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TECHNICAL DIGEST

Visible-wavelength lasers find new welding uses

This editorial guide covers growing welding applications for visible-wavelength lasers, including batteries, electric vehicle components, and semiconductor devices such as smartphones.

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Originally published 05/04/2021

Improving the production of battery cells

by **David Belforte**

ACCORDING TO A MULTITUDE OF PRESS RELEASES that cross our desk, battery manufacturing is a hot market now with substantive growth, led by accelerated demand from the electric vehicle (EV) industry. One, for example, cites General Motors' plans to sell one million EVs by 2025, and another states that Chinese automakers sold 1.21 million vehicles in 2020, projecting growth to almost 2 million this year. That's tantalizing to battery makers and more so to companies that supply battery welding equipment (especially laser-based), which has the laser industry drooling as it forecasts significant growth for this technology that had been stagnant in the mid-teens for many years.

As part of the AiF project MikroPuls, Fraunhofer ILT is developing laser processes for the efficient contacting of battery cells (pictured: laser-welded copper connectors on cylindrical cells). (© Fraunhofer ILT, Aachen, Germany)

Battery welding is not a new laser application. In one of my trips to China in the late 1980s, I visited a laser welding system builder in Wuhan that was supplying solid-state laser systems to join battery pairs, a booming job-shop industry then. But it wasn't until EVs caught on that laser battery welding started to take off. And over the ensuing years, thanks in no small part to Elon Musk's success with the electric Tesla, that e-mobility became a buzzword in the laser welding community. As an aside, I had the pleasure of driving a prototype laser-welded lithium battery-powered Tesla Roadster at the LASER World of PHOTONICS show in Munich in spring 2011.

That said, in a recent press release, the Fraunhofer Institute for Laser Technology (Fraunhofer ILT; Aachen, Germany) is working towards setting up high-performance production centers for battery cells for the automotive industry, and their scientists are investigating how laser technology can be used to economically contact and join dissimilar materials so that battery cells can be manufactured efficiently and reliably, and if they can be interconnected to form modules and packs in order to dependably cover the upcoming large demand for storage capacity.

Efficiency boost for lithium-ion batteries

One such is the BMBF project “HoLiB” with which lithium-ion batteries can be manufactured much more productively than before. Fraunhofer ILT is developing and qualifying a laser process that can be used to connect anodes and cathodes to the contacts: the arrester tabs. Because the anodes are made of copper, the cathodes of aluminum, and the arrester tabs of both materials, the Aachen researchers decided to test three different beam sources: a blue diode laser (wavelength: 450 nm), a green disk laser (515 nm), and an infrared fiber laser (1070 nm) are being used. Johanna Helm, a research associate at Fraunhofer ILT, explains, “The test of the three beam sources has already shown that the film stack can be welded through with process reliability. We are currently verifying the process windows and carrying out welding tests on the arrester tabs.”

A soliton suggested was using a turntable with several stations on which 20 anodes and cathodes are stacked by a stacking wheel at 0.1-second intervals so that a stack is ready within two seconds. When a stack is at a station on the turntable, the turntable continues to rotate rapidly so that the rotating stacking wheel can deposit further anodes and cathodes on the next free space. In parallel, the laser-based contacting process for the first deposited stack can start without any loss of time.

Nanosecond laser pulses protect heat-sensitive components

In the AiF project MikroPuls, scientists are examining how to bond battery cells more efficiently and Fraunhofer ILT is developing processes for joining copper, aluminum, and steel with an infrared fiber laser pulsed in the nanosecond range. These are demanding processes because the thin electrical contacts are thermally sensitive and may not be heated too much. A balance is important here: If too little welding energy is applied, the connection lacks mechanical stability; if too much energy is applied, the batteries' mode of operation is impaired or their service life is shortened. Elie Haddad, research associate at Fraunhofer ILT, says, "This is where the fast MikroPuls process can play out its advantages, which can even be used to generate copper welds at a maximum average power of 200 W while introducing little energy into the components."

Reliable laser welding of dissimilar materials

The dissimilar joints between copper and aluminum, for example, also pose a particular challenge because intermetallic phases form quickly, deteriorating the quality of the weld seam, leading to high contact resistances that result in either high losses due to heat or brittle joints that can no longer withstand mechanical forces. An important role is played by selectively identifying the optimum parameters with which users can also reliably generate dissimilar joints that have a consistent welding depth and high weld quality.

Tests with copper-aluminum joints on pouch cells and copper-steel joints on cylindrical cells showed that micro-pulse joining can achieve just as good joints as continuous-wave (CW) welding, with significantly lower energy consumption, higher repeatability, and fewer intermetallic phases. The only disadvantage is that the welding process generally takes longer, so there are still parameters that need to be improved.

A system is in operation that integrates both a CW fiber laser and a nanosecond pulsed fiber laser. The beam sources can be controlled individually. The system can not only join, but also remove material—for example, to structure surfaces.

The following institutes are working on the project "HoLiB – High throughput processes for the production of lithium ion batteries" funded by the German Federal Ministry of Education and Research (BMBF), (duration: Oct. 1, 2019 – Sept. 30, 2022):

- TU Braunschweig, Institute of Machine Tools and Production Technology IWF (Coordinator)

- TU Braunschweig, Institute of Joining and Welding Technology (IFS)
- TU Berlin, Institute for Machine Tools and Factory Management (IWF) and
- Fraunhofer ILT

For further information, see www.prozell-cluster.de/en/projects/holib.

The following companies are involved in the project-accompanying committee for “MikroPuls – Fine contacting of thermally sensitive materials in electrical engineering by means of short laser pulses,” which is funded by the Federal Ministry for Economic Affairs and Energy (BMWi) as well as by the AiF Arbeitsgemeinschaft industrieller Forschungsvereinigungen “Otto von Guericke” e.V. (German Federation of Industrial Research Associations “Otto von Guericke”) and the DVS Deutscher Verband für Schweißen und verwandte Verfahren e. V. (German Welding Society) (duration: Oct. 1, 2019 – Sept. 30, 2021):

- Fraunhofer Institute for Laser Technology ILT, Aachen (Coordinator)
- BBW Lasertechnik GmbH, Prutting
- BLS Lasertechnology GmbH, Grafenau
- Class 4 Laser Professionals AG, Lyss (CH)
- Hugo Kern und Liebers GmbH & Co KG, Schramberg
- Inovan Präzisionsteile GmbH & Co KG, Stolberg
- Copper Consulting Technology Laboratory, Düsseldorf
- LaserJob GmbH, Fürstenfeldbruck
- Laser Microtechnology Dr. Kieburg GmbH, Berlin
- Scansonic MI GmbH, Berlin

