Power and Energy Meters: From Sensors to Displays

From the time the first laser was built, physicists probably thought, “That’s great! Now how do we measure it?” Thus laser power and energy meters were born.

Since lasers are good sources of concentrated heat, it was probably assumed that heat sensing methods would best be employed for measurement. The simplest device to measure heat is a thermocouple. A simple device to measure light is a photodiode. So, some enterprising engineer designed and built such a device. Then they needed an instrument to display the results and give rapid feedback in order to tweak, align, or adjust the laser for maximum output. Early displays were basically analog meters that had a needle on a dial that went from left to right as the laser power went up.

Calibrating Devices

This approach was good for tweaking lasers for maximum output, but then calibration became an issue. How could one calibrate these devices to read the correct power? This is still a valid topic today.

The National Institute of Standards (NIST) in Boulder, Colorado and Gaithersburg, Maryland are where Gold Standards are developed that quantify the uncertainty of products that are used to measure laser power and energy. Manufacturers send their equipment to NIST to have them measure uncertainty values at various wavelengths where they have developed Primary Standards based on physical constants. In the case of Boulder, they use a water calorimeter and measure the temp rise of water, a known constant. This calorimeter approach is used to determine the uncertainty of a measured value of laser power at very specific power and/or energy levels.

These products then become the manufacturer’s Gold Standards which are used to calibrate Silver Standards and then Working Standards. Working Standards are used on a daily basis to calibrate production volumes of detector heads that are sold to many users of lasers in a broad array of laser applications.

As lasers progressed and developed other characteristics, like repetitive pulsing, variable pulse widths, high power, more wavelengths, etc., pyroelectric sensors were developed to measure the energy output. Many variations of form and factor were created to handle the widening array of lasers being developed for new and exciting applications. Measuring precise laser power and/or energy became an important issue in world that now included semiconductor manufacturing, micro-via drilling, dermatology, and ophthalmic applications such as LASIK vision correction.

In this article we will review the basic sensor types: thermocouple, photodiode, and pyroelectric, and cover the instruments that are used to display the power and/or energy of the lasers. We will explore what parameters one must look at to determine the best detector head for a particular laser and then match it up with a readout. The article will give some historical perspective on the evolution of power and energy meters and what the future holds.

Determining Sensor Type

One of the first things you need to do with any laser is find out whether the laser is Continuous Wave (CW) or pulsed. If the laser is CW, then just determining the wavelength minimum and maxim power that is expected tells you whether you will need to use a photodiode or thermocouple type sensor to measure it. The wavelength of the laser may be the first consideration as photodiodes have a limited wavelength range, typically UV to Near IR. Thermocouple sensors have a very broad wavelength response.

If your laser is pulsed, then you may want to consider a pyroelectric sensor which can measure pulse-to-pulse energy. In addition, they typically allow you to convert Joules to Average Power in Watts and measure the pulse repetition frequency when used with a display instrument that supports such functionality.

If you are just measuring the output of the laser in order to tweak it up or adjust optics, a thermopile (series of thermocouples) power meter works just fine. They are less expensive than pyroelectric energy probes and meters, and their associated processing electronics are much simpler. If you want to know the stability of the laser on a pulse-to-pulse basis, a pyroelectric or silicon joulemeter probe allows you to measure every pulse up to 20 kHz pulse repetition frequency.

Let take a closer look at the details of thermopile sensors, pyroelectric sensors, and photodiodes.

Thermopiles

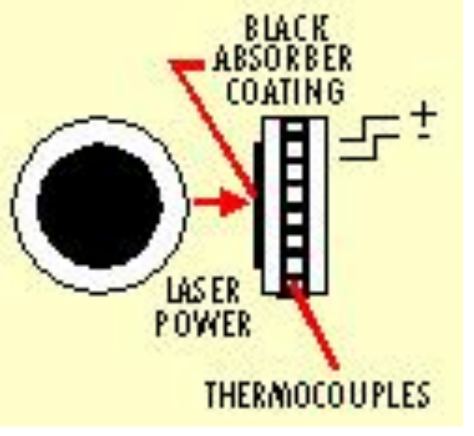
Thermopile theory and parameters:

- Generate voltage when there is a temperature difference at junction between two dissimilar metals, an array of thermocouples.
- Broadband spectral response: DUV to Far IR.
- Dynamic range is from 50 uW to 10 kW.
- Used to measure average laser power, such as for CW and repetitively pulsed sources.
- Can be used in ‘single pulse’ mode in which a single laser pulse is measured.
- Diameters of the sensing area range from 10 mm to 100 mm.
- Thermopiles produce a reading in 1-3 seconds.

