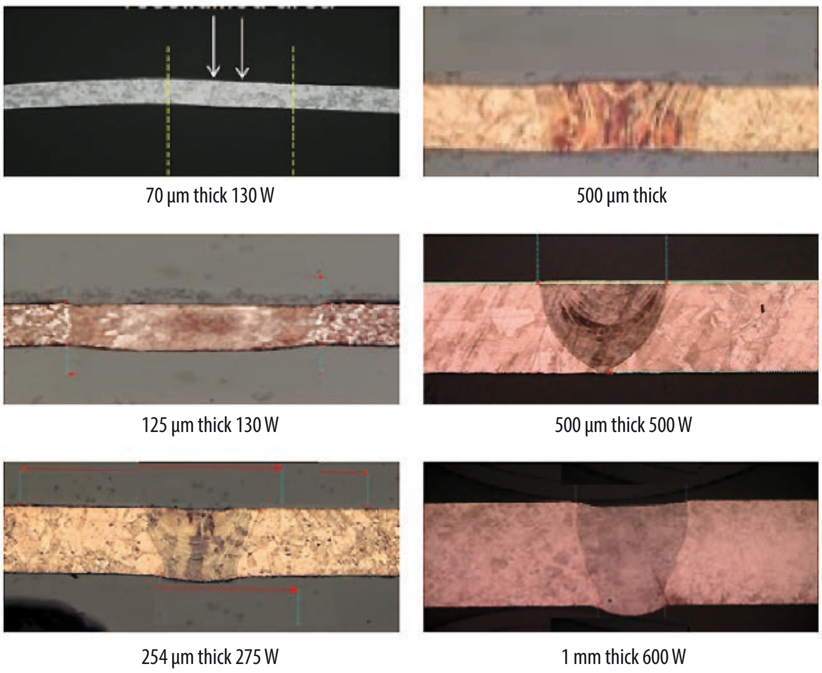
Seeing Things in a New Light

High power blue lasers for metal processing

Jean-Michel Pelaprat, Matthew Finuf, Robert Fritz, and Mark Zediker

Nuburu has introduced a new high-power blue laser that brings unmatched performance to many materials processing applications. Lasers are capable of delivering high energy density with pinpoint precision. The energy can be delivered without physical contact between the components of the laser and any material to be worked. These characteristics suit lasers for many materials processing applications – perhaps none more well-suited than laser welding. Common industrial lasers are high-power infrared (IR) systems operating at wavelengths around 10.6 µm or around 1 µm, or low- to moderate-power green light systems operating at a wavelength around 532 nm. The capabilities of these systems are constrained by either the physics of the interaction (in the case of infrared lasers) or the cost and technological capability of the laser (in the case of green lasers). Nuburu's AO-150 laser puts out a 150-watt high-quality beam of 450 nm laser light that brings game-changing capabilities to laser welding and other industrial applications.



(Source all images: Nuburu)

Fig. 1 The wide process window for blue laser welding means that the laser parameters can be set for high-quality welding for a wide range of copper thicknesses.

Welding is a conceptually simple operation. Energy is delivered to a specific location in a material, the energy is absorbed and melts the material. When the energy is removed, the melted material fuses. If the energy has been applied to overlapping or neighboring pieces, then the pieces are connected in a weld joint. Although seemingly simple, the quality and speed of the weld depends upon a myriad of factors. For laser welding, the primary factor is energy absorption.

Laser light can be directed almost arbitrarily to a small spot, but it does little good if most of that energy is reflected off the material. At infrared wavelengths – both the 10.6 µm of CO_2 lasers and the 1.08 µm neighborhood of fiber lasers – many materials absorb very little of the incident light. Copper, for example, reflects 95 percent of the incoming laser radiation. Of course that makes for an inherently inefficient process, but that's only the beginning of the problem.

To get the melt started in a copper workpiece, a lot of IR radiation is needed, but once the material has formed a melt pool the absorption becomes much higher. That means more energy is absorbed in the melt pool, so it's very common for the copper to vaporize, creating miniature explosions that result in the ejection of material from the melt (spatter) and the presence of holes in the fused material

Company

NUBURU

Centennial, Colorado, USA

NUBURU is leading the transformation to a world of high-speed, high quality metal machining and processing using a first-to-market class of high-power, high-performance blue lasers.
NUBURU technology breaks new ground – available as either a standard AO laser or high-brightness MISAKI laser – by enabling radical gains in speed and quality in existing metal processes, as well as also unlocking a path to new designs for both conventional laser-metal machining and additive manufacturing (3D printing). Spatter-free copper welding enables a large number of new applications not addressable with infrared lasers.

