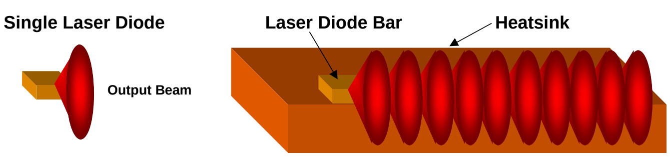
An Introduction to Diode Lasers for Materials Processing

Semiconductor diode laser technology offers a number of practical and cost advantages over both other lasers and traditional techniques for processes such as welding, cladding and heat treating.

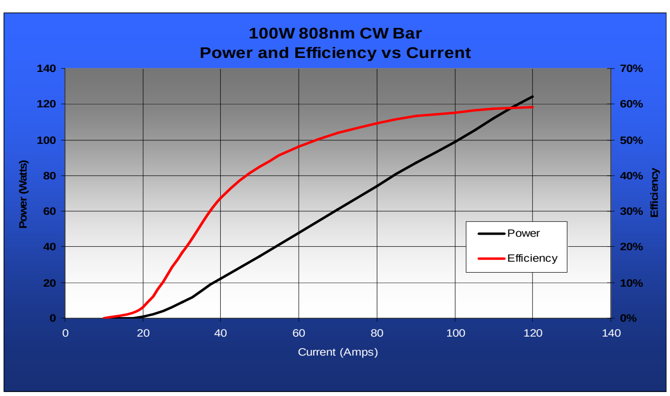
Low power diode lasers are a well established technology, used extensively in products such as DVD players, computer optical drives, fiberoptic telecommunications and even laser pointers. The reason for this success is that diode lasers offer a combination of high electrical efficiency, long maintenance-free lifetimes, small size, and short wavelength that far surpasses any other laser technology. While these commonly encountered low power diode lasers typically only provide a few milliwatts of output, diode laser systems are available with power levels in the multi-kilowatt range. These types of diode lasers are currently employed in a number of different materials processing applications. The basic construction and operation of these systems is described here.

Diode Laser Construction



Diode laser bars consist of multiple individual emitters on a single, monolithic substrate.

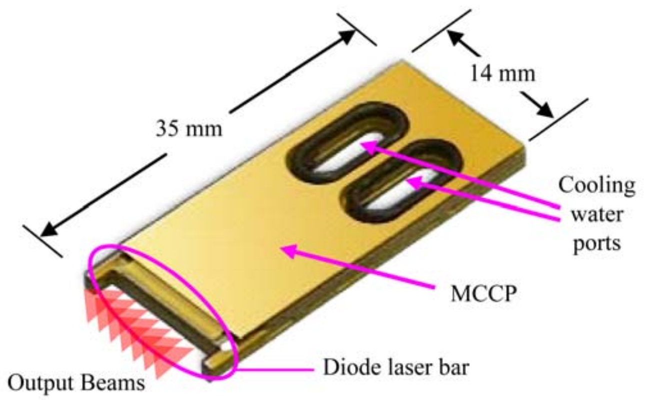
The diode laser is a semiconductor device which directly converts electrical energy into laser light. Typically, higher power diode lasers output in the near infrared, most commonly at either 808 nm or 980 nm. A typical, individual diode laser emitter might produce at most a few Watts of output power. However, numerous emitters can be fabricated on a single, monolithic semiconductor substrate or bar with a total output as high as 100 W. These linear bars can, in turn, be combined in horizontal and vertical stacks to produce high power direct diode laser systems with total output power in the multi-kilowatt range.



