Laser Power / Energy Measurement Today

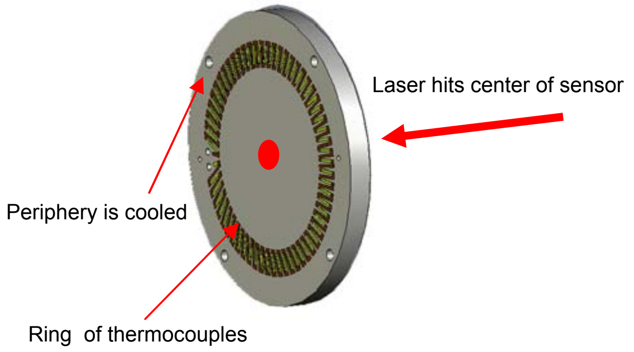
By Dr. Ephraim Greenfield
Ophir Optronics

The laser industry is advancing steadily with new wavelengths, higher powers and energies, and new applications all the time. As the power, energy and variety of new lasers advances, so measurement of these lasers has to advance.

The basic technology of laser power/energy measurement has not changed in the last 10 years. There are still three basic ways to measure laser power and energy

a. The first type of laser measurement device is the thermopile detector that measures the amount of heat flowing through the detector by its heating effect on an array of thermocouples. This type of detector operates as follows:

When a laser beam impinges on the central area of the sensor disc, then the heat flows radially towards the cooled periphery as shown in the illustration. Since the total amount of heat flowing through the thermopile ring is independent of the beam size or position, then as long as the laser beam is within the thermopile area, the reading will be quite independent of beam size and position.

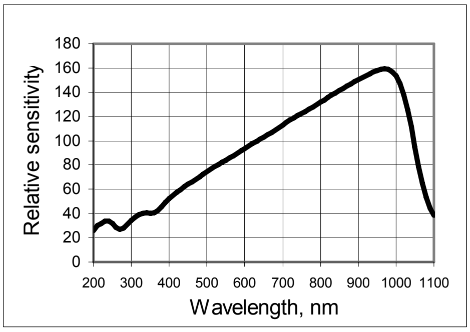


The thermal power meter is not measuring the absolute temperature of the sensor but rather the temperature drop across the thermopile. Therefore the reading is quite independent of ambient temperature. If the temperature of the cooled periphery goes up, the temperature of the inside of the thermopile goes up correspondingly and the temperature drop – hence the reading – remains basically the same.

Thermopile laser measurement is almost wavelength independent, durable and reliable. It is therefore the mainstay of laser power/energy measurement. It cannot, however, measure repetitive pulses or very low powers and energies

b. The second type of measurement device is the photodiode detector that converts light impinging on a photodiode into a current.

These photodiode detectors are based on a semiconductor P-N junction. When photons of light with energy greater than the characteristic band gap energy of the photodiode hit the detector, they create an electron hole pair that is collected in the associated circuit. The wavelength response of such a detector is shown at right. As can be seen, since only one electron is released for each photon, the shorter the wavelength the less efficient is the detector (a powerful photon of short wavelength releases as much current as a weak photon of longer wavelength). However, when the wavelength is so long that the photon is not powerful enough to release an electron, then the efficiency abruptly drops off as shown at the right.

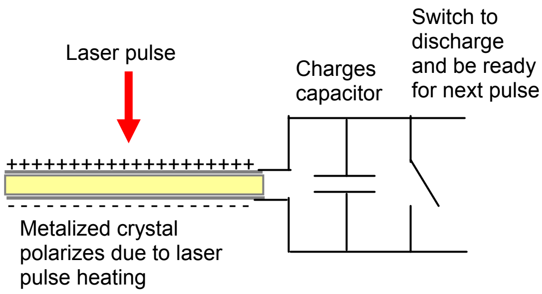


Photodiode detectors are very sensitive, have a wide dynamic range and are very linear at low powers. However, they are very wavelength dependent as shown in the graph, necessitating calibration over a complete range of wavelengths. They also saturate at low powers, becoming nonlinear. Therefore this type of power meter is mainly for low powers. With no additional filters, they are linear up to a few mW and with filters they can measure as much as 3 Watts.

c. The third type of detector is the pyroelectric detector consisting of a crystal that polarizes when heated.

   These detectors operate as follows:

   When a pulse of light hits the absorbing surface of the detector, it heats up and polarizes the crystal, thus creating a equal and opposite charge on the two surfaces of the detector. The detector surface is metalized so the charge is collected onto the parallel capacitor no matter where the laser beam hits the surface. The charge on the capacitor is thus proportional to the pulse energy.



   After the pulse is over, the voltage on the capacitor is read and the capacitor is electronically discharged to be ready for the next pulse.

