Novel Laser Power Sensor Technology for Process Control

The need to measure laser output characteristics, including average power, pulse energy, and pulse shape, is a common requirement across many industrial and research applications. However, this need takes on particular significance in industrial processes since even minor variations in laser characteristics can lead directly to producing scrap product or create the need for rework. Unfortunately, the traditional methods for measuring high power industrial lasers are slow, which may necessitate interrupting production, with an associated cost impact. Presented here is new technology that enables high speed average power, peak power and pulse shape measurements of industrial lasers, thus solving this problem.

Traditional Laser Power Sensors

The two technologies that have been in use for decades for measuring the average power of lasers are thermopile and semiconductor photodiode. Thermopiles have been the main choice for high power lasers. In thermopiles, thermal energy is converted into electrical energy.

The typical thermopile consists of a central, light absorbing disk, a series of thermocouples that surround this disk, and an annular heat sink around the ring of thermocouples. In operation, incident laser energy falls on the absorbing disk in the center of the detector and is converted into heat. This disk is typically coated with a material that absorbs light over a very broad wavelength range in order to enhance sensitivity. The heat then flows across the width of the thermopile disk to the heat sink, which is held at a near constant ambient temperature by either air or water cooling. The temperature difference between the absorber and heat sink is converted into an electrical signal by the thermocouples. Calibrated electronics in the meter convert this electrical signal into a laser power reading.

The advantages of thermopiles include an extremely broad spectral range, the ability to work over a wide range of input powers, high laser damage resistance and uniform spatial response (meaning insensitivity to changes in beam size, position or uniformity). The limitation of the technology is that the transfer of heat across the width of the thermopile disk makes this technology inherently slow. Specifically, it often takes several seconds before the heat flow induced by the laser reaches equilibrium, and the power measurement becomes steady on the display. Physically larger sensors take longer to reach this steady state. For example, thermopile sensors large enough to handle kW laser sources typically take a minute to stabilize.

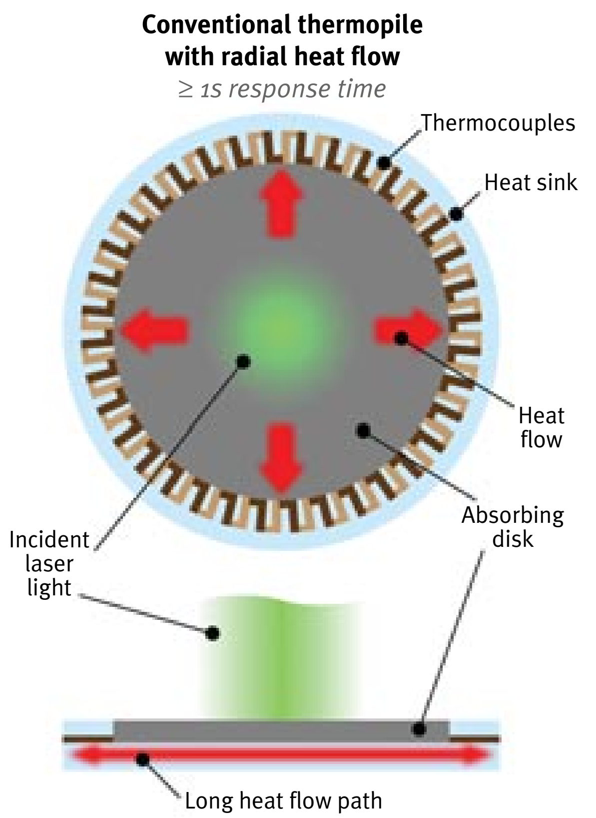

Figure 1. Construction of a traditional radial thermopile leads to slow measurement speeds.

A semiconductor photodiode sensor is quite different. It is a quantum device that utilizes a solid state diode (*pn* junction). Incident laser photons are absorbed by the device and converted into charge carriers (electron and holes). These can be sensed as current or voltage depending on how the junction is biased. Photodiodes offer high sensitivity, enabling them to detect very low light levels. And several different semiconductor material combinations are available to produce photodiodes that work in the visible, near infrared or far infrared. Photodiodes also have a fast response time, and thus can be useful for looking at pulse shapes. However, they saturate above approximately 1 mW/cm^2, so attenuating filters must be used when operating at higher powers.

The main drawbacks of photodiodes are that they have smaller active areas, a much more limited spectral range, and lower spatial uniformity than thermal sensors. The latter can affect the measurement repeatability of non-uniform beams or beams that wander over the detector surface between measurements. These characteristics make photodiodes most useful for low power measurements of CW lasers, as well as pulse shape characterization of nanosecond pulsed lasers.