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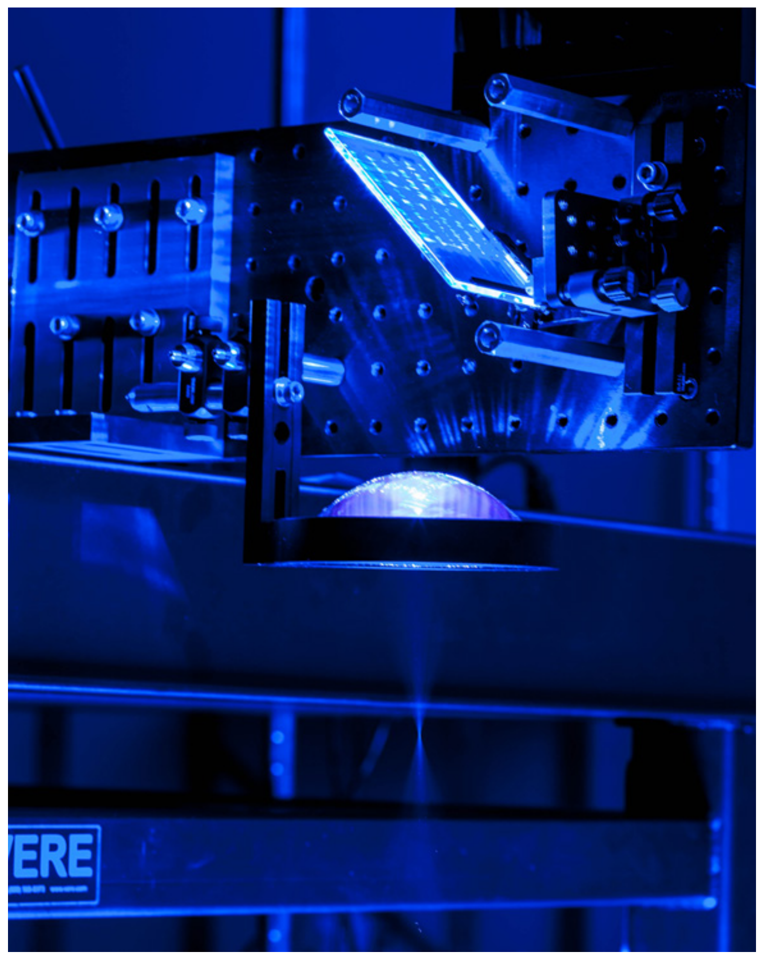
Originally published 03/24/2021

Blue Laser Welding: Blue lasers reach for the sky

High-power industrial lasers expand into new applications.

by **JEAN-MICHEL PELAPRAT, MARK ZEDIKER,** *and* **MATHEW FINUF**

WHEN THE FIRST high-power semiconductor blue laser was introduced in 2017, industry observers quickly learned of its unmatched ability to rapidly produce high-quality copper welds. Technological innovations increased the laser's power and brightness, quickly demonstrating similar performance for stainless steel, aluminum, gold, and even brass. Years of service have established the blue laser's reliability and stability, and now customers in a variety of industries are extending its range of applications.



The Nuburu high-power industrial blue laser combines the output of many individual gallium nitride (GaN) diode lasers to create a high-quality output beam.

Simultaneously, the technology is advancing. For example, the power and brightness of multimode blue lasers has advanced to the point where they can now integrate with standard industrial scanning systems. Increasingly sophisticated technology in turn is enabling expansion in applications, extending materials processing capabilities and improving 3D printing of metals by an order of magnitude.

The foundation

Blue lasers from Nuburu (Centennial, CO) attain their high output power by combining the outputs of scores of individual gallium nitride (GaN) diode lasers using a proprietary combination of spectral, spatial, and polarization control optics. Although the blue industrial laser was introduced only a few years ago, it is exceptionally mature because GaN benefits from the prior development of gallium arsenide (GaAs) technology. For example, GaAs diodes routinely achieve efficiencies around 70%, and GaN diodes are following that same path to rapidly increase present efficiencies. Blue laser performance depends in part on design features, but their performance rests equally on fundamental physics.

Materials processing applications benefit from the fact that many industrially important metals—copper, aluminum, gold, stainless steel, nickel, and others—absorb blue light far better than they absorb longer wavelengths. The absorption advantage leads directly to improved processing speed and product quality. Perhaps the most prominent example of that is the now well-known ability of the blue laser to weld copper up to 10X faster than infrared (IR) lasers, while producing none of the defects that are inevitable with IR.

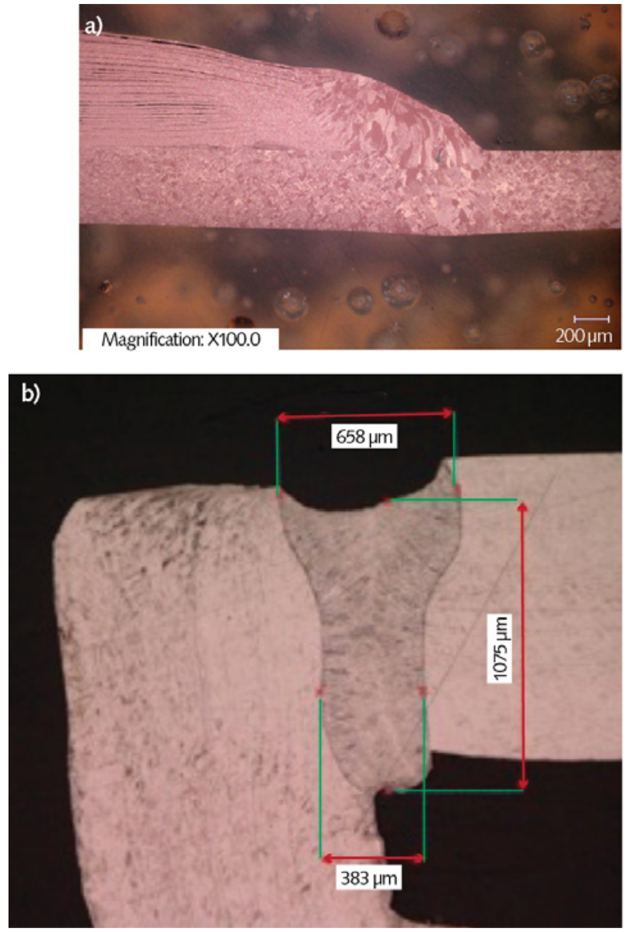


FIGURE 1. *Lithium-ion battery fabrication requires welding at several scales, with different materials; 80 8-µm copper foils joined to a 200-µm tab (a) and 1.2-mm thicknesses of steel joined in the case (b) are shown.*

The blue wavelength has another fundamental physical advantage. The minimum spot size in any optical system is a function of wavelength—the smaller the wavelength, the smaller the spot size. That provides another degree of flexibility for applications engineers, who can take advantage of the smaller spot where necessary or opt for longer focal-length optics where a larger spot size is acceptable.

The physical advantages, design features, and reliability and stability have all combined to create fertile ground for developing new applications for the blue industrial laser.

