# 2024 LaserEMobility Workshop

LASEREMOBILITY

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I July 17 – 18, 2024 I

I Technical University of Munich I

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# ABSTRACT BOOK

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# Introduction

The LaserEMobility section of the Italian Association of Manufacturing (AITeM) is pleased to present its 2024 Workshop. Following the success of the 2022 and 2023 editions, the LaserEMobility Workshop 2024 continues to be a place of discussion for an international audience from industry and academia working on laser-based processing in electric vehicle manufacturing. As the next decade will see an increased use of electric vehicles, laser-based manufacturing methods will be the key to efficient and high-quality electric vehicle production. To facilitate the collaboration in this field, the Technical University of Munich hosts the in-person two-day event with participants from research, laser component manufacturing, system integration, and application communities. The Workshop proposes a unique combination of industrial and academic presentations to an international audience, with technical presentations encompassing the latest technological trends. The presenting companies and universities represent over 8 different nationalities providing a broader vision.
This Abstract Book collects the abstracts of 38 oral and 7 poster contributions on laser-based manufacturing applications in electric vehicle manufacturing presented at LaserEMobility Workshop 2024. The works cover application-oriented topics over the whole field of laser material processing for electromobility, including:

- Battery cell and system manufacturing
- Processing of new battery materials and technologies
- Electric drivetrain manufacturing
- Fuel cell manufacturing
- Lightweight construction
- Process monitoring and control
- Digitalization and data-driven process optimization
- Sustainable electric vehicle manufacturing

## Workshop Chairs

Michael F. Zaeh
*Technical University of Munich*

Ali Goekhan Demir
*Politecnico di Milano*

Alessandro Fortunato
*Università di Bologna*

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# *Industrial – Lasers as Integrated Digital Tools for E-Mobility*

# IPG AMB & LDD Technology in 46XX Mass Production

Daniel Lück [1]

[1] IPG Laser GmbH & Co. KG; dlueck@ipgphotonics.com

**Abstract:** 46XX Cells and their fast implementation and evolvement in today's EV landscape are forcing companies to adjust and also evolve their mass production strategies for that specific cell type. This presentation addresses the four main topics of how to improve and maximize mass production with laser sources and equipment from IPG Photonics. Highspeed welding, high yield and spatter free production processes are required to manufacture products of the highest quality in the shortest possible time. The presentation will focus on four topics of the cell production process, namely welding collector to jellyroll, lid to jellyroll, lid to can and busbar to terminal, including process monitoring for keeping scrap as low as possible. Technologies such as AMB Laser sources and LDD 100% real-time process monitoring are aiding to bring production up to the level required for profitability.

**Keywords:** AMB, Adjustable Beam Mode, LDD, Laser Depth Dynamics, 46XX Cells, Mass production, Welding, Real Time Measurement

# Transform E-Mobility Challenging Laser Processes into Forgiving Ones with Beam-Shaping

Gwenn Pallier [1*], Avinash Kumar[1], Adeline Orieux [1], Guillaume Labroille[1]

[1] Cailabs; gwenn@cailabs.com
*Corresponding author

**Abstract:** The electric vehicle (EV) market is rapidly expanding, driving a significant push towards innovation. One of the key challenges in this domain is the laser welding of Copper and Aluminum. These materials present inherent difficulties in welding, with stringent criteria that include minimal porosity and spatter formation. To address these challenges, advanced beam shaping modules utilizing Multi-Plane Light Conversion (MPLC) technology have been developed. Beam shaping is achieved through two integrated mirrors situated between the collimation block and either a focusing block or a scanner. MPLC technology facilitates highly flexible beam shaping and boasts a depth of field that is four times greater than dual-core technologies, greatly simplifying its application.
The presentation will highlight the benefits achieved in welding real components such as battery modules, busbars, and hairpins. Additionally, it will include an X-ray analysis of the welds and simulations of various beam shapes and their effects on the welding process.

**Keywords:** Beam-Shaping, Laser Welding, Busbars, Hairpins, Cell contacting

# A Novel Battery Cell Foil-to-Tab Laser Welding Process

Thomas Hofmeister [1], Majid Abbasi [2]*

[1] Thomas.Hofmeister@coherent.com
[2] Majid.Abbasi@coherent.com
*Corresponding author

**Abstract:** Pouch and Prismatic battery cells require a welding process, that reliably joins a high number of foils to a current collector or terminal tab, to connect the inside of the foil stack with the outside of the cell. The foil stack usually consists of thin aluminum foils on the cathode side and copper foils on the anode side. LIB cells usually have between 30 to 80 foil layers, but the trend goes to even more foils. State of the art for welding the foil stack to the tab is a two-step ultrasonic welding (UW) process, or a two-step hybrid ultrasonic and laser welding (LW) process. Despite being a solid-state welding process, UW is known to have serious limitations in mass production. Frequent tool wear, production interruptions, foil tear, foil sticking, and formation of fine metal dust are few examples. Additionally, it is extremely challenging to reliably weld over 80 foils repeatedly. Therefore, the LIB cell producers are looking for an alternative non-contact laser weld process, to eliminate the disadvantages and increases the flexibility in production. Up until now, existing laser welding processes had limitations in the number of foils and with the weld quality, especially on the aluminum cathode side. Coherent was able to develop a new laser welding process to replace the two-step ultrasonic with a single-step edge welding. This innovative patent pending process works for stacks of more than 120 foils and with the same high quality on both, the anode and cathode sides. The key to process success is the special features of the newly introduced Coherent PH20 SmartWeld+ precision remote welding head with its advanced beam wobble capabilities and precise control of laser energy in combination with adjustable ring mode (ARM) laser.

**Keywords:** Foil welding, Laser welding, Non-contact process, PH20 SmartWeld+, ARM Laser

# Highly Integrated Lasersystems for E-Mobility Production

Matthias Beranek (IWE), Industry Management E-Mobility

[1] TRUMPF Laser- und Systemtechnik GmbH; Matthias.Beranek@trumpf.com

**Abstract:** E-Mobility has raised the bar for laser technologies as a whole. Rather than discussing single components such as the laser beam source or single sensors, highly integrated lasersystems have become a standard especially for single assemblies exhibiting a multitude of joints to be carried out. Before the background of sheer statistics, reliability and repeatability has turned even more into a key figure for production. The presentation will give an overview of the latest state of laser systems capabilities and functions. This will include multi-spot waveguides, combined and artificial intelligence aided sensors as well as adaptive welding processes that are used in the relevant battery-, electric drive- and power electronics productions to increase the processing windows and therefore reliability of the joining processes.

**Keywords:** Integrated, laserwelding, copper, aluminium, beam shaping, process sensors, artificial intelligence

# Flexible Beam Shaping for Enhanced Electrical Contacting of Cylindrical Cell Batteries

Lukas Mayr [1,*], Klaus Krastel [1], Francesc Caballero-Lucas [1] and Michael Lee [1]

[1] Maxphotonics GmbH, 82205 Gilching, Germany; lukas.mayr@maxlasers.com
*Corresponding author

**Abstract:** The process of electrical contacting for cylindrical cell batteries via laser beam welding remains challenging due to the high reflectivity of busbar materials such as aluminum and copper, together with the stringent quality requirements in the automotive industry. To address these challenges, the industry and research sectors are increasingly focusing on advanced beam shaping techniques. This study investigates the effectiveness of various laser systems, including a single-mode laser, a ring-core laser welding system, and a flexible beam shaping laser with a multi-fiber approach, for the welding of thin sheet copper and aluminum respectively onto hilumin. Comparative analyses show a significant reduction in spatters and humping for both materials at high welding speeds using the multi-fiber approach compared to the simple single-mode and even the ring-core systems. With four independently controllable fibers, welding speeds exceeding 1.000 mm/s for both material combinations were reached without humping and no significant spatters.

**Keywords:** flexible beam shaping, ring core lasers, battery welding, process analysis

# High-Performance Laser Welding for E-mobility Enabled by Laser Spatial and Temporal Control and System-Integrated Process Monitoring

Andrea Braglia[1,*], Alessio Califano[1], Tyson Lowder[2], and Dahv Kliner[2]

[1] nLIGHT Europe S.R.L.; andrea.braglia@nlight.net
[2] nLIGHT, Inc. US
*Corresponding author

**Abstract:** Laser welding is the second-largest industrial market for high-power lasers, with significant growth driven by automotive and e-mobility applications. These demanding applications require high productivity and high quality, and innovations within the laser source and in real-time process monitoring are providing dramatic increases in throughput, yield, and process stability while minimizing joining defects. Advanced spatial and temporal control of the laser beam can significantly stabilize the melt pool reducing spatter and porosity defects, while improving weld uniformity and productivity; this capability is available in fiber lasers at 500 W to 20 kW. Detecting process deviations and potential welding defects is enabled by in-process monitoring using real-time algorithms at a 250 kHz sample rate across a broad wavelength range of 400 – 1800 nm. Furthermore, integration of the optical process sensors into the laser system results in a solution that does not require modification of the processing head or scanner by adding hardware that can have detrimental effects due to limited access, additional weight, and reduction in overall system reliability. As a case study, we present results of high-productivity, high-quality laser welding of bipolar plates for fuel cells.

