Gradus Vol 4, No 2 (2017) 438-443
ISSN 2064-8014

LIGHT SOURCES FOR LASER-WELDING APPLICATIONS

*Ambrus Kőházi-Kis**

[1]Department of Natural Sciences and Engineering Basics, GAMF Faculty of Engineering an Computer Science, John von Neumann University, Hungary

Keywords:
Laser welding,
fiber laser,
disk laser,
direct-diode laser

Article history:
Received 25 September 2017
Revised 12 October 2017
Accepted 15 October 2017

Abstract
In up-to-date industry laser welding has become a well-founded joining technology. High productivity, repeatability, low heat input, and fast welding speed are some of the main advantages of laser welding compared to conventional joining technologies. In this publication I give a short survey of the recent progress of the laser-welding technology.

1 Introduction

High-power and high-beam-quality solid-state lasers, such as the thin-disk laser and fiber laser, have made laser welding popular in manufacturing industries. More recently, kilowatt direct-diode lasers have become commercially available with beam quality competitive to thin-disk or fiber lasers because of a laser beam combining method called wavelength beam combining, by which beam quality can be maintained without deterioration when power scaling. Replacing $\mathrm{CO_2}$ lasers (see Fig. 1.), these solid-state lasers are becoming the main players in the field of remote laser welding.

	2015 REV.	2016 EST.	2017 PROJ.
CO_2	\$518.3	\$502.2	\$490.0
y-to-y		-3.1%	-2.4%
FIBER	\$589.0	\$653.0	\$721.6
y-to-y		10.9%	10.5%
SOLID-STATE	\$195.7	\$203.0	\$210.2
y-to-y		3.7%	3.5%
DIRECT DIODE/ OTHER	\$125.0	\$133.9	\$143.5
y-to-y		7.1%	7.2%
TOTAL	\$1,428.0	\$1,492.1	\$1,565.3
y-to-y		4.5%	4.9%

Figure 1. Laser revenues for macroprocesses ($M) [1]

Theses changes can be explained by the efficiency benefit of the new competitors (20% for disk lasers, 35% for fiber lasers, and 45% for direct diode lasers – in contrast to the 10% efficiency of the $\mathrm{CO_2}$ lasers) and the better absorption properties of the important materials for the wavelengths values of the new actors (see Fig. 2.). In addition the light in the visible and in the near-infrared wavelength-range can be transferred through optical fibers while the far-infrared light of $\mathrm{CO_2}$ laser can only transferred by free-space propagation driven by mirrors.

After a short introduction of the field of laser welding technology I will overview shortly the new types of industrial lasers.

*Corresponding author. Tel.: +3676516436; fax: +3676516299
E-mail address: kohazi-kis.ambrus@uni-neumann.hu

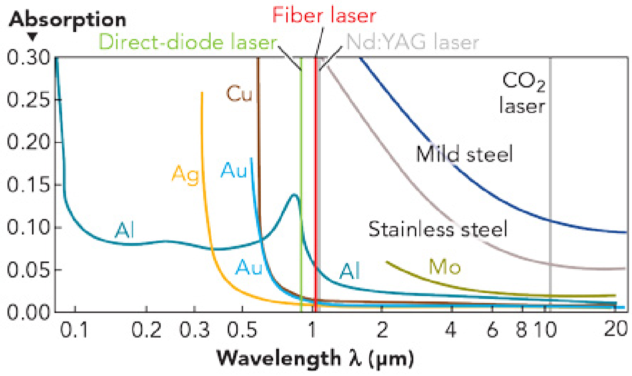

Figure 2. Wavelength dependence of absorption of the metals[2]

2 The laser welding process

The focused, concentrated laser light beam directed onto a metal surface is partially absorbed and reflected by the metal surface. This absorbed energy heats the metal surface at the focal spot until it melts. This molten pool is enlarged by thermal diffusion and is known as the conduction welding mode. For energy density larger than $10^5 - 10^6\,\mathrm{W/cm^2}$, the molten pool is heated rapidly at the focal point up to the vaporizing temperature, and the laser beam drills a hole in the metal surface to create the laser keyhole. The depth of the keyhole increases with the laser power and the linear energy; i.e., decreases with the welding speed (see Fig. 3.).

