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VEHICLE ELECTRICAL SYSTEM

## New Process for Secure Connection of Aluminum and Copper


# Passive Laser Welding of Aluminum and Copper

As the number of electric vehicles increases, aluminum is being used more frequently alongside copper in current-carrying structures, driven by cost pressures and higher range requirements. This results in connection points between aluminum and copper components where conventional joining methods reach their limits due to poor weldability capability. Kern Liebers therefore presents passive laser welding as a systematic approach.


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The ongoing electrification of vehicles increasingly drives the substitution of copper (Cu) with aluminum (Al) in electrical conductors and connection elements. The primary drivers are rising cost and weight pressures [1]. However, in electronic components such as electric motors, control units, power relays, or power semiconductor modules, copper remains indispensable in specific functional areas due to its electrical, thermal, and surface-related properties. This also applies to battery systems, where both copper and aluminum are required as electrode materials for electrochemical reasons. Consequently, there is a system-driven requirement to join both materials within an electrical circuit not only reliably and permanently but also using cost-efficient manufacturing processes. This article describes the potential of passive laser welding and its system-level application, for example in the connection of busbars, contacts in power electronics, or battery-cell contacting.

## CHALLENGES IN CU-AL CONTACTING

Joining this material combination poses significant challenges, **FIGURE 1**. Conventional thermal joining processes frequently lead to the formation of brittle intermetallic phases resulting from material mixing within the molten pool. These phases negatively affect both the mechanical properties and the electrical conductivity of the joint. Under electrical and thermal opera-

**FIGURE 1** Comparison of copper-aluminum joints exhibiting defects (left), intermetallic phase formation (middle), and no transition layer (right) (© Kern Liebers)

tional loading, long-term reliability further deteriorates [2]. Alternative joining technologies often encounter technological or geometrical limitations.

Against this background, passive laser welding represents a promising approach [3]. Novel laser-beam sources enable a highly controlled energy input, allowing the targeted suppression of intermetallic phases and the realization of electrically conductive joints without fully melting both joining partners, **FIGURE 1** (right).

Numerous automotive electrical systems show considerable potential for the use of aluminum. Typical examples include battery cells and modules as well as power electronics. During operation, thermal cycling presents a challenge, as it can promote the growth of brittle phases. In the long term, this may lead to increased contact resistance and impaired mechanical stability under dynamic mechanical loading [4]. The objective is therefore to realize Cu-Al joints with no or only minimal brittle phase formation. Such joints can meet the requirements of modern electrical systems in terms of efficiency, reliability, and service life.

