

Maximum Measurable Power for Photodiode Detector



INTRODUCTION

Photodiodes are one of the most common detectors used for measuring optical power of a light source. MKS Instruments' Newport photodiode detectors are spectrally calibrated for monochromatic light sources and specified to measure up to 2 watts of optical power. However, the maximum power specification is an oversimplified representation that provides easy information for the user to decide which detector to use. In reality, the maximum power that a photodiode can handle depends on multiple factors such as photodiode output current saturation, wavelength of the light source, use of an attenuator such as a diffuser or a neutral density filter, and power meter's maximum current input value. In certain cases, the user can measure a significantly higher power than the product specification indicates, so there is no need of purchasing a new detector. Often, the alternative detector with a higher maximum power level is a thermopile detector, whose characteristics are very different than those of photodiode detectors. For instance, the response time of a thermopile detector is on the order of one second, too slow for many applications such as fiber optic alignment and or modulated light measurements. Knowing the characteristics of the photodiodes allows accurate measurements even outside the product specifications.

Photodiode saturation

A photodiode detector is essentially a p-n junction semiconductor that will generate current if the energy of incident photons is greater than the bandgap of the material, spectrally calibrated detectors are typically operated in photovoltaic mode without a bias voltage.

Since the photon energy varies as a function of the wavelength, the responsivity, which measures as the output current per input optical power of a photodiode, exhibits the wavelength dependency. The response of different semiconductor materials is varied due to the different bandgap structure.

The first factor to consider is saturation of the output current generated by the photodiode, as shown in Figure 1. The output current linearly increases with an increase of the optical input power and starts to become nonlinear, independent of the wavelength of the input light. Photodiodes from different manufacturers will exhibit various levels of saturation current, typically at around 1 ~ 10 mA. Since measurement accuracy is important with the spectrally calibrated detectors, the detector manufacturers usually define the maximum current level as soon as the response of the diode becomes nonlinear.

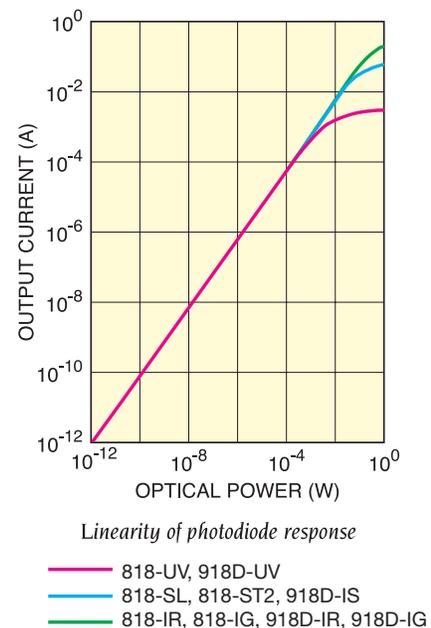


Figure 1. Output current vs. input optical power plot of various MKS Newport detector models.

From the wavelength dependent responsivity curve with the maximum current output of a photodiode, one can obtain the maximum power curve by applying the simple conversion relationship:

$$\text{Maximum measurable power} = \frac{\text{maximum output current}}{\text{responsivity}}$$

For Newport's 818-SL/DB silicon detector, for instance, the typical maximum power and the responsivity plot as a function of wavelength is shown in Figure 2, when the accompanying attenuator is not used (More on the attenuator below). The typical saturation current of the photodiode used in the product is approximately 2.5 mA. Because the maximum power is inversely related to the responsivity at a given wavelength, the maximum power is the lowest when the detector is the most sensitive, that is, when the responsivity is the highest. When a single number is provided as the maximum power of a photodetector, the manufacturers usually select this number as the specification. Therefore, at other wavelengths where the responsivity is lower, one can measure a laser beam with higher power without saturating the photodiode.

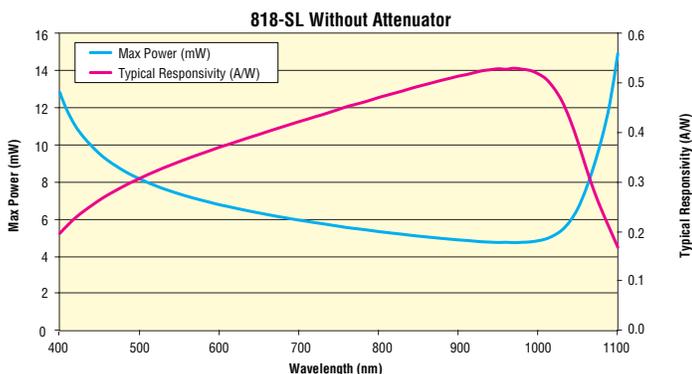


Figure 2. Detector responsivity and maximum power as a function of wavelength for an 818-SL/DB detector without the attenuator on. On the right is a photo of the product.

In many cases, if the optical power level is not far above the maximum value, and a larger measurement error is acceptable, it's usually ok to measure the power above the value specified in the plot. The reason is because the output current saturation does not happen abruptly, but the curve gradually curves into the complete saturation.

