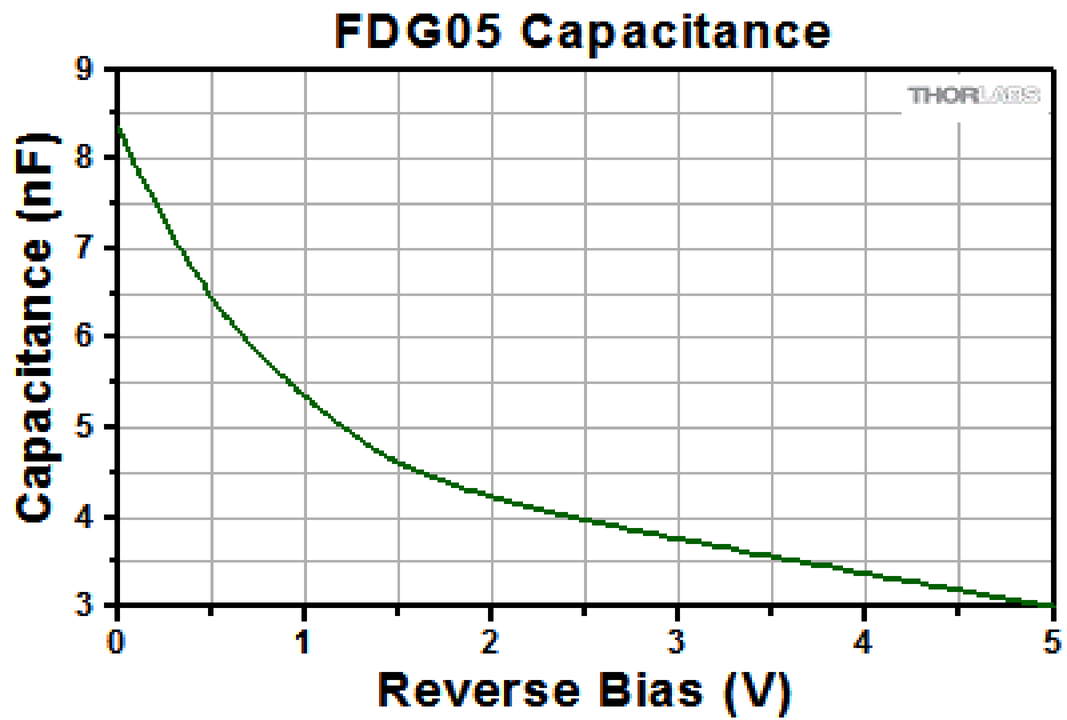
Specifications	
Sensor Material	Ge
Wavelength Range	800 - 1800 nm
Peak Wavelength	1550 nm
Responsivity	0.95 A/W
Active Area Diameter	19.6 mm^2 (Ø5 mm)
Rise/Fall Time (R_L = 50 Ohms, 5 V)	220 ns / 220 ns
NEP, Typical (1550 nm)	4.0×10^{-12} $W/Hz^{1/2}$
Dark Current (5 V)	10 µA (Typ.)
Capacitance (5 V)	3000 pF (Typ.)
Package	Ceramic
Max Ratings	
Max Bias (Reverse) Voltage	5 V
Operating Temperature	-55 to 60 °C
Storage Temperature	-55 to 60 °C


Pin 2
Pin 1
Detector
Active Area
Pin 2
Pin 1
Red Wire Denotes Anode
Top View


FDG05 Photodiode Responsivity
Responsivity (A/W)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
800
1000
1200
1400
1600
1800
Wavelength (nm)
THORLABS



FDG05 Dark Current
Dark Current (µA)
120
100
80
60
40
20
0
0.03
0.1
1
5
Reverse Bias (V)
THORLABS


FDG05 Capacitance
THORLABS
Capacitance (nF)
9
8
7
6
5
4
3
0
1
2
3
4
5
Reverse Bias (V)