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Direct Diode Heating: Shaped Light Delivery for Heating Applications

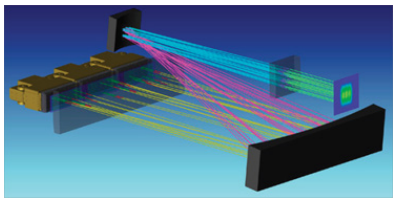
The need for the precise delivery of heat to a work surface is required for a wide range of applications. Almost all manufacturing processes rely on some form of heating operation during production, creating a high demand for continued technology improvement. Heat source options include IR lamps, microwaves, hot air, electric coils, and gas-fired furnaces. Heating with diode lasers allows for targeted, directional and highly controllable non-contact delivery of heat energy to a material and is the latest technology being used for many applications.

Diode lasers project infrared, or non-visible, radiation onto specific regions of a surface. Advantages of this new surface-heating method include:

- **Directional heating.** Heats specific areas on the material, leaving other areas unaffected.
- **Temperature.** Achieves very precise control of material temperatures.
- **Heating uniformity.** Allows for energy distribution accuracy above 99%.
- **Speed.** Reaches full power in milliseconds.
- **Maintenance.** Offers predictable operational lifetimes in excess of 50,000 hours.
- **Energy efficiency.** Achieves over 60% electrical-to-optical efficiency.
- **Low operational costs.** Offers significant return on investment considering maintenance and efficiency benefits.
- **High temperature ranges.** Offers over 10s of kilowatts and is effective for heating materials to 1,000s of degrees.

Direct Diode Heating Benefits

Precision Illumination Through Shaped Light Technology



Laser diodes emit powerful beams of infrared energy that create uniform illumination patterns. By using mirrors, lenses, and scanners, direct diode heating systems create exposure patterns with precise edges and homogenous brightness across the surface. The laser systems also switch on and off very quickly, allowing for exact control of exposure time. The precise control of both the exposure region and time speeds up production and improves yield.

Wavelength Selection

All materials have a range of wavelengths at which they are best at absorbing the laser energy and converting them to heat. Lasers naturally produce very narrow wavelengths, and diode lasers can be custom made to produce any infrared wavelength between 760nm and 1700nm. Options for single systems that offer multiple wavelengths are also available for either a multi-step process or multiple material types. These two capabilities allow an energy-generating diode laser to match the absorption wavelength of any material.

Power Efficiency

Energy conservation, cost efficiency, and environmental concerns all drive demand for improved power efficiency. Diode lasers address this issue in two ways. First, diode lasers typically offer over ***60% wall-plug efficiency***. This can be an order of magnitude better than other heating technologies available. Second, the ability to design the emission spectrum of the heating system means that energy is not wasted creating radiation at unused wavelengths.

Reliability and Lifetime

In automated production, equipment downtime is doubly expensive. Aside from the expense of repairs, lapses in production cause an immediate loss in profit. Diode lasers have predictable lifespans, requiring very little maintenance and performing with consistent energy efficiency over the entire period of use. The operating lifetime of a diode laser can be ***over 50,000 hours***. Housings can be environmentally sealed, improving ruggedness and simplifying ease-of-access for field service.

Form and Fit

For heating systems that must meet strict size or weight constrictions, diode lasers are ideal. When compared to other technologies, diode lasers by far offer the lowest size-to-weight ratio. Furthermore, because of spectrum optimization and power efficiency, the smaller size does not mean a sacrifice in performance.

Application Flexibility

For commodities linked to fast-changing technology, product cycles can be quite brief. It is therefore important that a heating system be adaptable to changes in process or application. The modularity of diode lasers make them an excellent choice for these situations. Diode lasers are comparatively simple to physically reconfigure or repurpose, tunable lasers can alter the emission spectrum, and systems can be designed so that the diodes themselves can be interchanged.

Applications

Adoption of direct diode heating is accelerating as more industries take advantage of the technology when replacing or upgrading equipment. The following represent three industries in which direct diode heating has made significant inroads.

Food and Medical Packaging

The health concerns related to food and medical packaging produce strict constraints on production environment and processes. Direct diode heating has proven to be especially valuable for two packaging processes: shrink wrapping and seam sealing. Diode lasers can target specific regions without creating ambient heat or heating undesired regions. Customized light shaping allows the customer to define the exposure area. This precise heat delivery via laser light allows for secure wrapping of the packages while protecting the contents from damage.

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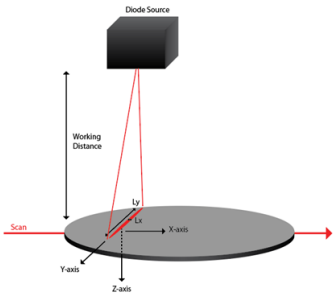
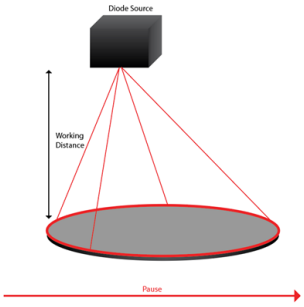
Semiconductor Substrate Heating

Semiconductor manufacturing employs several types of heat processes. Examples include surface treatments, rapid thermal annealing to secure materials to the substrate, and dopant activation. The power, brightness, and flexibility of a diode laser make it the preferred method of semiconductor material processing. Using light-shaping optics, the laser output can be formed into a thin line. The laser source is typically fixed in position and a wafer substrate travels underneath. The power of the laser can be designed to match a specific exposure time length and processing speed. If needed, a ring-shaped exposure region can be designed using light-shaping optics or specific regions of the wafer can be processed.

