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Blue Kilowatt Laser for Advanced Copper Processing

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The basic technology of cooling and electrically connecting and beam forming blue diode bars is well matured, meaning that fabricating a blue high power diode laser (HPDL) is possible. Results achieved so far with blue HPDLs and based on the development experience of HPDLs in the near-infrared (NIR) wavelength range, further increases in power and improvements in beam quality are expected. As such, Laserline GmbH believe that blue HPDLs are set to be the leading photonic tool in medium to high power material processing applications.

Keywords: High power diode laser (HPDL), blue laser, copper, Cu, near-infrared (NIR), continuous wave (CW)

1 INTRODUCTION

Over the last few decades, continuous wave (CW) laser applications have become established as a versatile tool in modern manufacturing, covering a range of processes including welding, cladding, surface treatment, hardening, brazing, cutting and many more. These applications are nowadays dominated by near-infrared (NIR) industrial lasers, predominantly working around the 1 μm wavelength. These lasers are suitable for the processing of steel alloys with over 50% absorption. With an absorption of <5% at 1 μm wavelength, the processing of materials such as copper and gold is, however, very difficult. In order to process these highly reflective materials, high laser intensity is used for the creation of a vapour channel in the material, which increases

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the absorption; however, this approach limits copper processing capabilities to a deep penetration process regime, with the inherent risk of sputter occurrence and the challenging control of energy deposition.

A wavelength below 500 nm is much more suitable for the processing of copper, since the absorption increases strongly towards 50%. Some laser sources are already available on the market in this wavelength range, which are based on frequency doubling, resulting in wavelengths of 515 and 532 nm of the green spectrum; however, these laser sources rely on a conversion process, in which a crystal is converting only a fraction of the pumped laser wavelength into the target wavelength. The conversion process leads to high power losses, complex cooling requirements and a sophisticated optical set up.

Today, the solution to the technical challenge of copper processing is addressed with additional urgency, due to the close connection to the social challenge for the reduction of greenhouse gases. The replacement of combustion engines with electric engines creates a vast demand for reliable processing solutions for copper, which is used in eMobility, as well as in other renewable energy systems such as wind turbines.

2 BLUE LASER DIODE TECHNOLOGY

In order to address this challenge, the company Laserline GmbH developed a high power diode laser (HPDL) with a blue wavelength of 450 nm in CW mode. In contrast to other laser source concepts, the diode laser based on GaN-material enables the direct emission of 450 nm, without further frequency doubling and therefore with higher energy efficiency. With a wavelength of 450 nm, an increase in the processing efficiency of up to 20× is expected for copper materials, compared to a wavelength around 1 μm.

Based on long-term proven scaling techniques, Laserline GmbH uses laser bars to mount, electrically connect and cool the blue laser bars on heat sinks, as shown in Figure 1. This is in contrast to the conventional use of single emitters, which are limited to a power of 3 to 5 W. Each laser bar on its own is actually

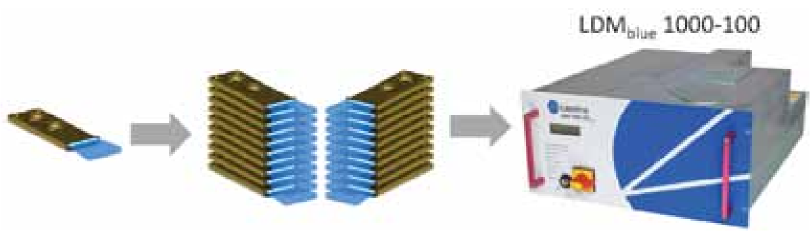

FIGURE 1
Concept of power scaling with diode bars for the blue HPDL LDMblue1000-100.

creating a power level of over 50 W. 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 unpreceded level of power scaling is possible.

