Fiber Laser Welding

High beam quality and efficient welding of a wide variety of materials

Fiber lasers have unique properties of high brightness, selectable beam quality, fine focusability, application flexibility, and a low cost of ownership. This opens up the fiber laser to a range of application opportunities as a welding source, especially at power levels from 100 to 1000 Watts (W).

The high power densities available from fiber lasers are ideal for use in high speed seam and penetration welding of steels, and also welding of more reflective materials, including copper. The fiber laser also offers a number of applications for conduction welding, which occurs at much lower power densities and therefore with larger optical spot sizes. In addition with fine control over pulse widths and pulse frequency welding of thin materials and very small components are also possible.

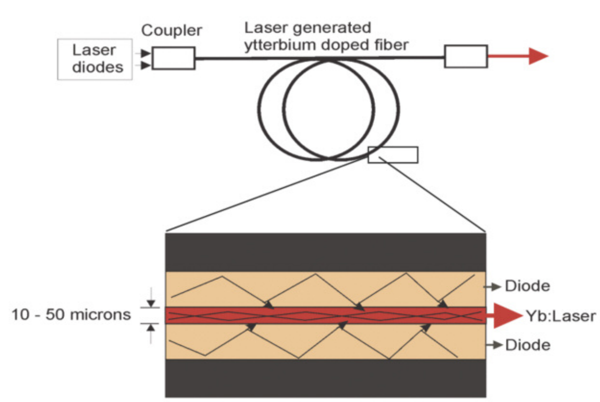
Furthermore, fiber lasers have the lowest cost of ownership on the market today. They are inexpensive to run, with extremely high wall plug efficiency, low electrical energy use, and very long life. Maintenance costs are low and there no internal consumables within the laser.

Their use in a wide range of core welding applications, together with their high speed and application flexibility, makes fiber lasers an excellent choice for automotive, medical, electronic, and aerospace industries.

FIBER LASER BASICS

A fiber laser is produced within a small core silicon fiber, typically between 9 and 50 microns in diameter, doped with Ytterbium. See **Figure 1** for a schematic of a typical fiber laser.

Figure 1 – Schematic representation of fiber laser



Detailed view of the interaction of the pumping diode light with the active core of the laser

Since the laser is generated wholly within a fiber, there is no need to align the medium to cavity mirrors, nor maintain optics and alignment as for other lasers. A unique feature of the fiber laser is its “focusibility.” For example, a 500 W laser can be focused to a 10 micron spot size. For many processes this would not a practical, but with effectively no lower limit on spot size, the fiber laser provides unique process parameter capabilities.

The fiber core medium can be pumped by either single emitter diodes that are spliced into the cladding surrounding the core or diode arrays that are launched into the cladding.

The fiber laser operating at 1070 nanometers (nm) can be delivered to the workpiece using a flexible fiber optic cable. This lasing fiber to focus head delivery fiber connection can be made either by direct splicing within the laser or by using an external mechanical coupler. The advantage of using a mechanical coupler is that if the delivery fiber is damaged it can be easily replaced. By comparison, if damage occurs with a typical spliced connection, the laser usually must be repaired by the manufacturer. The external coupler can also be useful in avoiding damage to the laser due to back reflections from the workpiece, most likely only an issue when welding such reflective materials as aluminum and copper.

LOW COST OF OWNERSHIP

Fiber lasers have a very low cost of ownership. The single emitter option offers estimated lifetimes of 100,000 hours and the diode arrays offer an estimated 50,000-100,000 hours of lifetime. To put this into perspective, 100,000 hours represents a continually-on operational lifetime of about 11 years.

In addition, the fiber laser has an excellent wallplug efficiency of around 30 percent, which minimized the need for the chiller (or the size of the chiller, if one is required), and also results in low electrical energy consumption. Also, there are no consumables or replaceable parts within the laser. It is worth noting, however, that fiber lasers tend to be non-repairable in the field, so if failure does occur, the unit would need to be repaired at the manufacturer.

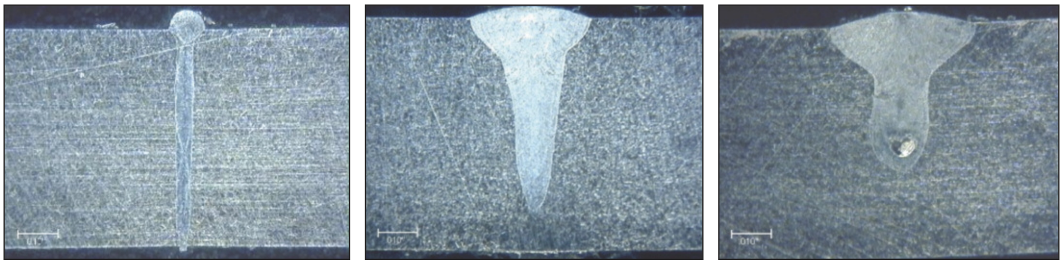
BEAM QUALITY – HIGHEST OF ANY LASER SOURCE

The fiber laser offers the highest beam quality of any laser source, and so can essentially be tuned to whatever is needed for the application. Increased weld penetration and speed are directly related to better beam quality. However, weld stability and accommodation of manufacturing variances, for example, part placement and joint fit-up requirements, tend to favor lower beam quality. There is always the option to reduce the quality of the beam to match the application, but it is impossible to increase the quality of the laser once it has exited the laser generator.

