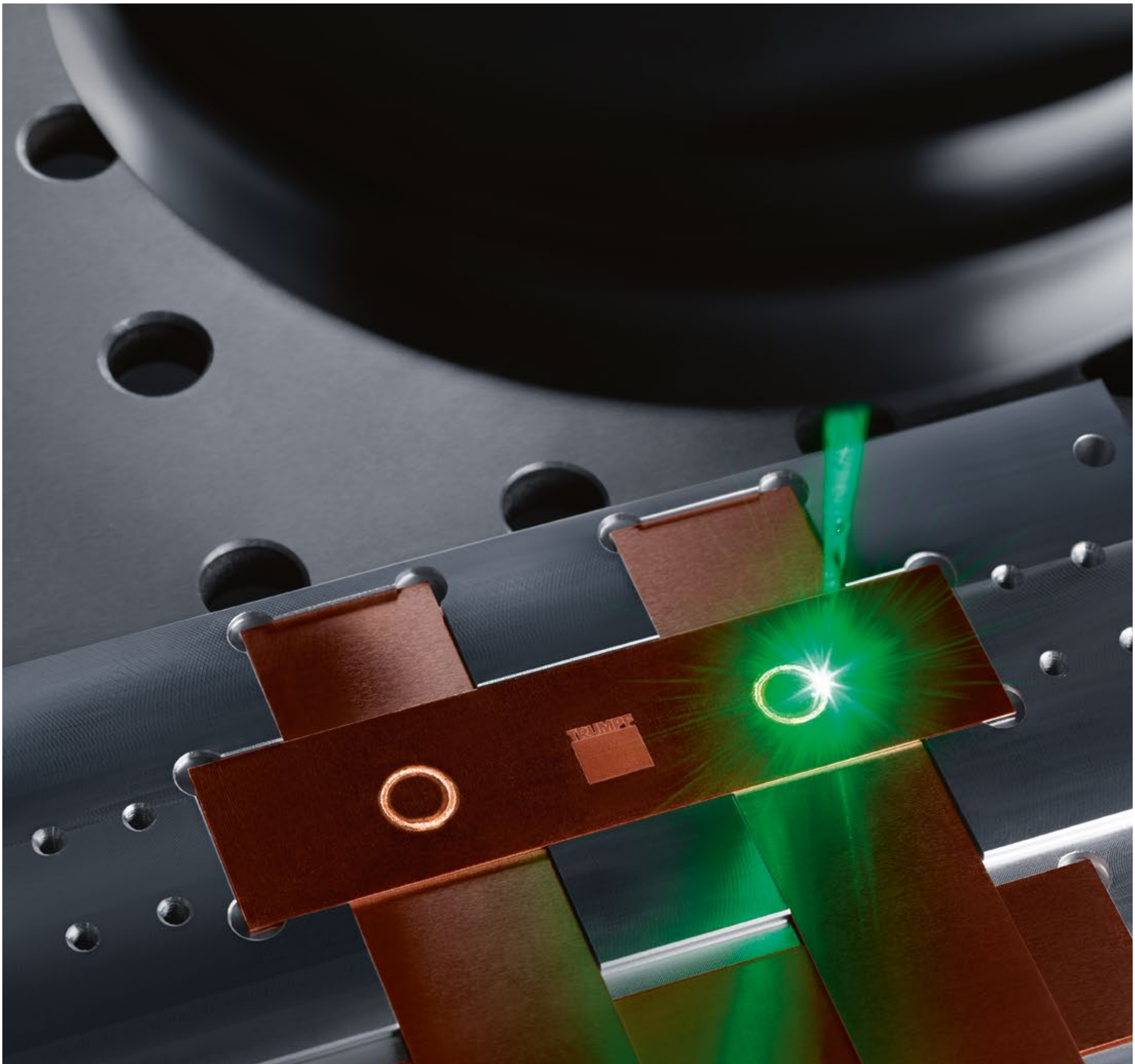

TRUMPF

White paper

Improved coupling behavior, along with green light: New developments in the laser welding of copper contacts, power electronics, and control units in the field of electric mobility

