Laser technology and process monitoring: guarantee for precise bipolar plates in fuel cell production

In today's industry, hydrogen is increasingly recognized as an indispensable energy carrier for various sectors. Especially in the context of energy production, storage and distribution, hydrogen plays a crucial role as it is a clean and flexible alternative to fossil fuels. Due to its high energy density and the possibility of producing it from renewable sources, hydrogen is the key to more sustainable industrial production.

From the laser source to the fuel cell

The following pages show the role of laser sources and process control in the manufacture of bipolar plates.

The chemical, steel and semiconductor industries in particular are increasingly relying on hydrogen as a CO2-free fuel and as a starting material for the production of important products such as ammonia and methanol. Its use in steel production, where it serves as a reducing agent for the production of steel without CO2 emissions, also represents significant progress. These industrial applications show how hydrogen as an energy carrier can revolutionize the industrial landscape by helping to meet climate targets.

The importance of hydrogen for industry is growing steadily as companies around the world look for innovative solutions to make their production processes more sustainable. However, to implement this transformation effectively, reliable and efficient technologies are required - especially in the production and processing of components such as bipolar plates, which play a central role in fuel cells.

Fuel cells and bipolar plates

Fuel cells are a key technology for the use of hydrogen in industrial applications. They convert hydrogen into electrical energy by using an electrochemical reaction between hydrogen and oxygen. This process takes place without combustion and is therefore an environmentally friendly method of generating energy, which is of particular interest for industrial applications such as in the chemical or steel industry.

The bipolar plate plays a central role in this context. It fulfills a triple function: it provides the gas supply, the cooling and the electrical connection to the fuel cell. In a multi-cell or stack configuration, the bipolar plate connects the anode of one cell to the cathode of the neighboring cell, both physically and electrically. This ensures the functionality of the fuel cell.

Stainless steel bipolar plates

Requirements

- Chemical stability
- Gas tightness
- Good plane parallelism
- High electrical conductivity
- Low material costs
- Low production costs

In addition, the bipolar plate guides the reaction gases - hydrogen on one side and air on the other - into the reaction zone of the cell.

A particularly important aspect is the flow profile (flow field) in the bipolar plates. Specific channels are milled or pressed into both sides of the plate to regulate the flow of gases and ensure that the fuel cell is operated efficiently. These channels direct the hydrogen to the anode and the air to the cathode, enabling a uniform reaction.

In order for a bipolar plate to reliably fulfill its function in a fuel cell, it must meet certain requirements in terms of its properties. These include high chemical stability against moist, oxidizing and reducing conditions, excellent gas tightness and high electrical conductivity. In addition, contact resistances must be kept low and precise plane parallelism (<20 μm) must be guaranteed. Finally, low manufacturing and material costs are also crucial to ensure cost-efficient production.

These properties are crucial to ensure the longevity and performance of the fuel cell. The precise production of the bipolar plates is therefore of the utmost importance to guarantee their optimum performance in industrial use.

Efficient laser welding

Laser welding has proven to be one of the most precise and efficient methods for manufacturing bipolar plates in fuel cells. Due to the high demands on accuracy and quality in the production of bipolar plates - especially with regard to gas-tight connections and structural integrity - the laser offers clear advantages over conventional welding methods.

A key advantage of laser welding is its high precision, which makes it possible to join even the smallest components with millimeter precision. This is particularly important, as a slight deviation in the production of bipolar plates can lead to leakages and thus to a loss of efficiency in the fuel cells. Laser welding produces weld seams that cause very low thermal stress on the material, which minimizes the risk of warping or other structural damage.

Another major advantage of laser welding is its performance. The laser beam can be guided through the bipolar plate at high speed, which results in fast production and at the same time increases the energy efficiency of the entire process. This is particularly relevant when considering the manufacturing costs and production time for mass production of fuel cells. In addition, laser welding allows flexible adaptation to the different requirements of bipolar plates. The laser provides the necessary flexibility to accommodate different designs and material properties.