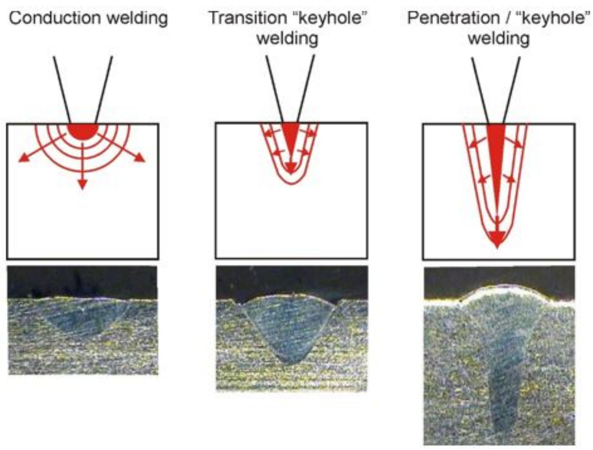

Figure 3. Laser welding modes [3]

Conduction welding is used in cases when extra fine surface quality is important, while keyhole welding is applied in cases where strong bonding is necessary.

Laser welding needs a high power density delivered by a laser beam. It can be achieved by creating a small focal width of the laser beam at the surface of the piece. The small values of the beam-power product (BPP – the product of the width of the beam waist and the divergence of the beam in the far field) [4] of the $\mathrm{CO_2}$, disk, fiber, and direct diode lasers make these lasers feasible for remote laser welding processing. Remote laser welding (RLW) is characterized by a long focal length and a fast-moving laser spot on a workpiece, generally by a pair of mirrors called a scanner (see Fig. 4). It permits a very fast processing [6].

Applying pulsed nanosecond laser for deep welding one can bond dissimilar materials also [7, 8]. It can be used for connecting consumer battery cells to copper wires (see Fig. 5). The small energy of the focused laser pulse can melt and even vaporize the metals but it cannot heat up bigger amount of material – the heat effected zone can be localized to a very shallow layer.

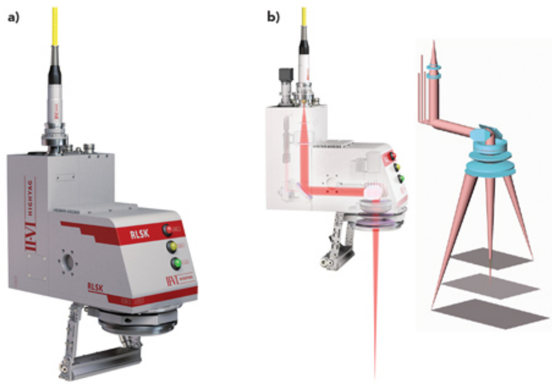

Figure 4. Scanner-based remote laser welding head (a), with its sectional view and functional principle (b)[5]

Figure 5. An 18650 consumer battery cell with a laser bond [8]

3 Fiber lasers

Cladding pumped fiber lasers have been a major success in the laser industry in the last decade. Both low-power fiber lasers for marking and high-power multi-kilowatt fiber lasers for cutting and welding are rapidly growing their market share (see Fig. 1). Recent tendencies suggest that the number of multi-kilowatt fiber lasers employed in industry for flat sheet metal cutting will very soon overtake the number of CO_2 lasers sold into the industrial laser market. Their high efficiency and compactness make them a very practical tool.

The difficulties associated with laser welding of materials such as aluminum and copper using $1\,\mu m$ lasers can largely be overcome by using high-brightness fiber lasers together with the latest 2D wobble-head technology for additional beam control of the keyhole melt during the welding process. In turn, this is shown to help eliminate porosity and sputtering associated with laser welding of these materials using traditional techniques. The additional degrees of freedom achieved through independent amplitude and frequency of the wobble-head oscillation, when combined with the high brightness and power available from the fiber laser, offer the level of control needed to achieve good-quality laser welding in difficult materials.

The pulsed nanosecond infrared fiber lasers are quite variable. They often adopt MOPA (Master Oscillator Power Amplifier) approach. They are the laser of choice for the majority of industrial marking and engraving applications. Their pulse energy is typically less than a few milli-joules, their average power is typically less then 100 W. More recently, they have begun to be used for a variety of micromachining and surface texturing applications and even for remote micro-cutting applications. Although these applications involve material removal they can be used also for welding [9]. Conventional wisdom suggests that long millisecond-type pulses with large pulse energies are needed to create welds and joints—well, evidently not! The capability of this genre of laser for materials joining is less well known, but their ability to join thin section materials is remarkable. It can also been used for welding dissimilar materials [7, 8, 9].

