Advanced Laser Solutions for the E-Mobility Industry

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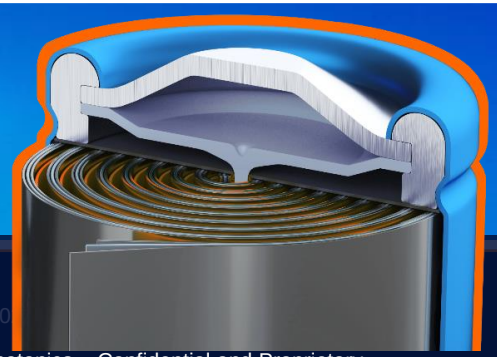
LASER APPLICATIONS IN E-MOBILITY

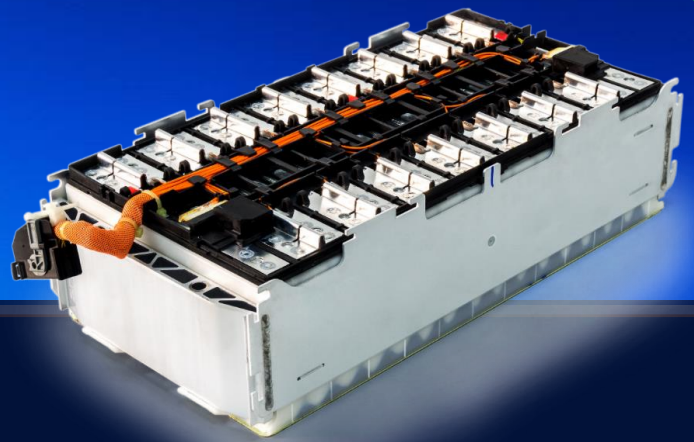
For All Battery Types (cylindrical, pouch, prismatic)

- Tab to Pole Welding ✓
- Cap to Can Welding ✓
- Pressure Relief Valve Welding ✓
- Injection Pin hole seal Welding ✓
- Foils Welding ✓
- Safety Cap Welding ✓
- Foils Cutting ✓



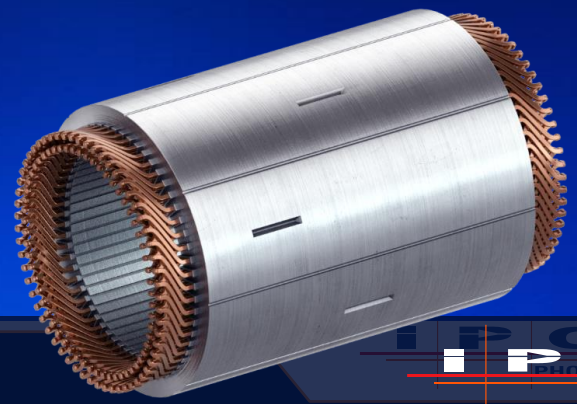
For All Battery Packs

- Bus-bar Welding ✓
- Terminal Welding ✓
- Case Welding ✓
- Real-Time Quality Monitoring ✓
- Battery Modules Marking ✓



For All Electric Motors

- Hairpin Welding ✓
- Rotor & Stator Stacks Welding ✓
- Hairpin Ablation ✓
- Electrical Steel Sheet Cutting ✓