**Keywords:** laser welding, laser beam shaping, fuel cells, process monitoring

# How CO2 Lasers Contribute to Battery Manufacturing and Help to Reduce Carbon Footprints

Christian Dini [1], Dr. Louise May [2]

[1] Luxinar GmbH, Röntgenstrasse 6, 21465 Reinbek, Germany
[2] Luxinar Ltd. Kingston upon Hull, United Kingdom
*Corresponding author Christian.dini@luxinar.com

**Abstract:** The best battery for each application is a challenge for R&D and manufacturing. We all hear about mining lithium or copper and their effects on nature. The result is that batteries have experienced a rapid change in their material composition. Raw earth material saving, electrode cutting and welding are some of the big topics. This talk will focus on a less obvious sector in the manufacturing process, the foil sector, for unwrapping completed battery cells or separating electrodes inside the cell. Currently, separator cutting is mainly a mechanical process, but with ceramic coatings this is cumbersome due to increased wear on the cutter and particles coming loose. At the same time, battery manufacturing has yield issues, and non-conforming cells need rework. Before they can be processed, the sticky plastic wrap needs removing. This ablation is a labour-intensive manual process and uses unwanted solvents. Using CO2 laser technology opens up new methods of cutting and unwrapping.

**Keywords:** Laser Cutting, Laser Ablation, Battery Foils, Lithium Battery Circular Economy, Lithium Battery Manufacturing

# Examples of Tailored Solutions in Laser Welding: High Power Blue Laser Application in Copper Welding, Benefit of Single Mode Laser in Aluminum Remote Welding, IR Beam Shaping Applied to Martensitic Stainless Steel

PhD-ing. Stefano Zarini [1], Ing. Salvatore Salerno2 [2], and Ing. Tugay Kurtay [3]

[1] Optoprim srl; zarini@optoprim.it
[2] Optoprim srl; salerno@optoprim.it;
[3] Optoprim srl; kurtay@optoprim.it;

**Abstract:** Laser welding offers a high degree of flexibility, making it an attractive choice for a wide range of applications and industries. Its precision, versatility, speed, and ability to work with various materials make it a valuable tool in modern manufacturing and fabrication processes. However, being able to select optimized set-up (laser source, optics, monitoring system and accessories) to perform a specific task efficiently in a specific production environment (24/7 or job shop) is the key factor for a successful application. Different materials require different wavelengths, different cycle time requires different type of integration and laser sources. A potentially infinite number of combinations that requires knowledge, competence and skill to effectively address the best choice In the present work three different application cases are presented highlighting how different processes benefit from different set-up:

1) Use of 3kw blue laser for copper welding. Laser diode are well know to have larger spot diameter compared to fiber laser. In this approach we present the complete welding of a stator using 720 um spot on the work peace without pattern recognition and without wobbling.

2) Use of single mode laser coupled with long f-theta lens for aluminum welding. Due to its high reflectivity at 1070 nm, small laser spot and the use of wobbling allow to reduce the amount of power to achieve same penetration level in laser welding. In this solution, a pro and cons analysis is shown of using this approach.

3) Use of beam shaping applied to martensitic stainless steel to enhance deformability in subsequent machining. In the following study, a comparison between standard laser and beam shaping is presented together with deformability of welded parts.

**Keywords:** e-mobility, welding, aluminum, beam shaping, blue laser, copper

# Laser Systems for E-Mobility Production

Richard Hendel [1], Johannes Schäfer [2]*
[1] Richard.Hendel@laserline.com
[2] Johannes.Schaefer@laserline.com
*Corresponding author

Laserline GmbH, Fraunhofer Straße 5, D-56218 Mülheim-Kärlich
Phone: +49 2630 964-1330
Mobile: +49 172 2009164
E-Mail: richard.hendel@laserline.com
Internet: http://www.laserline.com

**Abstract:** This presentation is split in 2 sections and presented by 2 persons.
The first part explores new diode lasers designed for energy-efficient drying and heat treatment processes. Emphasizing the advantages of large spots, we explore practical benefits such as enhanced coverage, uniformity, and improved coating quality by closed-loop temperature control. These diode lasers contribute to increased efficiency, reduced processing times, and enhanced throughput. Serving as enablers for the electrification of traditionally fossil fuel-driven heating processes, they significantly reduce CO2 emissions associated with heating. Attendees will gain valuable insights into the practical advantages of integrating Laserline's diode lasers into drying and heat treatment processes, enhancing sustainability and cost-effectiveness in manufacturing. Based on the diode laser technology described in the first part, further applications with IR and blue laser wavelength will be described. A focus will be put on welding with blue laser wavelength specifically designed for welding copper materials. By a higher absorptivity and therefore better process behavior, a more robust process for welding copper materials is possible. Besides that, the advantage of welding with IR diode laser technology will be described in detail.

**Keywords:** Laser drying, diode lasers, blue laser, remote welding

# Optical Coherence Tomography (OCT) in Combination with Actual Welding Tasks

Richard Steinbrecht [1], Marcel Baader [2], Dr. Marius Schwarz [3]

[1] Lessmüller Lasertechnik GmbH; rs@lessmueller.de
[2] Lehrstuhl für Fertigungsautomatisierung und Produktionssystematik der FAU; marcel.baader@faps.fau.de
[3] Mercedes-Benz AG, Marius.Schwarz2@de.bosch.com
*Corresponding author

**Abstract:**

**A.) The latest development of synchronous operation of remote welding with OCT for seam tracking and depth measurement is presented. Applications: Welding of prismatic cells, busbar and battery connectors.**

**B.) Depth measurement during hair pin welding**

Background: OCT is an upstream solution for industrial laser welding that enables high process flexibility, productivity, and reliability. OCT adapted to various laser processing optics guarantees precision and reproducibility of welded components by performing pre-, in-, and post-process control.
A.) The use of a Scanlab RTC5 card to control and synchronize both the main laser galvoscanner motion and the OCT beam scanning enables the measurement inside the key hole during oscillation welding. Studies show that keyhole depth measurements by OCT are in good accordance with actual weld depths measured by etched probes.
B.) The weld quality of hairpins is essential for the quality of the electric motor itself. So far only OCT can online measure the key hole depth during welding at industrial scale. The first results are shown.

**Keywords:** Optical Coherence Tomography, Seam Tracking, Key-hole Measurement, Laser welding, Hairpin, Busbar

# Dynamic Beam Laser Welding for E-Mobility Applications

Dr.-Ing. Robert Bernhard[1]*

[1] Civan Lasers Europe GmbH, Hollerithallee 16a, 30419 Hannover; robert.bernhard@civanlasers.com
*Corresponding author

**Abstract:** The burgeoning electric vehicle (EV) industry necessitates the development of high-quality, fast, and robust joining techniques. For example, aluminum and copper metals offer the ideal combination of lightweight design (aluminum) and superior electrical conductivity (copper), crucial for EV performance. However, conventional welding methods struggle with the unique challenges presented by high-strength aluminum alloys, aluminum die-cast structures, coated steel, copper spatter formation and gap tolerances in EV components. This presentation introduces Dynamic Beam Laser welding, a novel technology for metal joining. This method offers real-time manipulation of the laser beam during the welding process. By dynamically adjusting laser intensity, Dynamic Beam Laser welding enables precise control over the keyhole, overcoming the limitations of conventional laser welding. This presentation delves into the innovative principles of Dynamic Beam Laser welding and its potential to address the intricate aluminum, copper joining, and other challenges encountered in E-Mobility. The ability to achieve high-speed welding while maintaining maximum density and minimal spatter, particularly relevant for battery cooling plate assemblies, will be a significant advancement for the EV industry.

**Keywords:** Dynamic Beamshaping, Laser welding, E-Mobility.

# *Industrial – Lasers for the Electrification in Automotive*

# Service-Oriented AI Platforms for Process Monitoring in the Case of Laser Beam Welding

Georgij Safronov [1]

[1] Georgij.Safronov@bmw.de

**Abstract:** Service-oriented AI platforms are generally transforming industrial monitoring processes, with laser beam welding in electromobility serving as a cutting-edge example of this innovation. By aggregating data from both temporal and spatial dimensions, these platforms enable the implementation of advanced quality monitoring techniques. This research, conducted in collaboration with the Technical University of Munich (TUM) and Fraunhofer, aims to leverage these platforms to significantly enhance production efficiency and product quality in the field of electromobility. Service-oriented architectures enable the efficient extension of data pipelines to incorporate new applications, such as the aforementioned monitoring techniques, with minimal disruption. These services also improve accessibility for end-users by providing intuitive interfaces and modular functionalities, thereby facilitating the integration and utilization of advanced monitoring systems. The focus will be on exploring the potential of future developments in data aggregation and service-oriented platforms to advance the monitoring and control of welding processes, ultimately driving innovation and higher standards in industrial manufacturing.