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Summary

In order to meet increasing requirements regarding the quality and quantities of components within e-mobility power electronics adequately, manufacturers are looking for highly productive, viable processes which can be easily automated. This also concerns construction and connection technology. Common processes for copper connections are limited due to their long cycle times and/or insufficient welding quality. With welded connections in power electronics components, the following are particularly critical: spatter formation, the heat input, and possible mechanical stresses, as these disturbances could destroy nearby components. Fluctuating welding depths may also be problematic. Due to its flexibility and capacity for automation, laser technology is a good alternative to conventional welding; in terms of productivity and quality, it has, however, also reached its limits due to the difficult coupling behavior of the infrared laser systems available so far when it comes to highly reflective copper. Especially in the area of small components with a low welding depth (< 1 mm), NIR lasers are critical when it comes to the precision of welding depth and quality.

However, new developments with the beam sources are changing the scene: Laser light that is coupled to a much better extent with a green wavelength is now available to the industry, with sufficient power, resulting in more productive and practically spatter-free processing. For applications in which the still limited power spectrum of green laser systems is not sufficient (for example for larger component dimensions and welding depths > 1 mm), with BrightLine Weld there is a form of technology for infrared laser light that improves the coupling behavior too, thereby increasing the productivity and quality considerably.

Situation

Due to increasing demand, manufacturers of power electronics for the field of e-mobility are facing the challenge of using more productive processes that can be automated. They can no longer meet demands with common processes such as resistance or ultrasonic welding. This concerns, for example, the welding of internal direct copper-bonded contacts (DCB) and the welding of external busbars for inverters and control units.

When it comes to internal contacts, the following requirements for welding the copper contacts of inverter IGBT modules call for a solution in particular:

1. The heat input to the surrounding or joining parts must be as low as possible.
2. The connection cross-section of the join must be the same or larger in comparison to conventional processes in order to minimize electrical resistance.
3. Spatter, and therefore the possibility of destroying the components or a short-circuit during use, must be avoided.
4. Cycle times must be further shortened.

When welding the external contacts for busbars, conventional processes no longer meet the requirements for the highest conductivity (i.e. low contact resistance) with a simultaneous high level of mechanical strength. Furthermore, as a matter of principle, the manufacturers of e-mobility components require a smaller installation space than before, which means that modules must be designed to be more compact than classic screw joints will allow.

In consideration of all these requirements, laser technology emerges as a future-proof process. For laser welding in general, one-sided assembly is possible, which means that the installation space can be optimally utilized.

Solution

Using laser welding technology, contacts can be joined precisely and cleanly in a noncontact way. However, the low energy input of powerful infrared laser light when welding copper limits the processing speed and weld quality. New industry-ready beam sources (pulsed or CW) with green laser light and a technological further development for infrared laser light (BrightLine Weld) shift these boundaries considerably: our tests with these technologies show that they currently represent the most productive and highest quality solution for the requirements of the industry.

Green laser light is suitable especially for small components such as DCB with a low welding depth (< 1 mm, for optimal spatter-free processing rather ≤ 0.5 mm). With this, you can join an average contact to the DCM in t < 0.1 s. For large components with a large welding depth, such as IGTB modules, near-infrared CW laser light with BrightLine Weld is technologically speaking the best and most economical method. Here feed rates of ≥ 0.07 m/s are achieved.

The use of laser technology when joining contacts first of all has a positive effect on the quantity in production. There are also considerable positive effects regarding the quality of copper connections. This applies both to ceramic/FR4 printed circuit boards with DCB contact surfaces in power electronics – above all due to the much lower contact resistances in comparison to parts with screw joints – as well as the external copper contacts to the busbars.

