

# INDUSTRIAL APPLICATION OF HIGH POWER DIODE PUMPED SOLID STATE LASER FOR WELDING TECHNOLOGY

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**Abstract:** The evolution of technology during the last decade facilitated the design and construction of high power diode pumped solid state laser. The metal treating is one of the main domains that gained due to the technological progress, i.e. welding, cutting, drilling and laser marking. Thanks to the constant progress, the laser welding technology is soon to become a feasible alternative for the conventional welding procedures.

**Key words:** laser welding, laser diode, keyhole.

## 1. Introduction

Over the past years, the laser welding technology has benefited together with the laser cutting and marking of a significant progress, being recognized and used for its real value, thus obtaining quality products with lower costs. The laser welding technology can be used for micro joints as well as for thicker parts (25...30 mm).

The laser (Light Amplification by Stimulated Emission of Radiation) represents a device that eradiates electromagnetic radiation that is amplified by using an active medium and is then beamed through a lens system.

Although the laser started to be used during '70s, it had been used for welding only during the last decade thanks to the progress of technology that facilitated the use of laser beam for highly precise welding. These are the reason for which laser welding is used in the automotive and aviation industry, for military applications and medicine.

## 2. The Diode Pumped Solid State Laser Principle

Nowadays, the mostly used laser types for welding technologies are the solid-state and gas lasers ones. The solid state laser represents the one where the gain medium is a solid element. In the Diode Pumped Solid State Laser, the beam is formed when the laser diode pumps a gain medium (neodymium-doped yttrium-aluminum-garnet Nd: YAG crystal or a ruby).

The basic laser principle is presented in Figure 1.

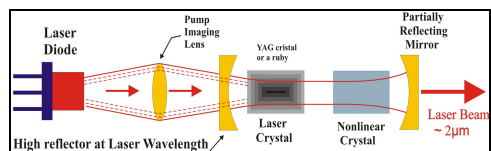


Fig. 1. DPSS Laser Principle

Laser diodes are designed to emit light either from their edge or their surface, the latter providing a circular beam that

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couples better for transmission through optical fibers. The many types of diode lasers known today collectively form a subset of the larger classification of semiconductor  $p-n$  junction diodes (Figure 2). The most common semiconductors used in laser diodes are compounds based on gallium arsenide (750 to 900 nm in the infrared), indium gallium arsenide phosphate (1200 to 1700 nm in the infrared) and gallium nitride (near 400 nm in the blue).

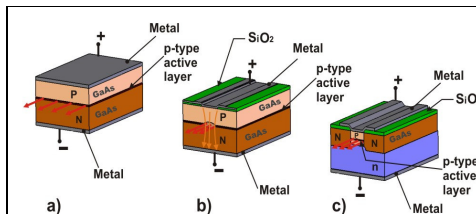


Fig. 2. Various type of diode: a) Double-heterostructure diode; b) gain-guided; c) index-guided

These lasers are made with diode which produces a light beam. The optical pumping is done with the help of the electric current that operates on the generating medium (on the gaps and the electrons). The light is produced on the junction level by means of gaps and electrons recombination. This laser type does not present mirrors in the resonance cavity due to the capacity of the semiconductor materials that are used and which permit the production of a certain and sufficient albedo to obtain the laser effect.

The emissions pass: when a semiconductor is exposed to a light flux, the photons are absorbed with the provision that the photon energy ( $E_{ph}$ ) to be higher than the prohibited band width ( $E_g$ ). This corresponds to the energy that is necessary for the electron to exceed the potential barrier that keeps it inside the solid. The existence of the prohibited band spells the existence of a break point so that  $h\nu_0 = E_g$ . In case of photon absorption two phenomenon's can emerge:

- Photoemission: represents the electrons emission by the photosensitive material (the electron cannot leave the material if it is not excited on surface).
- Photoconductivity: the electrons are free inside the material, they contribute to the electric conductivity of the material.