# Advantages of PC-based Control Technology in Battery Production

Karsten Schätzle
[1] k.schaetzle@beckhoff.com

**Abstract:** PC-based control technology plays a crucial role in modern battery production, which is becoming increasingly important due to the rise of electromobility and renewable energy. This technology offers significant advantages over traditional control systems. It is more flexible and scalable, allowing easy adaptation to various production requirements. Cost efficiency is achieved through lower acquisition and maintenance costs, as well as the use of standardized components. Additionally, PC-based control technology provides higher computing power, enabling complex calculations and real-time data processing. Integrated communication and networking support modern protocols and network technologies, improving data collection and analysis. Advanced HMI solutions enhance user-friendliness, and intuitive dashboards facilitate better decision-making. Practical examples demonstrate significant improvements in efficiency, quality, and cost-effectiveness. These advantages make PC-based control technology an indispensable component for forward-looking battery production.

**Keywords:** PC-based control, battery production

# Laser Hairpin Stripping: Comparison of Different $CO_2$ Lasers and Mechanical Milling

Giulio Borzoni [1], Daniele Nocciolini [1], Rubino Corbinelli [1], Alessandro Bartoli [2]

[1] IMA Automation; giulioborzoni@atop.it
[2] El. En. Laser; a.bartoli@elen.it

**Abstract:** Stripping of copper wires is a fundamental process in stators manufacturing. When welding of conductors has to be performed, the wires must be cleaned by the insulant layer, to not introduce damaging materials in the weld and to avoid the reduction of the weld characteristics. IMA Automation ATOP proposes two different stripping methods: laser stripping and mechanical stripping. Laser stripping is using $CO_2$ lasers to burn the insulant layer and expose the pure copper, ready for welding. Mechanical stripping has the same purpose, but the insulant is milled by four mills. Both processes are performed for the wire production on a continuous line. Advantages and drawbacks of both technologies are evaluated in terms of quality of the stripped parts with analysis of the residual layers and profiles. Moreover, welding of samples is comparing the mechanical characteristics of the joints for the different stripping technologies.

**Keywords:** laser stripping, mill stripping, de-insulation, line production

# Always in Focus! OCT-Based Position Detection and Automatic Focus Adjustment for the Contacting of Battery Cells

Habedank, Jan Bernd [1,*], Ghadimi, Reza [2], Lehmann, Wolfgang [3]

[1] RAYLASE GmbH; j.habedank@raylase.de
[2] RAYLASE GmbH; r.ghadimi@raylase.de
[3] RAYLASE GmbH; w.lehmann@raylase.de
*Corresponding author

**Abstract:** Billions of laser weld seams will have to be produced in the production of battery systems in the near future - reproducibly and with low reject rates. However, dimensional tolerances of the individual battery housings and irregularities in their arrangement in modules or packs lead to considerable deviations from an ideal focal plane. This poses a major challenge for reliable battery contacting - especially if the process window is narrow, as it is often the case for highly reflective materials such as copper. As a solution, RAYLASE presents a pre-focusing laser beam deflection unit with an integrated distance sensor, which operates based on the principle of optical coherence tomography (OCT). It enables precise z-position detection of the batteries (< 20 µm accuracy) and quickly readjusts the focus position for each individual contact. This guarantees optimum welding execution within the process window - regardless of possible workpiece or assembly tolerances. The distance measurement takes place within 10 milliseconds, which minimizes the influence on the overall process time. A particularly unique feature is that scan fields of up to 550 x 550 mm² can be covered, which is advantageous for the ever-increasing size of battery cells and modules. Various other possible applications of the sensor in the areas of laser machine calibration and quality assurance are foreseeable and will be discussed in the presentation.

**Keywords:** laser welding, battery, sensor, OCT, quality assurance

# Measurement Challenges of Green or Blue Lasers

Nicolas Meunier [1]

[1] Nicolas Meunier; nicolas.meunier@mksinst.com

**Abstract:** The automotive industry is facing tremendous change, including the advent of the electric car. Whether we are talking about connecting large battery packs or welding motor hairpins – there is a growing need to weld copper. As copper is highly reflective in NIR wavelengths, new high power green and blue laser technologies have been emerging. At the same time, both the production processes in the field of e-mobility and the packaging density of the batteries themselves are being increased. But there are challenges when dealing with green or blue lasers. Laser experts agree on the need to measure laser parameters to ensure the quality of the produced parts. What are the options with these new wavelengths and how can you measure in an automated production line? What are best practices for gaining reliable data for trouble shooting, predictive maintenance, and quality documentation?

**Keywords:** measuring green and blue lasers, copper welding, beam analysis, focal shift

# Increasing your OEE by Advanced Sensors

F. Hermann[1,*], L. Monaco[1], M. Kogel-Hollacher[1], and J. Reiser[1]

[1] Precitec GmbH & Co. KG; f.hermann@precitec.de
*Corresponding author

**Abstract:** Precitec stands for the passion for light, which we make use of in the fields of optical measurement, laser cutting and laser welding. In this contribution, we invite you on a journey along the battery production chain - starting with (i) electrode via (ii) cell up to (iii) module production. Various photonic technologies are used during production and some of them even interact with each other, enabling closed-loops or a roll-to-roll repair.

Example#1: After coating, the edge profile can be measured by chromatic confocal means and the superelevation can be removed by laser ablation. Example#2: Residual moisture during drying can be determined by lock-in thermography and the laser drying process can be adapted accordingly. Or, example#3: Thickness of insulation layer (stripe of Al2O3 on cathode) can be measured by interferometric means and the subsequent laser notching process can spare out regions of damaged insulation. The presentation concludes with an example showing an Machine Learning approach applied to advanced sensor data that greatly simplifies the operator's life and significantly increases throughput.

**Keywords:** In-line quality monitoring, Closed-loop control, Roll-to-roll repair

# Synchronization of Welding Tools, Camera Systems and Linear Stages for Mass Production of Battery Packs

Benjamin Bopp [1*], Ralf Nürnberg [2], and Thibault Bautze-Scherff [3,]

[1] Blackbird Robotersysteme GmbH; B.Bopp@blackbird-robotics.de
[2] Blackbird Robotersysteme GmbH; R.Nuernberg@blackbird-robotics.de
[3] Blackbird Robotersysteme GmbH; t.bautze-scherff@blackbird-robotics.de
*Corresponding author

**Abstract:** The welding tasks for busbars and batteries are growing in importance and remain a crucial step in the manufacturing of battery packs. With the rising interest in cylindrical battery cells, the demand for high-throughput machines is increasing, while simultaneously emphasizing the need for enhanced process control and monitoring. On-the-fly welding has always been a tool to maximize productivity, but camera-based systems for seam tracking have been limited in their on-the-fly usability. Blackbird has developed an innovative system solution that enables users to combine high-precision workpiece detection with 2D gantry systems and remote laser welding systems. This presentation outlines the challenges encountered, initial results, and provides an outlook on additional benefits for material processing applications.

**Keywords:** Remote Laser Welding, On-the-fly processing, Battery manufacturing

# *Industrial – Quality Assurance for the Use of Lasers*

# Innovative Laser Processes for Advanced Battery and Power Electronics Manufacturing

Luca Schmerbeck [1]

[1] Sonplas GmbH ; l.schmerbeck@sonplas.de

**Abstract:** In the rapidly evolving field of e-mobility, the demand for high-quality, efficient manufacturing processes and equipment is paramount. Sonplas GmbH, a leading special purpose machine manufacturer, leverages cutting-edge laser technologies to meet these demands. This presentation will explore our advanced laser processes, focusing on laser welding and laser cutting applications within the e-mobility sector. Our comprehensive support begins early in the design phase, where we assist customers in setting up laser systems, conducting testing, and trial runs, and providing support during production ramp-up. Our dedicated R&D team delves deeply into the intricacies of laser cutting and welding, ensuring robust solutions tailored to specific needs. In battery module production, we excel in welding busbars to cells with critical tolerances, achieving competitive cycle times. Our expertise extends to high voltage applications in power electronics, where our copper welding solutions demonstrate exceptional performance. For laser cutting, we achieve active material cutting with web speeds up to 180m/min for both cathode and anode materials. Notably, Sonplas is the sole provider of a cathode laser cutting solution featuring a tested and safe suction system. Our experience extends to all electrode materials, including solid-state battery materials, ensuring versatile and reliable cutting solutions of highest quality. This presentation will provide insights into our laser processes, showcasing real-world applications and success stories. Attendees will gain an understanding of how our innovative laser solutions contribute to the advancement of battery and power electronics manufacturing in the e-mobility industry.

