Sputter-free and Uniform Laser Welding of Electric or Electronical Copper Contacts with a Green Laser

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Abstract

Today’s commonly used IR-lasers suffer from two limitations: Firstly the process reproducibility can be quite low as copper is highly reflective at 1 µm wavelength, and secondly the process parameters used today typically result in splatters emerging from the welded region during the deep-penetration welding process, leading to short-circuits.

The most precise method to detect sputters is the recording of the welding process by means of a high-speed camera. This allows to find out exactly which types of sputters are to be distinguished and which process phase is responsible for their formation. The time and the type of coupling of laser light into highly reflective materials can be determined as well. Pulsed and continuous welding processes, 1 µm and 0.5 µm wavelength, local power density distribution and temporal progression of the power have been examined and optimized. A newly developed laser source meets all requirements of optimized process quality.

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1. Introduction

Pulsed solid state lasers are used in broad sectors of electro technology, precision engineering, medical technology and automotive production, as well as in tool and mold production. They weld, cut, mark, drill and structure. They are also used for deposit welding and ablation. Many of these components consist of copper materials of high conductivity for electronic and electrical contacts, including electronic switching devices or plug-in connectors. Although most running welding applications fulfill all requirements of solidity, conductivity and process stability, two questions are often asked:

(i) Can we reduce the amount of sputters from the welding process?
(ii) Can we raise the reproducibility of welding spots and reduce the influence of surface conditions?

These are important questions as (i) sputters can lead to failures of the work piece due to short circuits and (ii) often the surface has to be coated with tin or it has to be sandblasted prior to welding to ensure sufficient process reproducibility.

To answer those questions, laser parameters such as pulsed and continuous welding process, 1 µm and 0.5 µm wavelength, local power density distribution and temporal progression of the power have been examined and optimized. All tests have been performed into pure oxygen free copper with low resistance (SE-Cu), which is generally used for electronic and electrical contacts.

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1.1. Influence factors on the welding process of copper

Surface tension and viscosity of copper cannot be influenced by process parameters. Both are smaller compared to steel and therefore the melt bath is more unstable. Loss of energy by heat conduction is a lot higher. All other properties (see fig.1.) can be influenced by choosing the right laser parameters and will change the absorption of the laser beam into the work piece. The wavelength of the laser for example affects the influence of all other parameters: copper surface condition, inclination angle, temperature dependent absorption and form of the vapor channel. They behave differently with green laser beam compared to infrared.

![Fig. 1. Material parameters and process parameters.](image1)

1.2. Laser

In comparison to state of the art TruPulse lasers (infrared) a new laser source with a pulsed green laser beam was used for welding copper. Other than the wavelength, the laser properties are similar.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. power</td>
<td>500W</td>
</tr>
<tr>
<td>Max. pulse power</td>
<td>4…5 kW</td>
</tr>
<tr>
<td>Max. pulse energy</td>
<td>up to max. 50 J</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>0,1 – 15 ms</td>
</tr>
<tr>
<td>Output</td>
<td>fiber coupling, 2 outputs</td>
</tr>
<tr>
<td>LLK Φ</td>
<td>min. 100µm</td>
</tr>
</tbody>
</table>

![Fig. 2. Pulsed green laser.](image2)

2. Reproducibility of Welding Spots

On sanded copper material of thickness 0.3 mm welding spots of nearly full penetration have been welded. With a green beam, the diameters of the spots are much more consistent.
Also it does not matter, how the surface looks like. For green laser light it can be oxidized or rough, polished or etched with acid without changing the welding result.

3. Incoupling efficiency

A nearly full penetration into a copper plate can be achieved with different combinations of pulse power and pulse duration. The higher the pulse power, the less pulse duration is needed. For long pulse durations a great amount of heat is lost by heat conduction which defines a minimum pulse power that is necessary to raise the temperature to melting temperature (for a given beam size). The incoupling of green light is much higher compared to infrared, thus the needed pulse power is smaller. In fig. 4 the minimum pulse power for infrared is 2.6 kW whereas the minimum green pulse power is only about 1.4 kW. In our experiments we noticed that higher intensity leads to more splatter. On the other hand, smaller beam size results in reduced difference of minimum pulse power between infrared and green, but also increased splatter generation. Furthermore the power density needed for melting the copper is not constant but also depends on the beam size.
4. High speed measurement of incoupling

Using a high speed camera, the welding process can be determined in respect to defined process temperatures by inspection of the form of the weld.