The impact

Consider the blue laser's effect on lithium ion battery fabrication, a task that may require joining copper, aluminum, and steel. That range of materials is matched by an equal range of thicknesses, from less than 10 µm to more than 1.5 mm. That range of materials and thicknesses used to require a wide range of manufacturing techniques as well, such as ultrasonic welding, resistance welding, IR laser welding, and perhaps even soldering. None of these methods are said to be capable of producing all of those joints, which requires manufacturers to support several fabrication tools, along with their separate maintenance, operational, and training regimens.

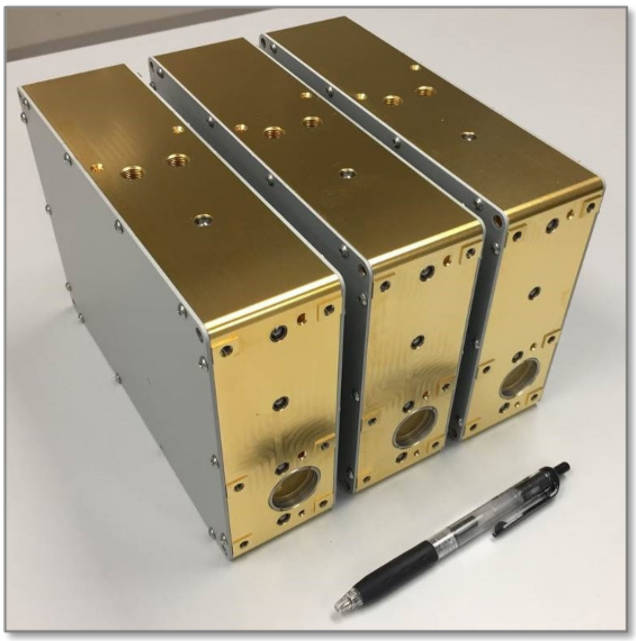


FIGURE 2. *These 400 W modules illustrate the compact form factor and robust design of the industrial blue laser.*

Because blue light is absorbed so well by reflective metals, welding with the blue laser offers a wide process window that allows manufacturing engineers to select combinations of spot size, beam power, and weld speed suitable for joining materials of significantly different thicknesses or material compositions. As shown in Figure 1, this also means the identical laser system can be used to address the many welding stages required for battery fabrication, streamlining factory operations by reducing maintenance and training costs at the same time as increasing process speed and product quality.

The blue laser also offers logistical advantages to the industrial engineer (see Fig. 2). Its physical footprint, for example, is smaller than many other lasers, and its wall-plug efficiency is 35% higher than that of green laser, with a clear roadmap to improve that by about an order of magnitude. The reliability has been proven, with power degradation measured at <0.5% per thousand hours and a projected lifetime in excess of 20,000 hours.

The next step

Recently, Nuburu's AI-1500 blue laser achieved a milestone that astounded many industrial observers—output power of 1500 W with a beam parameter product (BPP) of 11 mm-mrad, an important brightness threshold because it allows the blue laser to be integrated with industry-standard scanning systems. Those systems use *f*-theta lenses to convert angular shifts into position changes while maximizing beam uniformity at the workpiece. Those systems also unavoidably spread the beam, reducing the power density. The initial brightness of this laser is high enough that, even after expansion through the scanner, it maintains the power density necessary for welding, below the 2.3 MW/cm^2 maximum threshold for defect-free welding.

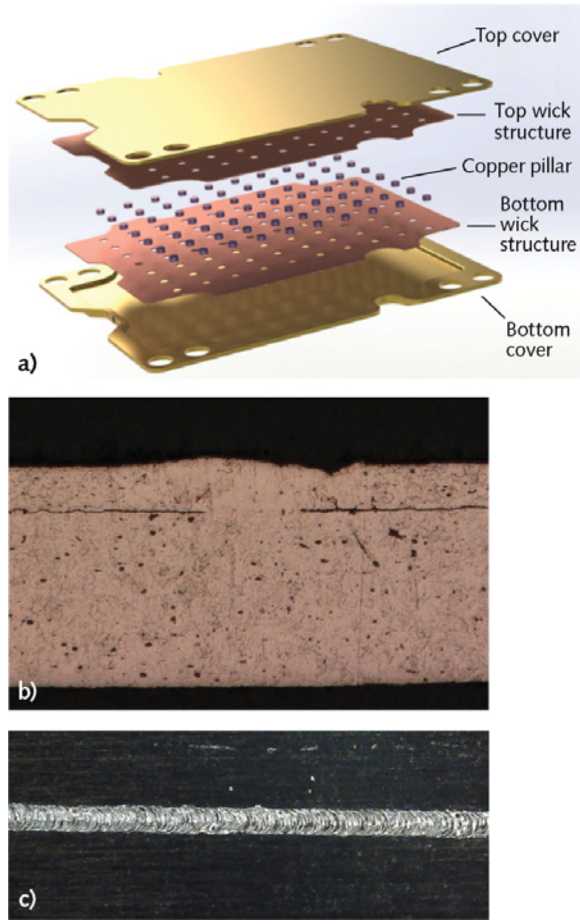


FIGURE 3. *High-density electronics as in 5G smartphones require the high-performance cooling offered by vapor chamber cooling; shown are a typical vapor chamber architecture (a), a blue laser lap weld of 50- to 200-μm copper in a vapor chamber (b), and a high-quality uniform bead representative of the performance needed for this application (c).*

That advanced capability has opened new application spaces. For example, semiconductor devices continue to migrate to higher density, with features on the order of 20 nm. That density of circuitry creates equally high thermal density, generating heat that must be dissipated—particularly in compact devices such as smartphones, especially 5G phones. Vapor chamber cooling is an efficient method for transferring heat out of the electronics. Vapor chambers contain a minute amount of liquid, which evaporates when heated, then cools and condenses at the heatsink.

Vapor chambers consist of thin copper or steel plates joined along their edges to create a hollow pocket, with some wicking structures within. They can handle high heat flux, up to 700 W/cm^2 or higher, because of the energy required for the phase transition. The interior pocket is maintained at a vacuum to optimize the physical conditions for the phase transition. The vacuum is essential to maintain high heat flux and high thermal conductivity, so the challenge is to join the 50- to 300-µm-thick plates with no defects and no compromises to the vacuum seal. In addition, the ultrathin form factor is required for integration into compact consumer electronic devices, so the joint must be uniform as well. The blue laser produces the required defect-free welds, as illustrated in Figure 3. The weld speed is 10–20 m/min, or even higher at power levels around 0.5 kW. Scanner integration means the high weld speed can be matched by rapid translation of the beam to address sequential welds at rates necessary for automated high-volume manufacturing, as anticipated for 5G smartphone production.