Thin Film Thermoelectric Technology

The ideal sensor for embedded power measurement would combine the broad wavelength sensitivity, large dynamic range and high damage resistance of a thermopile, together with the

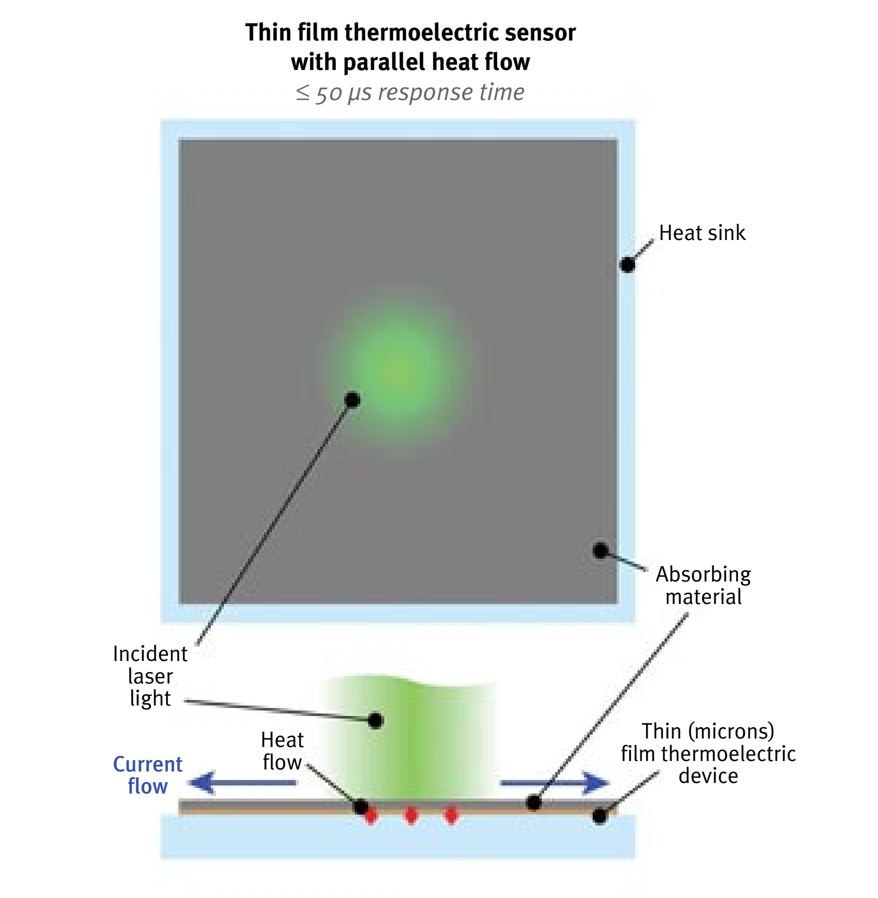

Figure 2. Basic configuration of a PowerMax-Pro sensor. The short heat flow path results in fast measurement speeds.

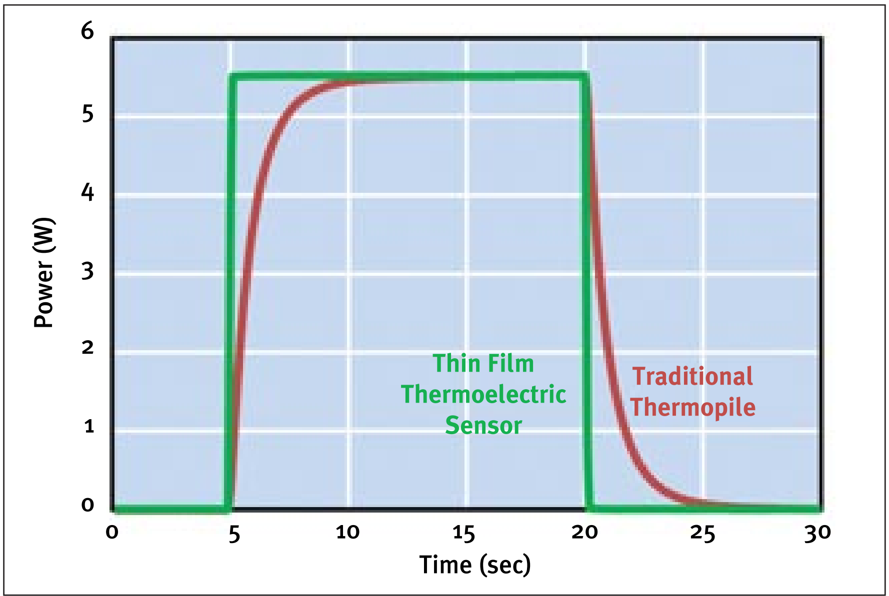

Figure 3. Comparison of the rise time of a typical mid-power thermopile (30W) and the corresponding response of a thin film thermoelectric sensor to an input square wave laser pulse.

fast response speed of a semiconductor photodiode. In 2014, Coherent developed a completely new, patented, sensor architecture that meets these requirements. It is based on thermoelectric technology, but it is constructed and configured very differently than traditional sensors. Specifically, in this device the heat flows vertically through the detector, and the electrical signal that is generated moves perpendicular to the heat flow.

The thermoelectric generating materials used in this sensor are a stack of films which have layer thicknesses on the order of microns. Incident laser light is absorbed and generates heat which is able to flow very quickly through these thin layers to the heat sink behind the detector where it is dissipated. The electrical signal from the thin film layers moves laterally to the edges of the device where it can be measured by tapping into the sensor electrodes.

