9th International Conference on
Photonic Technologies LANE 2016

Industrial Paper

Welding of copper with brilliant fiber laser sources.

Michael Lee[a,*], Nils Reinermann[a], Michael Grupp

[a]IPG Laser GmbH, Siemensstr. 7, Burbach 57299, Germany

Abstract

Welding of copper with an infrared fiber laser is still a challenge for current state-of-the-art laser. The high reflectivity leads to irregularities at the beginning of the process and the low surface tension and viscosity of copper causes a high sensitivity for sputter ejections especially at low and mid welding speeds.
Solutions to these challenges are presented in this paper.
Brilliant NIR single mode laser sources in the high power range up to 10 kW provide extremely high power densities for a reliable coupling into high reflective materials and proper welding process.
Our solution to avoid sputter ejections is a circular oscillation of the laser beam, the so called wobbling. Wobbling leads to a high beam speed at a low feed rate resulting in a stable key hole and a strong reduction of sputter at low welding speeds. Thereby the wobbling gives the opportunity to change the shape of the weld seam in a wide range.

Keywords: welding, copper, Fiber Laser, high reflective materials

1. Introduction

Fiber laser are widely used in welding applications as high economical solution nowadays. Sources are available with brilliant beam quality up to 10kW in near infrared wavelength at 1070nm.

Products as batteries in automobiles and mobile devices as well electrical contacts of microelectronic parts require reliable and low resistance welds. Unfortunately welding copper with near infrared wavelength can be challenging due to material properties in solid phase, such as the low absorption in a range of few percent and the relative high heat conductivity. These properties influence spatter ejections as well as random variation in penetration depth due to instable in-coupling of the laser power.

To overcome these challenges different techniques have been reported. E.g. the use of two laser sources (green and NIR wavelength) [1], power modulation of spatial multi-mode sources [3] or welding in vacuum [4]. All of them are complex to handle or mean extraordinary effort e.g. in equipment, optics and coatings. Furthermore they are bulky as well as not efficient in electrical power consumption.

Industrial end-users as well as consumers demand for reliable and cost efficient weld seams in products. Thus formulate the expectation on a widely controllable weld seam behavior in terms of spatter free, homogeneous joint with low electrical resistance.

2. Experimental Setup

For the welding tests a 1 kW single mode fiber laser was used with a fiber core diameter of 14 µm. The optical head is a galvo scanner with 30mm aperture (with a collimation length of 120 mm and a focus length of 254 mm). The spotsize in the focus is around 30 µm.

* Corresponding author. Tel.: +49-2736-4420-8355 .
E-mail address: malee@ipgphotonics.com

3. Results and Discussion

3.1. Avoiding irregularities at the beginning of the weld seam

The main reasons for the irregular beginning of copper weld seams are the absorption properties of copper. In the solid state copper absorbs only 4 % of the beam energy, Tab. 1. Thereby a high intensity is needed to liquefy, evaporate and open a keyhole to start the deep penetration welding process.

Table 1. Absorption of copper in different states.

”State of matter”	Absorption (%)
Solid	4
Liquid	10
Keyhole/vapour	> 60

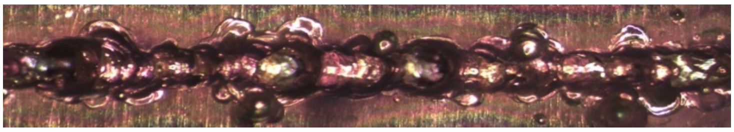
This intensity can only be achieved by the best beam quality or the shortest focal lengths. IPG Photonics high power single mode laser sources can reach intensities up to fifty times higher than multimode lasers in comparable power ranges and allows at the same time the use of long focal lengths for galvo systems, Tab. 2. These high densities lead to immediate and stable absorption from the beginning of the weld seams.

