

Precision Power Control in Electro-Optics

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As new laser devices become available, their complexity is met with increasingly sophisticated electronics that allow continuous refinement of precision. As optical systems mature, new processes and procedures are made possible. These include: lasers in medical diagnostic and treatment equipment (e.g. Optical Coherence Tomography (OCT)), increased sensitivity for environmental monitoring equipment, or spectroscopic analysis of pollutants at ppb levels. This article briefly exposes the design complexities of fiber laser systems used in materials processing. Compared to solid-state laser systems, fiber laser packages can deliver equivalent power in a smaller spot size, from a more compact package, with higher efficiency, and better long term reliability.

Consider building a laser diode sub-system to pump a fiber laser for material processing. The fiber laser amplifies the pump laser light to optical power levels suitable for welding or cutting. Several pump lasers are used in each fiber laser system. The fiber is the lasing medium.

There are many laser diodes available commercially for pumps. Single laser diodes coupled to fiber can be optically combined, laser diode bars (a one-dimensional array of laser diodes) can directly illuminate the fiber cladding or be packaged as fiber-coupled. For simplicity, we will consider a single laser diode optically combined with five others.

The pump laser diode chosen produces 10 W of optical power at 976nm. The Ytterbium-doped fiber laser has a narrow absorption band of approximately 8 nm, so wavelength stability of the pump is critical. Laser diode wavelength varies with power and temperature. For example, a typical specification is 0.35nm / °C shift with temperature. If the pump laser linewidth is 3nm, a temperature change of 10°C will shift the center wavelength 3.5nm, and significantly decrease the power absorbed by the fiber. A power shift of 1 W can move the center wavelength 1nm, so it, too, must be considered. Efficiency of this laser diode is 48%, so for every watt of electrical energy input, half a watt of optical power is output [higher efficiency laser diodes (~75%) are available]. Our goal is to pump 60 W into the

fiber laser.

First order design choices involve how to temperature stabilize the laser diode, extract excess heat from the system, and safely drive the laser.

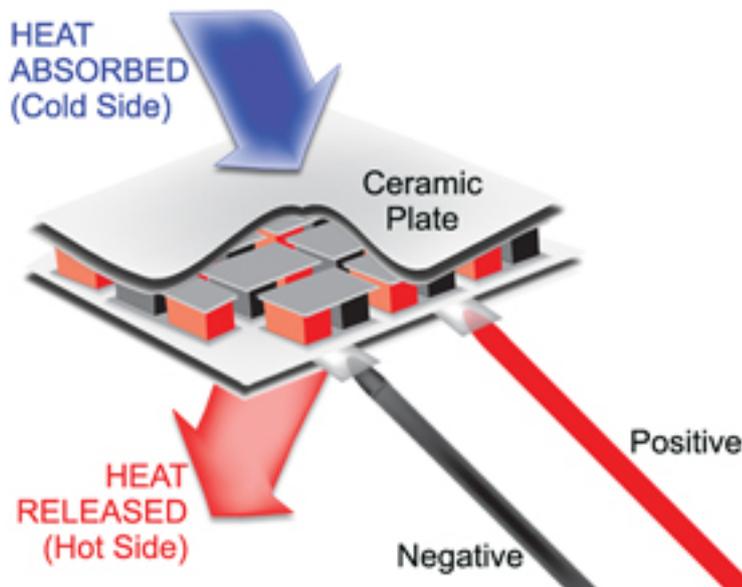


Figure 1. As current flows into the positive terminal of a thermoelectric, heat is absorbed on the cold side then transferred and released on the hot side.

Thermal Control

All together, the six laser diodes will produce 60 W + of heat that must be dissipated. Either they can be mounted on a water cooled plate or individually controlled with thermoelectric coolers (TECs). Chiller systems can stabilize to 0.1°C, while thermoelectrics can be controlled to 0.001°C. A combination of the two methods can be used to avoid the heat waste typical of TECs (10% efficiency) while taking advantage of their stability. In the thermal design, stability requirements will dictate the sensor. For higher precision, thermistors are used. These sensors change resistance with temperature and have optimal sensitivities around 40mV / °C. They are not linear, though. If a wide temperature range is necessary, more linear sensors, such as RTDs, LM335s, or AD590s are used. Best stabilities associated with these sensors are 0.05°C, 0.01°C, and 0.01°C respectively. Since laser diode systems are typically held at a single temperature, thermistors are usually pre-packaged with the diode.

The TEC requires a DC voltage and current input. The current is varied to precisely move heat from one surface to another. For 10 W of cooling power, expect currents of 10 A at 8 V.

The next choice is what type of controller to use. A closed loop system compares feedback from the temperature sensor to the desired setpoint temperature, generating an error signal. The error signal is processed by the control system to drive current through an output stage into the TEC. Pulse width modulated (PWM) controllers are very efficient, but cannot achieve high levels of stability (0.01°C typical). They pulse current to the TEC and vary the pulse width to control the power delivered to the TEC. The pulse generator can inject noise into the other

elements of the system. PID controllers are coupled to a linear output stage that varies the level of current to the TEC. They are used where the highest level of stability is required.