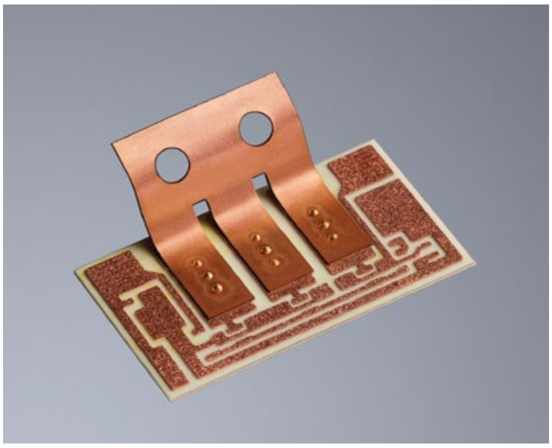

Figure 1: Direct copper-bonded contacts (DCB) welded using green laser light.

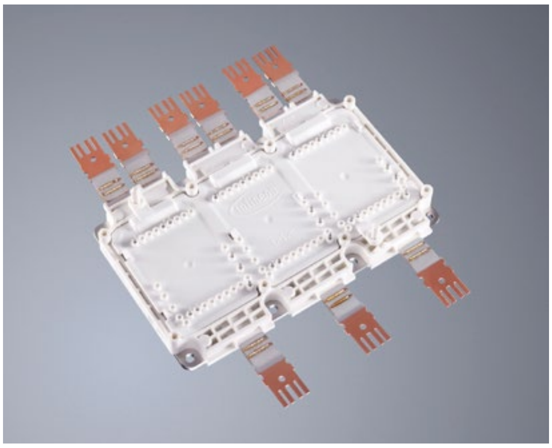

Figure 2: Practically spatter-free weld connection with the TruDisk 6001 and BrightLine Weld with NIR wavelength on an IGBT module and its external copper contacts in a power electronics part.

Green laser light on copper

Joining power and signal pins by welding with a green wavelength (pulsed: TruDisk 421 or CW: TruDisk 1020) permits – in comparison to standard infrared lasers so far – energy input (absorption) that is eight times better at room temperature and on a reflective, bare surface. It enables practically spatter-free welding with a high level of reproducibility with a depth of up to 0.7 mm: tests on copper-copper connections demonstrated spatter formation reduced by 97% in comparison to the infrared laser, which results in a lower error rate due to short-circuits, as well as less contamination of the material and the lens.

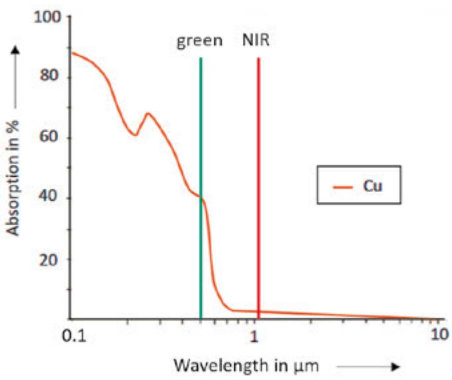

Figure 3: Laser light with a green wavelength is absorbed much more strongly by copper than near-infrared laser light at room temperature (diagram applies to straight beam incidence and a polished surface).

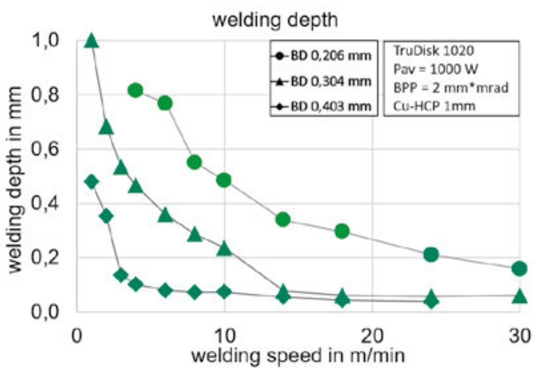

Figure 4: A comparison of CW welding curves for infrared and green laser light in copper, with the same intensity.

