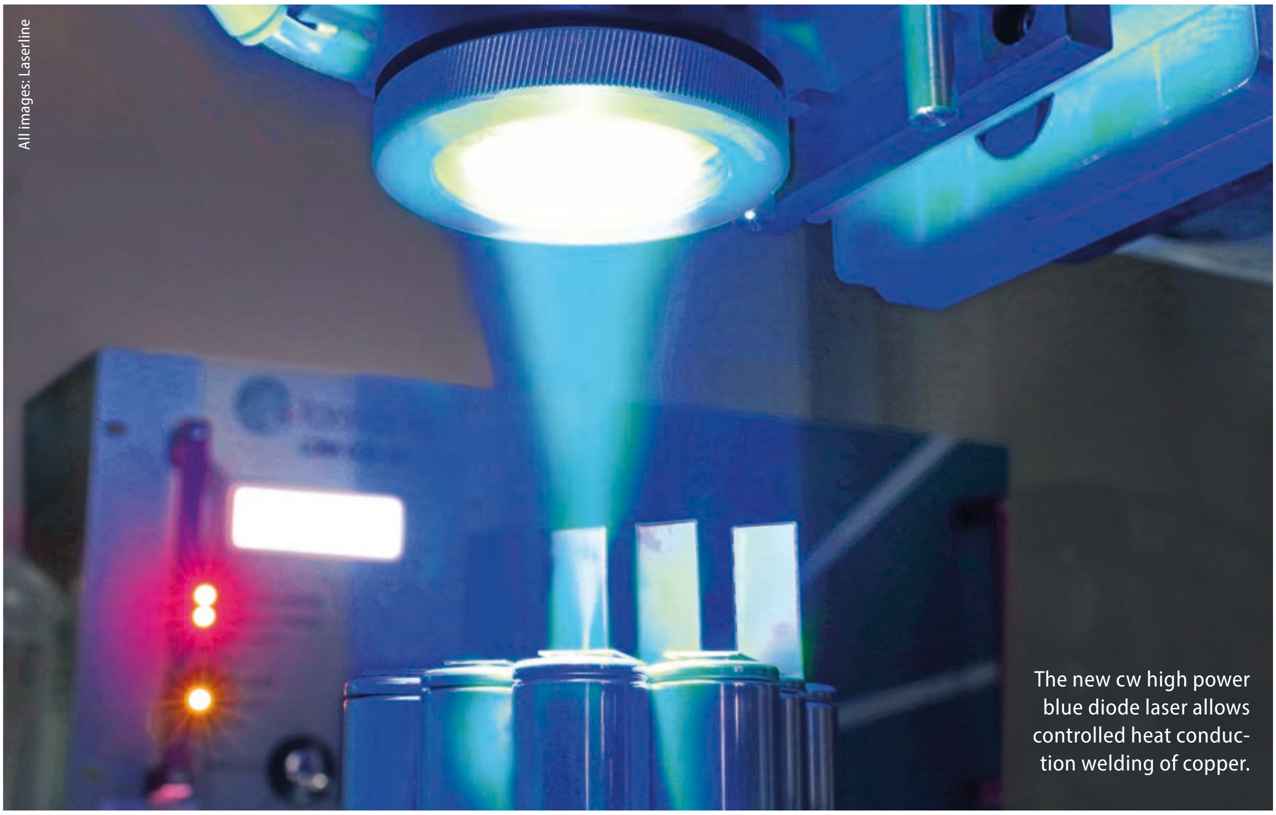

The new cw high power blue diode laser allows controlled heat conduction welding of copper.

Industrial Blue Diode Laser in the kw-class

New cw high power blue diode laser allows controlled heat conduction welding of copper.

Simon Britten and Volker Krause

Up to now, infrared lasers have been largely established for welding of copper, due to the unavailability of alternative continuous-wave laser sources with a lower wavelength. Despite the low absorption of 1 µm light on copper, conventional melting by evaporation is possible when using high laser intensities. But with thin components, only deep penetration welding can be achieved. Laserline's 450 nm diode laser enables process-reliable heat conduction welding with beyond 1 kW of laser power. The new laser system provides an unprecedented process stability and new application possibilities.

