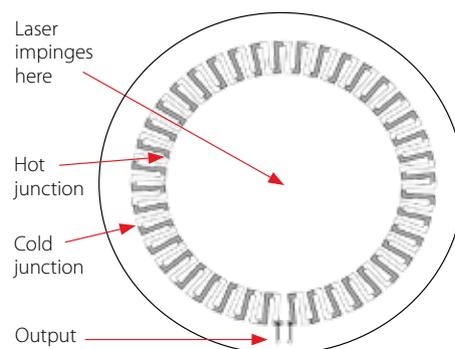


# 1.1 Power Sensors

## Thermal Sensors

As described in the general introduction, the thermopile sensor has a series of bimetallic junctions. A temperature difference between any two junctions causes a voltage to be formed between the two junctions. Since the junctions are in series and the «hot» junctions are always on the inner, hotter side, and the «cold» junctions are on the outer, cooler side, radial heat flow on the disc causes a voltage proportional to the power input. Laser power impinges on the center of the thermopile sensor disc (on the reverse side of the thermopile), flows radially and is cooled at the periphery. The array of thermocouples measures the temperature gradient, which is proportional to the incident or absorbed power. In principle, the reading is not dependent on the ambient temperature since only the temperature difference affects the voltage generated and the voltage difference depends only on the heat flow, not on the ambient temperature. Since all the heat absorbed flows through the thermocouples (as long as the laser beam is inside the inner circle of hot junctions), the response of the detector is almost independent of beam size and position. If the beam is close to the edge of the inner circle, some thermocouples become hotter than others but since the sum of all of them is measured, the reading remains the same. Generally, Ophir specifies  $\pm 2\%$  uniformity of reading over the surface or better.

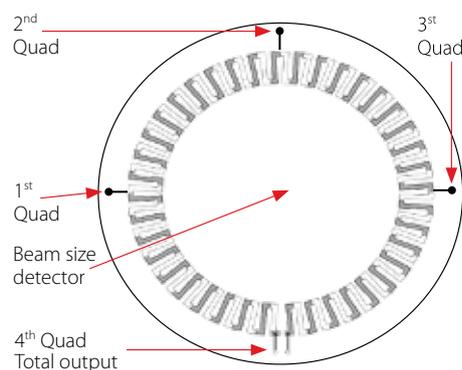


## Using Power Sensors to Measure Single Shot Energy

Although Ophir thermal power sensors are used primarily to measure power, they can measure single shot energy as well, where they integrate the power flowing through the disc over time and thus measure energy. Since the typical time it takes for the disc to heat up and cool down is several seconds, these thermal sensors can only measure one pulse every several seconds at most. Thus they are suitable for what is called “single shot” measurement. Although the response time of the sensor discs is slow, there is no limit to how short the pulses measured are since the measurement is of the heat flowing through the disc after the pulse.

## BeamTrack Power / Position / Size sensors

Ophir now has the new BeamTrack thermal sensor that can measure beam position and beam size as well as power. This innovative device provides an additional wealth of information on your laser beam – centering, beam position and wander, beam size as well as power and single shot energy. The BeamTrack sensor is illustrated schematically here and works as follows: the signal coming from the sensor is now divided into 4 quadrants so by measuring and comparing the output from the 4 sections we can determine the position of the center of the beam to a high degree of accuracy. In addition to the 4 quadrants, there is now a special proprietary beam size detector. After processing outputs from these various detectors, the user is presented with the beam position as well as beam size. Note that the beam size is calibrated only for a Gaussian beam of  $>3\text{mm}$  but for other beams it will give relative size information and will indicate if the beam is changing size. For more information on the BeamTrack sensors, please see section 1.1.3



## Types of Thermopile Discs

There is no single absorber which meets the needs of all applications. Ophir has developed several types for different applications, such as long pulses (0.1-10ms), short pulses ( $<1\mu\text{s}$ ) and continuous radiation. Absorbers optimized for long pulses and CW are characterized by thin, refractory materials, since the heat can flow through the coating and into the disc during the pulse. On the other hand, heat cannot flow during short pulses, and all the energy is deposited in a thin (typically  $0.1\mu\text{m}$ ) layer near the surface. This causes vaporization of the surface which ruins the absorber. Instead, a volume absorber that is partially transparent and absorbs over a distance of  $50\mu\text{m}$  -  $3\text{mm}$  is used. This spreads the heat over a larger volume allowing much higher energies.

Ophir thermopiles can measure from tens of microwatts to Kilowatts. Nevertheless, the thermal range of operation of the discs is limited. If the difference between the hot and cold junction temperature exceeds tens of degrees, the constant heating/cooling of the junctions can cause premature failure in the junctions. In order to accommodate different power ranges, discs of different thicknesses and sizes are used, thick ones for high powers and thin ones for low powers.

The response time of the discs is dependent on their size and shape: larger diameters and thicker discs are slower than thin small diameter ones. The response time is in general dependent on the mass of material which has to heat up in the thin absorber region of the disc vs. the speed the heat flows out of the same region. The response time is approximately proportional to the aperture, i.e. a 50mm aperture disc is three times as slow as an 18mm aperture disc.

