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New Opportunities for Copper Processing with Kilowatt Blue Laser Sources

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Abstract

The laser based copper processing gained significance in the last years due to the increasing demand for the interconnection of highly conductive connectors in the field of electric vehicles. In contrast to laser sources emitting in the near-infrared wavelength range of 1µm, blue laser sources emitting at 450nm can increase the process efficiency of up to factor 20 for the melting of copper. This high absorption level allows new process approaches, which were formerly however restricted by the conventionally low power level of blue laser system. With the availability of a kilowatt laser system with 450 nm wavelength, a major step has been achieved to reach industrial relevant power levels. In this contribution we will review the latest developments regarding the blue laser system technology and give an overview regarding welding applications on copper and dissimilar material combinations.

Keywords: Copper, laser welding, electric vehicles, battery, blue laser, 450 nm wavelength

1. Introduction

The material copper gained significant relevance in the last years due to the increasing demand for high conductive interconnectors for electrical applications. Especially for electric vehicles applications, which require a highly robust joint to batteries or power electronic components, the laser welding is emerging as state of the art [1]. The conventional laser welding process using near-infrared light around 1 µm wavelength has however a low absorption in the range of 5% [2]. This is in the state of the art process overcome by using a deep-penetration process, with high laser intensities. The deep penetration process however induces spatters by the pressure of the vapor capillary and presents a challenging control of the energy deposition, which is critical for temperature sensitive components such as batteries. By choosing the blue wavelength range, the absorption of the laser light on copper is improved to over 60% [2], which enables for the first time a welding process on copper without a vapor capillary, in the heat conduction mode. The availability of a 1kW continuous wave blue laser source [3] allows new applications, which will be presented in this paper.

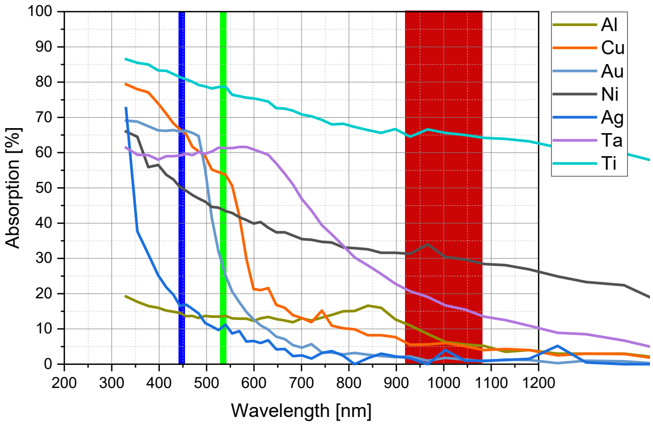

Fig. 1. Absorption for different metals at room temperature [2]

1.1. System Technology

The benefit of laser light in the visual wavelength range for processing of copper is already known for several decades, but was difficult to exploit from a point of technology. For the generation of visual laser light, technology solutions relied on frequency conversion of the near-infrared light. This approach enables the generation of green laser light, which improves the absorption on copper but requires a sophisticated set-up with non-linear crystals. This process is usually limited by the life-time of the crystal, which has to withstand high-energy, and inherits drawbacks in optical efficiency due to the required change of wavelength.

In contrast to this indirect generation of visual light, the blue laser light is directly generated by a diode laser.
With the availability of a novel blue laser bar technology, laser bars can be used that generate on its own a power level of over 50 Watts. Based on longterm proven scaling techniques known from the near-infrared wavelength, the diode laser bars are mounted, electrically connected and cooled with heat sinks. Using special optics it is possible to combine several mounted diode bars in a stack and even combine two stacks in one laser source. By this approach, an unprecedented power scaling is possible. While using diode laser bars, compact laser sources in the kilowatt range have been introduced [3].

1.2. Experimental Set-up

For the laser trials, the following laser system is used: The 19”-rack laser system LDMblue1000-100 with a 1000 µm fiber and NA0.2. The specification of the laser system is summarized in Table 1.