#### • Characteristics of the laser beam

**Coherent.** The light waves are in phase (in step).

**Culminated.** The laser beam does not diverge. It can be projected great distances without significant spreading. Because of these three characteristics the laser beam can be precisely focused to very small diameters, resulting in an enormous increase in energy density.

**Monochromatic.** All of the photons which compose the beam are of the same energy and therefore the same wavelength.

### 2.1. High-power Diode

In order to obtain a high output power the diode disposal in diode bars was used and thereby, a power beam was obtained through the beams optic overlap (Figure 3) [5]. They typically contain between 20 and 50 emitters, each being e.g. 100  $\mu\text{m}$  wide mounted on the bad-plate. The submount is then mounted on some heat sink, which is often water-cooled.

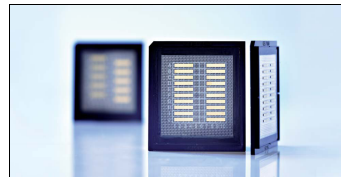


Fig. 3. High Power Diode Laser Bars  
940 nm, 120 W, cw

The most efficient mode to pump electromagnetic energy is the multi-bar module also called diode laser stack.

A diode stack contains a number of diode

bars, which are arranged in the form of a stack. The most common arrangement is that of a vertical stack as shown in Figure 4.



Fig. 4. Water-cooled diode stacks

Diode stacks can provide extremely high output powers of hundreds or thousands of watts, as used for pumping of high-power solid-state lasers, or used directly e.g. for material processing. There are also fiber-coupled diode stacks, delivering e.g. several kilowatts from a multimode fiber with a core diameter of 600  $\mu\text{m}$ .

Some applications such as welding of metals or plastics, where a high beam quality is not required, can directly utilize the output of such a laser system, which can have very high wall-plug efficiency. This is also attractive for other direct laser diode applications such as hardening, alloying, and cladding of metallic surfaces [6]. These diodes transform the electric energy into lighting energy one within a very narrow spectral interval, so that the neodymium absorption at 808 nm coincides with a maximum pumping efficiency (10 times bigger than the lamp pumped lasers); the diodes are very compact structures, secure in use and mechanically rigid.

These laser systems use a single crystal for the gain medium, but they offer the possibility to arrange up to 100 diodes in modules that take the form of a strip.

Recently Jenoptic [1], [3] have developed a high power diodes system (2 kW) with the diameter of the laser beam of 0.96 mm

and an intensity of  $2.35 \cdot 10^5 \text{ W/cm}^2$ , that supplies sufficient power to weld Al, Ti and steel [3].

### 3. Laser Welding Process

The laser diode has been in use for a long time but its application was limited by the low power. Nowadays, the technology has come to such level of progress that, by producing powerfull enough laser diodes, they can be used for melting and welding metal. The key process parameters for laser welding include laser power, focusing optics, and weld speed. All of these parameters are interactive. For a given focusing optic and material thickness, and assuming that full-penetration welds are desired, the higher the power, the faster the weld speed. A main parameter that has to be taken into consideration is the property of metals to reflect light (Figure 5).

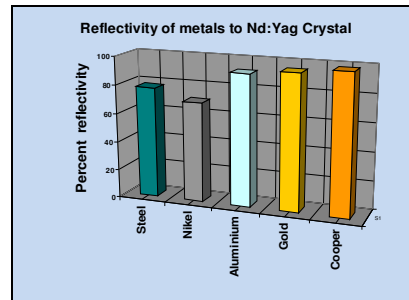


Fig. 5. Reflectivity of metals

Knowing that the laser radiation energy is transformed into thermo energy based on the absorption process, where from the intensity flow  $I_0$  that encounters an element, a  $RI$  part is reflected onto the surface and another part enters the material  $(I - R)I_0$ . The radiation intensity that entered the material will exponentially decrease, according to the absorption principle:

$$I(z) = I_0 \cdot (1 - R) \cdot e^{-\alpha z}, \quad (1)$$

where  $R$  represents the reflection coefficient, and  $\alpha$  the absorption coefficient; both parameters depend on the optical and thermo-physical properties of the material, the state of its surface and the radiation wavelength.