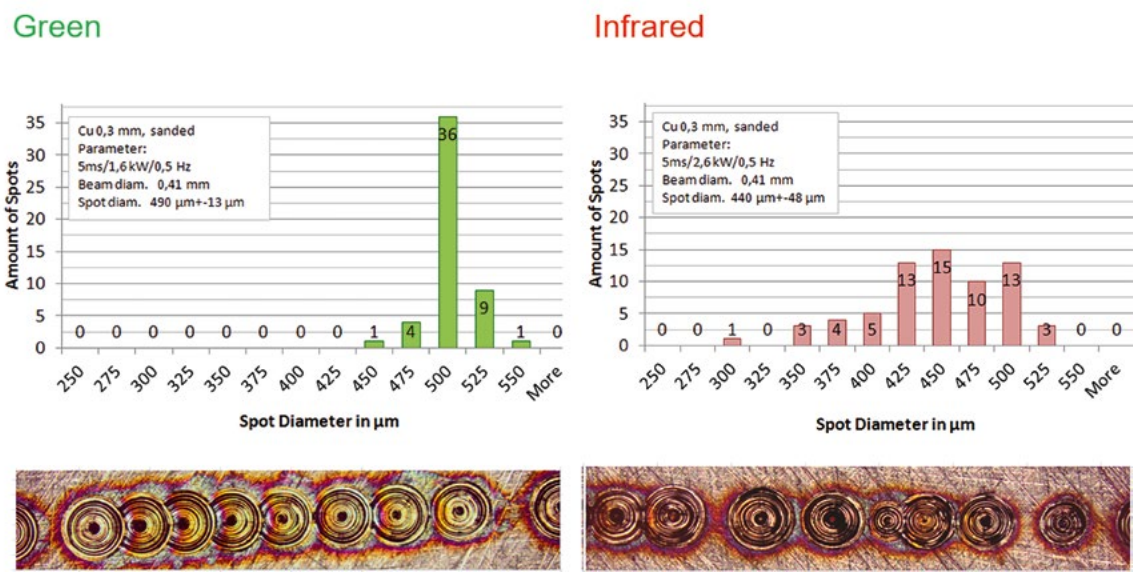

Figure 5: A comparison of spot welding with green and infrared laser light. Green light has a much higher level of reproducibility.

Tests with green wavelength for pulsed welding with a peak pulse power of 4 kW and a pulse energy of 40 J, or for CW welding with 1 kW, also demonstrated that the improved absorption of the green laser in copper leads to a constant seam width, few pores, as well as a constant welding depth. This is particularly important for welding DCBs. The process also permits a large process window and large tolerances; the results have a high level of reproducibility.

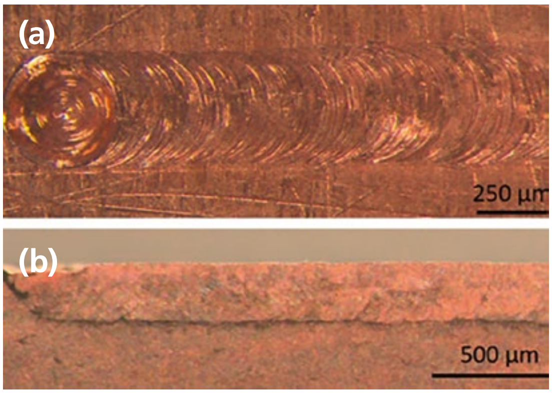

Figure 6: Green CW laser welding of copper: Both at the surface (a), as well as in the longitudinal section (b), you can see a homogeneous welding process.

Joining IGBT modules and busbars using the laser

In order to join external copper contacts of IGBT modules with the busbars, manufacturers classically use screw joints. This has a negative impact on the inductance, the size, and the resistance of the inverter. Together, TRUMPF and Infineon investigated the welding of contacts for the AC/DC side of the power electronics with infrared lasers using BrightLine Weld, above all as regards the reduction of spatter and preventing blowout.

This is because the most conspicuous fault pattern when welding copper with lasers is so-called blowout, which creates recurring holes in the seam and makes it unusable. As a general rule, blowouts and general weld spatter arise when processing is carried out at welding speeds < 5 m/min and when irradiance or fluence exceed critical values – i.e. when the selected focal diameter is too small or the welding power applied too large. This causes a chain of unstable circumstances regarding the dynamics of fluids and energy. Previously manufacturers countered the phenomena of blowout and spatter by welding at a high feed rate. With an increased feed rate, blowout no longer occurs. However, the process still demonstrates spatter behavior which cannot be completely eliminated. As at high feed rates the movement of the weld pool is also dynamic, the weld seam bead, particularly with deep penetration welding, is not very uniform. An alternative welding process is oscillating technology (wobbling), during which the laser beam is moved over the workpiece in a circular manner. This increases both the seam and process quality. However, it can generally be stated that productivity using oscillation technology is lower by a factor of 3 to 5 than for comparable linear welding. The tests with BrightLine Weld demonstrate that a high level of quality and energy efficiency, i.e. fast feed rates, do not have to contradict each other.

