Cladding with High Power Diode Lasers

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Cladding is a well established process used in a variety of industries for improving the surface and near surface properties (e.g. wear, corrosion or heat resistance) of a part, or to re-surface a component that has become worn through use. Cladding typically involves the creation of a new surface layer having different composition than the base material, as opposed to hardening, which simply entails changing the properties of the substrate itself in a thin surface layer. There are currently quite a number of different techniques for performing cladding, each with its own specific characteristics in terms of the materials employed, the quality of the clad layer and various practical issues including throughput speed, process compatibility, and cost. Laser-based processes are amongst these techniques, however, their implementation has been limited due to both cost and various implementation factors.

Over the past several years, a new type of cladding tool based on high-power diode lasers has become available. In many instances, this technology offers superior overall clad quality, reduced heat input, minimal part distortion and better clad deposition control than traditional technology, while also delivering lower operating cost and easier implementation than other laser-based methods. This article provides an introduction to high-power diode laser technology and its use in cladding. In particular, it compares the capabilities and characteristics of diode lasers with traditional cladding methods as well as alternative laser technologies. Various sample cladding results are also presented.

Traditional Cladding Processes

Current cladding technologies can be broadly classified into three categories; these are arc welding, thermal spraying and laser-based methods. Each of these methods has its own advantages and limitations and as a result, there are certain types of applications for which each is best suited.

There are a number of different arc welding techniques such as gas tungsten arc welding (GTAW), plasma arc welding (PAW), plasma transferred arc (PTA), gas metal arc welding (GMAW), submerged arc welding (SAW) and several others. In all these processes, an arc is established to melt the surface of the base material, usually in the presence of a shield gas. The clad material is then introduced in either wire or powder form and is also melted by the arc, thereby forming the clad layer. The various embodiments of this basic approach differ in the details such as using the filler metal as the electrode, the use of flux, or the ability to use a hot (pre-heated) or cold filler wire.

In the most general terms, all arc welding techniques deliver a fully welded, metallurgical bond having high strength, good impact properties and low porosity. Arc welding methods also offer high deposition rates (which translates into high throughput) and relatively low capital cost for the equipment.

The major negatives of arc welding cladding are high heat input into the part and, depending upon the particulars, relatively high dilution of the clad material (that is, unwanted mixing of the base material into the clad layer). Heat input into the part can cause mechanical distortion which may create the need for further processing after cladding. It may also cause volatile alloying elements to evaporate which can result in surface hardening of some materials. In addition, it is not always possible to realize in practice the high deposition rates of which arc welding processes are theoretically capable. This is because dilution, heat input, distortion, hardness and other metallurgical properties are sometimes negatively affected when the arc energy is increased beyond an optimum level that is generally at the lower end of deposition rate range.

In thermal spraying, the clad material, in powder form, is melted by a flame or electricity and then sprayed on to the work-piece. In most cases, this is a low-heat process, typically <200°C. The four most common embodiments of this approach are flame spraying, arc spraying, plasma spraying and high-velocity oxyfuel (HVOF).
Primary advantages of all thermal spraying techniques is the low heat input into the part, which means there is no heat affected zone and minimal dilution. It also enables the process to be utilized with a wide variety of substrate materials including metals, ceramics and even plastics. Thermal spraying also supports a very broad process window in terms of the range of coating thicknesses that can be achieved and the deposition rates supported. Typically, thermal spraying is relatively simple and inexpensive to implement.

The biggest drawback of thermal spraying is that the bond between the clad layer and the substrate material is mechanical, not metallurgical in nature. This can lead to problems with adhesion and poor wear resistance, especially with pinpoint loading. Also, thermal spray claddings are typically much stronger in compression than in tension and often exhibit some level of porosity.

