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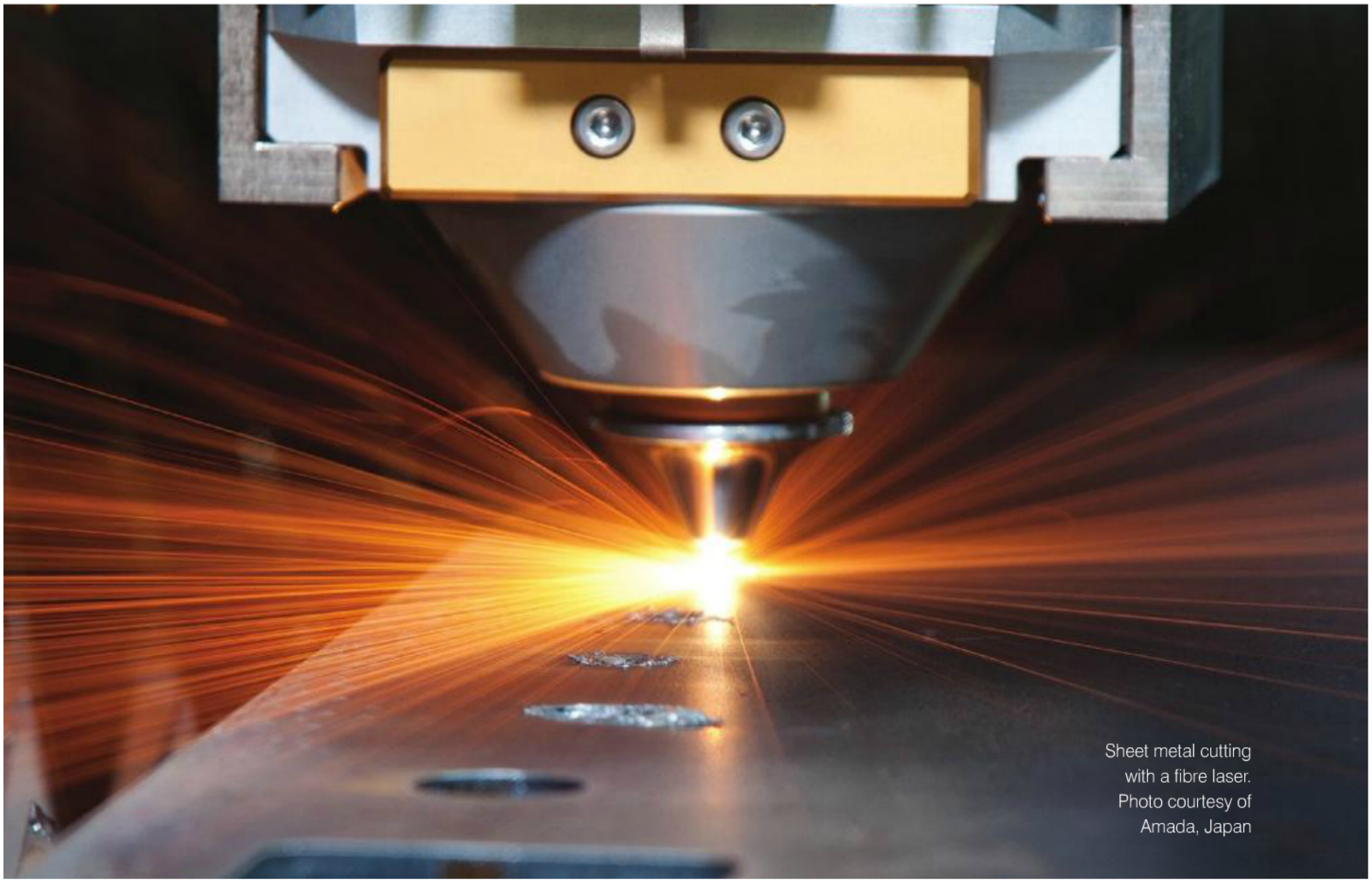

Sheet metal cutting with a fibre laser. Photo courtesy of Amada, Japan

Pumping up high-performance **fibre lasers**

Breakthroughs in laser diode and fibre-coupling technologies are enabling low-cost, high-reliability sources with remarkable sheet metal cutting capabilities