	LDMblue1000-100
Wavelength	450 nm
Max. Power	1000 W
Focus Laser Beam in Trials (1:1)	1000 µm

Fig. 2. Laser beam set-up and resulting focal diameter

The optical set-up consists of a fixed optic with a 100 mm collimation and a 100 mm fixed optic, including a camera outcoupler for positioning on the work piece.

2. Laser Welding with Blue Laser

2.1. Copper Processing

The high absorption of the blue laser on copper enables the heat conduction welding process by choosing a focus spot of 1000 µm. Due to the absence of pressure by a vapor capillary, the copper surface tension leads to a forming of a homogeneous, pore free weld bead with high cosmetic appearance. The closing of gaps by the surface tension of copper allows the application of weld configurations such as the corner weld, which would be challenging to weld with high brilliance laser sources in the infrared due to gap occurrence and high precision requirements. The blue laser melts the copper material at the edge, forming a single melt pool between the 0.5mm copper sheets while using a feeding speed of 3 m/min.

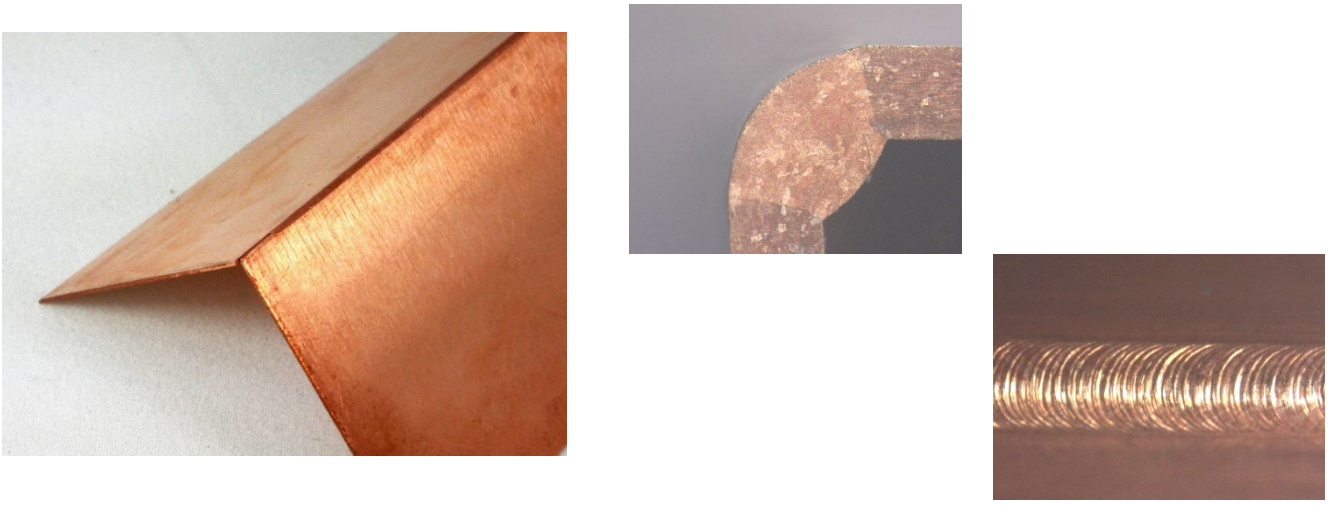

Fig. 3. Corner weld of 0.5 mm copper sheets (left) with Laser power 1000 W, 450 nm wavelength, feeding speed 3m/min, cross-section view (top right) and close up weld bead (bottom right)

2.2. Electric vehicles applications

The welding of copper interconnectors for electric vehicle applications requires highly stable energy deposition, which does not have a thermal impact on adjacent components as e.g. battery electrolyte. The requirement of a low penetration depth is usually in contradiction to a high joining width, which is needed in order to reach a high current rating for the later application.