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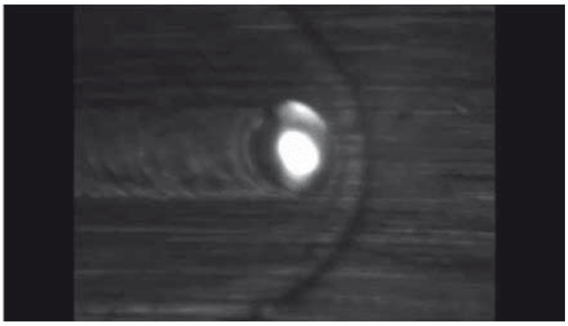


Fig. 2 Infrared welding produces an unstable melt pool in copper, with laser-induced vaporization leading to voids and spatter. In contrast, the melt pool of a blue laser is stable, far from the vaporization state, with no voids and spatter.

(voids). Spatter and voids degrade the quality of the weld, resulting in a joint with diminished mechanical strength and electrical conductivity, along with contamination outside the joint itself.

Fabricators using infrared lasers for welding copper, or other similar metals, are thus presented with a very narrow process window, or in some cases no possible window for a laser-based process. The laser must supply sufficient power to start a weld, but too much power leads to an unacceptable weld. This also limits IR lasers to only keyhole welding of copper. Various operational techniques have been developed, such as "wobbling" – moving the laser beam in some nonlinear pattern to moderate the deficiencies of the process –, but even those modes cannot eliminate voids and spatter. And those techniques also all add to the weld time.

Green light is more strongly absorbed by copper, which avoids the problem with poor absorption. Diode-pumped solid state (DPSS) lasers emitting at 532 nm are available, but they are generally low-power options suitable only for microwelding. There are few higher power DPSS lasers, and those that do exist are expensive, have a limited lifetime, and have poor wallplug efficiency. In short, cost and technology limitations keep green lasers from being a viable option for welding copper and similar materials.

Nuburu's AO-150 is a commercially available high-power, direct-emission blue laser. The straightforward modular design combines the output of dozens of individual gallium nitride (GaN) diode lasers into a single beam. A combination of micro- and macro-optics couples the light into a 200-µm core optical fiber. The output of the fiber is a highly symmetric beam of 450 nm light.

Copper absorbs blue light more than ten times better than it absorbs infrared. This physical characteristic makes blue laser welding inherently more efficient than welding in the infrared, but that's just the beginning of the story. The absorption of room temperature solid copper and absorption in the melt pool are much closer than they are in the infrared, which is another inherent physical characteristic that leads directly to a wider process window for blue laser welding.

The high room temperature absorption and smaller difference in absorption between room temperature and fusion temperature mean that welding can be done at lower power densities, never reaching the vaporization phase induced with IR welding. The laser output is highly stable, with demonstrated power stability of better than three percent per 1,000 hours. 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 conduction mode, transition mode, and keyhole mode.

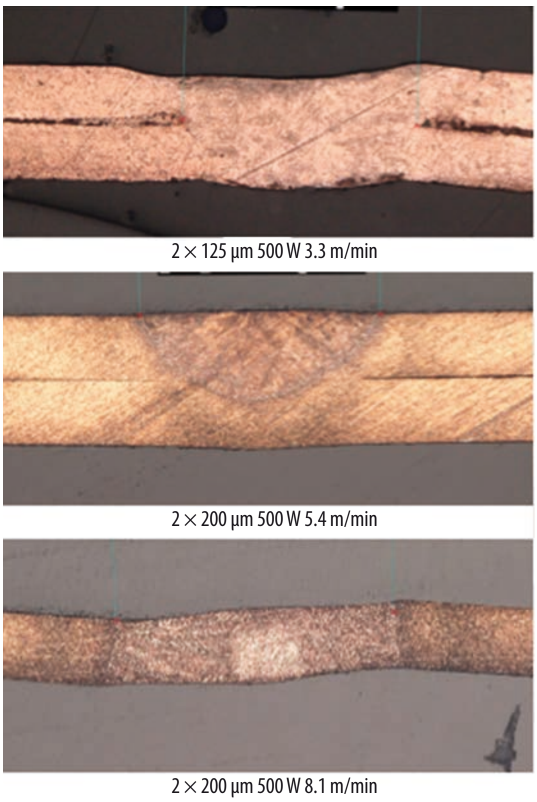


Fig. 3 High absorption in the blue is the foundation of the demonstrated unmatched performance of blue laser copper welding. These images of lap and butt welds illustrate the quality of the results with a 500-W blue laser.

Concrete demonstration of blue sky results

Clear logic motivates the desire for welding with blue lasers: There is a large overlap between the energy required to initiate a weld and the energy required to maintain it. A highly stable laser should be able to leverage the physics of absorption to produce high quality welds in a wide range of material thicknesses. As shown in Fig. 1, the blue laser lives up to those expectations. Laboratory tests demonstrate spatter- and void-free welds for copper thicknesses from 70 µm to 1 mm using laser output powers from 130 to 600 W.