The success of this approach is demonstrated with the presentation of a CW 1000 W blue HPDL with a wavelength of 450 nm and a beam quality of approx. 100 mm*mrad. The laser beam delivery to the work piece is achieved with a 1000 μm fibre and a conventional focusing optic, which is equipped with an adjusted anti reflection coating to the blue wavelength. The new process capabilities with this unprecedented laser power in the blue wavelength range opens up new applications for metals, especially in copper processing.

The absorption level of over 60% on copper material leads to a reproducible energy deposition, which is in contrast to the 1 μm wavelength, independent of the surface condition of the copper material. A weld over a copper sheet with an etched, oxidised and a polished surface zones generates a highly homogeneous weld bead surface, as can be seen from Figure 2.

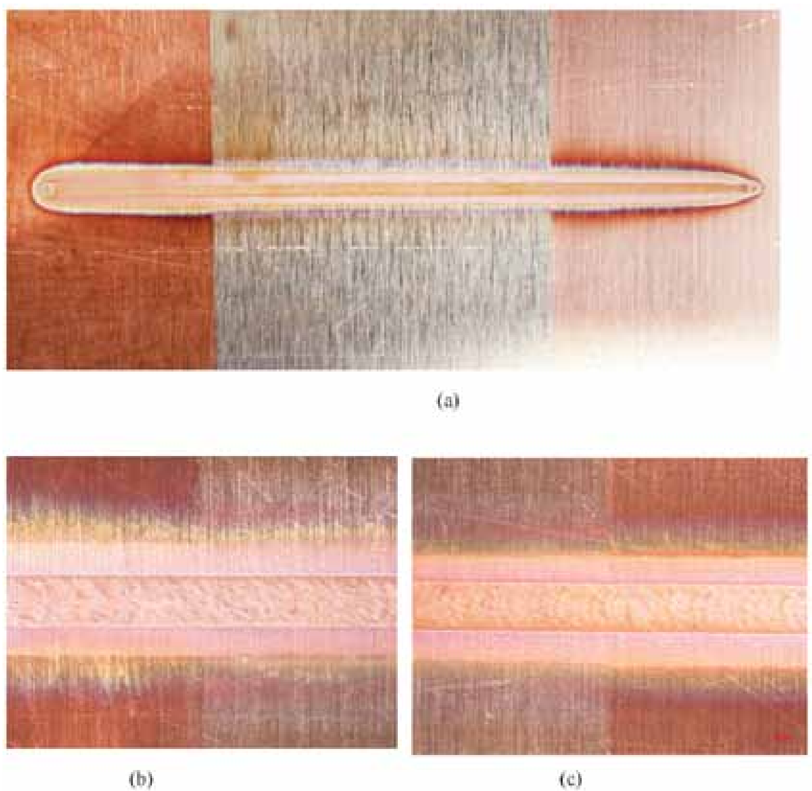

FIGURE 2
Optical micrographs showing blue HPDL welding of a 0.5 mm thick copper sheet prepared with three different surface conditions: (a) Etched; (b) oxidized; and (c) polished.

In addition to the welding results on varying surfaces, the high absorption level allows for the first time the capability to weld copper materials in the heat conduction mode. In contrast to the deep penetration welding mode of NIR lasers, the heat conduction mode does not create a vapour capillary and allows the precise adjustment of the melt pool geometry for thin copper materials also. The stable energy deposition of the heat conduction process mode is especially important for applications, where the high pressure of a deep penetration welding mode would lead to the cutting of the material or an undesirable splatter occurrence. This can occur while welding stacked thin copper foils, which may be subject to an uncontrolled gap due to warping of the stacked foils (see Figure 3).

While applying a butt welding approach with 580 W laser power and 2 m/min feeding speed on stacked copper foils, a weld bead width of more than 0.8 mm can be created with minimal porosity and low undercut. For a fillet weld approach with an irradiation on the edge of the foil stack, the foil endings are molten over a large cross-sectional area with a complete attachment to the solid foils. In both butt and edge welding the process results in a perfect mechanical joint, as well as creating a very good electrical conductivity.