   Pyroelectric detectors are particularly useful for repetitive pulses and can measure up to thousands of pulses per second. They are also quite sensitive. They are not particularly durable, however, so for higher energies and powers, an attenuator/diffuser is placed in front of the sensor crystal to lower the energy on the pyroelectric crystal.

While the basic measurement technology, as explained above has remained the same, lasers and laser systems have advanced in a number of ways thus necessitating improvements in power/energy measurement devices.

1. Lasers and laser systems have become more precise and system requirements for exact power or energy have become more demanding. If ± 10% in power was formerly acceptable then today in many instances a need for controlling a laser based device to ± 5% in absolute accuracy and ±1% or better in stability are common. Today, there are applications that need to measure pulse to pulse stability to 0.2% accuracy.
2. Lasers have become more powerful. Today we have commercial or medical lasers putting out 300 Joules per pulse or powers of 10Kilowatts. We have concentrated beams with up to several hundred Joules/cm² or over 10KW/cm². These powerful and concentrated beams challenge the most durable power/energy meters.
3. Lasers have proliferated and have become more diverse. We have today lasers of a tremendous variation in power, energy, wavelength, beam size and repetition rate. We have powers from picowatts to 10s of kilowatts, energies from picojoules to hundreds of Joules. We have beam sizes from very small to meters in diameter and repetition rates to tens of kilohertz. We have lasers from the far UV to the far IR. Power and energy measuring devices have to deal with this variety as well as possible. An example of a new type of source for which a measurement solution will be found is Terahertz lasers.

Although, as noted, the basic technology has not changed, over the last 10 years, laser power and energy meters have advanced to meet these new demands of new laser systems.
For one thing, there has been more specialization, where specialized power and energy meters have been developed for diverse purposes. There are photodiode power meters that catch the peak power and are useful for measuring scanned beams as in bar code scanners. There are photodiode detectors in an "integrating sphere" that catch uncollimated light radiating in various directions to measure total integrated radiation. There are special geometry meters that are designed to get into tight locations. There are meters to measure the pulsed light of IPL hair removal medical devices, meters to measure the light in photolithography machines and many other examples.

New general purpose power meters have also been developed to meet the demands of the proliferation of powers and energies both on the low end and high end.

There have been dramatic increases in resistance to damage. New coatings and absorbers capable of standing up to very high energies have been developed. Today there are power measuring surfaces from several manufacturers claiming more than 100KW/cm² damage threshold for moderate powers. There are power and energy measuring heads able to withstand hundreds of Joules/cm² especially for long pulse lasers.

Ophir model 3A for powers from 50uW to 3W

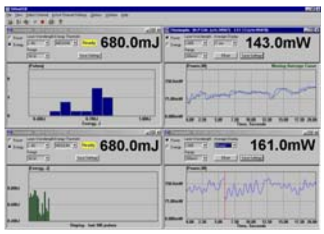
Power meter for powers up to 10KW

There are also new devices for the low end. There are broadband power meters capable of accurately measuring tens of microwatts or microjoules. Accuracy has also been improved. Accuracy of power or energy is now routinely quoted as ±3% and in some cases better than that. Stability of some energy meters is better than 0.2%. Manufacturers have perfected ways to more accurately calibrate power and energy meters. They have more laser wavelengths available for calibration and a wider range of powers and energies as well as more accurate calibration equipment.

Energy measuring head for up to 10KHz with pulse stability of 0.2%

Quasar wireless interface mounted on 30 Watt head

Some examples of new power/energy meters that have been developed to meet increasingly varied needs are shown here. At one end of the scale is a broadband thermal power meter that can reliably measure down to 50µW average power and single pulse energy down to 15µJ. At the other end of the scale is shown a power meter that can measure up to 10,000W at power densities of 10KW/cm².



4 channel PC interface display

At the same time there have been advances in power/energy heads, there have been advances in display technology. Displays and PC interfaces are able to work with up to 4 heads at a time, measure each pulse at rates to 20KHz and communicate by wireless where cables are not practical.

With this plethora of power/energy measuring equipment available, it is very important to specify to the vendor the range of conditions over which the equipment is going to operate. The relevant parameters are: laser beam diameter, wavelength, maximum and minimum power and for pulsed lasers maximum and minimum energy and pulse width as well. In general, a thermal detector will be less expensive and more durable than a pyroelectric, so for single shot energy it is preferable when the energies are in its measurement range. Some vendors now have a "head finder" program on their website where the user inputs the above parameters and the program then lists the relevant measuring heads.

To sum up, there are many options today for accurate and reliable laser power and energy measurement but this means that you may need guidance to choose the best solution for you and if you do, it is best to consult an expert in the company from which you wish to purchase.