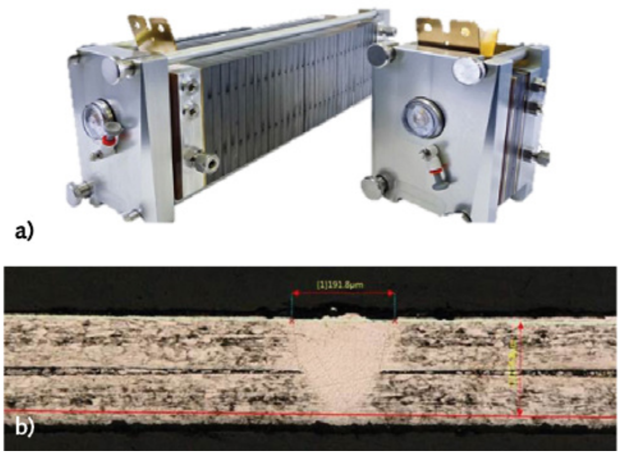


FIGURE 4. *Fuel cell assemblies consist of stacked individual cells (a); these two special steel plates are required elements of hydrogen fuel cells (b), and the defect-free weld shown here allows improved fuel cell performance and streamlined design.*

The blue laser is also making an impact on the rapidly growing renewable energy sector. For example, hydrogen fuel cell production is on the rise. These fuel cells consist of up to 400 individual cells, each centered around a membrane electrode assembly (MEA). Input and output ports on each cell route hydrogen and oxygen to different sides of a membrane, harvesting energy when they combine.

Currently, the perimeter of each individual cell is sealed with a compressed gasket, but gaskets can leak. Ideally, the perimeter of each individual cell would be welded, providing mechanical structure and maintaining a secure seal. Laser welding is fast and flexible, but IR lasers produce an unacceptably high level of weld irregularity, called “humping.” When the cells are stacked, this irregularity—on the order of 35 µm—leads to misalignment with the input and output ports. The blue laser welds faster than the IR and reduces humping by a factor of seven—sufficient to maintain the critical port alignment (see Fig. 4). This is another example where the quality of the weld offers new design options. In this case, welding of the cell perimeter allows a unibody design, eliminating gaskets and increasing the mechanical fidelity of the assembly.

The same advantages apply to 3D printing. Both the blue laser material interaction properties and the blue laser propagation properties improve performance. High material absorption leads directly to higher part density, while the smaller spot can either be leveraged to produce parts with finer details or be exploited to extend the fabrication volume to 10X that possible with an IR laser.

Continuous technological improvements and product maturity also open up applications in new areas, such as free-space laser communications, where blue can reduce aperture diameter by a factor of three. Blue light also transmits through water about 8X better than green light. For submarine laser communications, which currently are designed around green light, blue can reach significantly greater depths or provide higher data transmission rates, or some combination of both. The enhanced transmission through water also enables higher performance lidar.

The blue laser presents a fundamental advance in laser technology. Historically, carbon dioxide (CO_2) lasers demonstrated the value of the laser in various industrial settings. Then, Nd:YAG lasers leveraged their lower operating costs and improved reliability to displace CO_2 in many applications, and also introduce a new set of applications. Fiber lasers, in their turn, displaced Nd:YAG lasers from some applications and made new applications practical. Now, the blue laser is reproducing that pattern. Following historical precedent, blue is supplanting older technologies for some applications, and bringing practicality to a new set of applications. Given that the roadmap for blue laser development shows a clear path to improved capabilities, it seems likely that this trend will accelerate over the coming years.

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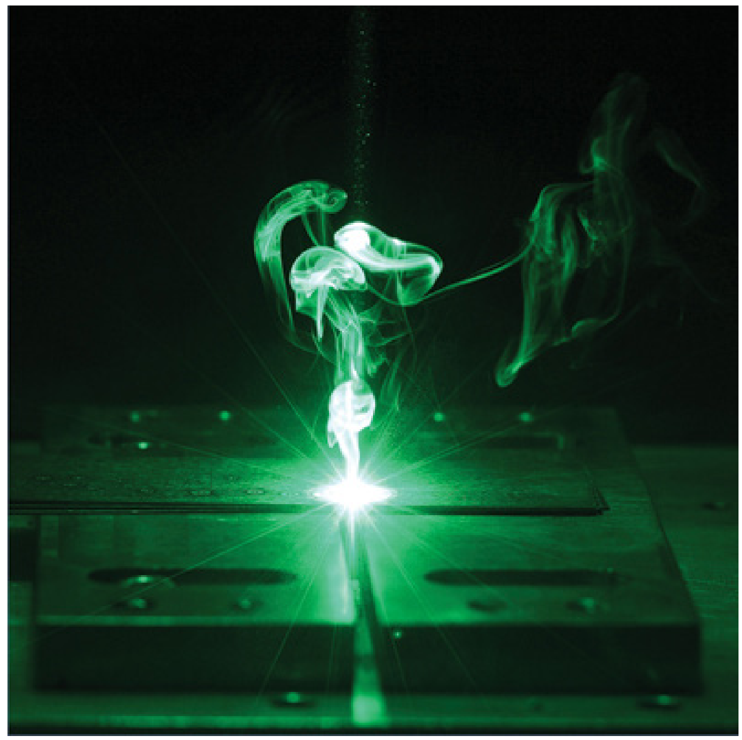
Originally published December 1, 2011

Laser welding at the green wavelength benefits electrified mobility applications



Green wavelength yields process stability, high absorption, and high feed rates

by **HENRIKKI PANTSAR, EVA-MARIA DOLD, MARC KIRCHHOFF,** *and* **OLIVER BOCKSROCKER**

E-MOBILITY HAS BECOME the most important development trend in the automotive industry worldwide during the past five years. Demand for electrified vehicles is increasing substantially because of high performance, driving comfort, ease of operation, reduced maintenance requirements, and environmental factors. Legislation is also driving electrification of transportation[1] and electrified cars are not a niche in the automotive market anymore.

One of the tasks for OEMs, suppliers, and machine builders in the automotive industry is to create reliable technologies from supply chains, and ramp up production of electronic components. This includes handling all aspects of production related to the electrified powertrain. One of the greatest challenges is that components and materials in the electrified powertrain are completely new or used in a different way than what is custom to the automotive industry.

For example, production volumes required of high-capacity batteries or suitable electric motors are unprecedented not only in the automotive industry, but any industry in general.

Crucial components

The most important component is the battery, which consists of single battery cells assembled to battery modules that are then assembled to a battery pack. Reliable battery management systems are needed, as well as housings for the cells and modules for integrating the batteries in the vehicle. Various other electrical components, such as charging systems, converters, and sensor systems, are required to charge the batteries and manage electrical power inside the car.

Besides the battery, an electric drive is needed to bring the power on the road. There are many different designs for the electric drives, from a hybrid drive (a drive concept where the electric drive is directly integrated into the gearbox) to a four-wheel drive, where four electric drives are mounted near the wheels.

What these components have in common is that they did not exist before in a car and, consequently, there is no substantial accumulated experience with these parts. One of the main materials in these components is copper.