The processing of copper gained importance significantly in recent years due to its application as electrical conductor material, especially due to the increasing demand for electric vehicles. In this application, copper material in various forms from thin foils to thick connectors is used in the production of battery cells, electric engines, and power electronic switches. The inclusion of copper into the systems is accompanied by the requirement of a thermally stable joint which must withstand the high electrical current that occurs during the product life time. This is usually achieved by welding. However, most welding processes carry the risk of excessive thermal impact or particle contamination which would lead, e.g., to a degradation of batteries lifetime or to short-circuits in power modules.

Due to the precise control of the energy output by laser beam sources, laser welding has established itself for these applications. However, industry-typical high-performance lasers are only suitable for copper welding to a limited extent.

Today, most industrial lasers operate in the near-infrared range (NIR) at a wavelength of around 1 µm. This poses a challenge for the reliable melting of copper: The low absorption at 1 µm and the influence of the copper surface state on the absorption of laser energy affect the process stability. In this wavelength range, the absorption of copper is usually 2 – 5 % which can, however, increase up to 10 – 20 % for highly oxidized or scratched surfaces. In order to achieve melting despite the generally low absorption, high laser intensities are used nowadays. In this approach, the copper evaporates immediately. This creates a vapor capillary that increases the absorption by multiple reflections inside the capillary. Up to 6 kW laser power are common with beam parameter products from 2 – 8 mm · mrad. This approach has become established in the industry. However, the required

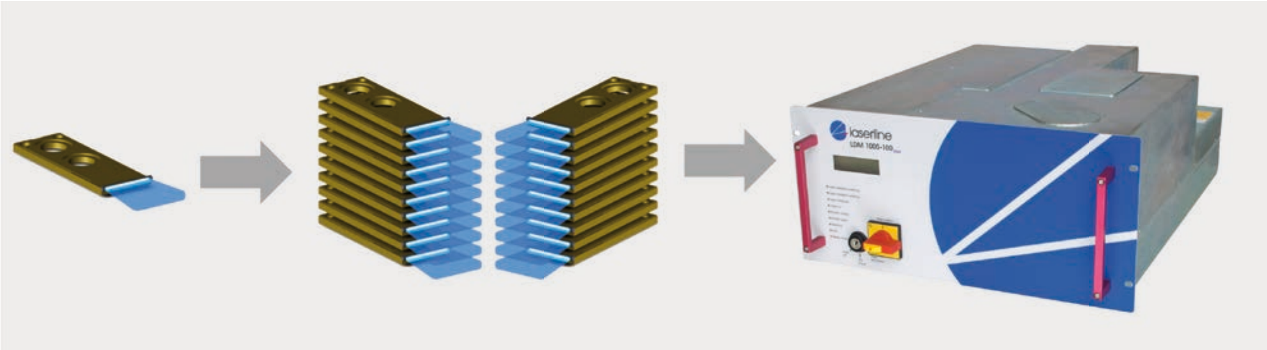

Fig. 1 Diode bars scale up the power for the high power blue diode laser.

vapor capillary is associated with a high vapor pressure, which implies a risk of spatters and pores. Today, countermeasures such as beam oscillations are used but for thin copper components this approach is at its limit. With the application of highly focused, high-intensity NIR irradiation, the vapor capillary either leads to a cutting of thin components instead of a welding process or to an instable welding process, in which the vapor capillary is not fully formed.

Heat conduction welding without a vapor capillary – as it is applied with great success in laser welding of steel parts – would be ideal. With copper, however, this process cannot be implemented with NIR lasers – a low energy input without vapor capillary is practically mirror-like reflected by the copper at 1 µm wavelength.

Direct emission of blue light

For some time many users have therefore been hoping for the development of a solution that also makes controlled heat conduction welding possible for copper with reduced welding depths and moderate energy input. Consequently, laser manufacturers have increasingly been looking for alternative approaches using different wavelength spectra.

A laser wavelength below 500 nm strongly increases the absorption towards fifty percent. This wavelength range was conventionally unavailable for high-power continuous-wave lasers, or only available by frequency doubling of the 1 µm wavelength. However, when converting the infrared to the green spectrum, only a fraction of the pumped laser wavelength is converted into the target wavelength. So this process leads to high power losses, complex cooling requirements, and a sophisticated optical set-up.