Optical Attenuator

An attenuator is often placed before a photodiode sensor to extend the optical dynamic range. Neutral density filters are typically used as the attenuator. A possible consequence, however, is that the optical density (OD) of the attenuator material may also vary with wavelength as well. To measure higher power laser sources, most of Newport's photodiode detectors have a removable or switchable OD1, OD2, or OD3 attenuator. The OD1 attenuator attenuates the input beam by a factor of 10, while the OD2 and the OD3 attenuators do by a factor of 100 and 1000, respectively.

These attenuators are removable, so the responsivity curve of the detector is obtained twice: once with the attenuator on, and once without it. Figure 3 shows the responsivity curves of various models with and without the OD3 attenuators. Certain detector series also have models with an OD1 or an OD2 attenuator. With the OD3 attenuator, the photodiode can respond linearly to more than 10 watts of optical power at certain wavelengths, if the saturation current alone is considered. However, at this point, the temperature of the detector body keeps increasing, and the readings become unstable. Therefore, Newport recommends maximum 2 watts of power, no matter what the wavelength is, when measuring with a photodiode detector with an attenuator.

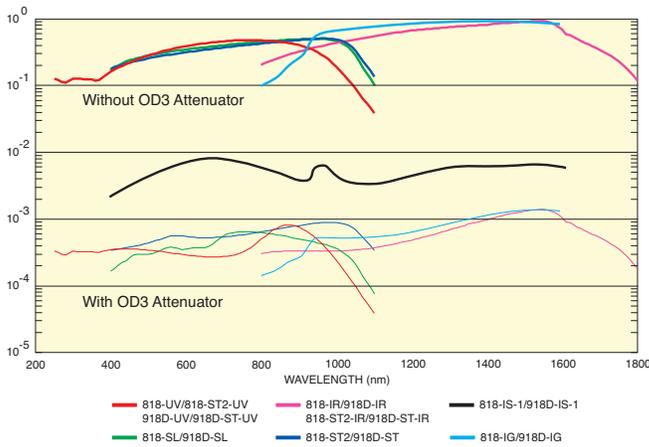


Figure 3. Responsivity curves with and without an OD3 attenuator for various Newport detector models. 918D-SL, 918D-IR, and 918D-IG series also have models with the OD1 and OD2 attenuators.

Maximum Input Current of the Power Meter

Finally, the maximum input current handling capability of a power meter must be considered. Power meter is a highly sensitive, calibrated ammeter, which reads the current output and converts it to power. A typical power meter has multiple stages of signal amplification through a transimpedance amplifier, to handle a wide range of input current levels. For each stage, defined as “Range” in Newport’s power meters, a maximum current value is specified. As the photodiode generates more current output with a higher input laser power level, the power meter will switch to a higher range so that it can handle the signal without getting saturated. The saturation current of the photodiodes Newport is using varies between less than 1 mA to 5 mA. Models 1936-R, 2936-R, and 1830-R series power meters can handle at least 10 mA of current input at the maximum Range, so that the full linear range of all the photodiodes can be utilized. In addition, with Newport’s long tradition of supporting the photonics research community, these meters were designed to work with third-party or home-made photodiodes that can have a high saturation current.

The maximum current of the models 1919-R, 841-PE-USB, and 843-R series is 1.3 mA, on the other hand, hence, the meter is the limiting factor. In this case, the goal is to guarantee that all the measurements can be done within the linear range no matter which photodiode model is used to make the measurements.

The typical saturation current of this model is approximately 2.5 mA. If this detector is connected to the 1919-R power meter, the maximum current capability of the meter is the limiting factor in calculating the maximum measurable power. When the detector is connected to the 1936-R power meter, however, detector saturation is the limiting factor. Figure 4 shows the plots of the maximum measurable power for the benchtop power meter models and the handheld power meters for the silicon detector model 918D-IS-SL, showing different levels of the maximum power, depending on the power meter models.

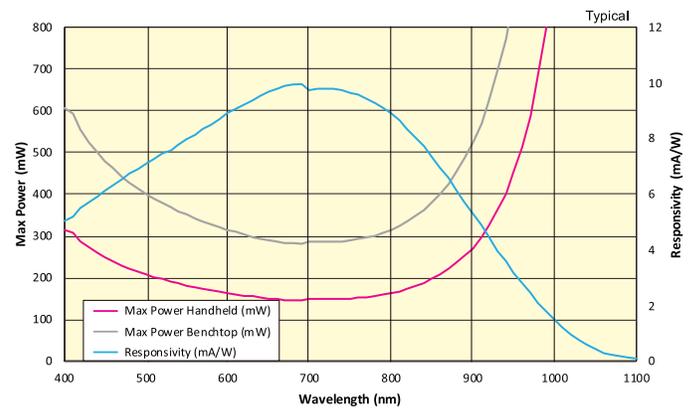


Figure 4. The typical maximum power curve of 918D-IS-SL detector as a function of wavelength for Newport handheld meters vs. benchtop meters.

CONCLUSION

It would be very convenient if the power meter is smart enough to consider all the factors and automatically inform the user the maximum power value at a given wavelength for each type of detector materials, while fully utilizing the linear region of each detector model. However, at present, no such meter exists. Newport provides maximum power specifications based on the power meter models, with and without an attenuator, and wavelength dependent maximum power level. With the knowledge of these factors that affect the maximum measurable power, the most appropriate detector for a given laser input power level can be selected.