Production of all these parts includes lots of challenges with a vast number of opportunities, as manufacturing processes are being defined without a prior gold standard. There is a lot of room for innovation—the laser, as a very flexible tool, can be the key for the eMobility. With this tool, it is possible to fulfill the new requirements in terms of productivity and quality, and scale up production from current small production volumes to high volumes needed in the near future.

Possibilities with lasers

The number of possible laser applications and volume of produced components increases with the eMobility market. Especially in the area of power electronics, powertrain, and battery manufacturing, the laser enables fast welding and cutting with minimal heat input. However, the requirements in each of these areas differ significantly. Welding of electronic contacts on direct bonded copper (DBC) plates requires an exact welding depth, minimal spatter, and heat input, as the surrounding components are very close to the welding position and would be destroyed if the process lacks stability. In the e-powertrain, the welding of hairpins requires high laser power and welding speed with minimal pores and spatters to generate good electrical properties. The same requirements are preconditioned in battery contacts, where accurate welding performance is a key factor for high quality and productivity. Again, most laser applications in these areas of eMobility components contain parts made of copper—the preferred domain for green-wavelength lasers (**FIGURE 1**).

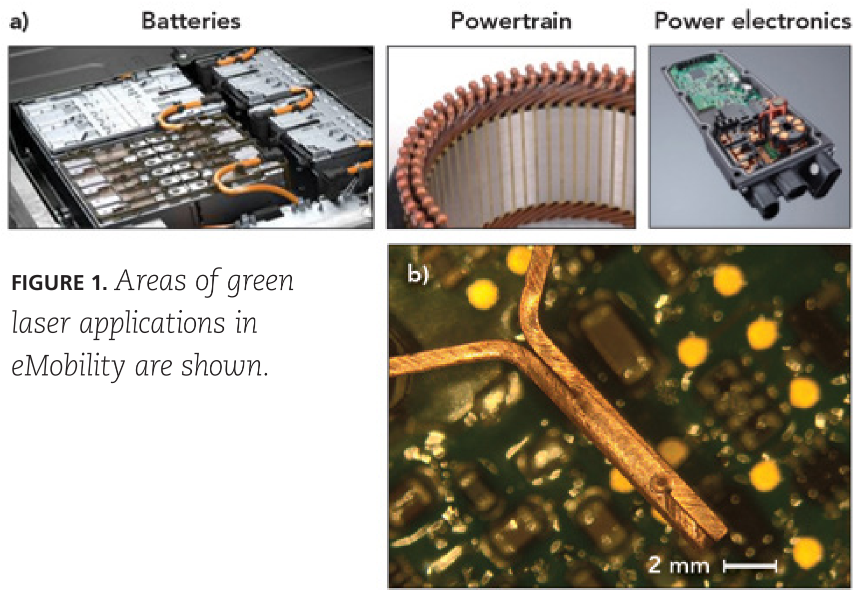


FIGURE 1. *Areas of green laser applications in eMobility are shown.*

The biggest advantage of copper, its high electrical and thermal conductivity, is also the biggest challenge for welding. Ten times higher heat conduction than in commonly used steels requires a very intense energy input. This could be solved with lasers, as this technology contributes high energy intensity on small interaction zones. However, similar material properties, which lead to high electrical conductivity, also lead to high reflectivity. Lasers deliver energy onto the workpiece in the form of light, typically in the near-infrared (near-IR) spectrum. Reflective metals and most transparent materials typically absorb only a small fraction of IR laser light, which creates a challenge for IR lasers.

Only about 5% of the laser energy could be used for heating up the material in copper welding.[2] High intensity is needed to initiate the welding process and heat the material from room temperature, where absorption of the laser light is low. The room-temperature copper surface reflects almost all the laser power to the surroundings, including optics. While this is very inefficient in terms of energy transfer, this could also damage sensitive parts. The absorption of the IR laser beam increases with the temperature up to more than 15% at melting temperature, but this transition is hard to control.[3] The process needs a high intensity to start, but with increasing absorption, the material could overheat. Therefore, heat conduction welding is not well-reproducible. Deep penetration welding, on the other hand, suffers, especially at a low feed rate from weld defects —for example, melt ejections.[4] And, because of lower surface tension and viscosity of copper compared to steel, the melt pool is less stable.

Green laser capabilities, benefits

Absorption of the green laser (515 nm) to copper is 35–40%, so the welding process can be very stable without problems with initial absorption and overheating. Parameters are easy to find and process strategies such as wobbling are not needed. The green lasers by Trumpf are based on thin disk-laser technology and systems are ready for industrial use. The laser light is fiber-guided for easy integration into the machine.

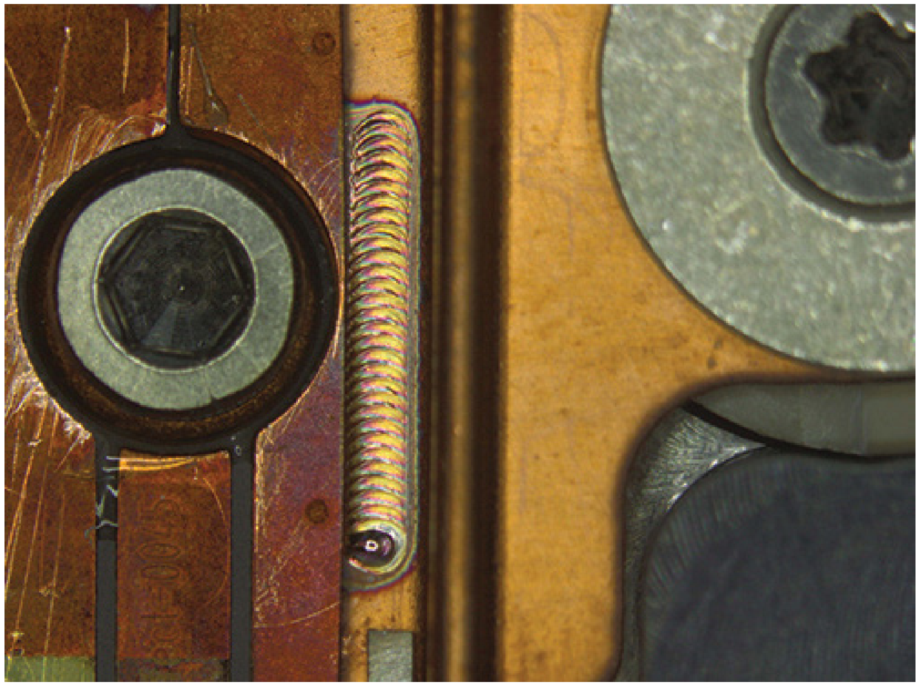


FIGURE 2. *Spatter-free copper welds made with green lasers exhibit very high quality and smooth weld surfaces.*

It is possible to reproducibly weld even foils and small copper parts up to 0.4 mm in thickness in the heat conduction welding mode due to the good absorption of the green laser beam to copper. In the absence of the keyhole and resulting melt dynamics, completely spatter-free copper welding with green lasers has been demonstrated (**FIGURE 2**). This was testified by high-speed video films in which one could see a perfectly smooth melt surface without motion. With comparable IR lasers, reproducible heat conduction welding with copper is not possible because the absorption is temperature-dependent, and the process easily shifts from heat conduction welding to deep penetration welding. Depending on the welding mode, copper foils are either not connected or destroyed.