BY ERIK ZUCKER FROM JDSU

CHANGE IS AFOOT in the sector of the laser market covering high-power sources for metal processing. This 'macro' material market has traditionally been dominated by CO_2 lasers, but lasers based on the optical pumping of a doped fibre are now winning significant market share, thanks to their combination of low cost of ownership and excellent cut quality on a wide variety of metals. According to Industrial Laser Solutions, which has been working with analyst Strategies Unlimited, the macro fibre laser market is growing at 24 percent per year, and should hit $536 million in 2014. In comparison, sales of CO_2 lasers in this sector are falling by 7 percent per year, and will be worth $647 million this year.

If the current trend in the macro fibre laser market continues it will not be long before the dominant source is a semiconductor-pumped fibre laser – a laser in which GaAs-based laser diodes are used to pump ten metres or more of fibre, which has a Bragg grating at either end to form a resonant,

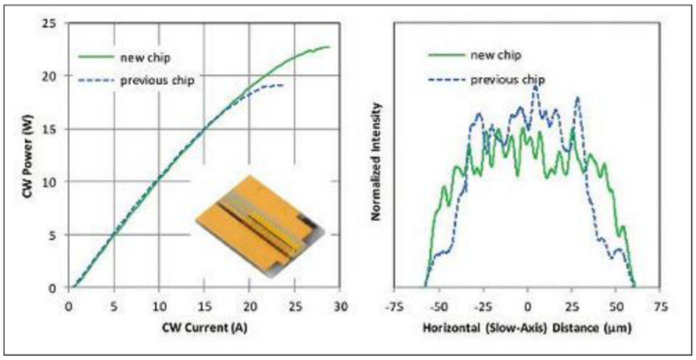

Figure 1. Left side: CW power versus drive-current at 25 °C for the latest laser diode and its predecessor. Both chips have 4.1 mm cavity length. Right side: near-field images of the intensity at the front facet at 12 W, 25°C. The new chip has better uniformity and lower peaks, which should lead to better facet reliability.

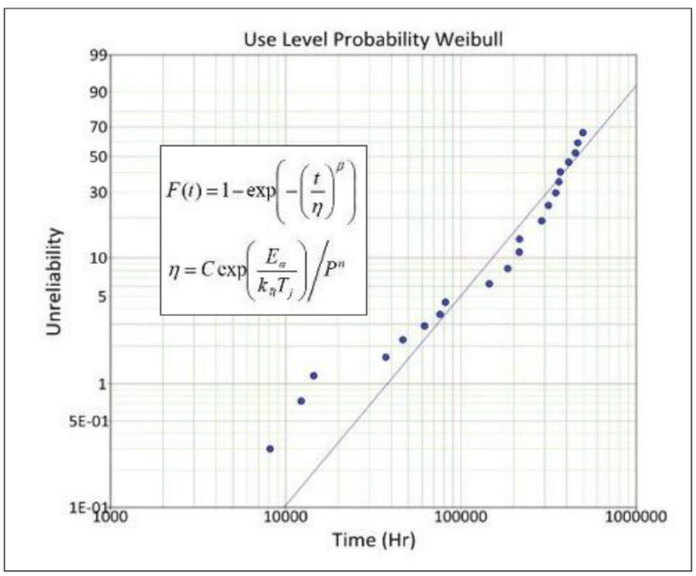

Figure 2. Reliability analysis employed the maximum likelihood method to fit a Weibull model with acceleration factors based on diode junction temperature and optical power. Activation energy, E_a, was fixed to 0.45 eV as in prior models, and laser diode junction temperature, T_j, is calculated from thermal resistance and dissipated power. The extracted shape parameter β is 1.7, and the power acceleration factor n is 6.5. The resulting scale parameter at 12 W, 25 °C is η = 570,000 hours, and cumulative failures from the model at 20,000 hours is 0.3 percent. Three early failures fell outside of the model and were removed. These can be treated as infants and eliminated with a longer burn-in.

high-power, laser cavity. In this form of laser system, gain is generated in the fibre by active ions, such as ytterbium or erbium, that are doped into the fibre core. The light that is coupled into this fibre from the GaAs diodes pump the active ions, generating light at a longer wavelength, which is guided within the fibre waveguide. The longer-wavelength light resonates between the two gratings, while being amplified with every pass through the cavity. Making one of the gratings partially transparent allows some light to pass through and impinge upon any material that needs to be processed.