Laser cladding typically produces a high quality clad having extremely low dilution, low porosity and good surface uniformity as demonstrated in the graph and photo. Moreover, laser cladding transfers minimal heat input into the part which largely eliminates distortion and the need for post processing. It also avoids the loss of alloying elements or hardening of the base material. In addition, the rapid natural quench experienced with laser cladding results in a fine grain structure in the clad layer which tends to improve the corrosion resistance. Except when using CO2 lasers, the laser power can be fiber delivered which provides substantial flexibility in terms of how the process is implemented.

Laser cladding is conceptually similar to arc welding methods, but in this case, the laser is used to melt the surface of the substrate and the clad material, which can be in wire, strip or powder form. Laser cladding is commonly performed with CO2, various types of Nd:YAG, and more recently, fiber lasers.

The limitations of traditional laser cladding are mainly practical in nature. Specifically, the capital cost is higher than other cladding techniques and the physical size of the equipment can make it difficult to integrate into some production settings. This can be particularly true of CO2 lasers, whose infrared light cannot be fiber delivered, thus necessitating that the laser be brought into proximity with the workpiece. Also, most metals are more reflective at the infrared output wavelengths of CO2 (10.6 µm) which results in lower process efficiency for this type of laser. Finally, in many cases, laser cladding doesn’t support the deposition rates achievable with arc welding (albeit usually with a sacrifice in clad quality for fast arc welding).

High-Power Diode Lasers

Laser-based cladding techniques provide (at least theoretically) several quality and process related advantages over both arc welding and thermal spray methods. However, traditional laser types have not always delivered on this promise and have also displayed significant drawbacks in terms of output characteristics, operating costs and ease of implementation. In response to the need for a more optimal source for this application, cladding systems based on high-power diode laser technology have been recently introduced.
Diode laser bars consist of multiple individual emitters on a single, monolithic substrate, each producing a divergent cone of light.

The diode laser is a semiconductor device that directly converts electrical energy into laser light. Typically, higher power diode lasers output in the near infrared, most commonly at either 808 nm or 975 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.

The small size of diode lasers makes them easier to integrate into workstations. It also 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.

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 that 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 photo on the next page shows the power scaling progression from individual MCCP mounted diode laser through assembled stack to an integrated, multi-stack assembly that can deliver as much as 4 kW of laser power.

Commercial Diode Laser Systems

Currently available high-power diode laser systems are offered in two different configurations, namely, “free-space” output and fiber-delivered. Free-space output systems currently offer powers of up to 4 kW at 808 nm. Their output beam is usually in the form of a long, thin line beam of about 1 mm x 12 mm at the point of focus. Optical accessories are available that enable this output to be shaped to better match the needs of specific applications.

Fiber delivered systems output range from 1 to 10 kW, with fiber size anywhere from 200 µm to 1 mm, based upon power. The combination of small size and fiber delivery (fiber lengths from 10 m to 50 m) make this product particularly easy to deploy in industrial environments where space and access to electrical and water service are an issue.
Individual diode laser bars are combined into stacks, and multiple stacks are assembled into systems with either free-space or fiber delivery.

High-power diode laser systems offer advantages in terms of reliability and ease of integration over most other laser types. 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 on/off cycle 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, at Coherent we’ve seen no diode array failures due to corrosion or erosion in our MCCP architecture in 10 years of actual industrial operation.

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

The output of both types of high-power diode laser systems are particularly well suited to the needs of laser cladding. Since the area illuminated by the laser beam on the work surface is typically smaller than the area to be clad, the beam is usually manipulated across the part. In the case of powder-based cladding with a free-space output system, the long axis of the line beam (12 mm) is oriented perpendicular to the scan direction thereby enabling large areas to be processed rapidly. Alternately, in the case of wire feed cladding, it is usually advantageous to orient the beam such that the short axis is in the direction of travel. In addition to process efficiency, this configuration allows the back of the line to smooth out the weld bead similar to a “follower” torch used in the GTAW or PAW processes.

Fiber delivery also offers the benefits of flexibility and remote access. The small spot size possible with fiber-delivery makes it a particularly attractive option for precision cladding of small areas or complex geometry.