In contrast to the traditional, radial flow thermopile, which has a sensing time constant value of several seconds, the time constant for the thin film configuration is in the microsecond range. This enables the sensor to provide an essentially instant power measurement without any overshoot. Coherent's first product based on this technology, called the PowerMax™-Pro, also preserves the main benefits of the traditional thermopile architecture, namely large active area (30 mm x 30 mm), wide dynamic range (50 mW to 150 W), and broad wavelength range (300 nm to 11 μm). More recently, the company extended the product to enable average power measurements of continuous wave beams up to 3 kW.

The response speed of thin film thermoelectric sensors allows users to move beyond just measuring average power, and enables visualization of the temporal pulse shape and peak power of modulated lasers with pulse lengths greater than 10 μs, which can be used to develop better process recipes.

Signal Processing

A sensor is just part of a measurement system, and can only deliver high quality data if it is matched with electronics to properly acquire, condition and process the raw signal from the sensor.

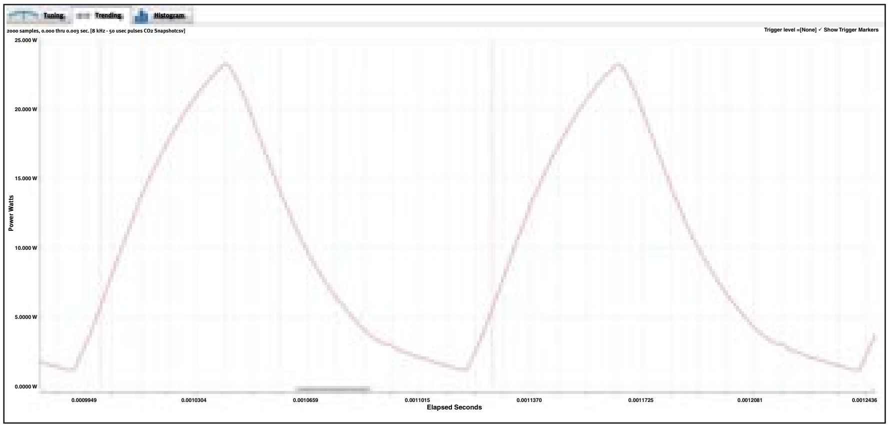

Figure 4. Pulse shape visualization of 50 µs long pulses (at 8 kHz) obtained in "snapshot mode" with a PowerMax-Pro sensor and LabMax-Pro electronics and software.

Figure 5. Thin film thermoelectric sensors are available with a broadband coating, which operates from 300 nm to 11 µm, and a higher damage threshold (up to 14 kW/cm²) coating, which covers both 355 nm to 1100 nm and 9 µm to 11 µm.

Coherent has developed new processing electronics and software to fully capitalize on the unique capabilities inherent to thin film thermoelectric detectors. Specifically, an interface module is used to process the raw signal from the detector; this module connects with a host computer through USB 2.0 or directly to laser system controllers via RS-232. A new Windows PC application then enables instrument control and displays measurement results, including laser tuning and pulse shape visualization, on a host computer. The software also performs a wide range of analysis functions, such as live statistics, histograms, trending and data logging. In addition, a complete set of host commands can be sent through either the USB or RS-232 interface, which is particularly useful for embedded applications.

The software is configured to work at three different data sampling rates. A 10 Hz sampling rate is used to provide essentially instantaneous power readings, much like a photodiode. This operating mode is best used to measure the power of CW lasers, or the average power of sub-microsecond pulse length lasers.

The two other, high-speed sampling modes fully exploit the rapid response speed of these sensors to enable advanced analysis of high-power, modulated lasers in a way that has never before been possible. The first high-speed mode utilizes a continuous data sampling rate of 20 kHz, allowing pulse shape analysis of modulated lasers with repetition rates of up to 2 kHz. These types of pulse trains are common in many laser-based medical treatments and some material processing applications, such as micro welding.

The second high-speed mode is called "Snapshot Mode," which provides burst sampling at a rate of 625 kHz for a period of time up to 384 milliseconds. This mode provides excellent pulse shape fidelity for pulse durations greater than 10 µs at pulse repetition rates up to 50 kHz, common in various commercial cutting, engraving and drilling applications.

This type of temporal visualization offers new insight into the true performance of the laser, previously masked by slow thermopiles. This new information now available to engineers eliminates some of the guesswork involved in developing recipes for material processing applications. It provides developers with more repeatable methods to transfer processes from engineering to manufacturing, and to control and monitor processes once they are up and running. Indeed, many thermal-based material processing applications can be better controlled with this information leading to cutting, drilling, and engraving with increased speed and higher yield; at the same time, the quality of laser produced features can be enhanced.

Conclusion

For high-speed industrial processes based on high-power lasers, there has long been an unsatisfactory tradeoff between laser power measurement frequency and production cost. Now, new power sensor technology, which even enables pulse shape visualization, eliminates that tradeoff, and should allow manufacturers to further refine and improve their processes.

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