Keeping the process temperature constantly between melting and evaporation temperature is not possible with IR laser beam welding. Because of process stability and high absorption, high feed rates are possible with the green wavelength, which reduces heat loss from thermal conduction and thermal

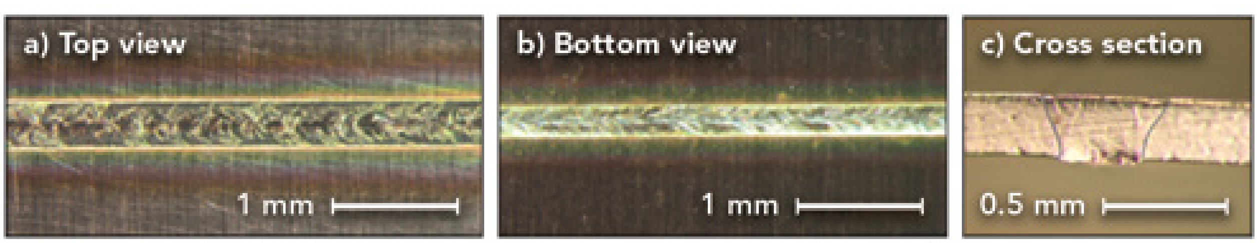


FIGURE 3. *Spot welding of a thermally sensitive component is shown.*

expansion. Heat conduction welding with green lasers is the first choice for battery foil welding and connecting small copper parts in electrical components (**FIGURE 3**).

For very heat-sensitive parts such as DBC plates or welding in heat-sensitive environments, it is recommended to use a microsecond-pulsed green laser. A pulse mode offers more possibilities for thermal process management. The pulse pause effectively reduces thermal stress on the parts and the surrounding material. Gaps up to 0.1 mm are easy to handle by increasing the pulse overlap of the green laser. The material will cool down after each pulse and the thermal input can be reduced. In contrast to IR lasers, welding with a green laser beam does not present a problem with the interpulse cooling and following lack of temperature-dependent absorption.

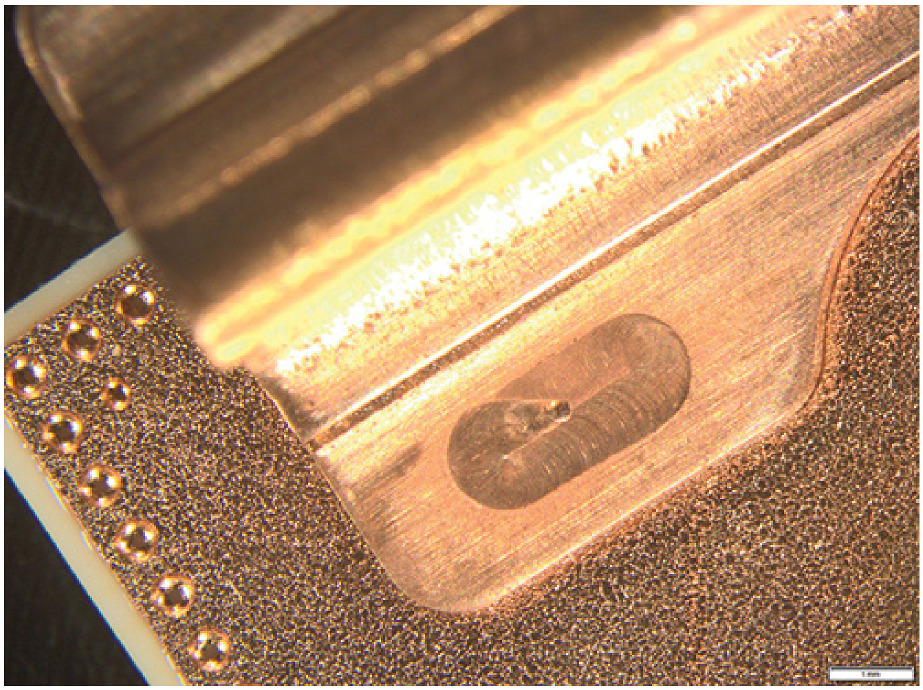


FIGURE 4. *An example of a copper contact on DBC plate, welded with the TruDisk 1020 continuous-wave green laser at 0.1 s, is shown.*

Welding of thicker copper components for higher current flow is also possible (**FIGURE 4**). Copper with high surface quality with thickness up to 0.8 mm is weldable. The maximum welding depth depends on the heat capacity of the part. Small parts or thinner sheets are easier to weld because the thermal conduction to the surrounding material is limited. This is a material issue and independent of the wavelength.

Absorption of an IR laser beam can be enhanced by surface coatings, oxidation, or other surface treatments.5 Coating of copper is not needed when using green wavelength lasers for welding. The absorption phenomenon starts efficiently even at room temperature, regardless of the surface condition. Tests done with polished, sanded, acid-etched, and oxidized surfaces show rather similar welding results. The green lasers show less affection on the surface condition (**FIGURE 5**). Oxidized or polished surfaces can be welded with the same parameters.

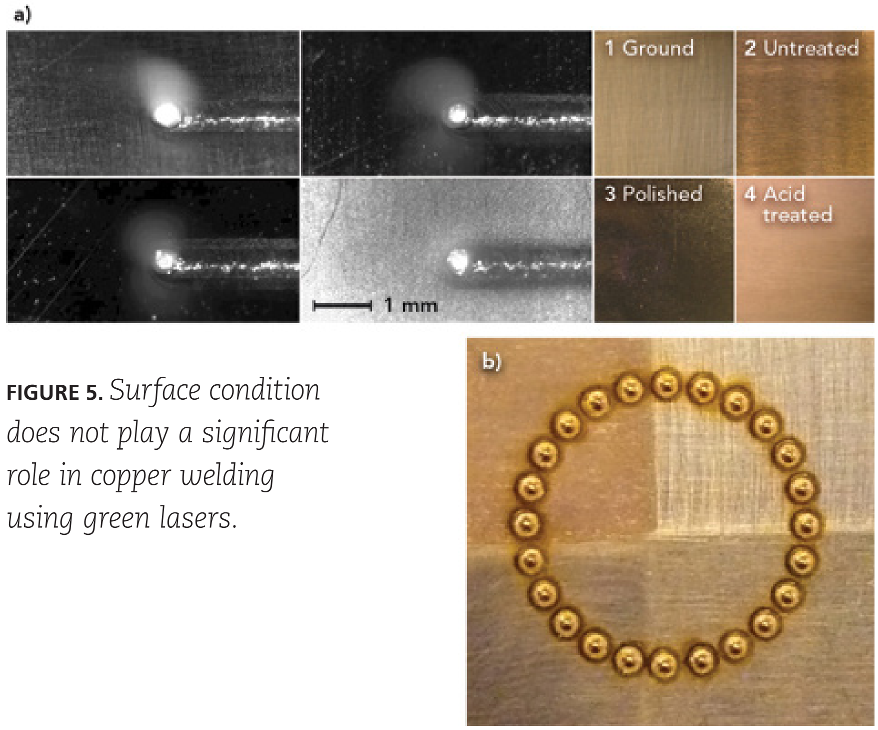


FIGURE 5. *Surface condition does not play a significant role in copper welding using green lasers.*