### 3.1. Keyhole Welding Effect

In order to perform the welding process, the minimum energy needed is of  $10^6$  W/cm<sup>2</sup> where the diameter of the beamer represents 30% of the part thickness. The reflectivity of the metal is only important until the keyhole weld begins. After forming the first drop of melted metal, the level of absorbed energy increases because the metallic bath has a low reflection degree, causing the temperature to significantly increase up to the point where metal steams form (Table 1) [2].

Table 1

*Level of absorbed energy at different temperature*

Metal		Al	Cu
Melting temperature $T_t$ [°C]		660	1083
Absorption factor at heating temperature	10% $T_t$	66 °C	108 °C
	20% $T_t$	132 °C	216 °C
	30% $T_t$	198 °C	324 °C
	40% $T_t$	264 °C	433 °C

As relative motion between the beam centerline and material occurs, the molten metal flows around from the front of the keyhole and solidifies at the back, forming a laser weld (Figure 6).

The keyhole effect allows welding procedures with deep diffusion due to the fact that the laser beam heat is well absorbed in a steamy medium.

The diameter of the laser beam used for the welding process generally varies between 0.1...1 mm, with a reference value of 0.3 mm. For the geometry of the elements, the lap joint is used, and only

seldom the add-on material. Lap welds melt a lot of metal to produce a small connection, but they have a much larger tolerance on position than butt welds.

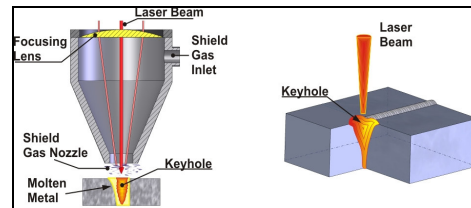


Fig. 6. *Keyhole effect*

Laser welding can be combined with MIG, TIG or plasma welding to create a process with the high speed and deep penetration of laser welding coupled with the superior gap-bridgeability and tolerance to misalignment of the conventional processes.

Hybrid laser-arc welding introduces a secondary energy source to the weld pool area (Figure 7). It combines typical laser welding benefits-high travel speeds, limited heat-affected zone (HAZ), narrow weld joint, and good bead appearance with those of gas metal arc welding (GMAW): process energy efficiency, gap-bridging, slow cooling rates, and energy coupling efficiency.

The GMAW wire can be introduced before or after the laser beam. Laser beam attenuation (scattering and absorption) caused by vapor particles evacuating the keyhole or weld area reduces the amount of beam energy coupled to the base material [4].

The main characteristic of the laser welding is the quick solidification of the metal bath. During this cooling, the material contracts, creating tensile stresses in the fusion zone. When using short welding intervals (5 ms), the welding belt might crack. It is possible the laser influenced areas of high-alloyed steel, turn into martensite with major drawbacks for the welding. These drawbacks can be avoided by increasing the welding

intervals or by a local preheating procedure. Another wide spread method used for obtaining high quality welding results consists in using the shield gas for preventing the oxidation of the metal bath.

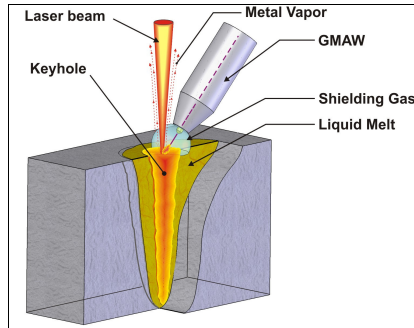


Fig. 7. Hybrid laser-arc welding. GMAW: MIG, MAG, PAW; Laser beam: CO<sub>2</sub>, Nd:YAG, High-power Diode; Shielding Gas: argon or helium