Challenges in laser welding of bipolar plates

Despite the numerous advantages of laser welding in the production of bipolar plates, there are some challenges that need to be taken into account during process control. These challenges are mainly due to the material properties of the bipolar plates and the complexity of the welding task.

A common problem when laser welding thin materials at high speeds is the so-called humping effect. This causes the weld pool to rise or the weld seam to collapse at periodic intervals. This can lead to the required tightness and stability of the weld seam being impaired. The humping effect is particularly problematic as it can jeopardize the function of the bipolar plate, especially its gas tightness - a prerequisite for the proper operation of fuel cells.

Further challenges also arise from the high process speeds. As fuel cell stacks consist of a large number of bipolar plates and the manufacturing costs of these plates make up a significant part of the production costs, fast production is crucial. High welding speeds reduce the production time per plate and thus lower the overall production costs. In addition, a high process speed enables scalable production, which is necessary to meet the increasing demand for fuel cells. Slow process times would limit production capacity and reduce competitiveness. Fast production is also necessary to integrate laser welding into automated production lines, which increases the efficiency of the entire manufacturing process.

nLIGHT AFX Programmable Fiber Laser

Specifications

- Wavelength: 1070 nm
- Maximum power: 1500 W
- Power tuning: 5 to 100 %
- Switchover time for beam profile: < 30 ms
- Power fluctuation, 8 hours: ≤ 1%
- Modulation frequency: ≤ 100 kHz
- Dimensions: 445 x 677 x 177 mm

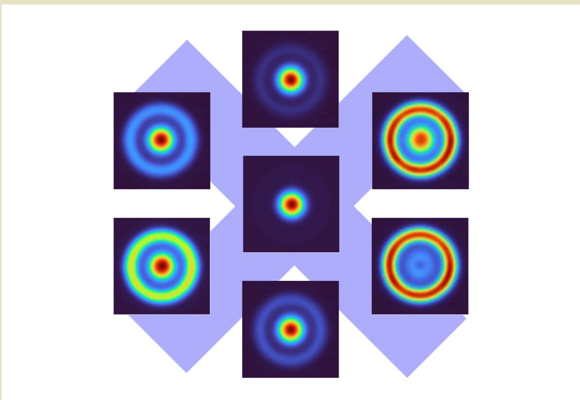
The AFX laser source

The AFX laser source from nLIGHT is an advanced solution for precision laser welding, specifically designed for applications such as laser welding of bipolar plates in fuel cells. The AFX laser uses Corona™ technology, which enables rapid adjustment of the beam shape and size directly from the fiber. This technology offers numerous advantages over conventional lasers and is particularly useful in industrial applications.

An outstanding feature of Corona™ technology is the ability to change the beam shape in less than 25 ms. This enables on-the-fly optimization of the welding process so that each work step can be precisely matched to the requirements of the material and geometry. This rapid adjustment not only increases the process speed, but also ensures greater flexibility and stability in the welding process.

The AFX laser source offers a large dynamic range and a variety of available beam shapes, including Gaussian (single mode, SM) and ring mode. This flexibility allows the laser to be used optimally for various applications, including laser welding of thin sheets. For the specific requirements of bipolar plate welding, the AFX laser has been equipped with a single-mode core surrounded by a ring. The laser beam can now be split between the single-mode core and the ring so that the beam profile can be adjusted between true SM (Gaussian) and a ring with a variety of shapes in between.

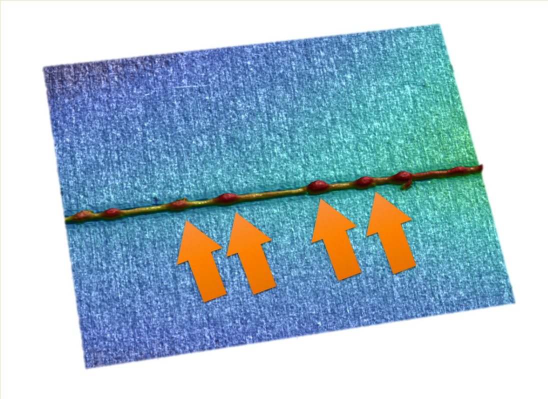
The AFX laser also offers all the standard benefits of nLIGHT fiber lasers, such as hardware-based back reflection protection, which enables uninterrupted processing of highly reflective materials. With power-stable modulation and the fastest modulation rate of 100 kHz, the AFX laser is able to generate precise waveforms and synchronize perfectly with external events or multiple lasers.