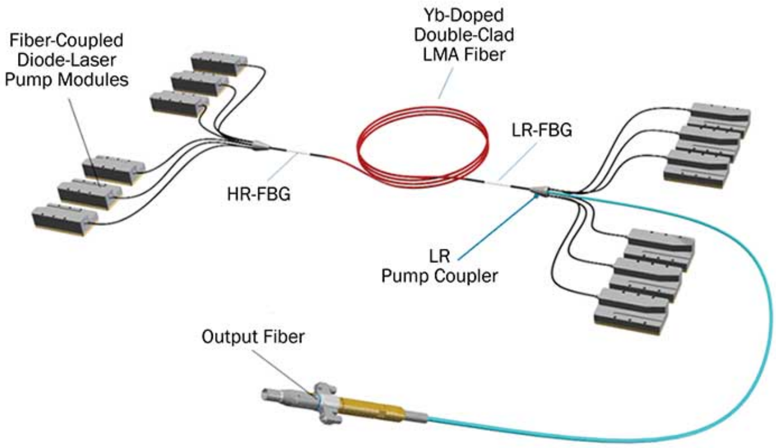

Figure 6. Several semiconductor laser diodes can be applied as a pump power source for the typically ytterbium as an active material of the fiber laser [10]. (HR-FBG and LR-FBG are high reflective and low reflective fiber Bragg-gratings, respectively)

4 MOPA

These lasers use a semiconductor seed to generate the pulses so they are not constrained by the limitations of conventional Q-switch technology. The MOPA approach allows users to vary the pulse duration and operate over a broader operating frequency range, enabling the pulse parameters to be easily tailored to suit individual applications.

The control of the pulse durations important because materials react differently to applied energy, and the ever-increasing diversity of materials being processed by lasers means that the tools need to be more sophisticated and versatile because one size does not fit all.

Some of todays MOPA based sources are capable of operating in a 3–500 ns pulse duration range, offering three orders of magnitude of controllability. Coupled with their ability to operate at $1\,\mathrm{kHz}$ to $1\,\mathrm{MHz}$, they offer an unrivaled capability in pulse optimization, allowing any pulse duration to be operated at any frequency. [7]

5 Disk lasers

It is an optically pumped solid-state laser with a solid heat sink, having the heat flow approximately collinear to its resonator axis (see Fig. 7). The active material has the shape of a disk, usually $100\,\mu\mathrm{m}$ to $300\,\mu\mathrm{m}$ thick, several millimeters in diameter, highly-reflective-coated on the backside, anti-reflective-coated on the front side, fixed with its HR-coating on a heat sink. It is pumped at an oblique angle from the front, mostly in a multi-pass configuration. The disk can be either an (active) end-mirror or a folding mirror in various resonator designs. Because of the effective heat sink there is no thermal lensing – a very good laser beam is generated. [12]

Ongoing increases in power per disk, beam quality, and efficiency, combined with ever-increasing choices in ultrafast pulse and alternate wavelengths like ultraviolet and green, not only prove the flexibility of the disk laser concept, but also have dramatically increased its utilization for material processing. Disk lasers are found in applications from tens of watts to over 30 kW, and from femtosecond pulses to continuous-wave (CW). These lasers are used in material processing applications such as cutting, remote cutting, conduction welding, conventional welding, remote welding, heat treating, laser metal deposition, drilling, ablation, and surface cleaning, and are found in a large variety of industries. [13]

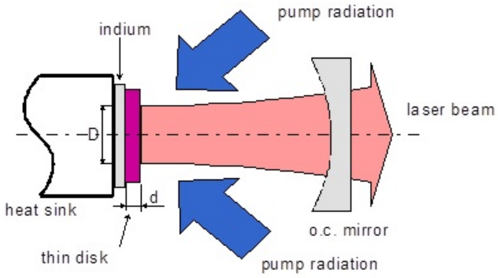

Figure 7. Standard design of a disk laser [12]

6 Direct diode lasers

From the year of 2014 several companies are working on ultra-high brightness diode lasers. The key technology they all share is dense wavelength multiplexing (see Fig. 8). Individual laser diodes or banks of them are lasing at slightly different wavelengths, typically in the 900–1000 nm range, and combined with filters or gratings. Multi-kilowatt lasers are available now. Their output beam has excellent shape.