**Keywords:** machine manufacturing, laser cutting, laser welding, R&D

# Modular Laser Cell Kit for Enhanced E-Mobility Manufacturing: Integrating High-Performance Control Technology with AI-Driven Precision

Dr.-Ing. Maximilian Schmöller[1,*], Michael Böhler[2], Martin Weber[3], Ben Schmid[4]

[1] S&B Automotive Engineering GmbH & Co. KG; m.schmoeller@sub-automotive.de
[2] S&B Automotive Engineering GmbH & Co. KG; m.boehler@sub-automotive.de
[3] S&B Automotive Engineering GmbH & Co. KG; m.weber@sub-automotive.de
[4] S&B Automotive Engineering GmbH & Co. KG; b.schmid@sub-automotive.de
*Corresponding author

**Abstract:** At S&B Automotive Engineering, we are proud to introduce our Modular Laser Cell Kit, designed specifically to meet the evolving needs of the e-mobility sector. This innovative system incorporates advanced control technology with Artificial Intelligence (AI) models, enabling high-precision in-line weld depth control, which is essential for the production of high-voltage storage units. Our presentation at the Laser-E-Mobility Workshop will demonstrate how this system not only meets, but exceeds the stringent joining technology requirements necessary for the production of electric vehicles. The key to our modular system is its flexibility and efficiency. By adopting a modular approach, similar to that used in the conventional automotive body shop, we enable rapid adaptation to changing manufacturing requirements, and significantly reduced lead times. This adaptability ensures that our customers can respond quickly to market changes without compromising performance or quality. In addition, our solution emphasizes a sophisticated level of process monitoring and control. By integrating a closed-loop system that uses real-time data and AI algorithms, we provide an advanced level of in-line process monitoring and adjustment. This ensures that each joint is performed with optimal precision, increasing the reliability and safety of the final product. Our presentation will provide an in-depth look at the technical aspects of our system and how AI-enabled control technology can improve manufacturing processes, simplify maintenance and ensure long-term operational efficiency. Join us to discover how S&B Automotive Engineering is working to create a new landscape for e-mobility manufacturing, with solutions that are as dynamic as the industry itself.

# Manz Approach in Advanced Laser Technology and Systems in E-Mobility

Dr. Karsten Contag [1], Dr. Michele Serri [2,*]

[1] Manz AG, Reutlingen (GER); kcontag@manz.com
[2] Manz Italy Srl, Sasso Marconi (ITA); mserri@manz.com
*Corresponding author

**Abstract:** In the field of E-Mobility, Manz AG has developed laser processes for cutting, scribing or welding of different materials, ablation of layers, and thermal activation of adhesive elements. The automotive industry applies these processes in the manufacturing of battery cells, battery modules, and inverter systems. Notching of electrodes is an essential production step in cell manufacturing. Manz has developed laser notching machines and processes that overcome the limitations of traditional mechanical notching. Various aspects of the laser notching process are shown. Also, for welding of electrode tabs to current collectors Manz has developed a serial production machine that makes use of the advantage of laser process over traditional ultrasonic tab welding. To meet the high demand of various other laser processes in battery cell and module production, Manz AG has designed a laser platform that allows the use of different laser beam sources and optical setups. To determine which laser process is most suitable for a required material combination, Manz offers companies the testing of 4 different laser welding processes in its Laser Application Center in Reutlingen.

**Keywords:** Laser battery production, laser notching, laser tab welding, serial production machines

# Hard Coated Disks for E7 Regulations Performed by Laser Cladding in Automotive Mass Production

Erica Librera [1], Federico Mussinatto [2], and Daniele Grossor [3,*]

[1] Affiliation 1; erica.librera@primaadditive.com
[2] Affiliation 2; federico.mussinatto@primaadditive.com
[3] Affiliation 3; daniele.grosso@primaadditive.com
*Corresponding author

**Abstract:**
The introduction of the European standard EURO 7 in 2026 concerning the reduction of PM10 pollution opens the doors to the use of laser coating and the additive manufacturing technology in the automotive industry. In the actual situation a large part of PM10 particles is produced by the braking system of vehicles: the friction on the brake disc surface generates a slow degradation of the surface itself which releases particles with diameter less than 10 µm into the atmosphere. The new legislation provides for a specific reduction of 27% of the particulate generated by the braking system. Hence the need to cover the outer surfaces of the disc with a material performing better in terms of wear and friction resistance. The promising solution is represented by the direct material report, in particular the Rapid Coating (RC) technology, able to guarantee a very good adhesion between the base material and the new metallic layer. RC is a technology with the same basics of the Direct Energy Deposition (DED) one, based on interaction between a laser source and a metal in form of powder, but has specific features to permit the deposition of very thin layers of material, as the focal position, the speed of the process and the technical specifications of the powder. Prima Additive has developed an efficient solution ensuring small cycle times in a compact and flexible cell, able to increase the lifetime of the discs.

**Keywords:** brake disc, rapid coating, additive manufacturing, laser technology, powder

# *Academic – Temporal and Spatial Beam Shaping*

# The Effect of Process Parameters on Cut Quality of Li-Ion Electrodes Using a Single-Mode Continuous Fiber Laser

Erica Liverani [1, *], Caterina Angeloni [1] , Alessandro Ascari [1], Alessandro Fortunato [1]

[1] Department of Industrial Engineering (DIN), Alma Mater Studiorum - University of Bologna, viale Risorgimento 2, Bologna, Italy; erica.liverani2@unibo.it
*Corresponding author

**Abstract:** Coated Al and Cu current collectors are employed for the production of Li-ion batteries, functioning as cathodes and anodes. The increasing demand and the need for net zero-defect cutting quality are driving industrial production to seek technologies that are fast and reliable at the same time. This is why laser-based cutting processes are currently considered the most valid alternative to conventional methods. The state of art in electrode cutting involves the application of short pulse ns lasers. Yet, the speed at which laser manufacturers release new laser sources, optics and scanning heads opens up new opportunities to improve process productivity and quality. This paper aims to study the laser-electrode interaction when a single mode SM continuous CW source is applied, by varying the power and the laser speed. The cutting performance for processing anodes and cathodes with scanning rates of up to 8 m/s, is thoroughly analyzed in this paper. Comparisons are carried out among the outcomes concerning kerf geometry, maximum and minimum cutting speed and power. Cut quality and the presence of defects such as burrs, clearance width and heat affected zone are analyzed and correlated with process parameters. The identification of configurations that lead to high and low-cut quality enables the definition of detailed process parameter windows for both materials.

**Keywords:** continuous fiber laser, lithium-ion battery, electrode

# Spatial and Temporal Beam Shaping for the Reduction of Hot-Cracking Susceptibility of 6XXX Alloys During Laser Welding

Francesco Galbusera[1*], Matteo Brambilla[1], Serge Dib[1], Ali Gökhan Demir[1]

[1]Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156 Milan, Italy
*Corresponding author francesco.galbusera@polimi.it

**Abstract:** The lightweight aluminum alloy grades are extensively utilized in the electromobility applications in battery casing, packs and modules as well as cooling plates due to their exceptional mechanical properties. The AA6XXX series are preferred for structural parts as they provide high mechanical resistance. However, during rapid solidification processes inherent to laser welding, AA6XXX grades are prone to developing hot cracks, either in solidification or liquation mode, which significantly limit their processability and applicability. The extended control of laser power intensity profile in space and time may allow to reduce or suppress the crack formation.
This work studies the laser welding of AA6082 with different temporal and spatial beam shaping strategies with the aim of assessing whether the hot cracking issue can be addressed and potentially resolved solely through laser/scanner-based strategies, without altering the chemical composition. A contemporary multi-core fiber laser system is employed to explore the possibility of using ring/core beam shapes, along with temporal and spatial oscillation strategies. The results indicated that hot cracks could develop regardless of the tested irradiance profile, ranging from a Gaussian to novel ring-shaped beams, and that mostly the scan speed of the beam regulated the cracking severity. Similarly, the use of temporal power waves, such as sinusoidal, square, or saw-tooth waves, at various frequencies, namely 0.1–1 –10 kHz, was found to reduce but not suppress completely crack formation. Instead, spatial beam oscillation, particularly with Chevron-like and Triangular-like patterns, was found to be the most effective strategy in the suppression of hot cracks.