Figure 7: Blowout in a weld seam (top view).

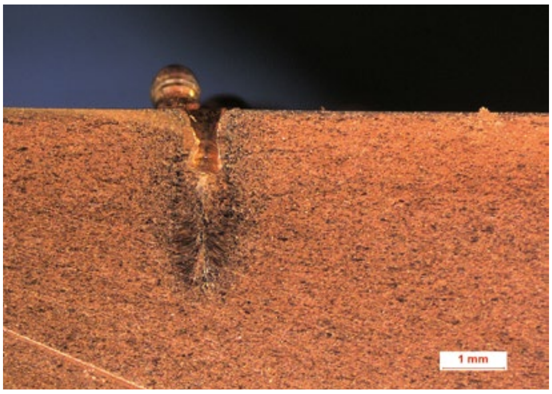

Figure 8: Blowout in a weld seam (cross-section).

BrightLine Weld is a new technology for beam control: The most important element is the 2-in-1 laser light cable (LLK) patented by TRUMPF. This involves two LLKs which are arranged coaxially. Inside there is the so-called core fiber, which is surrounded by the ring fiber. Using an optical component in the beam source (a TruDisk disk laser), laser light is directed into the core as well as the ring fiber simultaneously. The power distribution between the two fibers can be freely selected (10 to 90%) and can be adapted depending on the application. This means the best possible seam quality is achieved. In the process zone of the component, two laser beams then overlap, the irradiance of which can be set independently of one another. For small path geometries with a particularly high path velocity, programmable focusing optics (PFO, mirror-scanner system) are recommended.

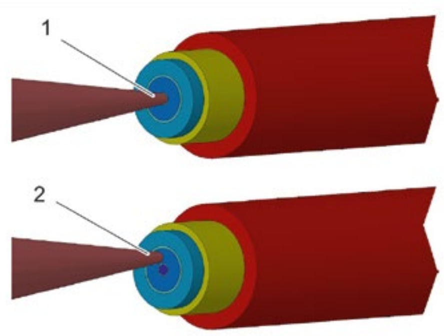

Figure 9: The principle of BrightLine Weld: The beam source simultaneously directs laser light into the core fiber (1) and into the ring fiber (2). The power distribution can be freely selected. Both laser beams overlap in the process zone.

Through suitable adaptation of the power distribution between the core and ring fiber, the energy input of the infrared laser into the copper is modified and has a positive effect on the weld pool dynamics.

Tests with a TruDisk 6001 laser with PFO 33 scanner optics showed that BrightLine Weld reduced the amount of spatter by two to four times. Here the unavoidable spatter had a noncritical size of 10 to 80 µm.