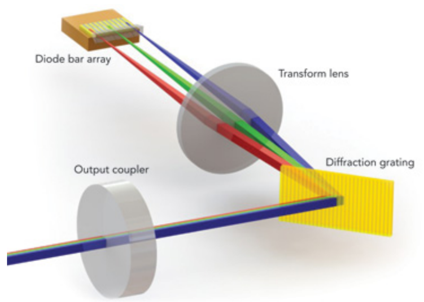

Figure 8. A schematic that demonstrates wavelength beam combining (WBC)[15]

With the availability of high-power diode laser systems in the kilowatt range, industrial high-brightness systems are being used for welding applications, whereas low-brightness devices are used in high-power applications such as cladding, additive manufacturing, brazing, and hardening. Often, the diode laser has significant advantages because of its inherent larger spot size (e.g., no need for wobbling a beam). The spot size also helps to bridge gaps in welding and brazing applications. Finally, the multiplexing of numerous wavelengths allows scalability of power levels for hardening or for cladding and additive manufacturing applications. [16]

7 Conclusion

The laser technology progresses so fast that one has to be quite conscious making dicisions about industrial lasers. There has been appeared new lasers in the industrial laser market in the past ten years that revolutionized, among others, the laser welding technology. In this paper I try to present the new trends in this area based on the latest literature available. From the point of view of our EFOP project the appearance of new welding technology for cabling accumulators [7, 8] is especially important.

Acknowledgement

The project has been supported by the European Union, co-financed by the European Social Fund. EFOP-3.6.1-16-2016-00014.

References

[1] D. Belforte, “Industrial lasers continue solid revenue growth in 2016”, Industrial Laser Solutions, vol. 32. No. 1, pp. 9-13 (2017).

[2] F. V. Saucedo, B. CHANN et al., “Direct diode vs. other laser systems used in laser cutting”, Industrial Laser Solutions, vol. 31. No. 2, pp. 28-30, (2016).

[3] ”Laser welding modes: conduction, transition, & keyhole welding”, Amada Miyachi Blog [Online]. Available: http://info.amadamiyachi.com/blog/conduction-transition-and-keyhole-welding-modes [Accessed: 20-Sept-2017].

[4] B. Paripás, Sz. Szabó et al., “Lézeres mérési és megmunkálási eljárások a gépészetben”, Nemzeti Tankönyvkiadó, 2009.

[5] M. Gillon, Ch. Gross, “Remote laser welding boosts production of new Ford Mustang”, Industrial Laser Solutions, vol. 32, No. 4, pp. 28-30 (2017).

[6] J.-B. Wang, “Laser robot system reduces remote welding time”, Industrial Laser Solutions, vol. 32, No. 4, page 14-17 (2017).

[7] J. Gabzdyl, D. Capostagno, “Pulsed nanosecond fiber lasers can join dissimilar materials”, Industrial Laser Solutions, vol. 32, No. 1, page 24-26 (2017).

[8] B. Mehlmann, J. Sedlmair, “Laser bonding: A new connection technology for high currents”, Industrial Laser Solutions, vol. 32, No. 5, page 12-15 (2017).

[9] J. Gabzdyl, D. Capostagno, “Pulsed nanosecond fiber lasers can weld, too!”, Industrial Laser Solutions, vol. 30, No. 5, page 21-25 (2015).

[10] W. Rath ”Fiber Laser Welding Cuts Costs and Improves Results”, Europhotonics, vol. 22, summer issue, page 24-26 (2017).

[11] ”Master Oscillator Fiber Amplifier”, RP Photonics Encyclopedia, Available: https://www.rp-photonics.com/master_oscillator_fiber_amplifier.html [Accessed: 20-Sept-2017].

[12] ”Advanced Laser Materials Processing”, Ed.: G. Schuocker, D. Schuocker, Available: https://www.esciencecentral.org/ebooks/ebookdetail/advanced-laser-materials-processing [Accessed: 20-Sept-2017].

[13] D. Havrilla, T. Ryba, Disk laser applications abound, Industrial Laser Solutions, vol. 30, No. 5, page 12-14 (2015).

[14] A. Sanchez-Rubio, T. Yee Fan et al. ”Wavelength Beam Combining for Power and Brightness Scaling of Laser Systems”, Lincoln Laboratory Journal, vol. 29, No. 2, pp. 52-66 (2014).

[15] J. Liebowitz, “High-power direct-diode lasers for cutting and welding”, Industrial Laser Solutions, vol. 29, No. 3, page 27-29 (2014).

[16] J. Neukum, “High-power diode lasers in metal processing”, Industrial Laser Solutions, vol. 30, No. 5, page 26-28 (2015).