There are two basic types of thermopiles:

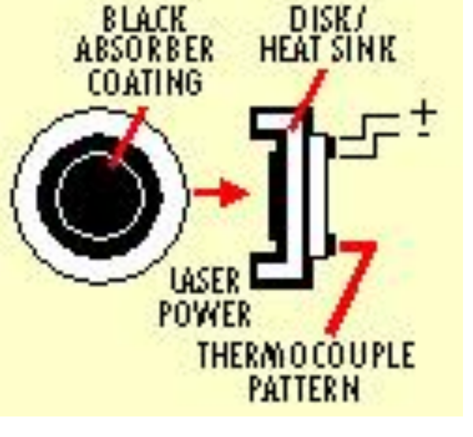
Axial Flow

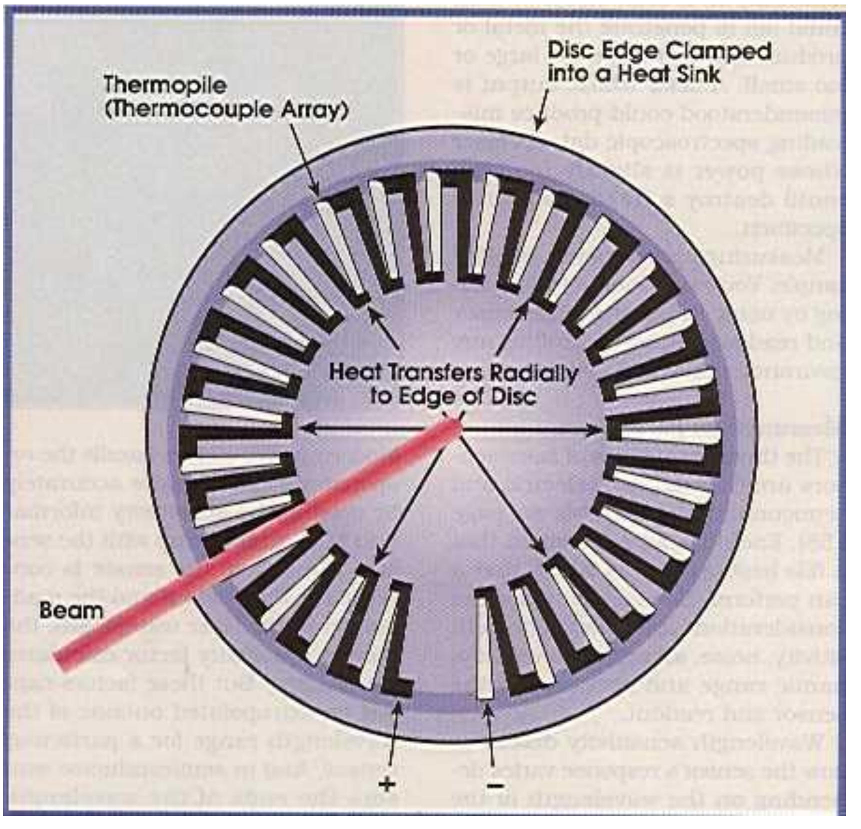
• Heat flows along the axis, these have long time constants…10's of sec to minutes



Radial Flow

- Heat flows from the center to the edges, shorter time constants-sec unless probe has very large area
- With radial flow thermopiles DC voltage is generated when heat flows from hot to cold junctions between two dissimilar metals
- Most companies today use thermopiles that are radial flow (primarily because of their faster speed of response).
- Discs are made of aluminum for powers to 300 Watts & Copper for kW probes.





There are two basic types of absorbers:

Surface Absorbers
The laser light is absorbed in the front surface of the sensor.