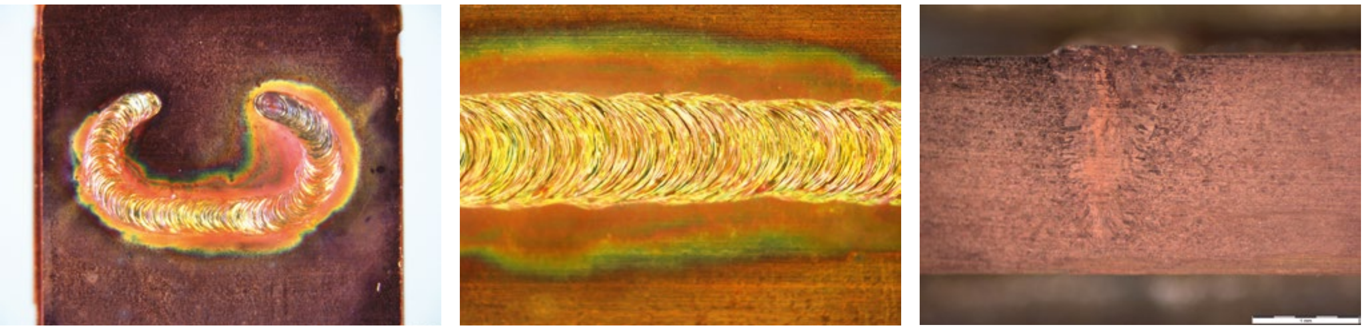

Figure 10: Contact connection on bare copper welded using BrightLine Weld laser technology.

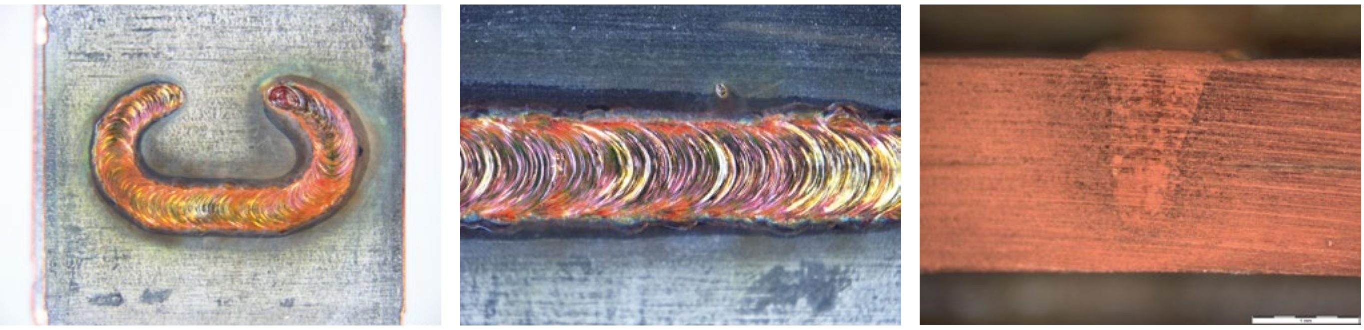

Figure 11: Contact connection on tin-plated copper welded using BrightLine Weld laser technology.

Laser welding also enables one-sided assembly. This means there is no need for a large flange, reducing the size of the inverter by around 5%. Further positive effects are lower inductance, faster switching, as well as electrical resistance that is improved by around 20% in comparison to conventional screw joints.

The results obtained using BrightLine Weld have the same high quality for both straight as well as C-shaped weld seams. High speeds of up to 16 m/min are possible, along with a large welding depth of up to 3 mm. If you oscillate the laser beam with BrightLine Weld, the speed may be reduced, but the amount of spatter is additionally reduced by two to four times and, therefore, all in all by up to eight times compared to laser welding without BrightLine Weld.

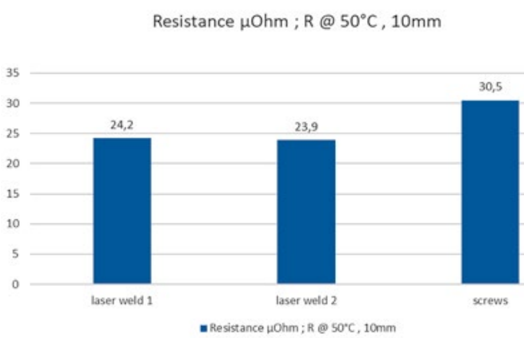

Figure 12: Measured resistance for two laser-welded contacts and a screw contact. The resistance of the laser-welded contacts is up to 20% lower.

Conclusion

For power electronics components within the field of e-mobility, new lasers and laser processes enable the flexible and noncontact welding of copper contacts, with reduced spatter, with much better quality, and short process times. This means less thermal and mechanical stress on the components themselves and their environment. Furthermore, laser technology enables welding in the event of small installation spaces, thereby facilitating a more compact design and more efficient electronics.

You can find more information on lasers with a green wavelength at: www.trumpf.com/s/trudisk-green-wavelength

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