**Powder Cladding**

**Wire Cladding**

**Diode Laser Cladding Advantages**

High-power diode laser systems offer unique advantages for cladding compared to other currently available technology.
When compared to arc welding methods, diode laser systems offer lower heat distortion, reduced dilution (typically < 4%), lower porosity (< 1%) and better surface uniformity. Together, these properties largely eliminate the need for post-processing and its associated time and monetary expense. The high quench rate of the diode laser produces a finer grain structure in the clad leading to better corrosion resistance. Furthermore, these benefits generally apply at any power level and hence, deposition rate; unlike most arc welding processes, in which clad quality suffers with increasing power and deposition rate. Finally, the line beam shape of the free-space laser can process large areas rapidly with a high degree of control over clad width and thickness.

When compared to other lasers, diode laser systems offer superior output characteristics and also a number of practical advantages. One reason for this is that the shorter wavelength output of the diode laser is better absorbed by cladding materials than the light of the Nd:YAG and especially the mid-infrared CO2 laser. This means that a diode laser can melt a given clad material using substantially less output power than a CO2 laser.

In addition, diode lasers offer a substantial cost advantage over other laser types. One reason for this is that their electrical efficiency (conversion of input electrical energy to useful light output) is four times higher than for CO2 lasers, about three times higher than diode-pumped Nd:YAG lasers and nearly twice that of currently available fiber lasers. When combined with the higher absorption rate this translates into lower operating costs, a smaller carbon footprint and increased deposition efficiency. Power costs are further reduced because the diode laser has instant “on” capability, meaning there is no standby power consumption.

Even larger savings results from reduced maintenance costs which are orders of magnitude less for the diode as compared to other lasers. Maintenance downtime is also minimized because the physically compact diode laser can be more rapidly replaced than bulkier laser type, and replacements can even be shipped via expedited courier services.

In terms of the process, the line beam output of the free-space delivered diode laser offers an advantage over the output of other laser types when processing large areas. In particular, it enables the production of wide, flat clads having low dilution. Furthermore, overlapping passes wet together well to produce a flat surface profile requiring a minimal amount of post-machining.

From a practical standpoint, the compact diode laser has a substantially smaller footprint than other laser types, thus allowing greater flexibility in its mounting and placement.

<table>
<thead>
<tr>
<th>Cladding Process</th>
<th>Power (kW)</th>
<th>Deposition Rate (lb/hr)</th>
<th>Efficiency (lb/kW*hr)</th>
<th>Heat Input/ Distortion</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Power Diode Laser</td>
<td>4</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>Powder Cladding Rate, Expect Greater Efficiency &amp; Higher Deposition With “Hot Wire” And “Hot Wire” x 2</td>
</tr>
<tr>
<td>CO2</td>
<td>5*</td>
<td>5</td>
<td>0.95</td>
<td>1</td>
<td>Coaxial Cladding nozzle</td>
</tr>
<tr>
<td>Plasma Arc Welding (PAW)</td>
<td>10</td>
<td>15</td>
<td>1.5</td>
<td>3</td>
<td>500 amps x 15 volts, + “Hot Wire” Power</td>
</tr>
<tr>
<td>Gas Tungsten Arc Welding (GTAW)</td>
<td>10</td>
<td>15</td>
<td>1.5</td>
<td>6</td>
<td>500 amps x 15 volts, + “Hot Wire” Power</td>
</tr>
<tr>
<td>Gas Metal Arc Welding (GMAW)</td>
<td>17</td>
<td>15</td>
<td>0.9</td>
<td>10</td>
<td>500 amps x 30 volts, 3/32” Wire</td>
</tr>
<tr>
<td>FCAW</td>
<td>17</td>
<td>20</td>
<td>0.9</td>
<td>10</td>
<td>500 amps x 32 volts, 3/32” Wire</td>
</tr>
<tr>
<td>Submerged Arc Welding (SAW)</td>
<td>32</td>
<td>50</td>
<td>1.6</td>
<td>20</td>
<td>1000 amps x 32 volts, 7/32” Wire, DC-</td>
</tr>
</tbody>
</table>
The option of fiber delivery also offers the possibility of remotely locating the laser from the process.