- Optical black paint: 500 W/cm2, 50 mJ/cm2 @ 10 nsec
- High Temp Ceramic: 26 kW/cm2, 600 mJ/cm2 @ 10 nsec

Volume Absorbers
The laser light is absorbed in a bulk material and then conducted to the metal disc. Typical lasers include Q-switched relative high energy Nd:YAG, Ruby, Alexandrite, and Erbium lasers with energy >100 mJ.

- Colored glass: Good for high peak power, 10 J/cm2 @ 1064 nm, but low average power threshold at 50 W/ cm2
- Combination glass/ceramic: Good for high peak power and moderate average power.

Thermopile sensors are cooled in one of three ways**:**

Air Cooled

Water Cooled

Fan Cooled

Generally air cooled sensors have a larger physical size and have fins in order to use convection to get rid of the heat. If one needs a smaller physical size, then either a sensor with a built-in fan or a sensor with water channels to get rid of the heat through water cooling would be considered.

When choosing a particular model of thermopile sensor, one needs to consider various laser parameters and match one that meets those parameters:

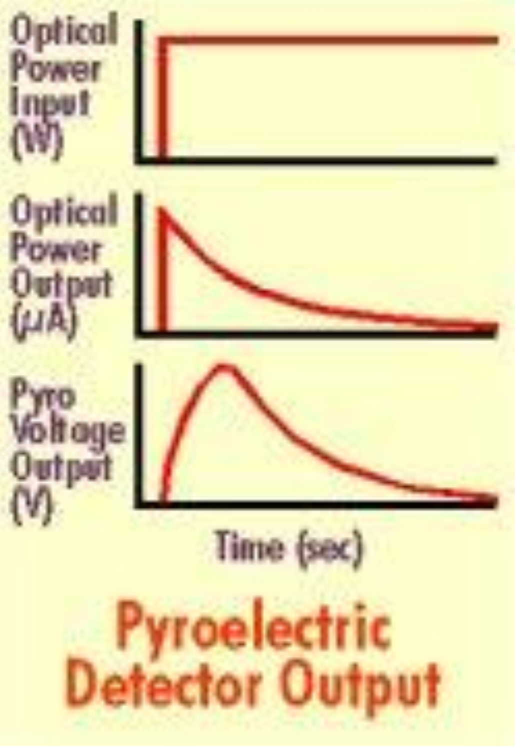
- Maximum Power
- Minimum Power
- Beam Spot Size
- Does one need a Surface Absorber or Volume Absorber?
- Are there any size constraints?

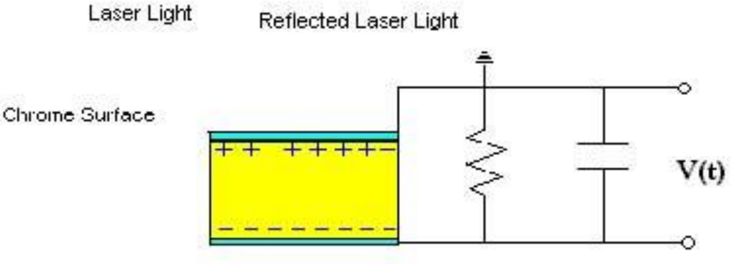
Pyroelectrics

Pyroelectric detectors are natural for measuring pulse-to-pulse energy from nearly any type of pulsed laser. They are spectrally broadband, from X-ray to sub-millimeter, so measuring lasers from Deep UV (i.e. 157 nm) to Far IR (i.e. 10.6 µm) is no problem. They can measure single pulses and repetitive pulses to 100's of kHz.

Pyroelectric theory and parameters:

- Respond to the *rate of change of temperature*, source must pulsed, chopped, or modulated.
- When designed as a joulemeter probe, they essentially act like capacitors in that they *integrate* pulses and produce an AC signal whose peak voltage is proportional to the energy in the pulse.
- Very fast, up to 20 kHz Broadband DUV to Far IR.
- Dynamic range from sub µJ to Joules.
- Ideal for measuring chopped or pulsed light sources (lasers).
- The current output from the sensor is proportional to the rate of change of temperature.
- Broadest band detector known…X-ray to millimeters
- All must be surface absorbers as any type of volume absorber would add heat dissipation time making them virtually useless as fast pulse detectors
- Four decades of range from single detector.
- 1 mm to 100 mm dia. active areas.