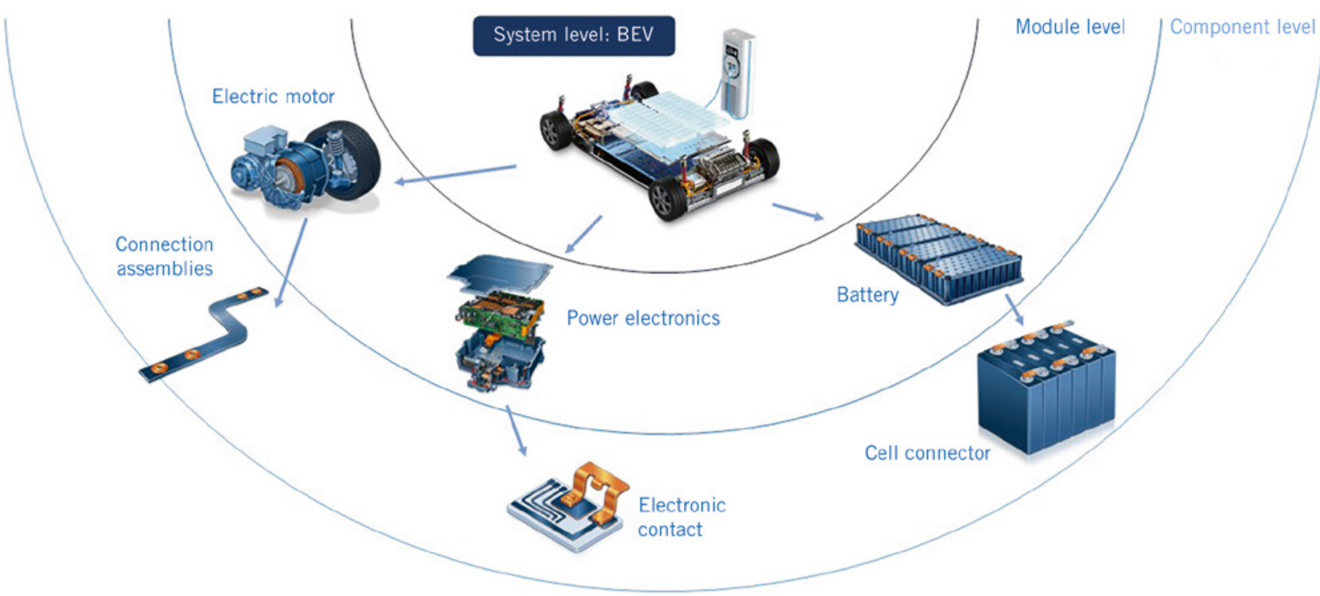
## ADVANTAGES OF THE PROCESS

In this context, passive laser welding is not merely a manufacturing process but acts as a system-level enabler for the controllable design of Cu-Al contact interfaces. From a system perspective, three key advantages arise.

First, passive laser welding allows application- and scale-independent use across the electrical architecture of a vehicle. **FIGURE 2** illustrates the classification of corresponding contact interfaces from the assembly level through the module level to the system level, enabling a wide range of applications to be realized using a uniform joining strategy. This ranges from fine Cu-Al contacts inside a battery cell, through cell connectors, to large cross section busbars at the module and system levels. The unified process logic enables the handling of widely varying conductor cross sections and allows the aluminum content to be significantly increased across the entire vehicle. From a process standpoint, these applications can be covered by scaling the process, which substantially simplifies industrialization.

What is more, the process opens up new degrees of freedom in the design of electrical systems. As shown in **FIGURE 3**, two sheets can be joined

**FIGURE 2** Classification of electrical contacting along the system, module, and component levels of a Battery Electric Vehicle (BEV) (© Kern Liebers)



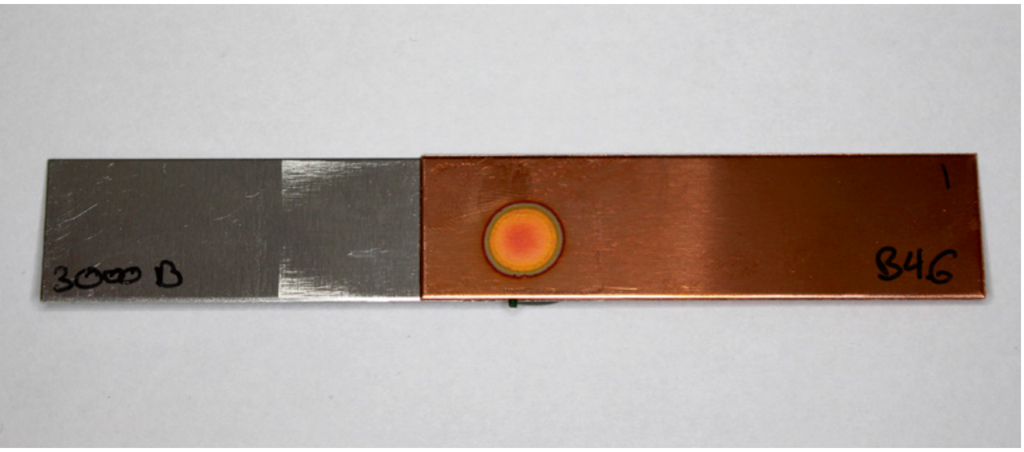



**FIGURE 3** Joint produced by passive laser welding with visible heat-affected zone (© Kern Liebers)

using planar, metallurgical bonding without additional mechanical fastening elements. Eliminating screws, clamps, or rivets enables compact contact interfaces, reducing both installation space requirements and the number of individual system components. This streamlines production lines and enables cost savings due to the reduced number of parts.

