Laser Power and Energy Measurement

This section introduces Ophir's wide range of laser measuring instruments for laser users. This general guide, which will assist you in choosing power/energy measurement instrumentation according to your specific needs, also serves as an introduction to other products available from Ophir Optronics.

Smart Heads and Displays

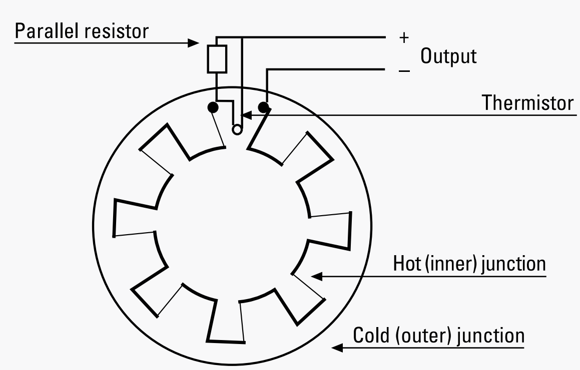
Ophir standard power and energy measuring heads and displays all use smart head technology. This means that all the configuration and calibration information is stored in a small memory chip inside the smart head plug, so that when the head is plugged into the display the correct power and energy are read. Except for some OEM heads, this technology is used in all Ophir heads: pyroelectric, photodiode, scanned beams, medical heads, etc.

Smart Head Advantages

1. Only one display needed for many different heads, even if used for widely different applications.
2. User does not have to keep track of head-display sets. Any head will work with any display and keep correct calibration.
3. Re-calibration of heads requires only head and not display.
4. New Ophir products will work with displays already in possession.
5. Ophir displays offer a wealth of features.
6. The user can set up configuration of favorite scales, measurement types etc. This information will be stored in the head memory. The configuration does not need to be set up each time the head is plugged into a display.

Thermal Heads

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 disk, flows radially and is cooled on the periphery. The array of thermocouples measures the temperature gradient, which is proportional to the incident or absorbed power.



Thermopile Sensor Disk with CAL Resistor

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.

A thermistor is used to compensate for the fact that the thermocouple effect is not exactly linear with temperature (the effect decreases about 10% at the highest operating temperature of Ophir sensors – about 80°C). The thermistor's resistance decreases as the temperature increases. The reduced resistance increases the effective voltage on the amplifier by the same amount that the thermocouple efficiency decreases, thus compensating for non-linearity.

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 ±2% uniformity of reading over the surface.

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 (<1µs) 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 0.1µm) 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 50µm-3mm 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 will cause premature failure and breaks 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 Heads

Principle of Operation

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 µs 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 - 1µm 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 50 Joules/cm^2 for 2ms pulses and up to 100 KW/cm^2 for low power continuous lasers.

Surface Absorbers for High Power Lasers

The traditional surface absorbers have a much lower damage threshold at > 1000W, where they can damage at 2-3 KW/cm^2. Ophir has developed coatings that improve the damage threshold for high power lasers. The new coatings are denser and have higher heat conductivity than previous coatings.

With these improvements, the standard broadband coating is now rated for 4KW/cm^2 at high powers and the "LP" absorber developed by Ophir Optronics can withstand 6KW/cm^2 of high power laser radiation with no damage, a factor of 2 or more better than former coatings. The improvement is even more pronounced for long pulse high power lasers. Whereas former surface absorbers were damaged by 30 Joules/cm^2 from a 10ms pulsed laser, the new LP1 absorber can stand up to 250J/cm^2 - 8 times as much.

Thermal Volume Absorber Heads

When measuring a laser with short pulses of tens of µs or less, the heat is deposited in a short time and cannot flow during the pulse (see illustration B). 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. These limitations catalyzed the development of volume absorbers which 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^2 (see illustration C). These ND glasses form the basis of the Ophir P type absorbers.

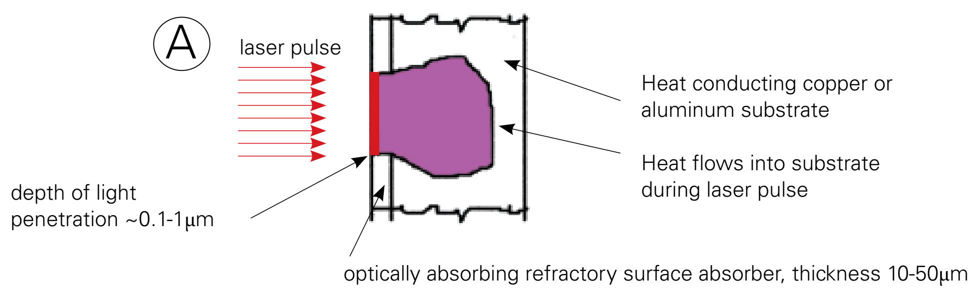
Volume Absorbers for High Energies and Average Powers

The P type is unable to withstand higher energy and average power lasers because of its poor heat conductivity and low melting point. Ophir has developed "HE", "HE1" and "SV" ceramic volume absorbers which are characterized both by a much higher heat conductivity and a higher melting point than the ND glass type. The new volume absorbers stand up to 500 Watts/cm^2 with no damage, a factor of 10 times better than the ND type for continuous radiation. Consequently, the HE/HE1 type power meter can be used for pulsed lasers with high average power.