Conclusion

Copper welding has become one of the most important research topics in the automotive industry because of eMobility. New techniques are needed to produce low-spatter, high-quality welds in copper. Using green wavelength lasers has proven to be a desired method for copper welding. Instantaneous absorption onto a copper surface, in combination with a stable process, is a great advantage when welding electrical components in batteries and electronics. Because of the lack of spatter, even pre-assembled electronic components can be welded without the risk of shorts. Industrial pulsed lasers with 400 W average power and 4 kW peak power are now available, as well as continuous-wave (CW) lasers up to 1 kW. Challenges of laser welding of copper have been overcome with this technology.

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- Laser Power as an Indicator of Process Quality

WHITE PAPER

The challenge of battery production

OPTIMIZING AND CONTROLLING LASER PROCESSES RIGHT FROM THE START

Automakers are investing heavily in electric cars: major investments that come with major challenges. But those who plan strategically and integrate the latest technologies directly into their production processes will not only save in the long term but also ensure both battery quality and safe vehicle operation. New manufacturing concepts and the technologies of e-mobility are tightly linked to laser welding. The goal is to achieve a consistently high level of production quality while continually guaranteeing and documenting this and/or to glean insights from the observed irregularities. This white paper explores where the challenges lie and why the quality of the laser beam plays such a pivotal role in the digitalization of manufacturing processes.

Laser power affects product quality

Irrespective of the specific laser welding process: The quality of the weld-spots or -seams exerts a decisive influence on the safety and reliability of the parts produced, which in turn significantly affects the overall quality of the vehicle. The impacts of a change in the laser profile can be clearly seen in Figure 1. But how can the manufacturers and the end-users of such laser systems – which are often built into automated production lines – ensure proper operation? And how can one document the measurements and glean sustainable insights from these changes? One thing is clear: anyone who relies on their lasers operating without wear and tear must simply live with losses in quality. Especially in production environments, external influences act on the laser beam systems, which in turn lead to changes. Only if these are recognized in time can quality losses, including potential product recalls, be prevented. Exactly this is the advantage of establishing a new production line. New technologies can be integrated individually for the respective application right from the very start.

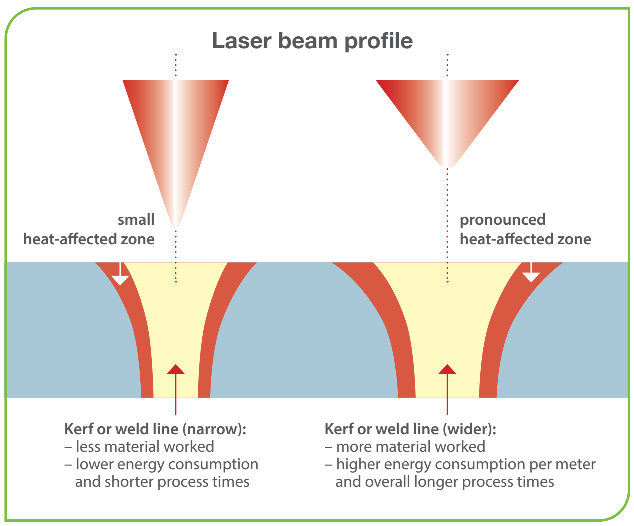

Figure 1: In battery production, high heat input is especially harmful.

Lightweight but stable

In automotive construction, weight plays a critical role; but while all components are made as light as possible, they must still be as rigid as required. Modern laser welding systems enable complex welding geometries and material combinations in car body construction. In drive control, this has led to design changes from bolted to welded constructions, resulting in considerable reductions in weight and space requirements at higher strengths. Plus, laser welding makes it possible to reliably process and join aluminum, high-strength steel and even new, fiber-reinforced materials. Given the above, the production of battery systems for electric vehicles places particularly high demands on laser welding systems. In order to make compact battery packs, the welded electrical contacts connecting the individual cells – whether in series or parallel – must be of very high quality, so that they can be configured to the desired operating voltage and capacity. Especially highly reflective materials, such as copper, are tricky for laser welding systems. Furthermore, a single bad cell connection can cause the performance of a battery module to suffer. A first indication of whether a laser system is working precisely can be obtained through power measurements.

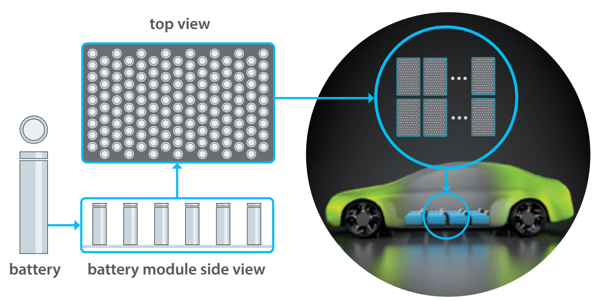

Figure 2: Modules are made up of numerous individual cells, the contacts of which also need to be welded. Several battery modules are then combined into a block, which is safely enclosed in a sealed housing.

Power measurement at the processing level

Lasers with powers in the kilowatt range are frequently used in the construction of auto bodies. To measure these lasers quickly and easily, Ophir®, a brand of MKS Instruments, has developed Ariel, a compact and robust power measurement device.

Figure 3: Ophir Ariel is a robust and self-contained power measurement device that can withstand high power densities.

The system measures a wide range of wavelengths, including 440-550 nm green and blue lasers, increasingly popular in copper welding; 900-1100 nm fiber lasers, used in most metal processing as well as 10.6 µm CO_2 lasers. The Ariel industrial power meter combines two modes of operation to deliver a large measurement range of 200 mW to 8 KW: (a) Measurement of the energy of a short time exposure for high power lasers up to 8 KW, and (b) Longer CW power measurements for lower powers up to 500 W. The system's high thermal capacity of 14 kJ means it can measure several consecutive pulses with an accumulated energy of 14 kJ before it needs to cool down. A detachable diffuser allows measurement of high-power density beams. That means that, for a pulse lasting half a second (as an example), laser powers of up to 8,000 watts can be measured cost-effectively and without requiring any additional cooling on the device. This aspect is particularly important when welding batteries, as water cooling should be avoided at all costs.