Power scaling

For copper welding, Laserline has developed the LDMblue, a high-power diode laser with direct generation of blue light by a laser diode (**Fig. 1**). The laser operates at a wavelength of 450 nm and is the first industrial laser to reach over 1000 W laser power in the continuous-wave mode. This power level in combination with the high absorption of copper in this wavelength range enables the controlled and reliable heat conduction welding of copper even at low intensities.

This power level is realized by the unpreceded use of diode bars which generate laser light of 450 nm wavelength. Conventional approaches for the generation of blue light rely on single emitters which are limited to a power of 3 – 5 W. Based on long-term proven scaling techniques, Laserline uses laser bars to mount, electrically connect, and cool the blue laser bars on heat sinks. In contrast to single emitters, each laser bar is already creating a power level of more than 50 W. Special optics combine several diode bars that are mounted as a stack and even combine two stacks in one laser source. This setup allows for an unprecedented power scaling.

The success of this approach is demonstrated with the LDMblue 1500-60, a continuous-wave 1000-W high-power diode laser with a wavelength of 450 nm and a beam quality of approximately 60 mm · mrad. The laser beam delivery to the work piece is achieved by a 600 µm fiber and a conventional focusing optic which is equipped with an optimized coating for the blue wavelength. The new process capabilities with the unpreceded laser power in the blue wavelength range opens up new applications for metals, especially in copper processing.

Fig. 2 This 0.5 mm thick copper sheet prepared with three different surface conditions (etched, oxidized, polished) was successfully welded.

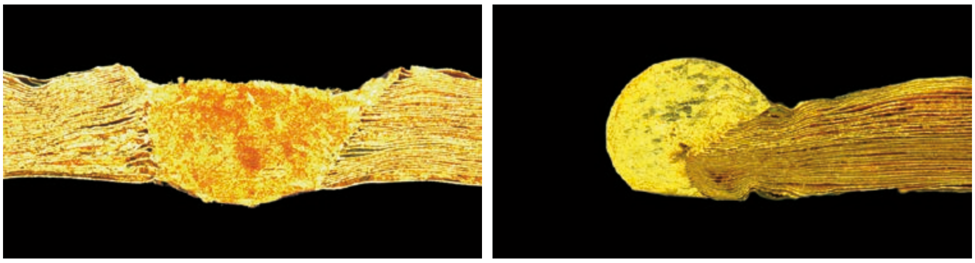

Fig. 3 Welding of 34 stacked copper foils (each 11 µm) in butt welding (left) and edge welding configuration (right) with $P = 580$ W, $v = 35$ mm/s, $df = 600$ µm.

Conduction welding on copper

With the heat conduction welding mode there is no material evaporation, so a very quiet melt bath of liquid copper can be formed, which does not cause spatters. Without evaporation, the driving process parameters change. In NIR processes, the intensity and the resulting depth of the vapor capillary is of importance. For the heat conduction welding mode, the laser power gains significance, which must be sufficient to melt the copper and compensate heat conduction in the work piece. By choosing a relatively low intensity, copper evaporation is avoided.

In contrast to regular NIR processes, the weld bead geometry of heat conduction is in width to depth towards 1:1. The process is driven by the temperature distribution inside the work piece which gives further degree of freedom by taking the work piece design into account for the welding strategy.

While working with the basic parameters power and feeding speed, the LDMblue can easily produce very clean and homogenous weld seams with excellent electrical conductivity. Reworking is largely unnecessary and defects like pores inside the seam are virtually non-existent.

These properties make the LDMblue also interesting for welding of design-oriented components where the cosmetic appearance of the weld matters. This consistently high weld seam quality is achieved regardless of the surface structure: Brushed copper parts are joined just as reliably as parts with etched or oxidized surfaces (**Fig. 2**).

The high absorption of the blue wavelength on copper allows for the high homogeneity on different surfaces: Even with different surface conditions, a minor change in absorption does not influence the process since it is already on a high level of nearly fifty percent. For NIR processes, an increase of five percent would double the energy input, whereas this means only a negligible variation for the blue process.