## Thermal Surface Absorbing Sensors

A surface absorber typically consists of an optically absorbing refractory material deposited on a heat conducting substrate of copper or aluminum. When a long pulse of several hundred  $\mu\text{s}$  or a continuous laser beam falls on such a surface absorber, the light is absorbed in a very thin layer of the surface – typically 0.1 – 1  $\mu\text{m}$  thickness (see illustration A). Although the light is absorbed in a thin layer and there converted into heat, the pulse is long enough so that while energy is being deposited into the surface layer, heat is also flowing out into the heat conducting substrate and therefore the surface does not heat up excessively. Ophir standard surface absorbers can stand up to 10 Joules/cm<sup>2</sup> for 2ms pulses and up to 28kW/cm<sup>2</sup> for low power continuous lasers.

## Surface Absorbers for High Power Lasers and Long Pulses

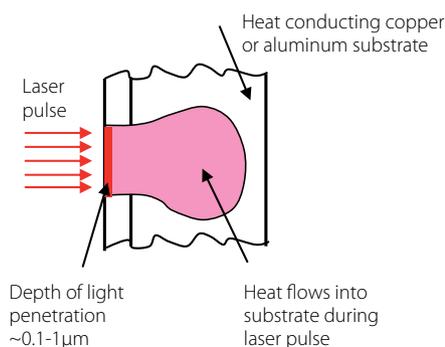
The traditional surface absorbers have a much lower damage threshold at  $> 1000\text{W}$ , where they can damage at 2-3 kW/cm<sup>2</sup>. Ophir has developed coatings that improve the damage threshold for high power lasers. These coatings are denser and have higher heat conductivity than previous coatings. This LP2 coating also has a much higher damage threshold for long pulses reaching power damage thresholds of up to 10kW/cm<sup>2</sup> and 300J/cm<sup>2</sup> for 10ms pulses. Surface absorbers are suitable for pulses longer than  $\sim 100\mu\text{s}$ .

## Surface vs. Volume Absorbers

When measuring a laser with short pulses of tens of  $\mu\text{s}$  or less, the heat is deposited in a short time and cannot flow during the pulse (see illustration B below). Therefore a surface absorber which absorbs the energy in a thin surface layer is not suitable. All the energy is deposited in a thin layer and that layer is vaporized. In this case, volume absorbers are used. These have traditionally consisted of a neutral density glass thermally bonded to a heat-conducting metallic substrate. The ND glass absorbs the light over a depth of 1-3 mm instead of fractions of a micrometer. Consequently, even with short pulses where there is no heat flow, the light and heat are deposited into a considerable depth of material and therefore the power/energy meter with a volume absorber is able to withstand much higher energy densities – up to 10 Joules/cm<sup>2</sup> (see illustration C). These ND glasses form the basis of the Ophir P type absorbers. In addition to the P absorbers, Ophir has PF and SV absorbers that can stand up to higher average powers and power densities as well as EX absorbers for the UV.

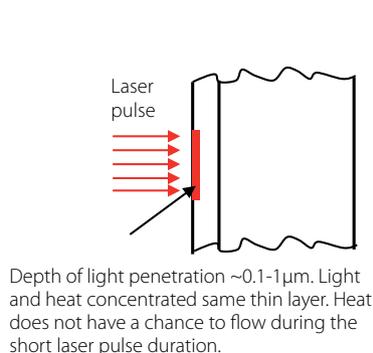
### Long laser pulse ( $>100\mu\text{s}$ ) or continuous

#### (A) Surface absorber

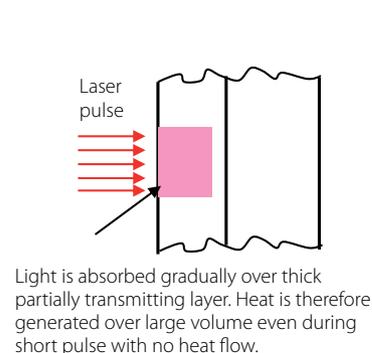


### Short laser pulse $<10\mu\text{s}$

#### (B) Surface absorber



#### (C) Volume absorber

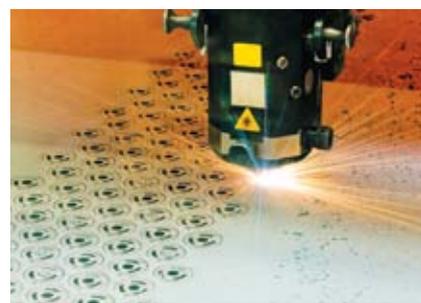


**Surface absorbers work best when measuring power or energy for long laser pulses (A). Volume absorbers can measure pulses with much higher energies than surface absorbers (B), (C) can measure.**

## Introduction to High Power Water Cooled Sensors

Ophir has many years experience in supplying measurement systems for high power industrial lasers and has the highest power measuring equipment available on the market – up to 120 kilowatts. Ophir meters also have the highest damage threshold available – up to 10kW/cm<sup>2</sup> at 10kW. Ophir supplies water cooled sensors from 300W up to 120kW and air cooled sensors up to 500W.