This graph of conversion efficiency and power vs. input electrical current shows that diode laser bars are far more efficient than any other laser type

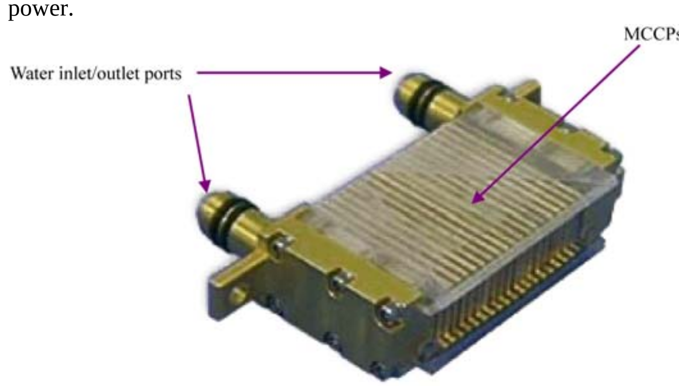
As shown in the preceding graph, the maximum conversion efficiency of transforming input electrical energy into light in diode laser bars is about 59%, which is many times higher than for any other laser type. This includes CO_2, lamp pumped solid state (LPSS), diode pumped solid state (DPSS), and even fiber lasers. The primary benefit of this high efficiency is that it lowers the operating cost of the system, since less electricity is required to produce a given amount of output power. Of course, this reduced power consumption also decreases the carbon footprint of the laser's operation.

The small size of diode lasers means that they produce their waste heat in a relatively small physical area. As a result, they can be effectively cooled with a small volume of circulating water and a chiller.



A single diode laser bar mounted on a MCCP

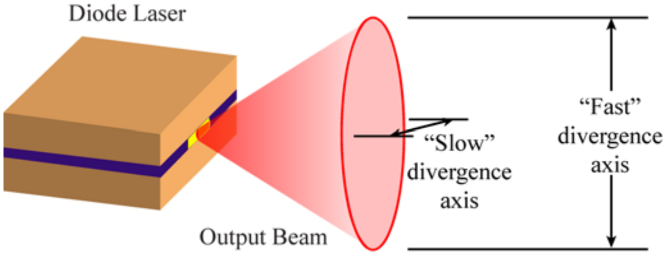
The photo shows a mounting configuration for diode laser bars called a Micro Channel Cooled Package (MCCP). Here, the diode laser bar is mounted on to a plate which contains internal channels for water circulation. The MCCP contains two large water ports, one for input and one for output, which each have an o-ring at their edge. These o-rings provide a water tight seal when two MCCPs are placed against each other face to face. This enables multiple MCCPs to be stacked together and water circulated through the entire assembly. The next photo shows just such an assembly of several MCCPs. The result is an extremely compact assembly that can deliver as much as 4 kW of power.



1.2 kW CW MCCP Diode Laser Stack

Diode Laser Output

The region of a diode laser which actually emits light is very small, on the order of just a few microns in size. Diffraction from this small region causes the light to spread rapidly after it exits the device. Thus, the output of a diode laser is highly divergent, rather than collimated, as is typical of most other lasers. Furthermore, this emitting region is rectangular, rather than square or circular. This results in an elliptically shaped beam, where the light diverges faster in one dimension than in the other. This means that specialized optics must be employed in order to convert the raw output from a diode laser system into a format useful for most applications.



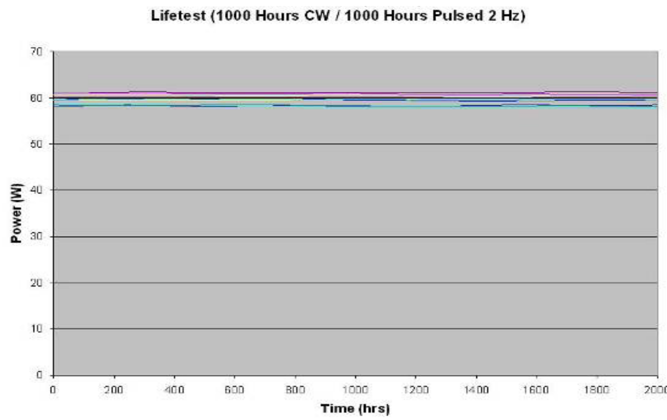
Representation of diode laser output showing its divergent and elliptical nature

There are two basic optical delivery approaches for diode lasers, namely, free space and fiber optic. In free space delivery, the output of the diode laser array is shaped and directly focused on to the work surface. Typically, the shape of the focused beam is configured to best match the processing needs of the application. So, in a welding application, the light might take the form of a long, thin line, while for heat treating, the beam might be nearly square, or a rectangle with a small aspect ratio. Typically, these regions are several millimeters in their longest dimension.