Constructing a fibre laser in this manner allows the production of high-power fibre lasers with a single resonator that can deliver an output of over 2 kW. That may not sound like much, since it is only equivalent to the power drawn by a hand-held hair dryer. But the key difference is that the output from the fibre laser can be focused to a spot the size of a few diameters of human hair – several hundred microns.

At such a high power density, the laser light can rapidly cut through mild and stainless steels, aluminium, brass, and copper, as well as weld, mark, or braze a wide variety of materials. It is possible to cut mild steel up to 25 mm-thick with a 2 kW fibre laser, while a cousin with double that power can cut 1 mm-thick aluminium at 75 m per minute.

The most costly component within the fibre laser is the set of fibre-coupled pumps, which can account for more than half of the bill of materials. This makes the macro fibre laser market a considerably significant one for manufacturers of high-power GaAs-based lasers, which can pump at wavelengths of 910 nm to 980 nm to enable lasing further in the infrared – doping a fibre with ytterbium, for example, leads to lasing around 1060-1080 nm.

To succeed in this market, laser diode manufacturers have to focus on supplying adequate pump brightness – that is, the power divided by the optical aperture in physical and angular space – at the lowest dollars-per-watt. There are also other criteria to consider: the laser must be reliable, because how long it lasts governs the lifetime of the system; and the packaging of the laser and the coupling into the fibre must preserve the hard-fought-for brightness from the chip, while ensuring that the product is competitively priced.

Serving the market

At JDSU of Milpitas, CA, we are meeting all of these requirements with our latest generation of GaAs-based, high-power lasers. Fabrication begins by using MOCVD growth technology to form epitaxial structures on 3-inch GaAs substrates. Processing creates broad-area multi-mode chips featuring separate confinement InGaAs/AlGaAs quantum wells, a lateral output aperture of 100 μm and a 4.1 mm cavity length. By varying the composition of indium in the well, the lasing wavelength can be tuned from 910 nm to 980 nm.

The length of the chip cavity is identical to that of its forerunner, but the near-field and far-field emission patterns have been improved through optimization of the lateral index-guiding step, lateral gain profile, and transverse (epitaxial direction) mode design. These refinements result in a more uniform near-field pattern with fewer high-intensity spikes – this means better long-term facet reliability.

For burn-in and test, the chip is bonded to an expansion-matched ceramic submount with AuSn solder and clamped to a copper carrier. Comparison at the chip-on-submount level shows that this latest chip has less thermal rollover than its predecessor, and can deliver a CW output in excess of 20 W at 25 °C (see Figure 1). Peak power conversion efficiency is greater than 60 percent.

We have carried out extensive reliability testing of our latest chip design. Only 10 percent of the tested population failed across seven highly-accelerated life test cell conditions, making it challenging to employ a reliability model. However, we have performed reliability analysis with a Weibull model, which uses acceleration factors based on diode junction temperature and optical power (see Figure 2). This study suggests that if our lasers were operated continuously for ten years, the expected failure rate would be below 4 percent.

Multiple emitters

To increase the output power of a source, laser chips can be combined to form a multi-emitter package (see Figure 3). We have done this, stacking chips in the vertical direction with a staircase-like layout, in two rows, polarization combined, and focusing their output into the fibre.

The result is a source that can deliver a continuous-wave output of 140 W from a 106 μm/0.22 NA fibre – and 95 percent of this power is contained within 0.15 NA. Note that power conversion efficiency, the portion of terminal electrical power that is converted to useful light, is almost 50 percent at 140 W.