Table 2: Intensity at 1kW power and f= 254 mm

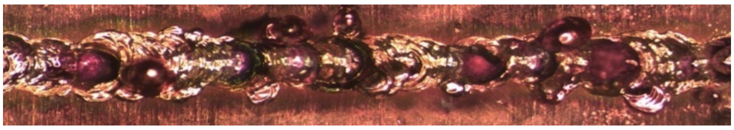
Spot diameter (µm)	Intensity (W/cm^2)
30	1.4E+8
100	1.3E+7
200	3.2E+6

3.2. Avoiding sputter at low welding speeds

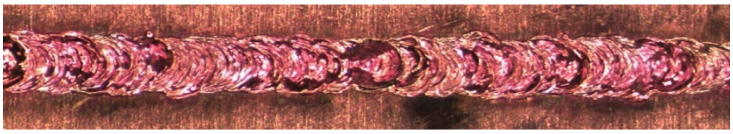
Liquid Copper has low surface tension and viscosity compared to other metals which leads to an unstable weld pool and a high vulnerability to sputter ejections at low welding speeds due to overheating of the melt pool. With increased welding speed these problems can be overcome at the expenses of the penetration depth. Fig. 1 shows improvement of the weld quality and decreasing welding depth depending on the welding speed



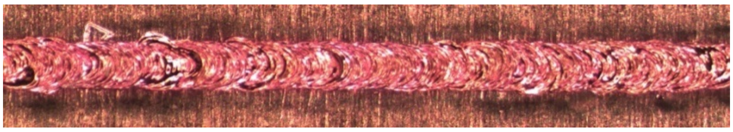
v=2 m/min   weld seam depth: 1,3 mm



v=4 m/min   weld seam depth: 0,9 mm



v=10 m/min weld seam depth: 0,55 mm



v=15 m/min weld seam depth: 0,49 mm

Fig. 1. Weld seams at different speeds and Power of 1,5kW.

With the high frequent circular beam oscillation of the so called wobbling it is possible to combine high beam velocity at moderate longitudinal feed rate. Thereby it is possible to stabilize the weld pool in the same way as in linear high speed welding of copper where ejection of sputter can be completely avoided.
As a result of the low feed rate one can reach a tremendous increase of welding depth compared to the normal high speed welding at moderate laser power.

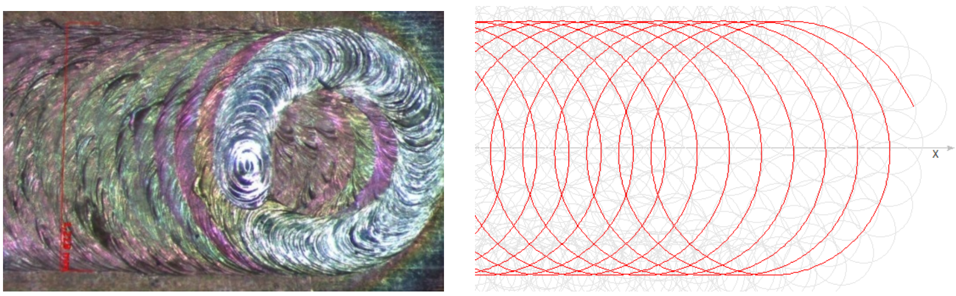


Fig. 1. Feed rate: 10 mm/s; Radius 0,5 mm; Freq.: 100 Hz.

The great potential of the wobbling technique becomes clear in the following figures, where weld seams done with a single mode laser and different wobbling diameters are shown. The linear welding speed was set to 1 m/min for all tests. Without wobbling at this low speed it wouldn't be possible to create an acceptable weld seam quality. With wobbling the process got stable and defect-free over the whole range and weld seam length.
Besides the enormous improvement of the quality and welding depth it is now possible to adjust the weld seam geometry in a wide range from V-shape to U-shape to rectangular cross section.