In fiber delivery, the diode laser output is first channeled into a single optical fiber. The output of this fiber is reimaged using optics on to the workpiece. Most commonly, this results in a round spot that is only a few millimeters in size. Fiber delivery generally yields a higher power density (laser energy per unit area) at the workpiece than free space delivery. Also, fiber delivery allows the laser to be located remotely from the process, over distances of as much as 30 meters. The combination of higher power and smaller spot size makes fiber delivery best suited for welding, while the larger beam coverage and lower power density of free space delivery is usually a better match for heat treating and cladding applications.

Building in Reliability and Convenience

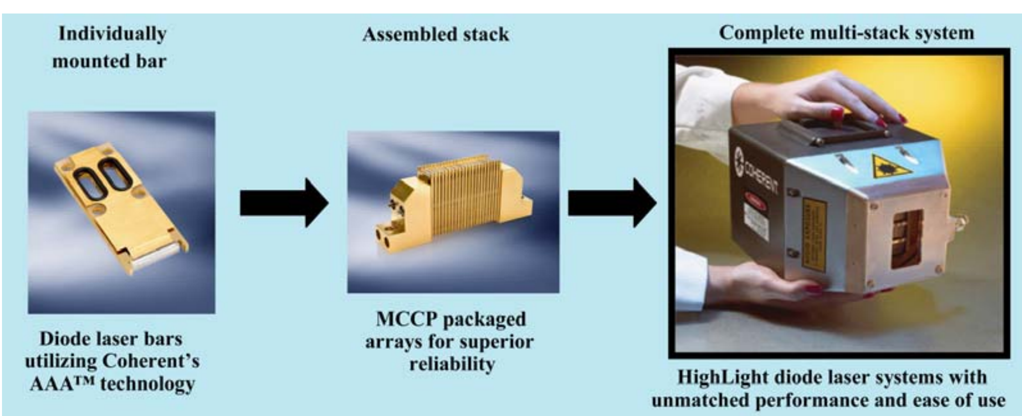
There are currently several manufacturers of diode laser systems for materials processing. However, Coherent HighLight™ systems deliver a superior combination of reliability and ease of use, thanks to the use of advanced technology in diode construction and packaging, as well as practical systems convenience factors. This is possible, because Coherent is a fully vertically integrated manufacturer. This means that we start with GaAs wafers, on to which we fabricate our own epitaxial layers. Once the laser structures are completed, we then singulate the individual laser bars and package these. Next, we mate the stack assemblies with optics, and finally, package these with a power supply, control electronics and a cooling system to produce a turnkey product. This gives us a higher level of control over product performance and reliability than can be achieved by any other supplier. The graphic summarizes this progression from components to turnkey system.



Testing indicates 20,000 hours MTBF for Coherent MCCP diode lasers with on/off cycling

We’ve also carefully engineered our MCCP technology to make it exceptionally robust and reliable, as confirmed by both field data and on-going life-testing. For example, the next graph shows output power from 10 different laser bars as they are on/off cycled over 20,000,000 times, at a cycling frequency of 2 Hz. These particular testing conditions were chosen to mirror the pulsed (on/off) demands of many real world materials processing applications. Note that there is no significant drop off in output power over the 2,000 hour test period in any of the devices, and these results can be extrapolated mathematically to indicate a projected array lifetime of at least 20,000 hours. Furthermore, we’ve seen no diode array failures due to corrosion or erosion in our MCCP architecture in 10 years of actual industrial operation.