In addition, the approach is particularly well suited for automated manufacturing environments. Laser systems are well established in industrial production, highly controllable, and can be reliably integrated into existing production lines. Overall, the process helps transform Cu-Al contacting from a potential system-level risk factor into a controllable and purposefully designable system interface.

## FUNDAMENTAL PRINCIPLE

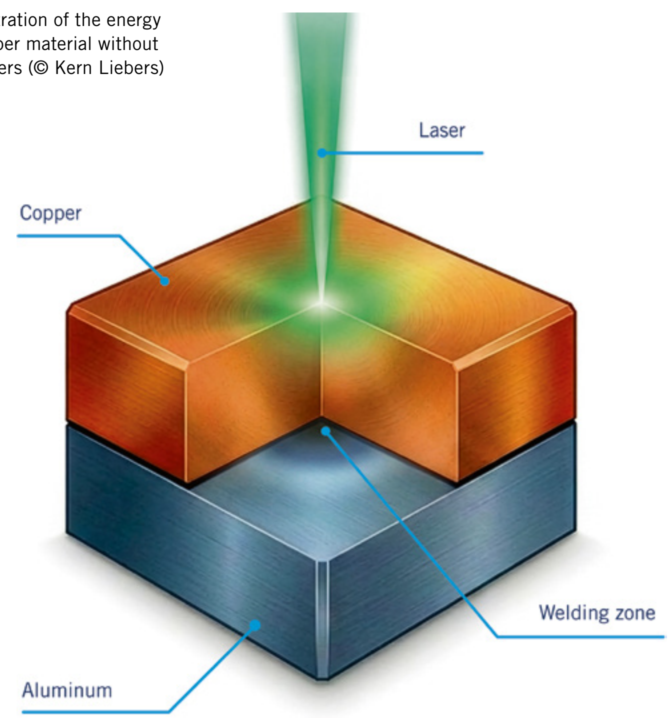
In contrast to conventional laser-based joining processes, passive laser welding deliberately avoids melting the joining partners. As schematically illustrated in **FIGURE 4**, energy input is applied via the copper material, with the introduced heat being transported to the interface due to copper's high thermal conductivity. In this way, a diffusion-based joint can form between copper and aluminum without the creation of a common molten pool.

From a system perspective, this approach is particularly attractive because it allows a significant reduction in the formation of pronounced intermetallic phases compared to conventional laser welding. Modern laser sources, for example those with green wavelengths, enable improved energy coupling into copper and contribute to controlled and stable process operation. Passive laser welding therefore complements established joining technologies, especially for applications with high demands on contact quality and long term stability.

## CONTACTING HIGH-CURRENT APPLICATIONS

The introduced process is particularly suitable for high-current applications such as power electronics or battery management systems. Owing to the tighly controlled energy input, thermally sensitive components such as semiconductor devices, insulation materials, or electronic components in the immediate vicinity are not adversely affected. As schematically shown in **FIGURE 5**, high-current-carrying busbars can be directly and metallurgically bonded to battery management systems. Busbars in battery modules, as well as connections to power electronic modules or phase connections in electric drives, can thereby be implemented using aluminum busbars and reliably joined by welding.

**FIGURE 4** Schematic illustration of the energy transfer through the copper material without melting the joining partners (© Kern Liebers)