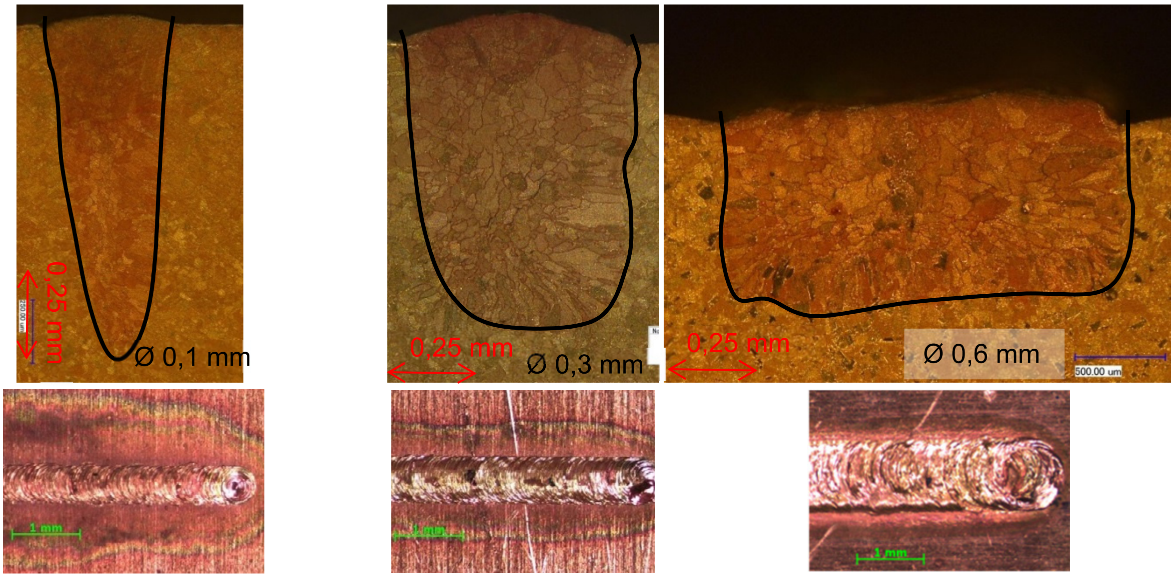


Fig. 2. Weld seams with variable wobbling diameter, Power: 1kW, 1m/min, 300Hz.

4. Conclusion

Brilliant high power fiber lasers provide the needed intensity to ensure a reliable coupling into the copper. Due to the fast coupling, high absorption of the keyhole and the stability against back reflection, these lasers overcome the issue of instable Copper welds known from the past. With additional use of the wobbling it is possible to achieve sputter-free weld seams even at low speeds and independent on the surface of the material (see Fig. 4).

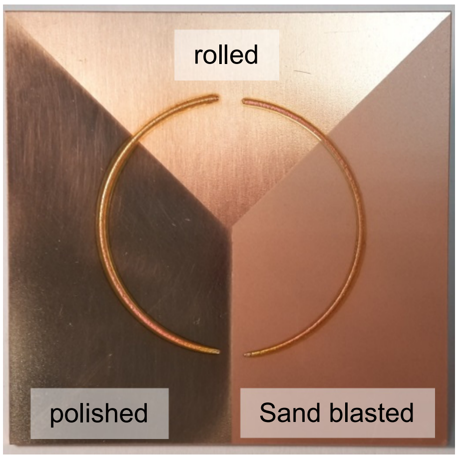


Fig. 3. Excellent weld seams at different material surface.

References

[1] Heß, A.; Schuster, R.; Heider, A.; Weber, R.; Graf, T., 2011, Continuous Wave Laser Welding of Copper with combined beams at Wavelengths of 1030 nm and of 515 nm. Lasers in Manufacturing (LiM) Munich 2011.

[2] Heider, A.; Stritt, P.; Heß, A.; Weber, R.; Graf, T., 2011, Process Stabilization at welding Copper by Laser Power Modulation, Lasers in Manufacturing (LiM) Munich 2011.

[3] Katayama1, S.; Kobayashi, Y.; Mizutani, M.; Matsunawa, A. 2001. Effect of vacuum on penetration and defects in laser welding, J. Laser Appl. 13, 187.

[4] N.N.: Final report CuBriLas Project (Laserstrahlschweißen von Kupferbauteilen mit brillanten Strahlquellen im infraroten und grünen Wellenlängenbereich) funded by Bundesministerium für Bildung und Forschung.).