- Room temperature: No melt, but surface looks different
- Melting temperature: Flat surface of small melt bath
- Vaporization temperature: Vapor channel and vapor plume

With infrared and green pulses of the same diameter and the same pulse duration a spot welding into copper of 0.3 mm thickness was performed. Pulse power was adapted, so that there is nearly a full penetration in both cases. After 5 ms both setups performed the same task. Infrared laser beam takes much longer to achieve melting temperature. Afterwards another 50 % of pulse duration is needed to raise temperature to vaporisation temperature. No substantial welding depth is achieved until then. Most of the depth of penetration is performed at the pulse end, with the channel and multiple reflexions. The time for melting temperature and vaporisation temperature varies strongly. The part of the pulse that performs the welding (yellow, in fig. 5) differs from spot to spot, leading to different sizes of spot diameter and different depth.

Using the green laser beam, welding starts earlier and at exactly the same time for each and every pulse. In this example no vaporisation temperature is needed, as the full welding depth is reached beforehand. (But it will of course be needed for deeper penetrations)

The laser power input into copper is a lot more stable and uniform with the green laser beam than with an infrared one. It is more stable, because it does not have a time jitter and it is more uniform because the isotherms advance into the work piece steadily from the beginning of the pulse.

![Fig. 5. Laser penetration time into copper 0.3 mm.](image)

5. Assist gas

Using assist gas (Argon or Nitrogen) while welding copper with infrared is not recommended. The energy loss by reflection is much higher compared to using no gas and therefore more pulse power is needed to get the same spot size. The spot results are even more unpredictable.

Doing the same with green laser beam doesn’t affect the penetration depth much, but it has a positive effect on the quality of the joint. The cross sections have a better filling degree. (See Fig. 6)
The experiments also show that an assist gas, if used with a green laser beam, does not have a positive effect on the formation of sputters.

6. Welding depth with low sputtering

For good quality of spot welding with low sputtering, an adaptation of spatial pulse power distribution and of pulse shaping over time is needed. Sputters are formed at different stages of the welding process. The sputters forming at the closing of the vapor channel can be easily avoided. A laser power ramp is enough to extinguish those.

It is more difficult to avoid the sputters that are generated during the last third of the welding time and originate from too much liquid melt in the pool without enough room to form a stable bath. Melt pool size is a good parameter to help here. Nevertheless, there is a limit to the stability of the melt ring around the vapor channel. The deeper the spot weld, the more melt volume is inside the ring around the channel. If the volume is too big, the surface tension of molten copper is not strong enough anymore to overcome the pressure from within the channel. Expulsions result. The maximum depth which could be realized with a stable melt ring is 1 mm. At 1.3 mm depth some small sputters are emitted and at 1.6 mm expulsions get bigger in size.

7. Welding with cw compared to pulsed

Making short seam welds with a high power, high beam quality infrared cw laser instead of overlapping welding spots was much faster. A sputter free welding was not feasible with weld penetrations above 0.8 mm. Nevertheless the same causes as above apply: less sputters occur with optimized spatial pulse power distribution and laser power shaping over time.
8. Summary

The pulsed green laser shows great potential for welding copper with low sputtering and with stable and uniform size of welding diameter and depth. The absorption of the laser beam is much higher and faster which results in a shifting of process type from deep penetration welding to heat conduction welding. Therefore a much improved weld quality and splatter free welding has been achieved. There is no influence of surface condition anymore on the welding process (see fig 8).

Fig. 8. Surface polished and sanded and etched with acid and oxidized.

<table>
<thead>
<tr>
<th>Copper spot welding</th>
<th>Green</th>
<th>Infrared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incoupling</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Welding time</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Sputters</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Fig. 9. Summary result.

References