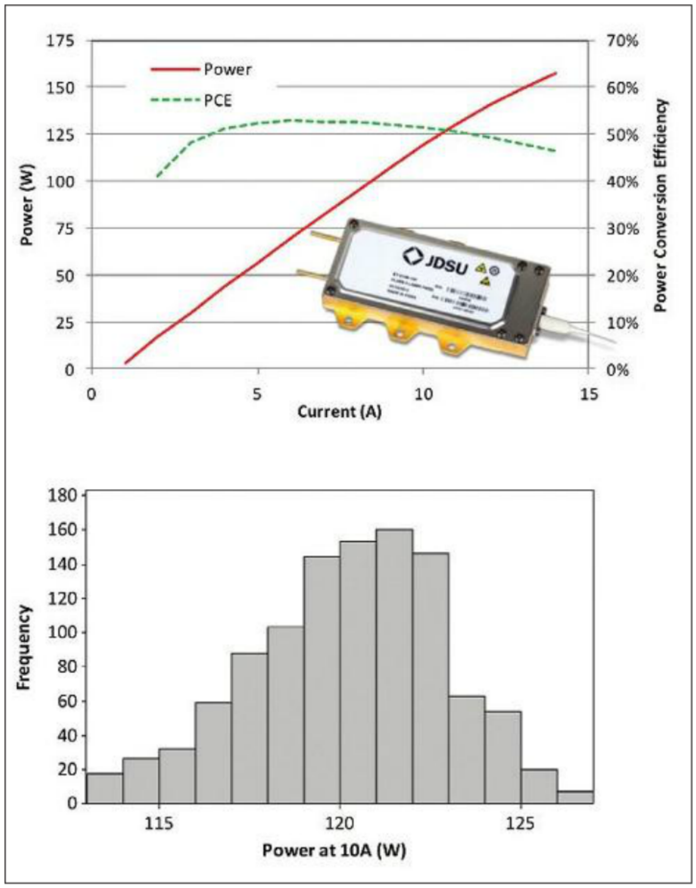

Figure 3. (a) Optical power versus drive current at 35 °C case temperature for the multi-emitter, fibre-coupled package. The laser is rated at 140 W and achieves nearly 50 percent power conversion efficiency at the rated power. (b) Optical power reading at 10 A from 1,000 units assembled. Typical optical power is about 120 W

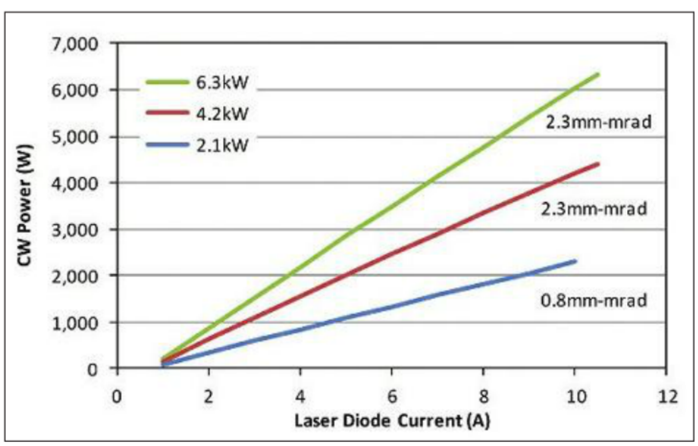

Figure 4. Fibre laser power versus pump diode current for 1-, 2-, and 3-module combined engines