With the high absorption of the blue wavelength in combination with a focus spot of Ø1000 µm, a large joining width of 0.8 mm can be realized with a single pass of the laser beam for batteries of the type pouch cell.

In Fig. 4 the full penetration joint of two pouch cell tabs is shown.

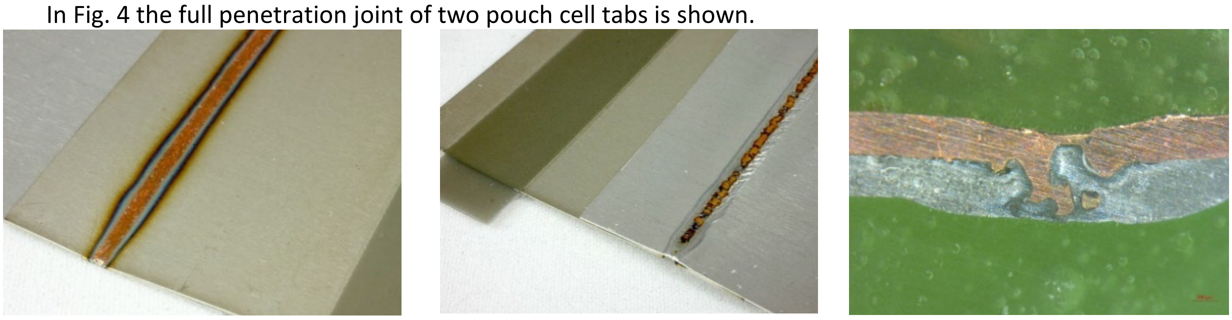

Fig. 4. Full penetration weld of Ni-coated copper (0.3 mm) to aluminum sheet (0.3 mm) (v=75 mm/s, 450 nm wavelength)

The joining width of the 0.3 mm nickel-coated copper and 0.3 mm aluminum sheet is approx. 0.8 mm, showing a pore free cross section. In contrast to conventional near-infrared lasers, the heat conduction welding mode creates a commingling of the melts without a coherent mixed cu/al zone. Therefore, intermetallic compounds are minimized and restricted to the direct intersection between the melts, which is strengthened additionally by the mechanical locking effect of the two commingled melt pools.

For cylindrical cells, usually intermetallic compounds present a challenge while joining copper to nickel-coated steel (Fig. 5).

Fig. 5: Two welded 21700 cylindrical battery cells with the LDMblue1000-100 (v=75 mm/s, 450 nm wavelength)

The highly controllable energy deposition by the blue laser allows a control of melt between of the joining partners, which can be adjusted between a full melt of the copper and steel or a restricted melting solely of copper. By melting the copper on a larger area, a diffusion process to the nickel coating is realized, achieving a high joining width while at the same time restricting the temperature impact inside the battery can.

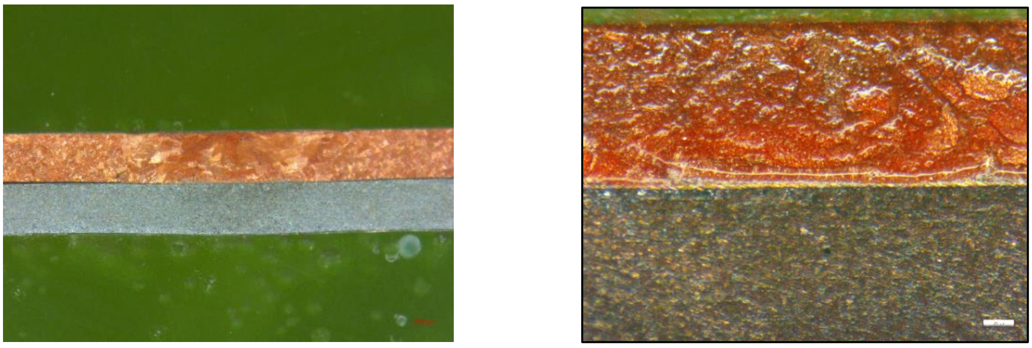

Fig. 6. Cross-section of welded 21700 cylindrical battery cell, 0.3 mm Cu on 0.3 mm steel (Left: overview, right: Detail)

The cross-section detail (Fig. 6) shows the restriction of the melt to the copper sheet, which forms with the nickel coating of the steel a diffusion zone without melting the steel can.