**Keywords**: Beam shaping; Wobbling; Beam oscillation; Power modulation; Al-alloys

# Challenges and Opportunities in Laser Beam Shaping for Advanced Laser Welding in E-mobility Manufacturing and Beyond

S. Jabar [1,*], M. H. Khan [2], Q. Hayat [3], V. V. Pamarthi [2], T. Sun [3], H. R. Kotadia [2], D. Ceglarek [3] and P. Franciosa [2]

[1] WMG, University of Warwick, Coventry CV4 7AL, UK; sharhid.jabar@warwick.ac.uk
[2] WMG, University of Warwick, Coventry CV4 7AL, UK; mir-hamza.khan@warwick.ac.uk
[3] WMG, University of Warwick, Coventry CV4 7AL, UK; qamar.hayat@warwick.ac.uk
[4] WMG, University of Warwick, Coventry CV4 7AL, UK; venkat-vivek.pamarthi@warwick.ac.uk
[5] WMG, University of Warwick, Coventry CV4 7AL, UK; tianzhu.sun@warwick.ac.uk
[6] Liverpool John Moores University, Liverpool L3 3AF, UK; h.r.kotadia@ljmu.ac.uk
[7] WMG, University of Warwick, Coventry CV4 7AL, UK; d.j.ceglarek@warwick.ac.uk
[8] WMG, University of Warwick, Coventry CV4 7AL, UK; p.franciosa@warwick.ac.uk
*Corresponding author

**Abstract:** With a mandate to deliver high-quality products and high-volume throughput, the demand for laser beam welding is rapidly growing, catalysed by the need for diverse manufacturing sectors, such as production at scale of battery systems, e-drives, electrolysers, and fuel cells in e-mobility. With unprecedented advancements in ultra-fast scanning technologies and new ways for beam shaping, new avenues are being explored to tailor weld profile and microstructure, while optimising the functional performance of welded structures. This paper reviews current challenges and opportunities for applications of both static and dynamic beam shaping in the joining similar and dissimilar material combinations used in e-mobility manufacturing. The paper aims to provide a view on the available technologies and readiness level, selection of the optimal beam profiles to fit the application, and then discuss current applications in welding high reflective materials (i.e., copper), crack-sensitive alloys (i.e., high strength 6xxx series aluminium) and dissimilar metals (i.e., steel-to-aluminium) used in e-mobility manufacturing. Discussions on the impact of laser beam shaping on controlling weld profiles, keyhole stabilisation, reduction of porosity, microstructure refinement and IMC growth will be provided, supported by advanced metallographic techniques and process modelling via multi-physical CFD simulation. Case studies will be drawn from manufacturing of battery packs (cell-to-tab welding, busbar welding, battery enclosure manufacturing) and e-motors (hairpin welding) which require electrical and structural joints to comply with OEM requirements.

**Keywords:** Beam shaping, laser beam welding, e-mobility manufacturing, advanced material characterisation, digital twins and multi-physical CFD modelling (list 3–5 keywords describing the broader context of the performed research)

# Effect of Beam Shaping and Laser Beam Oscillation on the Weldability of Al to Cu Joints for EV Battery Pack Applications

Atharv Agarwal [1*], Simone D'Arcangelo [2], Ilkka Poutiainen [1], Ali Gökhan Demir [2]

[1] Laboratory of Laser Processing and Additive Manufacturing, LUT University, Yliopistonkatu 34, Lappeenranta 58510, Finland; atharv.agarwal@lut.fi
[2] Department of Mechanical Engineering, Politecno di Milano, Via Giuseppe La Masa 1, Milano 20156, Italy; simone.darcangelo@polimi.it
*Corresponding author

**Abstract:** Laser welding is an industrially accepted method to join highly reflective and conductive materials such as aluminum and copper for EV battery pack applications. Joining dissimilar materials such as Al to Cu is particularly challenging with laser welding because hard and brittle intermetallic compounds (IMCs) are formed in the weld zone. These IMCs based on their distribution and thickness can deteriorate or enhance the electromechanical properties of the welded joint. This work aims to investigate the novel in-source beam-shaping consisting of a ring and core provided by a 5 kW fiber laser to weld 0.5 – 0.5 Al to Cu in a lap joint configuration. The central core provides the necessary keyhole formation enhancing the penetration depth whereas the ring helps in enlarging the melt pool resulting in improved material mixing, controlled cooling rates, and reduced spatter. An optimum core-to-ring power ratio can provide an optimum material mixing and a more distributed IMC formation in the weld zone and, therefore, help mitigate the detrimental effect of IMCs. Industrial laser systems also provide the flexibility to dynamically oscillate the laser beam to improve the melt pool mixing. An experimental plan is devised to systematically investigate the effect of ring and core beam shape in tandem with beam oscillation. The welded joints are characterized by optical microscopy, SEM (Scanning Electron Microscopy), EDS (Electron Dispersive Spectroscopy), tensile strength, and electrical contact resistance. The results confirmed that beam shaping with ring and core helps widen the melt pool increasing the material mixing and joint surface area and beam oscillation improves the material mixing by preventing the hard and brittle IMCs from forming in the interface region.

**Keywords:** EV Battery pack, Dissimilar metal welding, laser beam shaping, Intermetallic Compounds, Tensile strength, electrical resistance, microstructures.

# *Academic – Laser-Based Efficient Manufacturing*

# Exceeding the Limits of Laser-Based Additive and Subtractive Manufacturing of E-mobility Components by Combining Cw and Ultrafast Lasers

Christian Hagenlocher*, Matthias Buser, Manuel Henn, Kathrin Cirakoglu, Johannes Michel, Volkher Onuseit, Thomas Graf

Institut für Strahlwerkzeuge (IFSW), Pfaffenwaldring 43, 70569 Stuttgart, Germany
*Corresponding author; christian.hagenlocher@ifsw.uni-stuttgart.de

**Abstract:** Laser-based additive manufacturing in the powder bed (PBF-LB/M) using cw-lasers, as well as subtractive laser processes like ablation and drilling using ultrashort laser pulses, are inherently limited in their geometric capabilities. Parts produced with the PBF-LB/M process typically yield surfaces with limited quality, while microholes drilled with ultrashort laser pulses can only reach a limited depth for a given diameter. To overcome these constraints, a novel process combining ultrafast and cw-laser sources has been developed. The results demonstrate that post-processing with ultrafast lasers enhances surface quality compared to parts manufactured with conventional PBF LB/M. Sequential ablation of local material after each added layer enables the fabrication of holes and slits with depths constrained solely by the powder bed height. Furthermore, this new process allows for additional control over the heat flow inside the printed parts to adjust local solidification. Heat-dissipating structures can be added and removed during the build process, while ablated slits can serve as a thermal barrier.

**Keywords:** Additive manufacturing; combined laser material processing; ultrafast laser; cw-laser; PBF-LB/M; laser ablation.

# Joining Process Life Cycle Assessment of an Automotive Battery Case

Max Biegler [1,] *, Christian Brunner-Schwer [2], and Michael Rethmeier [3,1,2]

[1] Fraunhofer Institute for Production Systems and Design Techology IPK, Pascalstraße 8-9, 10587, Berlin, Germany; max.biegler@ipk.fraunhofer.de
[2] Bundesanstalt für Materialforschung und –prüfung, Unter den Eichen, 87 12205, Berlin, Germany
[3] Institute of Machine Tools and Factory Management, Technische Universität Berlin, Pascalstraße 8-9, 10587, Berlin, Germany
*Corresponding author

**Abstract:** The evolving ecological, economic, and social dynamics are driving a shift in the development, design, and production of future vehicles. Manufacturers are committed to advancing environmentally friendly vehicles and achieving climate-neutral production across their entire supply chains.This study presents a comparative life cycle assessment of various joining processes including laser beam welding, laser brazing, and resistance spot welding. A tailored approach for assessing welding processes is introduced and applied using a battery case for electric vehicles as an example. The environmental impact categories resulting from the welding processes are evaluated and compared, with a focus on identifying the primary influences. The study also discusses the requirements for ecologically efficient welding processes and highlights areas for improvement. Notably, the materials involved, including the consumption of filler material, emerge as key contributors to environmental impact and present significant opportunities for reduction.

**Keywords:** life cycle assessment; laser beam welding; laser brazing; battery case;

# Interconnect Solutions for the Production of State-Of-The-Art Battery Modules

Hans-Georg von Ribbeck [1,*], Johannes Heilmeier [2], Bernhard Klier [3], and Franz Schlicht [4]

[1] F & K DELVOTEC Bondtechnik GmbH; hans-georg.vonribbeck@de.fkdelvotec.com
[2] Technical University of Munich, Institute for Machine Tools and Industrial Management (iwb); Johannes.heilmeier@tum.de
[3] F & K DELVOTEC Bondtechnik GmbH; bernhard.klier@de.fkdelvotec.com
[4] F & K DELVOTEC Bondtechnik GmbH; franz.schlicht@de.fkdelvotec.com
*Corresponding author

**Abstract:** In the rapidly evolving landscape of electric vehicles (EVs) and renewable energy storage, the design and assembly of battery modules play a crucial role in achieving optimal performance and safety. Our presentation focuses on interconnect solutions tailored for state-of-the-art battery modules, addressing key challenges and introducing innovative techniques. Starting by comparing various interconnect technologies for cylindrical battery cells. From traditional resistance welding to cutting-edge laser bonding, we explore which approach best suits different cell configurations. Next, we delve into interconnect strategies specifically designed for high performance battery modules. Factors such as electrical conductivity, ease of design, and process stability are carefully considered. High-power applications present unique hurdles, including heat dissipation, current distribution, and voltage drop. We discuss strategies and welding technologies to overcome these challenges effectively.
The introduction of the Delvotec Laserbonder, based on oscillation micro keyhole welding, offered precise and reliable interconnects. Thus enabling zero gap conditions in challenging clamping situations and flexible process engineering even in the pre-production phase.