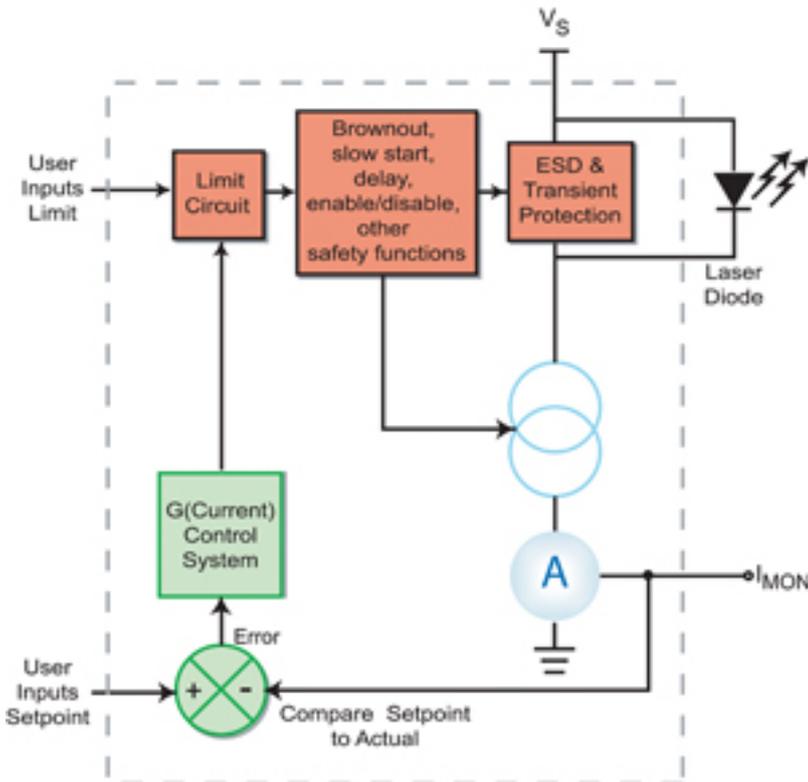


Figure 2: Block diagram of very basic laser diode driver

Laser Diode Control

Laser diodes are very sensitive to over-power or over-temperature conditions, switching transients and electro-static damage (ESD). Control systems to avoid those conditions are critical to protect multi-thousand dollar laser diodes and avoid down-time in the field. Laser diode controllers include a variety of protection circuitry in addition to the precision current source that actually powers the laser diode. Figure 2 is an example block diagram of an off-the-shelf controller.

Additionally, at these currents, capacitive and inductive loading become an issue, so cable lengths and design contribute to overall performance of the control system. Similar to the TEC design, the control system needs to be chosen. With the laser diode driver, however, noise is a higher consideration. PWM is usually too noisy for precision systems. The laser diode chosen requires 11.5 A at 1.8 V. An optimized PID controller offers low noise and precision current control.

PID stands for “Proportional, Integral, Derivative” control. The error term is simultaneously modified by three different sections. PID control loops can be implemented in analog or digital form. Simpler control loops utilize only the proportional gain stage. Proportional controllers are inherently stable for low gains, but cannot produce a zero error between the temperature setpoint and sensor feedback. A non-zero error must be maintained to produce a finite output control signal. The addition of the integrator function reduces the error to zero. The integrator produces a finite output even when the error term is zero because the output of the integrator is a function of past errors. Past errors charge up the

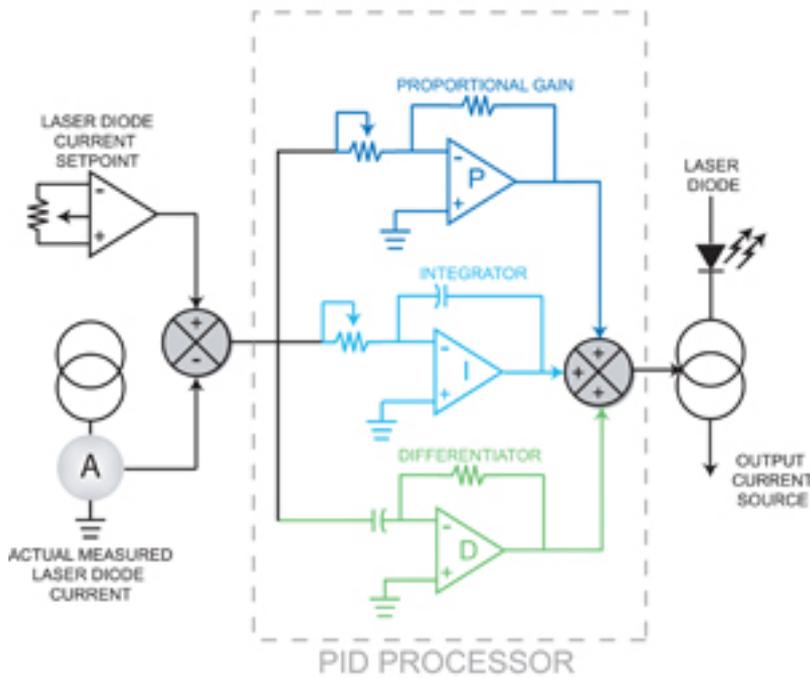


Figure 3. Example analog PID control system.

integrator to some value that will remain, even if the error becomes zero. The addition of the derivative term can increase stability of the loop by increasing the dampening. Since the addition of the integral term usually results in larger overshoots the protection circuitry must be capable of limiting the current to the laser diode despite the control signal output.

Second order design choices influence reliability, cost of goods, and manufacturability. As complexity of systems increases, qualification processes also take more time, but companies eager to post growth figures need to maintain or speed up time to market. Specialized knowledge is required to coordinate system integrations, develop sub-sections of the designs, and to devise thorough test protocols to ensure proper operation. Many companies have chosen to increase organizational efficiencies by keeping system integration skills in-house and outsourcing specialized engineering knowledge. Outsourcing can mean using contractors or choosing an off-the-shelf design and strict vendor qualification systems. Specialist companies that focus on optimizing typical sub-systems are developing to meet these changing needs.

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