The HE/HE1 is also dramatically better in withstanding individual pulses. Whereas the ND type could reliably withstand up to about 0.7 Joules/cm^2 for a 30Hz Q switched laser, the HE type can withstand up to 2 Joules/cm^2 - an improvement factor of 3. Whereas the old volume absorbers were damaged by less than 2 Joules/cm^2 with a 30Hz Erbium laser of 300µs pulse length, the HE type can withstand up to 50 Joules/cm^2 with no damage - an improvement factor in excess of 25. Whereas the old volume absorbers could withstand up to 10 Joules/cm^2 for a single shot long pulse Ruby laser, the HE type can withstand over 100 Joules/cm^2 - an improvement factor of 10. Because HE/HE1 absorption is not constant with wavelength, for pulses longer than 1ms, it is preferable to use the surface absorbers, in particular the high damage threshold LP1 absorber.

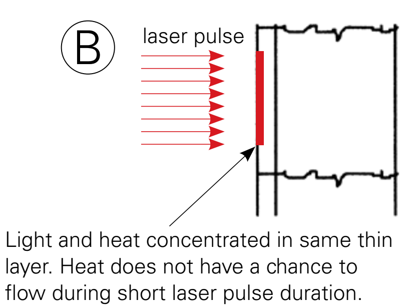
Long laser pulse (>300µs) or continuous laser

surface absorber

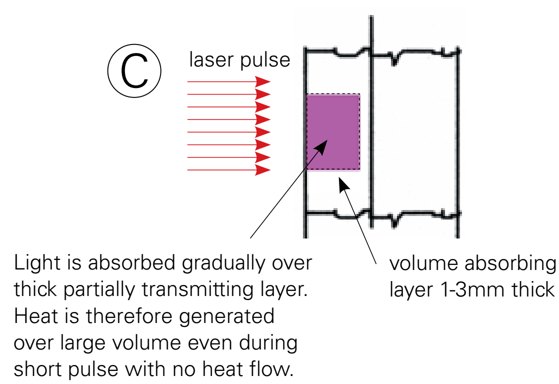


Short laser pulse <100ns

surface absorber



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.

Thermal Excimer Absorbers

Ophir excimer absorbers are moderately volume absorbing and have excellent absorption in the UV. Having almost complete spectral flatness from 193 to 400 nm, they can also be made in large aperture sizes ideal for excimer lasers. Their ability to absorb well at 10.6µm allows them to be used for CO_2 lasers too.

High Power Measurement

Calibration Method and Estimated Accuracy of Models 5000W and 10K-W

Ophir models 5000W, 10K-W and Comet 10K are calibrated using a relatively low power ~ 150 - 300W lasers. Using such low power lasers to calibrate the instrument vs. the high power at which it is used raises the question of calibration accuracy. The following explanation clearly demonstrates that the 5000W, 10K-W and Comet 10K are indeed accurate to ±5% over their measurement range. The 5000W and 10K-W heads 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 is shown to be linear at powers which are a significant fraction of the maximum power, 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 3.5µV/W (a typical value) and there is a zero offset of only 0.1µV, this will cause a calibration error of 7%. 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 meters.

In order to verify this, model 5000W, 8000W, and 10-KW heads have been measured by various standards laboratories. These measurements have shown Ophir heads to be well within the claimed limits of linearity.

Besides the accuracy of the initial calibration, there arises the question of the change in calibration due to damage or discoloring of the absorbing coating.

This problem has been tested by focusing a high-powered beam down onto the absorber until damage occurs. The damage threshold is defined as the damage to the surface that will cause a change in reading of more than 1%. This occurs at about 4KW/cm^2. At this level, the surface becomes visibly discolored but the reading does not change by more than 1%. Thus if the power density does not exceed 4KW/cm^2, the calibration should not change significantly. Note, however, that with a Gaussian beam, the average power density may only be half as much as the peak power density in the center of the beam.

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 this method on NIST traceable high power heads have shown that it is accurate and reproducible.

Photodiode Sensors

A photodiode sensor 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. Ophir heads have a built-in filter that reduces the light level on the detector and allows measurement up to 30mW without saturation. In addition, another removable filter allows measurement up to 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 head has been constructed with a built-in filter so the basic head can measure up to 30mW without saturation. With the removable extra filter, the PD300 heads series can measure up to 3W depending on the model.