**Keywords:** battery module, cell interconnection, laser welding

# Impact of Torch-Nozzle Angle on Shielding Gas Flow in Manual Laser Welding for E-Mobility Applications

Deniz Kaya[1,*], M. Kemal İşman[2], and Murat Reis[3]

[1] Durmazlar Makina Sanayi Ve Ticaret A.Ş., 16215 Bursa; dkaya@durmazlar.com.tr
[2] Şahterm Elektrikli Isıtıcılar Sanayi ve Ticaret A.Ş., 16225 Bursa; mkisman@gmail.com
[3] Department of Mechanical Engineering, Bursa Uludag University, 16059 Bursa; reis@uludag.edu.tr
*Corresponding author

**Abstract:** In this research, the effects of the angle between the welding torch tip and the welding surface on the shielding gas flow in manual laser welding systems are examined using numerical and experimental methods. In manual laser welding in e-mobility, the operator roughly adjusts the welding angle, which uncontrollably changes the gas outlet width, affecting the shielding gas flow and velocity at the nozzle tip. In addition to causing differences in weld quality, this may facilitate the penetration of molten metals into the gas flow direction and cause contamination of the protection lens with molten metal slags. In this study, the shielding gas flow in the welding torch for different torch angles was examined using numerical methods and the results were compared with experimental studies. Numerical analysis and experimental results show that the shielding gas flow rate is significantly affected by the stricture of the shielding gas outlet, and due to this stricture, the gas pressure in the section in front of the shielding lens increases significantly. Based on these results, an innovative manual laser welding torch was developed, which includes a pressure sensor placed in the front of the protective lens and intervenes in the system at welding angles that disrupt the protective gas flow. In this way, the system adjusts the gas output flow rate by intervening in the gas supply pressure at safe intervals, and in cases where this is not sufficient, it cuts off the laser pulse, preventing contamination of the protection lens and faulty welding.

**Keywords:** manual laser welding, shielding gas, welding angle, pressure sensor, process control

# *Academic – Process Diagnostics, Monitoring, and Control*

# Optimizing Ultrashort-Pulsed Laser Structuring Applications: A Photodiode-based Approach to Process Monitoring

Pawel Garkusha [1*], Benjamin Kasper [2], Christian Geiger[3], Michael F. Zaeh[4]

[1] Technical University of Munich, TUM School of Engineering and Design, Department of Mechanical Engineering, Institute for Machine Tools and Industrial Management (iwb), Boltzmannstrasse 15, 85748 Garching, Germany; pawel.garkusha@iwb.tum.de
[2] Technical University of Munich, TUM School of Engineering and Design, Department of Mechanical Engineering, Institute for Machine Tools and Industrial Management (iwb), Boltzmannstrasse 15, 85748 Garching, Germany; benjamin.kasper@tum.de
[3] Technical University of Munich, TUM School of Engineering and Design, Department of Mechanical Engineering, Institute for Machine Tools and Industrial Management (iwb), Boltzmannstrasse 15, 85748 Garching, Germany; christian.geiger@iwb.tum.de
[4] Technical University of Munich, TUM School of Engineering and Design, Department of Mechanical Engineering, Institute for Machine Tools and Industrial Management (iwb), Boltzmannstrasse 15, 85748 Garching, Germany; michael.zaeh@iwb.tum.de
*Corresponding author

**Abstract:** Ultrashort-pulsed lasers are pivotal in precision structuring applications and crucial for enhancing the performance of diffusion media in PEM fuel cells and graphite anodes in lithium-ion batteries. This presentation details a photodiode-based method developed for process monitoring in structuring applications with ultrashort-pulsed laser radiation. The developed approach enables accurate focus monitoring, ensuring optimal laser beam positioning and energy delivery, essential for uniform and high-quality structures. Additionally, we present a technique for junction detection in multi-layer systems, improving the detection and adjustment for material property variations and thickness during structuring. The method's effectiveness was demonstrated through experimental results, capturing process emissions data. The findings underscore the potential of photodiode-based monitoring as a powerful optimization tool for ultrashort-pulsed laser applications.

**Keywords:** Lithium-ion-battery production, Anode structuring, polymer electrolyte membrane fuel cells, condition monitoring, applied artificial intelligence

# Integrating Spectral and Acoustic Signals for In-Process Diagnosis of Weld Defects During Remote Laser Welding of 1050 Aluminium Busbars

Dario Basile[1]*, Rehab Al Botros[2], Valentino Razza[1], Manuela De Maddis[1] and Pasquale Franciosa[2]

[1]DIGEP, Politecnico di Torino, Torino, Italy 10129;
[2]WMG, The University of Warwick, Coventry, United Kingdom CV4 7AL;
*Corresponding author: dario.basile@polito.it

**Abstract:** In-process monitoring of laser weldments plays a crucial role for reducing defects/rework, material waste and energy consumption. Sensor technologies have been extensively studied and some level of success has been achieved. Yet, the weld quality is below the expected target, with production systems failing to deliver the ambition of “repair-free” products. Recent advancements in membrane-free optical microphones represent an interesting solution for in-process monitoring of weld defects, providing the broadest frequency range from 10 Hz up to 1 MHz. This does enable clear separation between valuable process signal and unwanted background noise (i.e., cross jet). Although research has shown promising results for detecting weld cracks during laser-based additive manufacturing, only scatter results are available in laser welding applications. This study aims to determine if variations in the features of laser weldments can be isolated and diagnosed by fusing spectral emissions (photodiodes) and acoustic signals (membrane-free optical microphone). Three manufacturing scenarios are considered during remote laser welding of 1.0 mm AA1050 busbars: variation in laser power, part-to-part gap and surface contaminations. The research further investigates the synergy/complementary between spectral and acoustic emissions for diagnosis of weld defects. The underlying physical processes will be studied by combining signal processing with observations from high-speed camera, backed-up by metallographic analysis. The results show that over-penetration, variations in part-to-part gap and changes to the dynamics of the keyhole/molten pool can be successfully diagnosed. Additionally, opportunities for automatic diagnosis of defective welds will be discussed based on sensor fusion and latest developments of machine learning.

**Keywords:** Laser Beam Welding, In-process Monitoring, Busbar Manufacturing, Spectral and Acoustic Signals, Membrane-free Optical Microphone.

# Defect Formation at Laser Welding of Batterie Cells Due to Electrolyte Contamination

Markus Hofele [1]*, Theresa Willburger [2], and Harald Riegel [3],

[1] Aalen University of applied science, 73430 Aalen; markus.hofele@hs-aalen.de
[2] Aalen University of applied science, 73430 Aalen; theresa.willburger@hs-aalen.de
[3] Aalen University of applied science, 73430 Aalen; harald.riegel@hs-aalen.de
*Corresponding author

**Abstract:** Laser welding is widely used in lithium-ion battery cell production for its precision, productivity, and accessibility. The respective joints inside the battery must require good mechanical and electrical properties and a low contact resistance. In contrast, welded joints in the battery cell housing must have a defect-free, gas-tight joint. The cell-internal contacting of the arrester tabs with the battery cover and the closing of the filling opening after electrolyte filling represents a major challenge with regard to a stable welding process, particularly due to the possibility of surface contamination of the joining surfaces with electrolyte. This investigations aims to systematically examine the influence of different electrolyte contamination states on the formation of weld seam defects, depending on laser beam wavelength, process parameters, and welding strategies. For this propose a modular research platform was developed, which enables laser-welding investigations in variable process gas atmospheres on different battery cell types. The transfer between a glovebox, in which the specific electrolyte contamination takes place, and the respective laser-welding cell, takes place in a mobile transfer shuttle. The transfer shuttle ensures a continuous process gas atmosphere and has interchangeable clamping devices for the different cell types. The process analysis is carried out using high-speed camera imaging and subsequent metallographic analysis of the weld seam with regard to seam dimensions and defects. Tensile tests were conducted in order to assess the joint strength and the existing connection areas were identified. The investigations revealed that electrolyte contamination significantly reduces the process stability and process windows depending on the level of contamination.