The table above summarizes the main benefits of the diode laser as compared to other cladding technologies. Here it is clearly seen that diode technology offers an unmatched combination of low heat input and high operational efficiency.

**Typical Results**

The following gallery presents some typical cladding results obtained with Coherent HighLight diode lasers and should indicate the quality, capabilities and flexibility that can be readily obtained with this process technology.

**Print Roller Shaft**

Substrate material.........................Mild Carbon Steel  
Cladding material..........................Hoganas C22 Hastelloy  
Laser type..................................Coherent Highlight 4000L  
Laser power..................................4 kW  
Spot size....................................1 x 12 mm  
Travel Speed .............................0.6 m/min  
Powder Feed Rate ..........................25 g/min  
Step Size....................................8 mm  
Clad Thickness............................0.5 mm  
Process notes..............................Helium cover gas
Circumferential Laser Cladding of Shaft Journal

Substrate material ........................................ High Alloy Steel
Cladding material...................................... Hoganas 3550 “Super Stainless”
Laser type .................................................. Coherent Highlight 4000L
Laser power .................................................. 4 kW
Beam Shape ................................................ 1 mm x 12 mm
Actual Clad Width ........................................ 16 mm
Effective Clad Width (step size) ...................... 8 mm
Linear Process Speed .................................. 0.53 m/min
Clad Rate ................................................... 4240 mm²/min

Circumferential Laser Cladding of Shaft Journal

Substrate material ........................................ High Alloy Steel
Cladding material...................................... Inconel 625
Laser type .................................................. Coherent Highlight 1000F
Laser power .................................................. 1 kW
Spot Size ................................................... < 1 mm
Process Speed ............................................ 0.75 m/min
Circumferential Laser Cladding of Small Stainless Steel Shaft
Substrate material .................. 8620 Stainless Steel (19 mm dia)
Cladding material.................... Hoganas 74-M-60
(nickel-based chromium, silicon/boron alloy)
Laser type ................................ Coherent Highlight 1000F
Laser power .................................................. 1 kW
Spot Size ..................................................... 3 mm
Overlap ....................................................... 50%
Clad Width ................................................. 1.5 mm
Clad Thickness ......................................... 1 mm
Process Speed ......................................... 0.5 m/min
Spot Size ..................................................... 3 mm
Cover/Delivery Gas ......................... Argon
Spot Size ..................................................... 3 mm
Pre-heat ...................................................... Yes
Large Area Cladding of Steel Shaft and Plate
Substrate material .......... 1018 Steel (3” dia & 6.5 x 6.5 plate)
Cladding material .......................... 316L
Laser type .................................. Coherent Highlight 4000L
Laser power ...................................... 4 kW
Beam Shape .................................... 1 x 12 mm
Clad Width ........................................ 8 mm
Clad Thickness ................................. 1 mm
Process Speed ................................. 0.75 m/min
Roller Teeth Mock Up
Substrate material ........................................Mild carbon steel
Cladding material................................. Deloro 60 clad powder
Laser type .............................................. Coherent Highlight 1000F
Laser Power ..................................................1 kW
Spot Size .........................................................2 mm
Process Speed ...............................................0.35 m/min
Clad Thickness .............................................1.2 mm

In conclusion, high-power diode lasers are a unique source for cladding that deliver a number of advantages over traditional technology as well as other laser sources. In particular, diode lasers produce a high quality clad with excellent physical characteristics and a true metallurgical bond, yet without significant heat input into the part. In addition, they are more economical to operate than other cladding laser sources and their small physical size and optional fiber delivery simplify their integration and use.