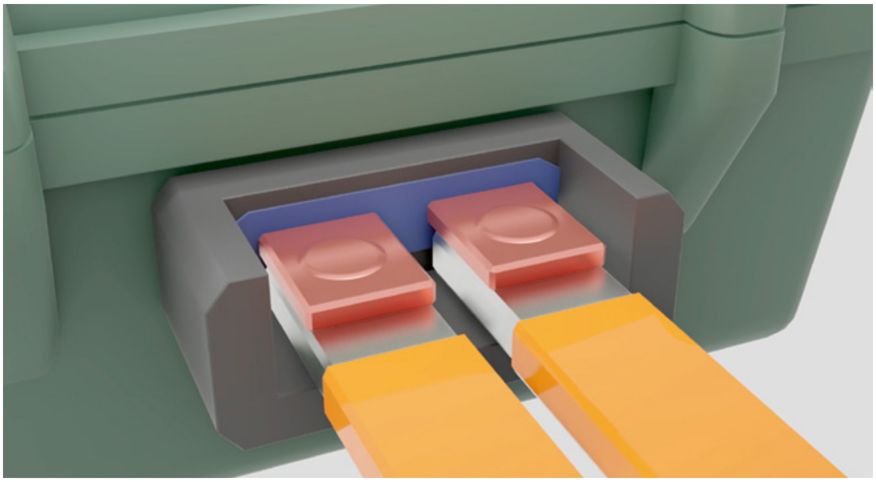


**FIGURE 5** Systematic illustration of a joint interface for connecting high-current-carrying busbars to battery management systems (© Kern Liebers)

## CU-AL CONTACTING IN BATTERY SYSTEMS

In modern lithium-ion cells, a combination of copper and aluminum is used internally for electrochemical reasons. While aluminum is used as the current collector on the cathode side, the corresponding structures on the anode side are made of copper. These internal current collectors, to which the electrode foils are connected, must be guided out of the cell interior and connected to external electrical terminals. At the system level, battery terminals and downstream connections in modules and packs are predominantly made of aluminum for reasons of weight, cost, and packaging.

As a result, a Cu-Al transition inevitably occurs on the anode side between the internal copper-based contacts and the external aluminum terminals. **FIGURE 6** illustrates this using the example of the battery cover of a prismatic lithium-ion cell with a separately depicted copper current collector for anode contacting and a welded aluminum tab that leads the electrical connection out of the cell.

This high-current and safety-critical system interface must ensure low contact resistances as well as high mechanical and thermal stability throughout the entire service life. Passive laser welding provides a suitable systematic solution and contributes to improving the long-term stability of the contact interface. At the same time, the process enables compact and function integrated contact designs, supporting slim housing concepts and efficient automation.

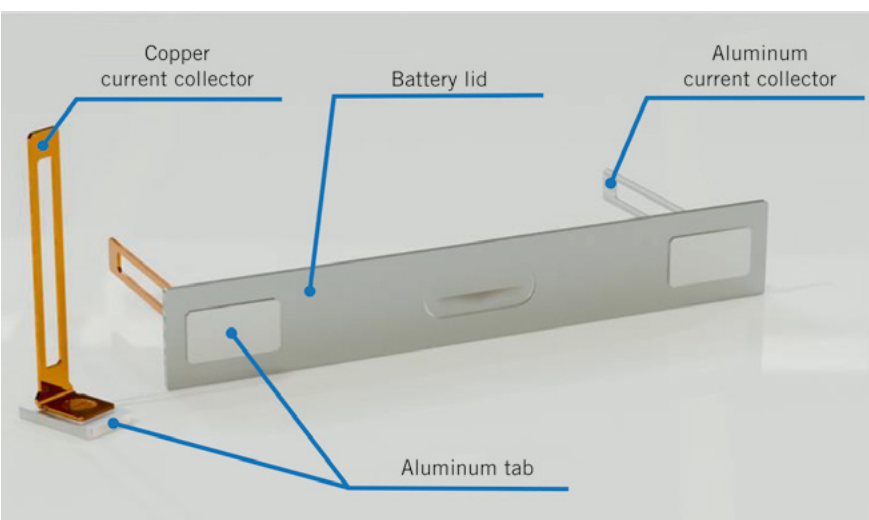



**FIGURE 6** Battery lid of a prismatic lithium-ion battery with a separately shown copper current collector for anode connection and a welded aluminum tab (© Kern Liebers)

## CONCLUSION

The presented examples demonstrate that the development of new joining technologies for Cu-Al connections can be considered as a key enabler for the use of aluminum in electrified vehicles. This material enables significant vehicle-level weight reduction, directly leading to increased efficiency while maintaining unchanged long-term stability of single vehicle components.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