nLIGHT AFX Corona beam profiles

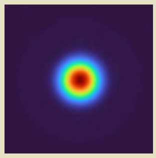
Setting options

- Beam profile adjustable in 7 stages
- Beam diameter
  16 µm to 47 µm
- Power distribution (core / ring)
  95 / 5 to 10 / 90 [%]



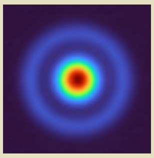
Humping effect

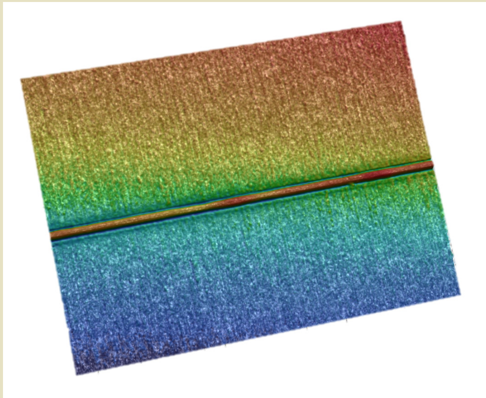
- Caused by the dynamics between cooling and solidification
- Material: Stainless steel
- Thickness: 2x 50 µm
- Feed rate: 1.3 m/s
- Laser power: 1 kW
- Beam profile: 100 % power in the core



No Humping effect

- Optimized thermal profile changes the dynamics of the melt pool
- Material: Stainless steel
- Thickness: 2x 50 µm
- Feed rate: 1.3 m/s
- Laser power: 1 kW
- Beam profile: 65% / 35% (core / ring)





Online process monitoring with processobserver

Process monitoring plays a decisive role in quality assurance and increasing efficiency in production using laser welding. Especially when welding high-precision components such as bipolar plates, it is essential to monitor the welding process in real time in order to detect errors at an early stage. This is where the processobserver from nLIGHT plasmo comes into play - a system that has been specially developed to monitor and optimize the entire laser welding process in real time.

The processobserver enables continuous monitoring of key parameters such as laser power, beam position and weld seam quality. The system uses advanced sensors and algorithms to immediately identify all relevant process deviations. This enables not only quality assurance, but also a rapid response to unforeseen problems in the production process.

A particularly important aspect of online process monitoring is the ability to detect welding defects, such as the humping effect or weld spatter caused by excessive welding power or incorrect focusing of the laser beam, which jeopardize the tightness of the weld seam.

nLIGHT plasmo processobserver 6.0

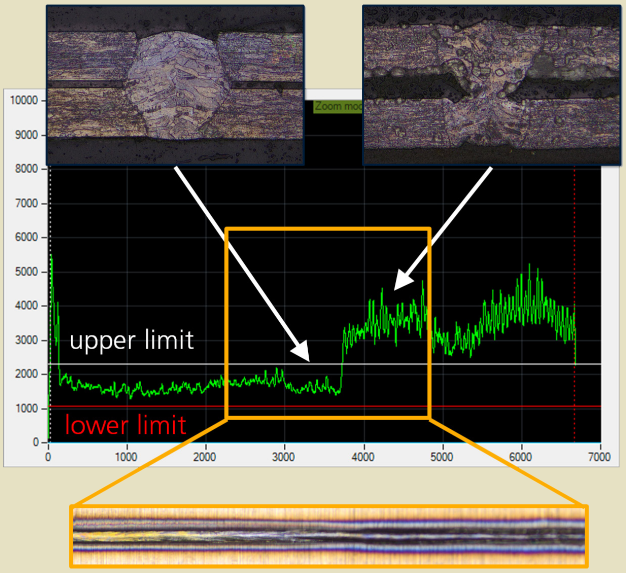
Specifications

- Wavelength spectrum: 400 - 1800 nm
- Sample frequency: 250 kHz
- Optical sensor inputs: 1
- Multiple sensors can be combined for maximum flexibility
- Dimensions: 50 x 50 x 150 mm
- Weight: 450 g per sensor

If the gap between the bipolar plates is too large, this can lead to a faulty connection known as a "false friend" - a visually perfect weld seam, but one with no connection.