**Keywords:** electrolyte contamination, laser welding, defects, battery joining, cell contacting

# A New Modeling Method of Thermal Error Based on LSTM and Imbalanced Data Based on Transfer Learning

Isaac Kuma Yeboah [1*], Kwabena Agyapong Kodua [2], and Joseph Ignatius Teye Buertey [3],

[1] Affiliation 1; ikyeboah@pentvars.edu.gh
[2] Affiliation 2; kagyapong-kodua@pentvars.edu.gh
[3] Affiliation 3; jbuertey@pentvars.edu.gh
*Corresponding author

**Abstract:** In recent years, the research of leveraging deep learning algorithm to develop thermal error compensation which is the main factor that affect machining accuracy and thermal error caused by thermal deformation. The improvement of modern machine tool manufacturing technology has most significantly influenced the accuracy and energy efficiency of machining tool quality. Traditional machine learning modeling methods of thermal error relied on the selection of temperature sensors location and have a lack of prediction data validation. However, in actual production the working conditions are complicated and it is relatively easy to collect the data of the rest and idling states, while the data collection under the processing state is difficult. To solve these problems, this paper proposes a new modeling method based on generative adversarial network which predict thermal error before the beginning of machining. This method generates the thermal error in every moment of machining, both for idling with constant speed and milling. The method does not rely on troubling selection of many temperature sensors or complicated mathematical inference. This method was easy to be implemented, which was able to achieve energy savings and smooth compensation. Experimental results showed that the method reached an accuracy of 91% for idling prediction and 70% for milling prediction. In conclusion the case of insufficient data volume, the proposed method was superior to traditional machine learning methods in terms of prediction accuracy and model training efficiency.

**Keywords:** Thermal error, Machining accuracy, Predictive model, LSTM

# *Academic – Process Fundamentals and Modeling*

# Description of Keyhole and Melt Pool Behavior in Laser Beam Welding of Aluminum-Copper Joints using High-Speed Synchrotron X-ray Imaging and Multi-Physics Simulation

Klaus Schricker[1,*], Marc Seibold[1], Patrick Lemm[1], Leander Schmidt[1], Hannes Friedmann[1], Christian Diegel[1], Fabian Fröhlich[1], Stefan Eichler[1], Alexander Rack[3], Herwig Requardt[3], Yunhui Chen[3,4], Jean Pierre Bergmann[1]

[1] Technische Universität Ilmenau, Production Technology Group, Ilmenau, Germany; klaus.schricker@tu-ilmenau.de
[2] ESRF – The European Synchrotron, Grenoble, France
[3] RMIT, School of Engineering, Melbourne, Australia
*Corresponding author

**Abstract:** Welding of aluminum-copper joints is an important issue in joining technology for various applications in the energy sector, e.g., battery technology and electronics. Large differences in material properties, such as thermal conductivity, melting and evaporation temperatures, and absorption coefficients, are challenging for industrial applications. However, a fundamental understanding of the phenomena related to joint formation by mixing both materials at the interface is not yet fully understood, i.e., a time-dependent description of the behavior of the keyhole and melt pool, the resulting flow between the two materials, or the corresponding seam defect formation is not yet given. This talk addresses the analysis of the keyhole and melt pool behavior based on high-speed synchrotron X-ray imaging of aluminum-copper spot welds with recording frequencies up to 100,000 Hz. Advanced image processing enabled a time-dependent visualization of the keyhole and melt pool, as well as quantification of keyhole dynamics based on geometric parameters and Fast Fourier Transformation (FFT) due to the high phase contrast of the synchrotron x-ray imaging. Accompanying multi-physics simulations of the process based on a multiphase volume of fluid model in Flow 3D provided further information about the flow field at certain time steps to provide a generally valid description of the process dynamics.

**Keywords:** aluminum copper joints, laser welding, synchrotron, keyhole, melt pool, multi-physics simulation

# Beam Shaping + Green – Living the Dream?

Dominic Bartels[1,2,3,*], Julian Schrauder[1,2], Florian Kaufmann[2], Stephan Roth[2], and Michael Schmidt[1,2,3]

[1] Institute of Photonic Technologies, Friedrich-Alexander-Universität Erlangen-Nürnberg, Konrad-Zuse-Str. 3/5, Erlangen 91052, Germany
[2] Bayerisches Laserzentrum GmbH, Konrad-Zuse-Str. 2-6, 91052 Erlangen, Germany
[3] Erlangen Graduate School in Advanced Optical Technologies, Friedrich-Alexander-Universität Erlangen-Nürnberg, Paul-Gordan-Str. 6, Erlangen 91052, Germany
*Corresponding author

**Abstract:** Laser beam welding is continuously gaining importance in e-mobility applications. High laser powers in combination with small spot sizes support a precise joining of fine metal sheets. However, the laser processing of copper is difficult due to its high reflectivity. This can result in excessive spatter and defect formation during processing due to the complex laser-material-interaction. Potential levers for addressing these challenges can be found in either using lasers with shorter wavelengths or adjusted intensity distributions through beam shaping. Green lasers for example are absorbed better comparable to established infrared laser sources. Beam shaping, on the other hand, helps to adjust the energy input into the workpiece, which can be beneficial to avoid local peak intensities.
In this work, different beam shaping approaches for influencing the resulting melt pool properties and thus the weld seam quality are presented. A green laser was used for performing the experiments. The advantages and disadvantages of the various beam shaping approaches when using a green laser are discussed within this presentation. It was found that a reduced spatter formation could be observed when applying beam shaping. For example, when using elliptical beam profiles, a spatter reduction of up to 60 % could be observed. Applying ring-shaped intensity distributions helps to tailor the weld seam quality, which is also beneficial to reduce spatter formation. Finally, a conclusion on the use of beam shaping in combination with green lasers is provided in this work.

**Keywords:** Green Laser; Beam Shaping; Laser Welding; Laser Material Processing; E-Mobility

# Use of blue laser in dissimilar welding Cu/Al for E-mobility sector

Carlo Alberto Biffi[1*], Jacopo Fiocchi[1], Stefano Zarini[2], Tugay Kurtay[2], Mario Pisapia[2], Ausonio

[1] National Research Council of Italy, CNR ICMATE, Lecco, Italy; carloalberto.biffi@cnr.it*; jacopo.fiocchi@cnr.it; ausonio.tuissi@cnr.it
[2] Optoprim, Monza Italy; zarini@optoprim.it; kurtaly@optoprim.it; pisapia@optoprim.it

**Abstract:** The electric mobility sector has been growing in recent years. Joining using power lasers, with near-infrared emission (for example, 1060 nm), suffers from the low value of the absorption coefficient, making the welding of highly reflective alloys very difficult and inefficient. Currently, new laser sources have appeared on the market, with emission at 450 nm (blue), which allow the absorption coefficient to be increased from 5% to 80% in the case of Cu. In this work we propose to explore the dissimilar welding between thin, overlapping sheets of Cu and Al, and vice versa, using a blue laser source. The evolution of the shape and size of the welding beads, performed as the power and process speed vary, is evaluated. The characterization involves a compositional and microstructural investigations, as well as mechanical tests to evaluate the tightness of the joints.

**Keywords:** Laser welding, blue laser, dissimilar welding.

# Computational and experimental study of copper current collector laser cutting

Caterina Angeloni [1,*], Samuele Piandoro [1], Erica Liverani [1], Alessandro Fortunato [1]

[1] Department of Industrial Engineering (DIN), Alma Mater Studiorum - University of Bologna, viale Risorgimento 2, Bologna, Italy; caterina.angeloni2@unibo.it
*Corresponding author

**Abstract:** The laser cutting of zero-defect batteries current collectors is challenging due to high-speed production rates (>20 m/s), the different geometries and thicknesses between different foils. In order to prevent the formation of defects and process parameters, a thorough understanding of the physical phenomena associated with the interaction between laser and material is crucial. Herein the interaction between a single mode (SM) continuous wave (CW) laser source and an 8 mm thick copper current collector is studied, classifying three main situations occurring: good cut, recast and dross, spatter. The main causes that lead to defects formation on the edge profile and the parameters that affect cutting accuracy are analyzed by experimental studies and numerical simulation. In particular, a Computational Fluid Dynamics (CFD) model was developed with the aim of identifying the main parameters that influence the physical phenomena involved and the optimum cutting windows. Model validation was carried out by comparing experimental results obtained using process parameters responsible for different interactions and defect formation. The model was finally able to predict and compare the results of laser cutting on copper current collectors of various thicknesses in a wide range of process parameters. The results show the process windows in which each defect occurs considering laser speed from 2-25 m/s and laser power from 200-1000W. Finally, the model was used for preliminary consideration on cutting quality expectations that are not feasible with the hardware that is currently available (>25 m/s), opening up future possibilities both in terms of productivity and quality.