Fig. 2 is a still from a video of a 600 W, 200-µm diameter blue beam welding copper in keyhole mode. In contrast to IR welding, this keyhole weld is very stable, and there is no spatter at all. The same high quality is apparent in lap and butt welding, as shown in Fig. 3. Those 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.

The quantitative advantages of blue laser welding have also been demonstrated with traditional industry metrics. Using a 500-W laboratory system, not fully optimized, copper bead-on-plate (BOP) tests show full penetration depths of about 300 µm at a speed of 4 m/min. That performance is with a 400 µm spot size. Smaller spot sizes will lead to even more impressive performance. That same laser system has demonstrated 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

Fig. 4 This lap weld of 200-µm thick copper and stainless steel was produced by a 300-W blue laser working at 5 m/min. The joint displays reduced formation of intermetallics and minimal to no spatter and defects.

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.

Copper is a particularly difficult material for infrared laser processing, but conventional welding lasers also have trouble processing stainless steel and aluminum. Stainless steel and aluminum are additional examples of materials for which the absorption at infrared wavelengths is also lower in the infrared than 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 a 500-W blue laser with 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.

Traction for intractable problems

Welding copper and similar metals is challenging, but welding dissimilar materials is an even more severe challenge. Metals of different composition have distinct melting points and mechanical properties, and unique behavior when melted. This intrinsic behavior puts limits on the required power: enough energy needs to be delivered to melt both materials but not so much as to induce vaporization in either.

Dissimilar welds are also prone to forming intermetallics – regions of variable metallic ratios. Those intermetallics can have poor mechanical strength and decreased electrical conductivity. Blue lasers mitigate the problem. For many common metal combinations, such as copper and aluminum, the high absorption at blue wavelengths and the deterministic behavior of the welding process maximize the quality of dissimilar metal welding. As shown in Fig. 4, lap welding of stainless steel on copper with a 300-W blue laser minimizes the formation of intermetallics and other defects common with dissimilar metal welds.

Blue laser welding produces just as remarkable results for more delicate jobs, such as joining the thin metal foils that comprise lithium-ion battery cells – a job simply not possible with IR lasers. For example, as shown in Fig. 5, the AO-500 has demonstrated welding of thirty 10-µm thick copper foils at a rate of better than 3.5 m/min. As in all the other cases, the welds are void- and spatter-free.

Ready to sail into the blue

The availability of convenient and powerful blue light sources has revolutionized many fields, from lighting to chemical analysis. Nuburu engineers have leveraged the advances in GaN laser diodes, creating a modular design that efficiently couples light into a flexible optical fiber. The intrinsic advantages from higher absorption, combined with the precision engineering of the AO series, has led to unprecedented performance in many materials processing applications. Welding is the first application to benefit from the availability of high-power blue industrial lasers, but the same advantages are present in other applications. Blue lasers are now poised to revolutionize a wide range of materials processing operations.

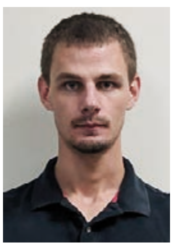
Fig. 5 Because blue laser welding is deterministic and stable, even very thin copper foils can be joined at high speed and with no defects.

Authors

Jean-Michel Pelaprat is a co-founder of Nuburu. He previously worked as CEO for Novalux Inc. and Vytran LLC, and as vice president and general manager for Coherent Inc. He also co-founded Force A, Figulus, and A2E Partnership Inc. He holds a physics degree from Montpellier University in France and has extensive international management experience as a CEO, senior executives, and founder. Jean-Michel has also held board positions at both small private and large public companies.

Matt Finuf has been with Nuburu since 2015. Where he has spent time overseeing the mechanical design and currently the application development group. Mathew works closely with partners and clients to develop applications as well as strategic long-term relationships. Prior to Nuburu Mathew was a project engineer in the renewable energy market sector. He has graduated from the University of Missouri – Columbia in 2007 with a BSc degree in mechanical engineering.

Mark Zediker is a co-founder of Nuburu and has over thirty years experience as an entrepreneur. He has co-founded two other laser companies, Nuvonyx Inc. and Foro Energy Inc., and has successfully sold one of his companies to Coherent. Mark graduated from the University of Illinois with a PhD in nuclear and plasma engineering in 1984, he received his MSc in 1983, and his BSc in engineering physics in 1978.



Robert Fritz has been with Nuburu since 2016 and works as an applications engineer. He works closely with the application manager and prospective customers to understand their applications and demonstrate the possibilities with the blue laser. He graduated from the University of Central Missouri in December of 2016 with a BSc degree in engineering technology.