Optical Power Input (W)
Optical Power Output (μA)
Pyro Voltage Output (V)
Time (sec)
Pyroelectric Detector Output


Laser Light
Reflected Laser Light
Chrome Surface
V(t)

50 mm diameter pyroelectric head.

An array of various size pyroelectric heads.

Silicon Photodiodes

A silicon photodiode is a solid-state device which converts incident light into an electric current. It consists of a shallow diffused p-n junction

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, the electron density in the photodiode becomes too great and its efficiency is reduced causing saturation and a lower reading. Some manufacturers have heads with a built-in filter that reduces the light level on the detector and allows measurement up to 3 W, depending on the model.

Photodiode theory and parameters:

- Spectral range from 190-1100 nm.
- Dynamic range from sub nW to mW, up to 3W with filters.

50 msec response time.

- Can measure cw power and average power of repetitive pulses.
- Can be designed to measure energy per pulse up 10 kHz.
- Diameters of sensors are typically 5 to 10 mm.

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Displays

When power meters were first developed, they were typically used with just one type of sensor. There was one type of display that you could plug into one type of sensor: pyroelectric, thermopile, or photodiode.   This was well before the advent of microprocessors and E-PROMs.   One had to use dials and switches in order to adjust the gain and correction factors for each head.

Initially most displays were analog meters, which worked for tweaking or tuning lasers. To read the actual laser power, one then had to be familiar with the intricacies of reading

Analog laser power meter.

With the coming digital and computer electronics transformation, displays became a lot smarter.   Almost overnight, displays had small computer chips and heads had E-PROMs. A display could read the contents of the E-PROM of each individual head, know what type it was, and what dynamic range it had so that it could automatically set range limits. One could even program each individual head's discrete calibration points and thus utilize a complete spectral curve to produce more accurate measurements. This revolutionized the world of power and energy meters.   Meters and heads became plug-and-play. All three sensor types could be used with one display. This not only made life much easier for users of power and energy meters, but reduced the cost of ownership as one meter could be used with multiple heads.

With LCD's and, later, dot matrix displays, one could more easily read laser power, although many people still liked to use analog meters for tweaking and tuning because of their fast response and ease of observation as readings trend up or down.   Some manufacturers started making instruments with both analog and digital displays, and some simulated analog meter movement with a dot matrix display.

As part of the computer revolution, the ability to record data became easier. With older analog displays, some had analog outputs that could be connected to an analog recorder which then plotted on paper a record of the meter's recordings. Then along came direct computer connectivity. The first was a serial interface, RS-232, and then a parallel interface, IEEE-488 (GPIB). Computer programs were created to collect and analyze the data on a computer.

Some instruments, like Ophir's Nova, could actually record up to 54,000 data points in non-volatile memory for viewing and later downloading to a computer over its RS-232 port.

Today, RS-232 and GPIB seem to be fading while the connector of choice is now USB.

Into the Future

Ophir-Spiricon recently introduced "wireless" heads that use Bluetooth technology and eliminate the cables and display, altogether. Smart electronics and a battery operated transmitter can be built right into the head and it transmits the data wirelessly to a laptop or desktop where it is collected, displayed, and analyzed. This approach eliminates many of the headaches of long cables or having to put a head and meter in places that are difficult to access.

Power detector head with built-in wireless transmitter.

Power detector head with cable plugged into wireless transmitter.

Riding on the coattails of the display technology evolution, with the proliferation of color screen in devices like PDAs, GPSs, and cell phones, the power and energy meter manufacturers can now afford to put color screens on their displays. Vivid, vibrant display color can be altered, depending on the type of laser used and the laser safety glasses needed. For this technology the future has arrived.

Color screen laser power and energy meter.

Who knows what other developments may occur in the future? I for one am looking for the unobtainium and indestructium materials that will be able to stand up to the most powerful lasers ever developed with nary a burn mark or fracture or pit in the absorbing surface. Data will be instantly analyzed and transmitted anywhere in the world in picoseconds and displayed on some kind of 4-dimensional interactive display. The possibilities are endless.