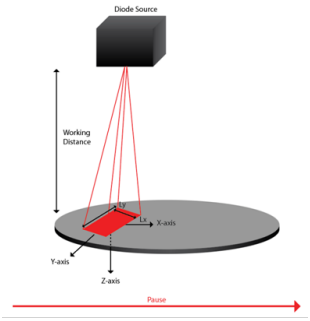
Line Generation



Ring Heating



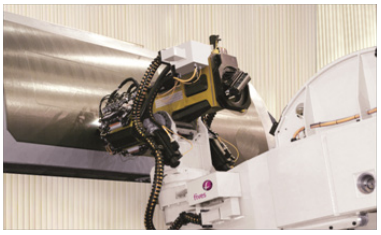
Regional Heating



Carbon Composite Joining

Carbon composite materials are somewhat of a modern miracle, providing extraordinary structural strength with a light weight rivaling that of aluminum. Joining carbon composite parts is a difficult task. The two existing methods are adhesives and machined bonds. Adhesive bonds have inconsistent reliability depending on the application and the environment. Mechanical bonds are subject to many kinds of failure due to factors such as differential thermal expansion between joining materials, delamination and fretting at the drill site, and water intrusion.

A direct diode heating system delivers heat in a focused area and allows quick on/off operation. This alternative heating method leads to markedly improved thermal efficiency as direct diodes enable precise control of the heating profile. The process also minimizes parasitic heating. By including a non-contact temperature feedback control, the composite material temperature can be actively monitored, creating a closed-loop system that controls the current to each diode, allowing for the power to be adjusted accordingly.



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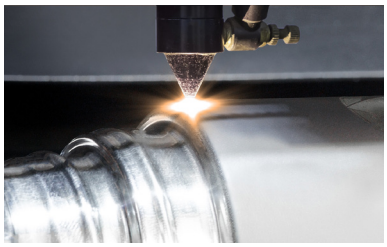
https://www.industrial-lasers.com/articles/2016/08/carbon-fiber-composite-consolidation-using-free-space-direct-diodes.html

Heat Treating and Cladding

Compared to CO_2 lasers, diode lasers offer a lower cost of ownership with higher reliability. A diode laser with shaped light technology allows for precise application of the illuminated area. Size, shape, uniformity, brightness and power of the laser can be easily controlled. A diode laser can be designed to provide multiple, user-selectable spot sizes or power levels to process different types of parts. The compactness and weight of a diode laser allows for flexibility of mounting platforms such as small robotic arms.



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How to Specify a Diode Laser

There are many variables that determine which type of diode laser is ideal. Through beam shaping capacities, a great deal of design flexibility is available. Below is a list of some of the key variables to take into consideration when discussing a diode heating system.

VCSEL or Edge Emitters: Vertical cavity surface emitting laser diode (VCSELs) are a highly scalable form factor and offer a convenient form factor that is easily manipulated through light-shaping optics. In contrast, edge emitters offer elliptical shaped beams that frequently require a more complex optical design to shape the light into the desired form factor. However, edge emitters provide a higher spatial brightness and better efficiency. Both technology options are viable as a diode laser system.

Wavelength: The wavelength of the diode laser is fixed, but designed around a specific wavelength needed within a region of 760nm up to 1700nm. If needed, a system can be designed to offer multiple, fixed wavelengths. Eye-safety concerns can also dictate system design.

Processing mode: Is the application best served through a constant (continuous) exposure to the light source or in a pulsed fashion?

Power: The power of a diode laser, measured in watts, can be customized from just a few watts to 10s, even 100s of kilowatts. The power of a diode laser varies as a function of operating current and can be adjusted by the user.

Beam shape or energy distribution: A diode laser can be designed to provide a customized beam shape. A spot (circle), line, rectangle, ring or any other beam shape can be designed. User-selectable beam shapes or sizes can also be customized.

Spot size and brightness: The spot size is the area that is exposed to the laser light. The brightness is the amount of power the laser provides divided by the spot size.

Depth of focus: The spot size, energy homogeneity, and other parameters vary as a function of the distance between the emission source and the target surface. If the material to be processed is not planar, the depth of focus of the diode laser needs to be taken into consideration so limited variation in the spot size or brightness occurs.

Stray light mitigation: Some amount of laser light may be outside the target area. Laser design efforts can be made to mitigate, even eliminate, the amount of light occurring outside the desired processing area. This can be especially critical with materials that are easily processed or when there are eye-safety concerns.

Beam uniformity: Across a target area, the amount of light and heat, within any one region may vary. With beam conditioning optics, diode lasers can be designed to provide up to 99% uniformity across a given spot size.

Working distance: The distance from the emission output of the laser to the processing surface can be defined in the laser design. This can range from a few centimeters to many meters of distance.

Size and weight: The volumetric size and weight of the laser can also be a critical design parameter. Special effort can be made during the design of a customized diode laser to minimize size and weight.

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Conclusion

Advances in laser diode technology are driving increased interest in using diode lasers as replacements for older heating systems. Direct diode heating is particularly well-suited to industrial applications because it addresses the major technological issues that plague existing methods. The specific ability to pattern the thermal exposure region is the feature that sets direct diode heating apart from all other methods. Some form of thermal heating is required in almost any material processing application. Direct diode heating may have a broad impact across a wide range of industries.

Lasertel is a manufacturer of both VCSELs and edge-emitting diodes as well as custom micro-optics. The beam size, shape, and homogeneity can all be designed and built to order. Multiple operating modes offering the user options for these parameters can also be engineered. Lasertel has experience making a wide variety of systems that offer as much as 30kW of optical power across a line 0.1mm x 300mm with 95% energy uniformity or 100W across a 3mm x 5mm rectangle.

Are you ready to take your laser to the next level?

Contact us to discuss how our technology can address your needs.