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IN THIS ISSUE:

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Full programme inside

GAME-CHANGING BLUE LASER SOURCES:
SHORTER WAVELENGTHS & IMPROVED APPLICATIONS

HAPPY TO HAVE THE BLUES

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In 2017, NUBURU® introduced the first industrial blue laser to the market which demonstrated the inherent physical advantages of blue wavelengths for materials processing applications. Copper, for example, absorbs more than ten times more energy from blue than from infrared wavelengths, which leads directly to qualitative and quantitative advantages for tasks such as copper welding. Extending the product line, a higher power blue laser at 450 nm opened up an entirely new range of applications for battery fabrication, e-mobility, electronics packaging, and automotive component manufacturing.

Traditional industrial lasers

Traditional industrial lasers emit infrared wavelengths, at ~10.6 µm or ~1 µm. These lasers offer significant materials processing advantages over alternative fabrication tools. Lasers deliver their energy remotely, without the need for physical contact with a tool. This allows for flexible etching, cutting, and joining of many materials. A 12 mm-wide ultrasonic welding head, for example, cannot join two materials with a radius of curvature of 5 mm. Lasers do not have that limitation, nor are they subject to tool wear. Those advantages have led industry to adopt laser systems at a fast rate.

But “yellow metals” — prominently including copper and aluminium — absorb infrared wavelengths very poorly. Copper, for example, absorbs less than 5% at these wavelengths. This is, of course, very inefficient, but it also leads to other specific processing problems.

Consider welding, for example. The poor absorption means a lot of excess energy must be delivered to initiate welding — and it is also delivered to the melt pool. The melt pool, however, absorbs a much higher percentage of the incident radiation. The excess energy pushes the metal into the vaporisation state, with bubbles in the melt pool, leaving voids and “spattering” material from the joint. Various complex irradiation patterns (i.e. wobbling), can minimise — although not eliminate — spatter and voids, but they add to the process time and processing equipment cost. Infrared laser welding of copper, or other similar metals, is inherently limited to a very narrow process window, or in some cases not possible at all.

The physics and engineering of Blue

Blue wavelengths are absorbed more then ten times more efficiently. In addition, the energy required to maintain a weld is essentially the same as the energy required to initiate a weld. This consistency allows for a high degree of process control, and it directly leads to rapid, high-quality copper welds — completely free of voids and spatter.

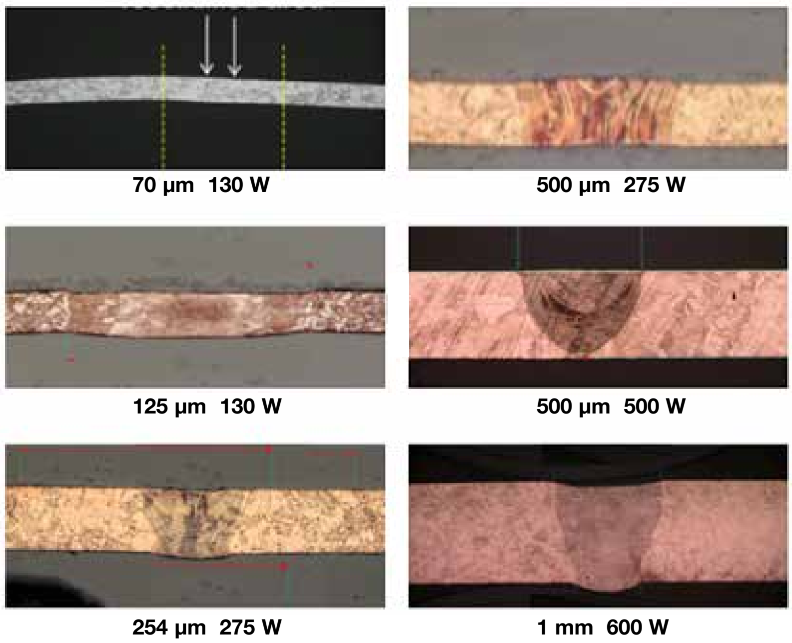

Figure 1: Blue laser welding has a wide process window — laser parameters can be set and maintained to produce high-quality welding for a wide range of copper thicknesses.

The physical advantages of blue wavelengths are no secret, but engineering a high-power blue laser has been a technical challenge. NUBURU’s AO-150 was the first commercially available high-power, direct-emission blue laser, and the AO-500 follows the same design path. The AO® series is built on a straightforward modular design, combining the output of dozens of individual gallium nitride (GaN) diode lasers into a single beam and into a 200 µm-core optical fibre. In the AO-500, micro- and macro-optics combine the individual diode beams into a 400 µm-core optical fibre. The output of the fibre is a highly symmetric 500 W beam of 450 nm light.

Because 500 W is transmitted through a 400 µm fibre, the brightness is high. This is particularly important for materials processing applications, where the effectiveness of a process is determined by the energy density delivered to a workpiece. Even in situations where the output beam is conditioned with relay optics, the optical efficiency is limited by the initial beam parameter product: higher brightness means more effective energy delivery.

The wide process window and laser stability combine to make blue laser welding a highly deterministic process. In practice, that means the blue laser can produce void-free and spatter-free welds in all three different welding modes: conduction, transition, and keyhole modes.

Results

The theoretical advantages of higher absorption are clear, but how does that translate to real-world conditions?

Results from laboratory tests show spatter- and void-free welds for copper thicknesses from 70 µm to 1 mm. These results, shown in Figure 1, illustrate the process control possible with stable laser output powers from 130 to 600 W. As earlier mentioned, this performance is built on the foundation of fundamental physics: blue laser energy can produce a stable melt pool, well under the vaporisation threshold. High quality joining can be seen in the lap and butt welds shown in Figure 2. These images demonstrate the performance of a 500 W blue laser lap welding two 125 µm copper sheets at a rate of 3.3 m/min, lap welding two 200 µm sheets at 5.4 m/min, and butt welding two 200 µm sheets at 8.1 m/min. Again, there are no voids and no spatter.