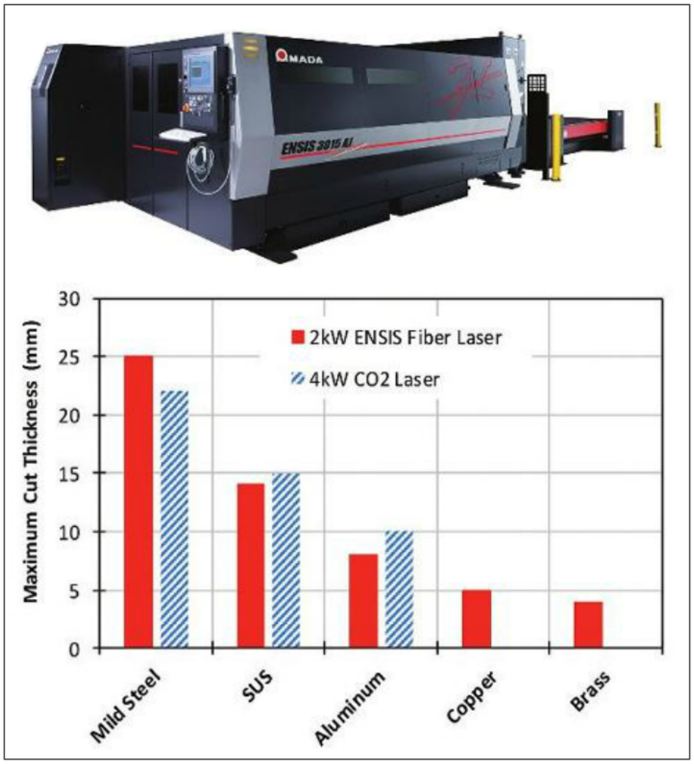

Figure 5. Maximum cut thicknesses for a variety of materials for the Amada fibre laser cutting system, ENSIS 3015 AJ, with integrated 2 kW fibre laser compared to a 4 kW CO_2 laser. Image coutersy of Amada

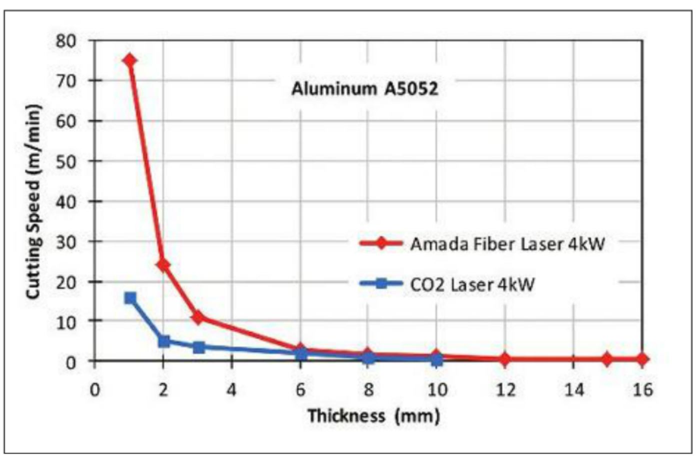

Figure 6. Cutting speed comparison for aluminium between the 4 kW Amada fibre laser and a 4kW CO_2 laser

Historically, this platform has shown excellent process stability in ongoing production. Differences in ex-facet chip power/efficiency, polarization-combination and optical coupling efficiency can lead to variations in power output, but these are very small as monitored at a driving current of 10 A and a typical output power of 120 W.

We have partnered with Amada, Japan, integrating the high-brightness, multi-emitter pump described above into a more powerful fibre laser. Pump output fibres are fusion combined and spliced to end-pump a 2.1 kW fibre laser module with dimensions of 433 mm x 153 mm x 650 mm. This source has a typical electrical-to-optical efficiency of 35 percent, rise and fall times of 16 µs, and a beam parameter product (BPP) from the feeding fibre of 0.8 mm-mrad.

This 2.1 kW module may be used as a standalone source or combined with additional modules for higher power. Using a 3:1 signal combiner can create 4.2 kW or 6.3 kW fibre laser engines with a BPP of 2.3 mm-mrad (see Figure 4 for plots of fibre laser power versus laser diode pump current for one, two, and three module fibre laser engines).

Superior cutting

Amada has developed a cutting system, ENSIS 3015 AJ, that incorporates the 2 kW module (see Figure 5). It delivers an exceptional cutting performance that is comparable to that of a 4 kW CO_2 laser. To our knowledge, this is the first 2 kW fibre laser with a maximum cut thicknesses of 25 mm for mild steel and 14 mm for stainless steel.

Using this class of laser, it is possible to cut a variety of metals at high speeds (see Figure 6). A 2 kW source can cut 1 mm-thick aluminium at up to 40 m per minute, while a 4 kW version can hit 75 m per minute.

Due to such exceptional cutting performance, the adoption of fibre lasers as a superior alternative to conventional CO_2 lasers is well underway. To accelerate this trend, manufacturers are focused on further reducing total cost of ownership of these systems – through lower initial selling price, faster cutting speed, higher cut quality, and higher efficiency.

One way that we will meet these needs is through continuous reduction of pump dollar-per-watt cost, and higher brightness and power per pump package. This will be enabled by yet higher powered and more reliable laser diode chips.