The creation of a process state with low evaporation pressure allows the exploitation of physical effects for the first time, which previously was not possible in copper welding. In the liquid state, copper has a lower surface tension than steel. While in combination with NIR laser welding, the vapor capillary dominates the melt dynamic, now the surface tension and the temperature distribution dominate the melt flow. This allows an increased gap bridging and favors a wetting effect between the liquid copper and the joining partners.

For thin foil stacks, direct butt joints and edge welds are possible (**Fig. 3**), whereby at 450 nm, the generated melt flow compensates for non-optimal seam preparations with ease.

The connection cross sections are wider and therefore significantly more stable than when welding with NIR lasers. Sheets and foils can be welded just as reliably, suitable for applications in heat sinks or copper terminals for electrical interconnection.

By applying the blue wavelength, the welding of dissimilar metals is given a new perspective. Now, a direct energy incoupling into copper material can be realized. This breaks with the NIR laser convention that copper material should be on the bottom of dissimilar material combinations. This is demonstrated by joining copper to aluminum (**Fig. 4**). For the copper to aluminum full penetration joint, the melt dynamic leads to an intermixing of the melt, which strengthens the joint additionally by a form fit of the materials.

Economic process advantages

For the end user, the use of blue laser radiation is a new experience: Due to the high absorption, considerably less laser power is required than with classical infrared sources, while heat conduction welding enables a new approach taking into account the design of the workpiece.

In addition to the numerous technical advantages, there are also economic benefits: By reproducible melting with a large focus diameter, blue diode lasers can produce wide joining seams in just one welding pass, whereas conventional processes often require se-

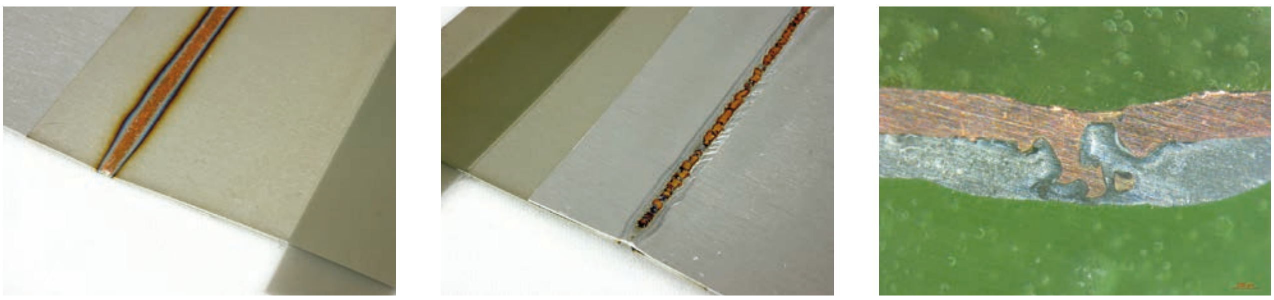

Fig. 4 Full penetration weld of Ni-coated copper (0.3 mm) to Al sheet (0.3 mm) with $P = 1000$ W, $v = 75$ mm/s.

veral passes for the same joint diameter. The process is therefore much faster, although the feed rate is slightly lower than with NIR lasers.

Industrially proven architecture

Technologically, the construction of a blue laser was achieved by specific adaptations of the classical diode laser configuration. The changes mainly addressed the optical system which had to be adapted to the wavelength of 450 nm.

The high power diode laser at 450 nm is based on the industrial proven Laserline LDM-series which integrates the laser head, cooling, power supply, and system electronics all in a 19” rack. The LDMblue will be available in different product configurations, ranging from 300 to 1500 W laser power. The systems are all operating in the continuous wave mode and can be modulated with rise times in the microsecond range.

Conclusion

With the new blue diode laser LDMblue, Laserline has developed a laser type that closes a technology gap in the market. It is the first industrial laser to make process-safe, reliably reproducible heat conduction welding of copper components possible with continuous wave emission. In addition to highly improved absorption, its major advantage is the reproducible and homogeneous weld bead appearance and significantly higher gap bridging capability. It opens up new welding options and significantly improves material efficiency. Standard configurations vary from 300 W with 20 mm · mrad up to 1500 W with 60 mm · mrad. With the world’s first availability of blue, continuously emitting kilowatt laser beam sources, the development of fields of application for novel copper applications and beyond has been opened up.

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