Furthermore, the availability of 1000 W laser power at 450 nm allows new engineering design approaches, which are based on the high gap bridgeability of the liquid copper melt. In contrast to NIR laser processes, the liquid copper in the heat conduction mode exhibits a very stable meltpool. The stable meltpool in combination with the surface tension of the liquid copper, closes gaps, which would otherwise be challenging in the processing of corner welds or butt welds. This characteristic opens up new perspectives regarding improved material efficiency, compared to conventional overlap joints.

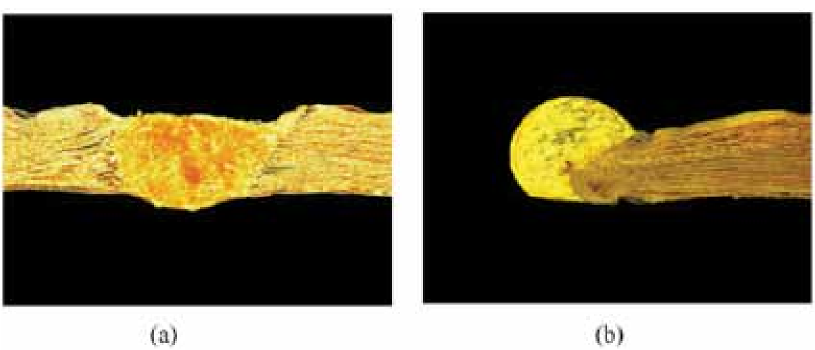

FIGURE 3
Optical micrographs showing the blue HPDL welding of 34 stacked copper foils (each 11 μm) in (a) a butt welding configuration and (b) an edge welding configuration.

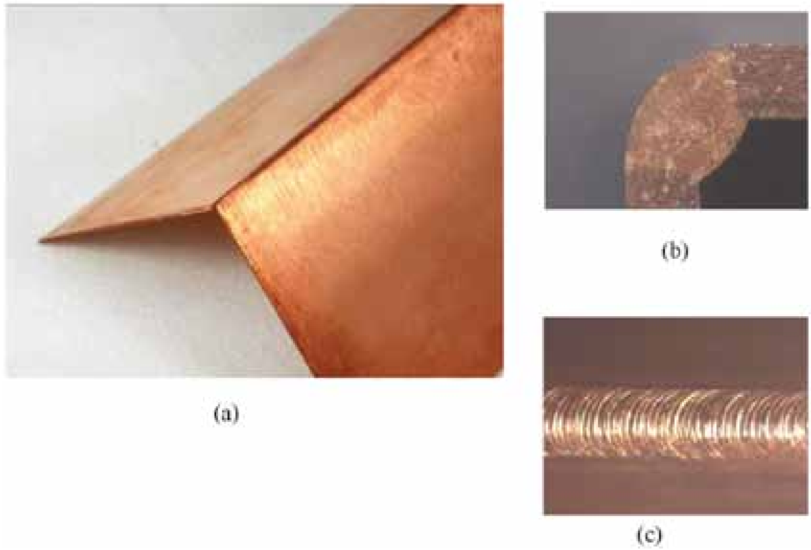

FIGURE 4
Optical micrographs of (a) blue HPDL corner welded of 0.5 mm copper sheets at a feeding speed of 3 m/min, (b) cross-section view of the weld in (a) and (c) close up plan view of the weld in (a).

3 CONCLUSIONS

Having shown the motivation, technology and some results of a blue high power diode laser (HPDL) with continuous wave (CW) high power output, it is obvious that this technology will establish once again a new generation of industrial processes and also unexpected applications, which may be coming up in the near future. The basic technology of cooling and electrically connecting and beam forming the blue diode bars is available, well matured and running in 24/7 installations for more than 20 years. Based on the development experience of HPDLs in the near-infrared (NIR) wavelength range, an outlook to a further increase in power and an improvement of the beam quality is expected. Laserline GmbH is convinced that HPDLs are going to be the leading photonic tool in medium to high power material processing in the near future.