So, the key differentiator for the fiber laser is that it offers the maximum “tunable” range for beam quality, so a particular process can use the optimal beam quality rather than compromising due to a laser technology limitation. In addition, the high beam quality offers unique laser parameter combinations, such as very small spot sizes of less than 0.0010-inch, or very high power densities that can access new welding applications. One excellent example of this is high speed welding of thin copper sheets for battery applications.

The fiber laser is provided in two brightness configurations: single mode, the highest brightness used primarily for cutting and multi-mode, primarily used for welding. **Figure 2** indicates the correlation of beam quality to penetration/speed performance and weld width for fit-up accommodation. It is clear from **Figure 2** that a large range in welding performance exists according to beam quality, and that the selection must be made from a standpoint of overall process reliability and not simply best penetration. The center picture indicates the compromise selection made between the two extremes of beam quality and brightness.

Figure 2 – Single mode and multi-mode fiber lasers



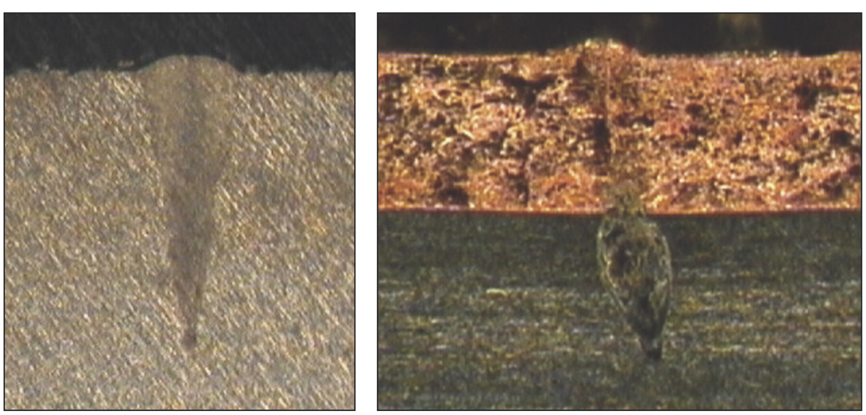
(a) (b) (c)

Cross section in 0.06" thick stainless steel of (a) Single mode fiber laser at 500 W, 300 ipm with a 30 micron spot size (b) Multi mode laser at 700 W, 100 ipm with a150 micron spot size (c) Multi mode fiber laser at 1 kW, 80 ipm with a 250 micron spot size.

MICRO WELDING – IDEAL FOR FINE SPOT WELDS AND WELDING OF COPPER

The fiber laser can be routinely focused to 0.001-inch spot size, so it can be used to produce sub 0.004-inch weld widths for very fine spot welds or high speed lap geometry seam welds. Typically the laser power for these types of applications is around 200-500 W, according to penetration and welding speed. With a high degree of control over the pulse width, the weld aspect ratio (weld width/weld depth) can be tailored according to the application. Two examples of spot and seam welding are shown in **Figure 3**.

Figure 3 – Spot and seam welding



(a) (b)

Cross section of (a) 100 micron wide spot weld in steel (b) High power density is able to overcome reflectivity in seam welding 0.015-inch thick copper to steel at 600 IPM. To prevent issues with back reflection, the head is angled, which produces the angled weld.

As well as being able to lap weld thin steels at very high speeds up to 50-100 inches per second range, the high power density that results from high beam quality enables the fiber laser to weld copper, which has traditionally posed a challenge to lasers because of the high surface reflectivity and reflectivity variation of copper to 1064 and 1070 nm wavelengths. This meant that laser welding was unstable and unrealistic for production. The fiber laser's high brightness overcomes this limitation, because the high power density enables consistent absorption of the laser power. In addition, the relatively high welding speed that can be used avoids overheating the weld and so stabilizes the process. The welding of copper in the sub kilowatt range can only be effectively achieved using a single mode laser.

CONDUCTION WELDING – STABLE AND LESS SENSITIVE TO PART FIT-UP VARIANCE.

In addition to keyhole welding, the fiber laser offers a number of applications for high speed conduction welding, which occurs at much lower power densities and therefore larger optical spot sizes. Conduction welding is extremely stable, because it has no keyhole and no welding plume. In addition, the larger spot size tends to be less sensitive to part fit-up variance. This method can be very effective for barrier sealing that requires a penetration of 0.01-inch. The resulting weld has a very smooth, highly aesthetic appearance. **Figure 4** shows a step down circumferential weld in a pressure sensor.