Coherent has also improved convenience and ease of use by integrating the water chiller directly into the laser head. This closed loop chiller contains deionized water to



Coherent is the only vertically integrated supplier of high power diode lasers, producing everything from the wafer level through to finished systems maximize the lifetime and reliability of the MCCP, but it is completely self contained, meaning that the user does not have to supply this. Integration of the chiller into the laser head also yields a simpler, more robust and more compact system. Plus the elimination of water hoses and cables to connect the head to a separate chiller simplifies use for both the systems integrator and end user.

HighLight Industrial Solutions

The Coherent HighLight diode laser product line currently consists of two models. The first is the 4000L, which offers 4 kW of output at either 805 or 940 nm. The nominal beam size from this laser is 1 mm x 12 mm at a 90 mm working distance. However, a variety of optical accessories are available so that the output can be well matched to the needs of specific applications. For example, beam shaping optics are offered that transform the output to sizes as large as 12 mm x 12 mm. In addition, process accessories, such as a cladding nozzle kit, a gravity powder feeder kit and a beam purge compressor kit are available to adapt the laser for ancillary tasks, such as assist gas handling or fume elimination. The HighLight 4000L is compact and self contained, utilizing microprocessor control to simplify operation, ensure reliability and enable communication with other process equipment.

The Coherent HighLight 4000L

The HighLight 1000F is a high brightness, fiber coupled system that delivers 1 kW at 975 nm from a 600 µm core optical fiber. This laser also integrates a microprocessor to enable external control of laser operation via both analog and digital input signals, and to provide the operator with various status indicators. The combination of small size and fiber delivery (fiber lengths from 5 m to 20 m) make the 1000F particularly easy to deploy in industrial environments where space and access to electrical and water service are an issue. The 1000F is also easy to adapt to the requirements of specific processing; in particular, the optical fiber is terminated with an industry standard fiber connector making it compatible with common beam delivery accessories and process heads.

The Coherent HighLight 1000F

Summary

Diode lasers offer a number of advantages over other materials processing lasers in terms of cost of ownership, reliability and convenience. These are summarized in the chart (next page). However, the unique characteristics of diode lasers mean that they are best employed for a specific range of applications in welding, cladding and heat treating. To learn more about when and how to implement diode lasers in these applications, please refer to our detailed white papers and other references listed at the end of this document.

References and Related Publications

1. *Heat Treating with High Power Diode Lasers,* Coherent, Web Site, *URL*
2. *Welding with High Power Diode Lasers,* Coherent, Web Site, *URL*
3. *Cladding with High Power Diode Lasers*, Coherent, Web Site, *URL*
4. *Hardening Using Direct-Diode Lasers Suits Many Niche Applications*, Heat Treating Progress magazine, Volume 8, March/April 2008
5. *Direct Diode Lasers Conquer New Markets*, Laser Technik Journal, November, 2007
6. *High Power Diodes in Materials Processing*, Industrial Laser Solutions for Manufacturing, July, 2007

Summary of materials processing lasers characteristics

	Laser Type				
	Diode	**DPSS**	**LPSS**	**Fiber**	**CO_2**
Wavelength (µm)	0.98	1.06	1.06	1.07	10.6
Power Range	10's of watts to 10 kW	100's of watts to a few kW	100's of watts to few kW	100's of watts to 10's of kW	100's of watts to 10's of kW
Size	**Very Small**	**Large**	**Large**	**Medium**	**Large**
Electrical Efficiency	**40%**	**15%**	**5%**	**25%**	**10%**
Maintenance Interval	**2 years**	**1 year**	**3 months**	**2 years**	**6 months**
Initial Capital Cost	**Low**	**High**	**Medium**	**High**	**Medium**
Cost of Ownership*	**$23/hour**	**$53/hour**	**$51/hour**	**$43/hour**	**$49/hour**

*includes capital and operating cost