Process monitoring also helps to optimize the welding process by enabling a detailed analysis of the welding process. With the help of the collected data, companies can better understand and continuously improve the manufacturing process.

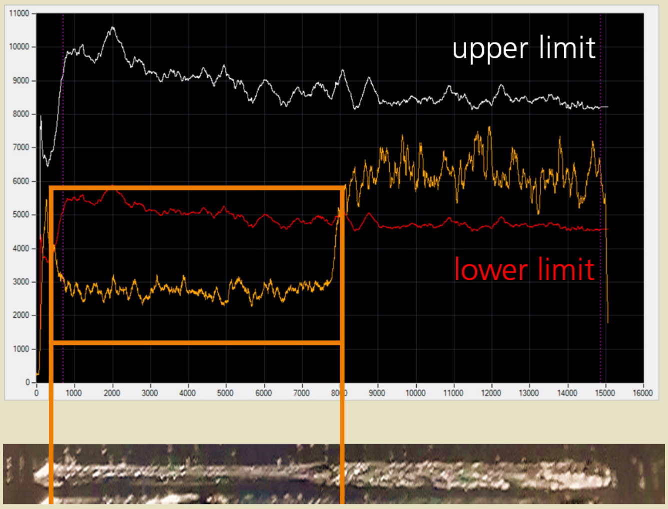
By integrating the processobserver into the manufacturing process, manufacturers can ensure that their laser welding processes are not only fast and efficient, but also high quality and reliable. This type of process optimization is particularly valuable for the mass production of bipolar plates, as it helps to reduce production costs while ensuring the consistency and longevity of manufactured components.



Evaluation with nLIGHT plasmo processobserver 6.0

Error case: Gap

- Process monitoring with nLIGHT plasmo processobserver 6.0
- Material: Stainless steel
- Thickness: 2x 50 µm
- Feed rate: 0.75 m/s
- Gap: ≈ 20 µm
- Sampling rate processobserver: 250 kHz



Evaluation with nLIGHT plasmo processobserver 6.0

Error case: False friend

- Process monitoring with nLIGHT plasmo processobserver 6.0
- Material: Stainless steel
- Thickness: 2x 75 µm
- Feed rate: 0.5 m/s
- Cause of error: Gap ≈ 30 µm
- Sampling rate processobserver: 250 kHz

Innovation und Präzision in der Bipolarplattenfertigung

Laser welding technology has established itself as one of the best solutions for the precise and efficient production of bipolar plates for fuel cells. In particular, nLIGHT's AFX laser source offers outstanding flexibility and precision, enabling laser welding to be tailored precisely to the requirements of bipolar plate production. The rapid adjustment of the beam shape and the exceptional beam quality optimize both the production speed and the quality of the weld seams.

Online process monitoring with the processobserver makes it possible to monitor the welding process in real time and detect faults such as gaps, weld spatter or the " false friend" at an early stage.

The combination of precise laser welding and reliable process monitoring ensures that the bipolar plates produced meet the high requirements of fuel cell technology. This is an important step in the further development of hydrogen technology and sustainable energy generation.

In the future, the continuous improvement of laser technology and process monitoring will further contribute to increasing efficiency and reducing costs in the production of fuel cells. In addition, new developments in materials science and laser technology will offer new opportunities to further increase the performance and longevity of fuel cells.

nLIGHT plasmo GmbH
Dresdner Str. 81-85
1200 Vienna/Austria
phone +43 1 890 1366
www.plasmo.eu

Email plasmosales@plasmo.eu

Produce **Quality.** Always.

nLIGHT plasmo

Status 2025. nLIGHT plasmo GmbH reserves the right to make technical changes.