Measurements in automated manufacturing

As soon as a laser is deployed in a fully automated environment – as is usually the case in automotive manufacturing – the requirements on the measurement technology change. In the course of digitizing an automated production environment, companies often need the measuring device – in addition to its pure power measurement capabilities – to send its data into the production data network. This requires a compact and robust measuring instrument that can be easily integrated into the production process. MKS developed Helios Plus just for such applications, as it is based on Ophir's same pulsed power sensor technology.

The power gauge determines power and energy of industrial diodes, fiber or Nd:YAG lasers during a short irradiation period between 0.1 and 10 seconds. In addition to measuring infrared wavelengths between 900 and 1100 nm, Helios Plus is able to measure blue and green lasers used in copper welding in the automotive industry. It can calculate the total power up to a maximum of 12 kW or the total energy up to 10 kJ – without requiring air or water cooling. The measurement itself takes a few seconds (or mere fractions thereof), so power measurements can be carried out during the loading and unloading process. Profinet or EtherNet/IP and RS232 interfaces make it possible to store and evaluate the measured values as required. And should the power of the laser on the machining plane drift out of the selected tolerance, immediate countermeasures can be taken to ensure production quality.

Figure 4: MKS developed Ophir Helios Plus for fast measurement of laser power in automated processes. It measures up to 12 kW without additional air or water cooling.

Beam profile reveals power density

Knowing the power of the laser at the machining plane gives a first indication of whether the laser is working within specifications. Details of the focus position – or changes in focus position over time – can only be determined with a device that measures the beam profile. The focus position exerts great influence on the power density and therefore on the quality of the weld seam.

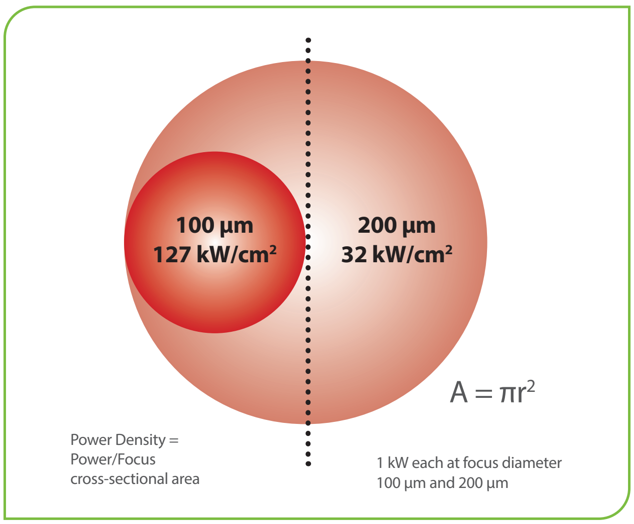

Figure 5: This illustration shows the relationship between focus size and power density: when the focus diameter is only half as large, it results in an intensity that is four times higher.

As Figure 5 shows, even a slight shift in focus position causes a significant change in power density. This in turn directly influences the quality of the weld seam, which, especially in sensitive welding processes, means that only very narrow tolerances can be permitted for changes in power density. Here too, the crux of the issue are the high powers involved.

Non-contact measurement

For this purpose, Ophir developed a non-contact measurement method based on the Rayleigh scattering, which describes how electromagnetic waves scatter as they are deflected off particles in the air that are smaller than the radiation's wavelength, e.g. oxygen or nitrogen molecules. The electric field of the laser radiation induces an oscillation in the dipole molecule at the laser's frequency, thus leading to elastic scattering at that same frequency. The scattered laser light is imaged from the side using a telecentric lens assembly on a CCD or CMOS camera. Each individual pixel in a single line of the CCD camera detects the scattered light as a measuring point of intensity in the beam profile. From these measurements, and using an integrated software with high accuracy, it is possible to calculate beam and beam-quality parameters according to ISO 13694 and ISO 11146 standards, including focus diameter, focus position, divergence, ellipticity, M^2 (1/k) and beam parameter product (BBP).

Since the systems of the BeamWatch® product line are based on this measuring principle, they allow for real-time monitoring of the beam profile. This makes changes to the focus visible. A comparison of different measurement methods recently showed that non-contact measurement technology, although not yet documented in the ISO standards, is fully ISO compliant. Users thus obtain ISO-compliant measurement results that are reliable and repeatable, since there is neither influence on the beam caused by the measuring instrument nor deterioration of the measuring instrument caused by the beam. In the manufacturing process, these measurements can also be combined with the aforementioned power measurements: As a rule, the laser power is briefly tested and then, after a specified production period,

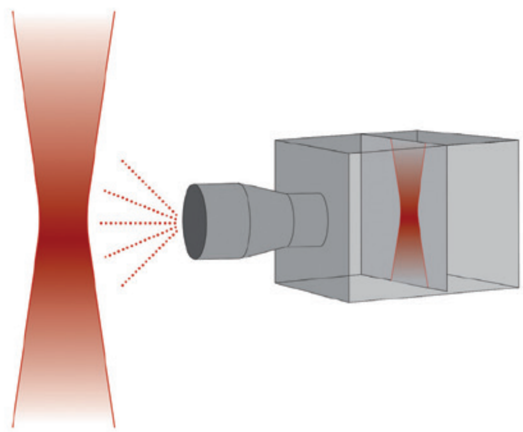

Figure 6: This diagram clearly shows that, during non-contact measurement, the beam is not affected by the instrument. And the device suffers no wear and tear, either.

the beam profile is checked again. Alternatively, integrated systems that measure both power and beam profile can be used. MKS offers different variants for this purpose:

- Ophir BeamWatch - The lightweight and portable BeamWatch measuring devices can be easily transported and have no power limitations because measurement of the laser beam proceeds completely without contact.

Figure 7: Ophir BeamWatch enables non-contact laser beam measurement.

- Ophir BeamWatch Integrated - This robust measurement device is based on non-contact beam profile measurement, but it has an additional power gauge that also acts as a beam trap. It was developed in cooperation with the automotive industry and is particularly suitable for integration into production lines. If desired, the beam profile can be measured during each loading process. Ophir BeamWatch Integrated is fully automated, and all measurement results can be read out and processed via an integrated interface.

Figure 8: Ophir BeamWatch Integrated is optimized for use in automated production lines.

In summary

Which measuring method is best for any given application is an individual choice. Often, only a test measurement can provide a true basis for a decision. But one thing remains clear: just-in-time series production of battery packs poses new challenges for measurement technology. Not only are the battery units the central and most expensive part of any electric vehicle, their performance and safety are directly dependent on their quality. Because these batteries can contain up to several thousand welded joints, it is well worth the manufacturers' while to continuously monitor the reliability of their production process. Only then can quality and maximum productivity be ensured in the long run.

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Whitepaper_E-Mobility_04/2021