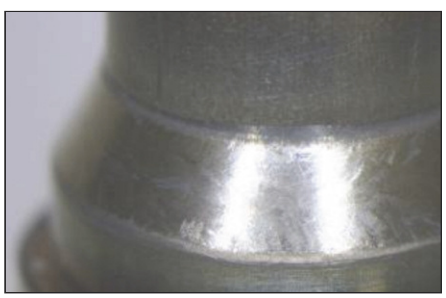
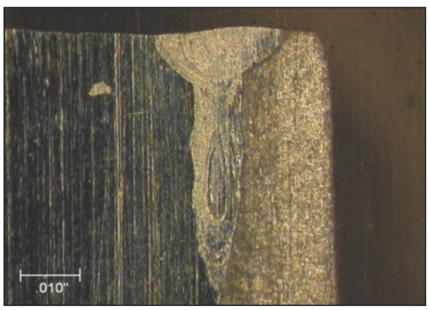


Figure 4 – Conduction welding

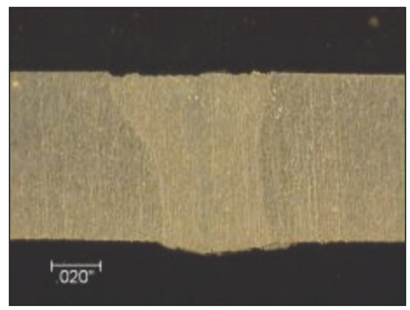
PENETRATION WELDING – FIBER LASER OFFERS MOST DEPTH PER WATT OF LASER POWER

Penetration welding generally refers to welding depths beyond 0.04-inch and in most cases up to 0.25-inch thickness. The beam quality of fiber laser sources offers the most penetration depth per watt of laser power of any laser, with even a 500 W laser capable of welding up to 0.08-inch thick. This welding performance is achieved by using a relatively small spot size, around 0.003-inch. To take advantage of this, the joint geometry must be either a lap weld or a butt weld with very high control of fit-up tolerances. In most cases this is not practical for manufacturing, and so typical laser powers range from 1-6 kW for most penetration welding applications.

Figure 5 – Examples of weld cross sections with a 1 kW fiber laser



Steel edge butt weld at 120 IPM



Aluminum bead on plate 0.06" thick at 60 IPM

Even if the particular process cannot take advantage of the fiber laser's welding performance due to part fit and joint configuration, the fiber laser offers other benefits that result in increased process stability and implementation flexibility. The 1 micron wavelength of the fiber laser has much less effect from the weld plume compared to a CO_2 laser, and so the gas shielding used to suppress the welding plume requires a minimal flow rate with a low sensitivity to positioning relative to the weld.

FIBER LASER – FLEXIBLE AND EFFICIENT

The fiber laser's high beam quality and the single and multi mode options enable efficient welding of many materials and applications. The flexibility of implementation along with the low cost of ownership contributes to the technology's appeal.

AMADA MIYACHI AMERICA, INC.
1820 S. Myrtle Ave. • Monrovia, CA 91016 US
T: (626) 303-5676 • F: (626) 358-8048
info@amadamiyachi.com • www.amadamiyachi.com
ISO 9001 Certified Company • 24/7 Repair Service: 1-866-751-7378

MIYACHI UNITEK | MIYACHI PECO | MIYACHI EAPRO

AMERICAS
Amada Miyachi America Midwest
Wixom, MI 48393
T: (248) 313-3078
midwestsales@amadamiyachi.com

Amada Miyachi America Mexico
El Paso, TX 79925
T: (915) 881-8765
mxsales@amadamiyachi.com

Amada Miyachi do Brasil Ltda.
Sao Paulo, Brasil
T: +55-11-4193-3607
antonio.ruiz@amadamiyachi.com

EUROPE
Amada Miyachi Europe GmbH
Puchheim, Germany
T: +49 (0) 89 83 94 030
infode@amadamiyachi.eu

ASIA
Amada Miyachi Co., Ltd.
Noda, 278-0016 Japan
T: +81-4-7125-6177
sales@miyachi.com

Amada Miyachi Shanghai, Co., Ltd.
Shanghai, China
T: +86-21-6448-6000
zqzhang@msc.miyachi.com

Amada Miyachi Korea Co., Ltd.
Gyeonggi-do, Korea
T: +82-31-8015-6810
dykim@mkc.miyachi.com

Amada Miyachi Taiwan Co., Ltd.
Taipei, Taiwan R.O.C.
T: 886-2-2397-4778
keigaku@miyachi.com

Amada Miyachi (Thailand) Co., Ltd.
Samutprakarn, Thailand
T: +66-2751-9337-8
info@mtl.miyachi.com

Amada Miyachi Vietnam Co., Ltd.
Ho Chi Minh City, Vietnam
T: +84-8-3771-7972

Amada Miyachi India Pvt., Ltd.
Bangalore, Karnataka
T: 080-4092-1749 & 3549
info@miyachiindia.com

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