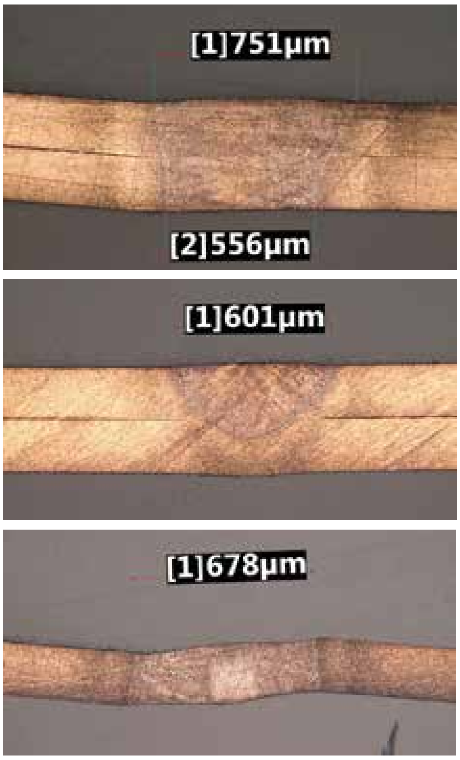

Figure 2: Lap and butt welds illustrate the joint quality routinely achieved with a 500 W blue laser.

The quantitative advantages of blue laser welding have also been demonstrated with traditional industry metrics. Even a pre-production version of the AO-500 achieved full penetration depth of 300 µm in copper bead-on-plate (BOP) tests at a speed of 4 meters per minute. That same laser system has demonstrated a penetration depth of greater than 150 µm at 12 m/min for both lap welding and butt welding. In BOP tests of 1 mm-thick copper the laser achieved full penetration at a speed of greater than 1 m/min. Again, these results are for welds that demonstrate no spatter and no voids — unprecedented performance for laser welding.

Although copper is a particularly challenging material for conventional industrial lasers, stainless steel and aluminum also present problems. Aluminum also does not absorb much energy at infrared wavelengths — absorbing more than 3 times more energy in the blue. Although the differences are not quite as dramatic as with copper, the fundamental physics leads to the same qualitative and quantitative advantages with blue laser welding. Laboratory tests with 500 W of blue light in a 400 µm spot, for example, have demonstrated lap welding of stainless steel to a penetration depth of 600 µm at a speed greater than 4 m/min. That same laser has demonstrated aluminum butt welding with a penetration depth of 200 µm at a speed of 10 m/min.

Welding of dissimilar metals is another recalcitrant problem that can be solved with blue laser welding. The different thermomechanical characteristics of aluminum and copper, for example, can lead to the formation of intermetallics — regions with inconsistent ratios of the two metals, leading to poor mechanical and electrical joint characteristics. Because these metals both absorb a high percentage of incident blue light, the welding process is deterministic. As shown in Figure 3, 300 W of blue laser light produces a lap weld of stainless steel on copper that minimises the formation of intermetallics and other defects common with dissimilar metal welds.

Applications for today and tomorrow

The AO® series of blue industrial lasers brings the flexibility of laser materials processing to an entirely new range of materials. Copper and aluminum are of growing importance in our increasingly electronic world. The ability to laser weld copper-copper and copper-aluminum joints offers the opportunity to significantly enhance the speed and quality of existing joining methods.

Consider the fabrication of lithium-ion batteries. Lithium-ion batteries consist of many separate foils. Chemistry at the surfaces creates the electrical potential, so the greater the surface area, the more battery capacity. But the individual foils must be joined together. Ultrasonic welding could be used, but physical contact of the ultrasonic welding tool generates unwelcome particles, limits the minimum thickness of the individual foils, and also requires frequent tuning. The blue laser can weld foils as thin as 6 µm, with no spatter. The AO-500 has also already demonstrated impressive reliability. All those advantages add up to a higher quality, more reliable process that produces batteries with higher energy density. That same kind of advantage extends to consumer electronics. The flexibility, speed, and quality of blue laser welding can, for example, bring new levels of automation to cell phone and computer assembly.

Laser processing has long been adopted in automotive manufacturing, where its versatile

Figure 3: Lap weld of 200 µm-thick copper and stainless steel. This dissimilar materials weld illustrates reduced formation of intermetallics and minimal to no spatter and defects.

Figure 4: This hairpin weld of two 1.5 mm x 2 mm copper wires demonstrates the quality and compact size possible with blue laser welding.

energy delivery options make it well-suited to automation. But autos themselves are becoming increasingly electronic, with extensive sensors and actuators, and electric or hybrid vehicles, of course, require batteries and motors. Reducing the size and weight of those components is critical for vehicle performance. As discussed above, no other joining method offers the combination of speed, quality, and form factor of blue laser welding. For example, Figure 4 shows the cross section of a hairpin assembly for an electrical motor. Replacing traditional coils with hairpin assemblies can reduce size and weight and improve performance in electric motors, but protruding ends of the copper wirdings need to be joined. The blue laser produces void-free, compact, thermally-focused and rapid joints — something not possible with other joining methods.

Automotive vehicles are not the only application where the size, weight, and performance of electrical assemblies must be optimised. One can easily see how the advantages of blue laser materials processing could be useful in autonomous vehicle assemblies, renewable energy generators, factory automation machines, and other applications. The power of blue has already been demonstrated, and it is likely to be found in a growing number of applications.

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SEE OBSERVATIONS P32