**Keywords:** Laser cutting, Current collector, Computational model, Single mode fiber laser

# *Poster Session*

# Process Strategies for the Laser-Based Surface Cleaning of LLZO-Ceramics Used in All-Solid-State Batteries

Alena Gruendl [1,] *, Michael F. Zaeh [2]

[1] Technical University of Munich (TUM), TUM School of Engineering and Design, Department of Mechanical Engineering, Institute for Machine Tools and Industrial Management (*iwb*), Boltzmannstr. 15, 85748 Garching; alena.gruendl@iwb.tum.de
[2] Technical University of Munich (TUM), TUM School of Engineering and Design, Department of Mechanical Engineering, Institute for Machine Tools and Industrial Management (iwb), Boltzmannstrasse 15, 85748 Garching, Germany; michael.zaeh@iwb.tum.de
*Corresponding author

**Abstract:** Given the rising demand for energy storage systems characterized by a high energy density and safety, garnet-based all-solid-state batteries (ASSBs) are gaining increasing significance in research. In particular, the application of the ceramic solid electrolyte $Li_7La_3Zr_2O_{12}$ (LLZO) is receiving growing attention due to its high ionic conductivity and exceptional stability towards lithium metal (Li). However, LLZO reacts with $H_2O$ and $CO_2$ in the ambient air, forming an insulating layer of lithium carbonate ($Li_2CO_3$) on the surface of the garnet material. This insulating layer leads to a reduction in the wettability of the LLZO by the Li, resulting in an increased Li/LLZO interfacial resistance. In this work, the laser-based surface cleaning of LLZO under an argon atmosphere was investigated experimentally. Both continuous wave (CW) as well as ultrashort pulse (USP) laser systems were employed, each in the green and near-infrared wavelength range, resulting in four different laser configurations being tested. This approach enabled a comprehensive evaluation of the influence of the pulse duration, the type of laser system as well as the wavelength on the surface modification of the LLZO. The effects on the surface characteristics were analyzed using a laser scanning microscope and a scanning electron microscope. To investigate the impact of the laser-based surface cleaning on the wettability by the Li and the interfacial resistance, Li/LLZO/Li symmetric cells were assembled and tested by means of electrochemical impedance spectroscopy.

**Keywords:** laser-based surface processing, $Li_2CO_3$ insulating layer, interfacial resistance, interfacial engineering, lithiophobicity

# Analytical Modelling of Multi-Pulsed Material Interaction for Laser Cutting of Lithium-ion Battery Electrodes with Ultra-short Pulses

Pourya Heidari Orojloo[1,*], and Ali Gökhan Demir[1]

[1] Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156 Milan, Italy; pourya.heidari@polimi.it
*Corresponding author

**Abstract:** Laser cutting of electrodes is gradually becoming the dominant method in lithium-ion and solid-state battery production due to its high productivity and geometric flexibility. Additionally, the advent of high-power ultra-short pulsed laser systems presents new opportunities to scale up electrode laser cutting to Gigafactory levels. Ultra-short pulsed laser systems offer new features, such as burst mode, which helps manipulate the peak fluence. However, optimizing the process parameters for ultra-short pulse laser systems to cut the cathode, anode, and separator requires significant effort. Analytical modelling methods for laser-material interaction used in other pulsed laser micromachining processes can provide a useful starting point for determining the initial process parameters for laser cutting LIB electrodes. An optimal processing condition can be determined for maximizing the machining depth as a function of fluence. The selected fluence can be interpreted for the selection of the beam size and pulse repetition rate for industrial scale-up Such models have not been used in remote laser cutting in general, and specifically not in the remote laser cutting of LIB electrodes. This study examines the specific removal per energy of each pulse and how cutting productivity varies with changes in fluence on different Li-ion battery materials. Additionally, the basic mechanism of coating removal of anode and cathode has been investigated.

**Keywords:** Remote laser cutting, Lithium-ion battery electrodes, Ultra-short pulse laser, Analytical model.

# Innovative All-Reflective Laser Beam Shaping for Precision, Speed and Robustness of Laser Processing in E-Mobility

D.Dung[1] *, C. Böttinger[1], C.Grossert[1], F. Wolf[1] and C. Wahl[1]

[1] Midel Photonics GmbH, Maarstr. 96, 53227 Bonn, Germany www.midel-photonics.de; david.dung@midel-photonics.de
*Corresponding author

**Abstract:** We introduce an innovative all-reflective laser beam shaping technology, enhancing precision, speed and robustness in e-mobility laser production. The approach is capable of handling multi-kilowatt power levels for continuous-wave to ultra-short pulsed lasers. Beam shaping is achieved through micro-structured laser mirrors, designed to meet the increasing demand for precision in laser material processing. The micro-structured mirror surface continuously and spatially modulates the laser phase, similar to high-efficiency transmissive diffractive optical elements (DOEs). Unlike conventional technologies, our reflective beam shapers are resistant to thermal effects, ensuring high performance and durability. Our unique production process, which involves laser-induced micro-delamination of prefabricated laser mirrors, allows for rapid customization of beam shaping solutions tailored to e-mobility applications. We demonstrate several examples of this technology, including beam shaping, beam splitting, focal shaping, and combinations of these functions in a single component. Furthermore, we provide insights into how these advancements enhance material processing, highlighting their versatility and effectiveness in addressing the specific needs of the e-mobility industry.

**Keywords:** Laser Beam Shaping; Laser Beam Splitting; Laser Focal Shaping; Diffractive Optics; Diffractive Optical Element; Laser Material Processing

# Strategies for Overcoming Challenges in Laser Welding of High Carbon Steels for E-Mobility Applications

Gökan Yılmaz[1,*], Deniz Kaya[1,2], Burak Kişin[2], A. Alper Özalp[2], and Kadir Çavdar[2]

[1] Durmazlar Makina Sanayi Ve Ticaret A.Ş., 16215 Bursa, Türkiye; gyilmaz@durmazlar.com.tr dkaya@durmazlar.com.tr
[2] Department of Mechanical Engineering, Bursa Uludag University, Görükle, 16059 Bursa, Türkiye; burakkisin@uludag.edu.tr aozalp@uludag.edu.tr cavdar@uludag.edu.tr
*Corresponding author

**Abstract:** Numerous developments are being made in the production process to reduce the weight of electric vehicles and make them more sustainable products. Expanding the use of naturally hard martensitic sheet metals will significantly contribute to this effort. In this study, the laser welding process of AISI 1075 steel, which has a thickness of 3 mm and a high potential for creating lightweight constructions in e-mobility applications due to its high strength, hardness, and wear resistance, was investigated. The martensitic microstructure formed after welding due to its high carbon content causes high brittleness and internal structure defects. Therefore, the main objective of the study was to prevent unwanted phase transformations by reducing the cooling rates with preheating applied to the material using the laser. This preheating process was compared with the conventional heating method, which completely heats the part. Thus, energy and time savings can be achieved without the need to fully heat the part, leading to a more sustainable solution. During experimental investigations, the entire process was monitored via a thermal camera, and cooling rates were tracked using the CCT diagram. As a result of the process optimized with laser parameters, metallographic analyses were performed, resulting in a reduction in the amount of martensite in the microstructure and hardness values. In conclusion, this study presents a strategy for the applicability of heat treatment and welding processes performed solely with lasers to high-carbon steels, demonstrating the potential for industrial advancements in the field.

**Keywords:** laser welding, heat treatment, high carbon steel, microstructure, martensite

# Production of Lightweight and Functionally Graded Lattice Structures from AlSi10Mg Using Laser Powder Bed Fusion

Omer Furkan Ersoz [1,*], Turker Turkoglu [2]

[1] Department of Industrial Engineering, University of Padova, 35131, Padova, Italy; omerfurkan.ersoz@studenti.unipd.it
[2] Department of Mechanical Engineering, Balikesir University, 10145, Balikesir, Turkey; turker.turkoglu@balikesir.edu.tr
*Corresponding author

**Abstract:** The next decade will see a significant increase in the use of electric vehicles, with laser-based manufacturing methods playing a key role in the efficient and high-quality production of these vehicles. In this study, different lattice structures were produced from AlSi10Mg using laser powder bed fusion (L-PBF). Specifically, fluorite, octet, and diamond structures were designed as functionally graded lattices. The production was carried out on an EOS M290 machine with a 150 W laser power, 900 mm/s scanning speed, 30 µm layer thickness, and an island scanning strategy. The design parameters were varied gradually according to the lattice thickness, optimizing the structures to reduce weight while enhancing mechanical properties. This study thoroughly investigates the effects of different lattice thicknesses on mechanical performance. Experimental results demonstrate how these optimized lattice structures can be utilized to manufacture lightweight and durable components for the electric vehicle industry. This research highlights the potential and application of laser-based manufacturing methods in the field of electromobility. The findings contribute significantly to the development of innovative and efficient techniques for producing electric vehicles, enabling the production of lighter, stronger, and more efficient vehicles in the future.

**Keywords:** (laser powder bed fusion, functional graded materials, component lightening)