All sensors supplied by Ophir have been tested at up to full power and their linearity verified over the entire power range. This is done by deflecting a fraction of the power with a beam splitter into a lower power sensor whose linearity has previously been verified by NIST or PTB. In some cases, it is done by measuring the reading over the power range against a higher power sensor that has been previously measured. The accuracy, linearity and damage specifications have been carefully verified over many years of development and use by the largest existing user base. In addition to power meters for high powers, Ophir also has beam profilers, beam dumps and protective enclosures for industrial lasers.



## Calibration Method and Estimated Accuracy for Ophir High Power Sensors

Ophir models 5000W, 10K-W, Comet 10K and 30K-W are calibrated using relatively low power lasers not exceeding 1000W. Using laser powers that are in many cases much lower than the power rating of the sensors being calibrated raises the question of calibration accuracy. The following explanation clearly demonstrates that these highest power sensors are indeed accurate to  $\pm 5\%$  over their measurement range as specified. The 5000W, 10K-W and 30K-W sensors work on the thermopile principle, where the radial heat flow in the absorber disk causes a temperature difference between the hot and cold junctions of the thermopile which in turn causes a voltage difference across the thermopile. Since the instrument is a thermopile voltage generating device, it must be linear at low values of output. Therefore, if it has been shown to be linear up to full power – as it has - it will necessarily be linear at very low powers and if the calibration is correct at low powers, it will remain correct at high powers as well. On the other hand, although the output may be linear at low powers, there may be a zero offset that, due to the relatively low output at low powers, will cause an error in calibration.

For example, if calibration is performed at 200W and the output of the sensor is  $10\mu\text{V}/\text{W}$  (a typical value) and there is a zero offset of only  $1\mu\text{V}$ , this will cause a calibration error of 10%. Ophir's calibration method always measures the difference between the reading with power applied and without power applied, thus eliminating error due to zero offset. This measurement is taken several times to insure accuracy. The above measurement method assures that the calibration inaccuracy due to measurement errors is less than 1%, comparable to the expected errors in our lower powered sensors. In order to verify this, all of our high power sensors have been measured by comparison to various calibration standards. These measurements have shown Ophir sensors to be well within the claimed limits of linearity. The Comet 10K series measures the heat rise of the absorbing puck when irradiated by the laser for 10s. In order to calibrate the Comet 10K, we simply irradiate with a lower power laser for longer e.g. 150W for 60s. Thus the heating effect is similar to that of a higher power laser. Tests of the Comet calibrated by this method vs. NIST traceable high power sensors has shown that it is accurate and reproducible. For more information on calibration please consult our website at

[www.ophiropt.com/calibration-procedure/tutorial](http://www.ophiropt.com/calibration-procedure/tutorial)

## Photodiode Sensors

A photodiode sensor is a semiconductor device that produces a current proportional to light intensity and has a high degree of linearity over a large range of light power levels - from fractions of a nanowatt to about 2 mW. Above that light level, corresponding to a current of about 1mA, the electron density in the photodiode becomes too great and its efficiency is reduced causing saturation and a lower reading. Most Ophir PD sensors have a built-in filter that reduces the light level on the detector and allows measurement up to 30mW without saturation. Most sensors have an additional removable filter allowing measurement to 300mW or 3 Watts depending on the model.

## Principle of Operation

When a photon source, such as a laser, is directed at a photodiode detector, a current proportional to the light intensity and dependent on the wavelength is created. Since many low power lasers have powers on the order of 5 to 30mW, and most photodiode detectors saturate at about 2mW, the PD300 sensor has been constructed with a built-in filter so the basic sensor can measure up to 30mW without saturation. With the removable extra filter, the PD300 sensors series can measure up to 300mW or 3W depending on the model.

The Ophir power meter unit amplifies this signal and indicates the power level received by the sensor. Due to the superior circuitry of the Ophir power meters, the noise level is very low and the PD300 series sensors with Ophir power meter have a large dynamic range from picowatts to watts. The PD300 is shown schematically below. The PD300 and PD300-1W have the exclusive patented dual detectors connected back to back which eliminate any signal illuminating both detectors equally (background light).

## Calibration and Accuracy

The sensitivity of various photodiode sensors varies from one sensor to another as well as with wavelength. Therefore, each PD300 sensor is individually calibrated against a NIST standard, which has been calibrated at several nm intervals over the entire spectral range. The calibration is done over the entire spectral range against the NIST standard using a computer-controlled monochromator.

Since the instruments are calibrated against NIST standards, the accuracy is generally  $\pm 3\%$  over the wavelength range the calibration has been performed. The linearity of the photodiode detector is extremely high and errors due to this factor can be ignored, as long as saturation intensity is not approached. For more information on calibration accuracy please see our website at:

[www.ophiropt.com/calibration-procedure/tutorial](http://www.ophiropt.com/calibration-procedure/tutorial)