#### 4. Miscellaneous Facts Regarding the Use of Laser in the Welding Procedures

The properties and the forces of the laser sources are becoming more and more important, and the high automatic level of the new installations allow the laser to be used in various domains, with the following properties:

##### 4.1. Laser welding advantages

- The possibility to weld almost any metallic, plastic or dielectric material, no matter the hardness of the pieces. Its important for the surface of the treated material to have a sufficient capacity to absorb the laser radiations;
- It offers the possibility to weld very small pieces or pieces with complex configurations;
- Avoid the possible deformations that might appear after completing the welding process, due to the lack of any mechanic contact between the tool and the piece;

- Aesthetically pleasing welds without post processing;
- The lack of deformations caused by temperature or internal tensions, because the thermo-influenced area around the spot where the laser is beamed, is minimal;
- Significant decrease of the welding intervals, the process takes place almost instant;
- No secondary processing and high repeatability;
- Can be weld even pieces that are located in translucent areas;
- The processing allows full automation and numerical control or C.N.C.;
- It is possible to perform several simultaneous welding processes in the same installation with special optic devices;
- It is possible to ensure a precise positioning of the piece in front of the laser beam, thus guaranteeing precise welding;
- The laser can be used to weld plastic material either by directing the laser beam on the surface of a laser-absorbing plastic and welding by fusion or by transmitting a laser beam through a laser transparent layer and welding at the interface with the laser absorbing material.

##### 4.2. Laser welding disadvantages

- It requires controlled atmosphere in the work area and special protection measures needed;
  - High energy consumption relative to the achieved energy;
  - In the case of diode pumped lasers it is necessary the usage of certain performant stabilization source;
  - High system acquisition and introduction costs.
- Due to the high costs and low productivity of the laser welding processes, we recommend to use it only in the situation that do not allow other methods, with lower costs or when there is no other possibility to perform a joining.

### 4.3. Applications

**Heat treatment and cladding.** Through laser transformation hardening a material can be case hardened with negligible distortion. With laser beam hardening the applied light radiation instantaneously heats the surface. There is no radiation spillage outside the optically defined area. The bulk of the material acts as a heat sink for the extraction of heat from the surface. The major advantage of laser surface treatment is high processing speeds with precise case depths.

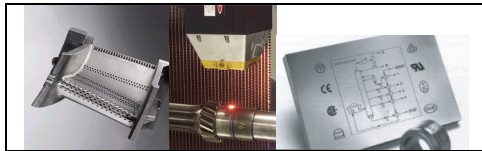


Fig. 8. Left: aircraft engine turbine blade; Middle: cladding with high power direct diode laser (HPDDL); Right: 3 mm deep engraved

**Laser micromachining** is defined as laser cutting, drilling, etching, stripping, skiving materials such as plastics, glass, ceramic and thin metals with dimensions from 1 micron to 1 millimeter. Recommended maximum machining thickness is 1 mm (Figure 8 left). Typically, laser drilling holes are tapered where the entrance diameter is larger than the exit diameter [7].

**Laser engraving.** Many electronics manufacturers require high volume, permanent, clear, laser engraving of small fragile devices (Figure 8 right). Only non-contact laser marking can produce permanent images without compromising material integrity.

### 5. Conclusion

Although the conversion relation of the electric energy into thermal energy does

not surpass 2...18%, all the energy is transmitted and beamed on a submillimetric area, allowing high-precision welding to be produced. Using the DPSS Laser system together with a high-performance beam system, enables the welding process to take place in airtight closed areas, that suits metal such as Ti, Au, Ag, this procedure is widely spread in the medical applications. Thanks to the optimal beaming of the welding systems based on laser diodes, it was possible to obtain welded joints with the same resistance as the basic material, as well as precise welding between similar or different material, such as nickel, niobium and beryllium or aluminum and titanium.

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