3. Laser Welding with superposed blue and infrared laser beams

The blue laser achieves a high weld quality with minimal spatter occurrence by applying the heat conduction welding mode on copper. For applications in which a high penetration depth in the range of multiple millimetres is required, a deep penetration welding process is however needed, which usually comes along with spatters. In order to combine the advantages of no spatters by the blue laser process and a high penetration depth by near-infrared lasers, a hybrid welding process is demonstrated.

For the laser trials, two laser systems are used: The 19”-rack laser system LDMblue1000-100 with a 1000 µm fiber and the near-infrared diode laser system LDF 5000-30 with a fiber of 600 µm. A hybrid optic is used for the coaxial guiding of both laser beams, which uses a focusing optic of 100 mm focal length.

The result of a weld of 1 mm copper on 2 mm copper sheet is shown in Fig. 7 and Fig. 8.

The top weld bead appearance is completely homogeneous, which reflects the spatter free welding process.

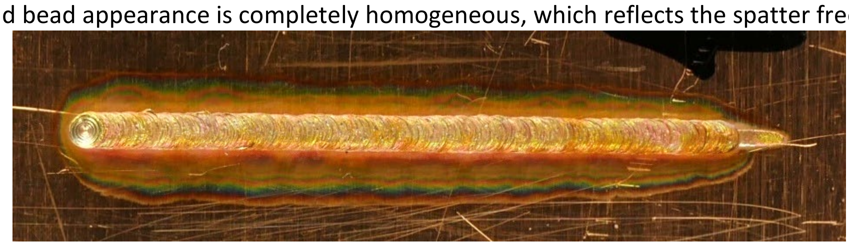

Fig. 7. Weld bead surface of an overlap weld (1 mm copper on 2 mm copper sheet), showing a homogeneous weld bead surface with spatter free process (P_{blue}=1000W, P_{IR}=3000W, v=2 m/min)

The cross-section view shows a welding depth of approx. 1.5 mm with a joining width of approx.1 mm. The copper in the cross-section is pore free.

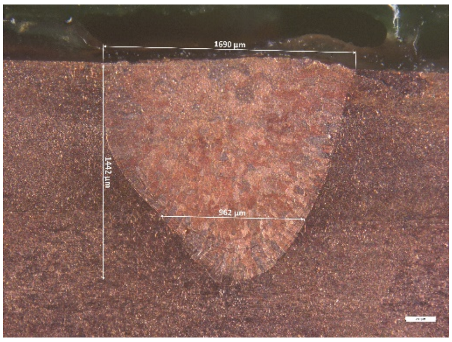

Fig. 8. Cross-section view on 1 mm copper welded on 2 mm copper, resulting in approx. 1 mm joining width.

This result demonstrates a welding quality increase to conventional near-infrared welding processes, in which the high intensity in the center of the weld bead creates a vapor capillary with high vapor pressure. The blue laser wavelengths provides for deep penetration welds a melt pool stabilizing effect, that strongly reduce the conventional spatter behavior of deep-penetration processes.

Conclusion

With the continuous wave blue laser source LDMblue1000-100 new applications for the processing of copper by using the heat conduction mode are enabled. The 450 nm blue laser wavelength provides a highly stable welding process without spatters on copper material. This provides new processing capabilities with highly controllable energy deposition for battery interconnections e.g. pouch or cylindrical cells.

While welding copper material in the range of multiple millimetres thickness, the blue laser acts as a stabilizer of the melt pool in combination with the deep-penetration weld of a near-infrared laser. This is successfully realized with a hybrid optic. The result of the superposition of the two lasers beams is a high penetration welding process with a spatter free process, which leads to pore free joint and high joining width.

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