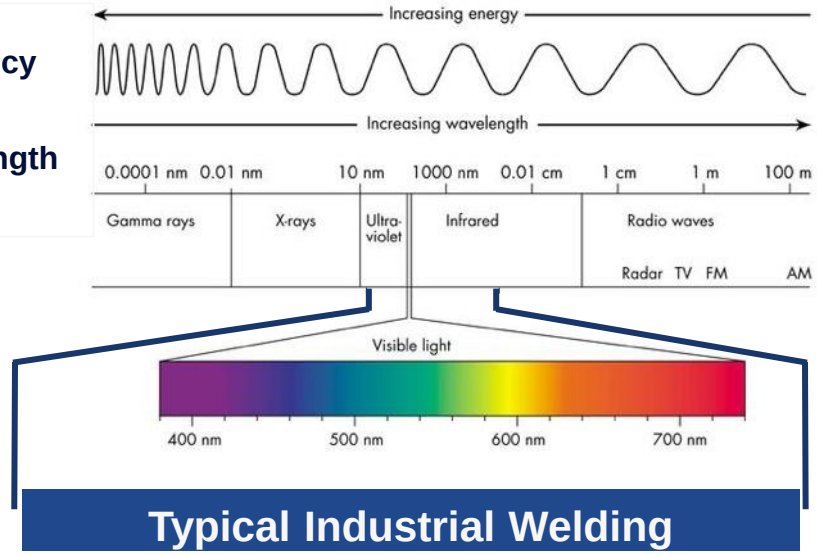


Laser Properties
and
Advanced Technologies for EV Manufacturing

Properties of Industrial Material Processing Lasers

Wavelength

- Higher frequency
- Shorter wavelength
- Higher photon energy



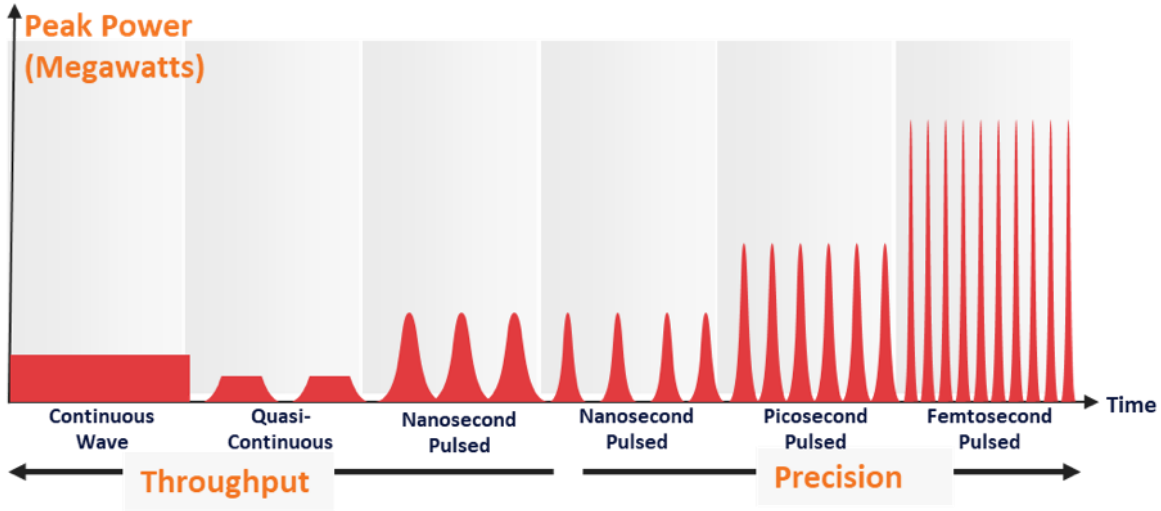
- Lower frequency
- Longer wavelength
- Lower photon energy

Typical Industrial Welding Wavelengths

Commercial products available to address most materials processing tasks

Pulse Characteristics

From Continuous Wave to Picosecond Pule Widths

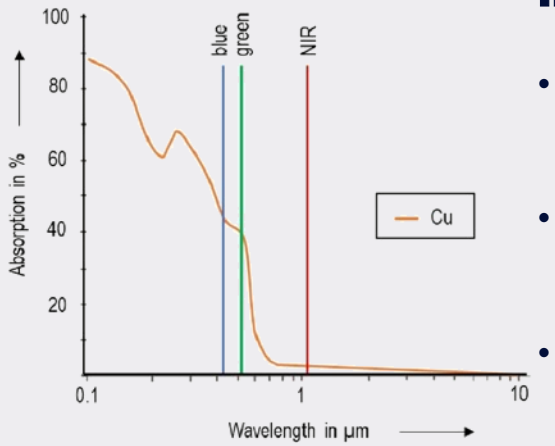


Challenges of Welding Copper

29
Cu
Copper
63.546

Material Properties:

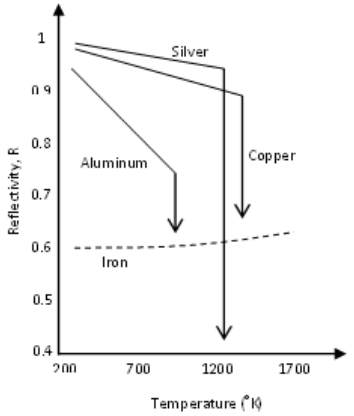
- High electrical and thermal conductivity
- High reflectivity
- Low Normal IR laser absorption



Initial Absorption Properties:

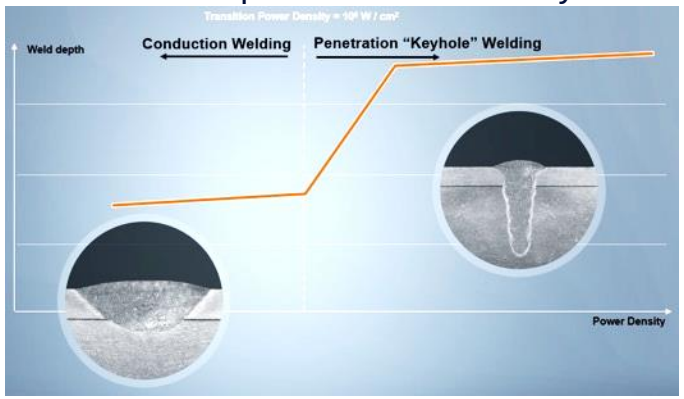
- Blue and Green Wavelengths have higher absorption rates
- Copper absorbs ~5% of IR laser energy at room temperature
- Absorption of IR on Copper depends on surface temperature

After Initial Absorption (< 1 ms),
Green/blue and **IR lasers are equally effective**



Absorption of Copper	
State	**Absorption (%)**
Solid	4
Liquid	10
Keyhole/Vapor	> 60

Weld Depth vs. Power Density



Conduction Welding
- Slower welding
- Larger weld area
- Shallow weld depth

Keyhole Welding
- Keyhole welding
- Faster welds
- Deeper weld depth

Keyhole Welding is Preferred as Conduction Welding is typically slow and > 0.5 mm in size

World Leading Fiber Laser Portfolio

IPG has an un-matched portfolio of technologies to optimize weld processing

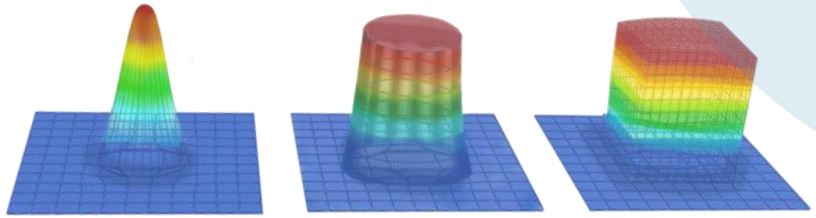
Broad Fiber Laser Offering:

Up to 120,000 W
CW to Femtosecond
UV to Mid IR

Beam Delivery Options:

Beam Formation:

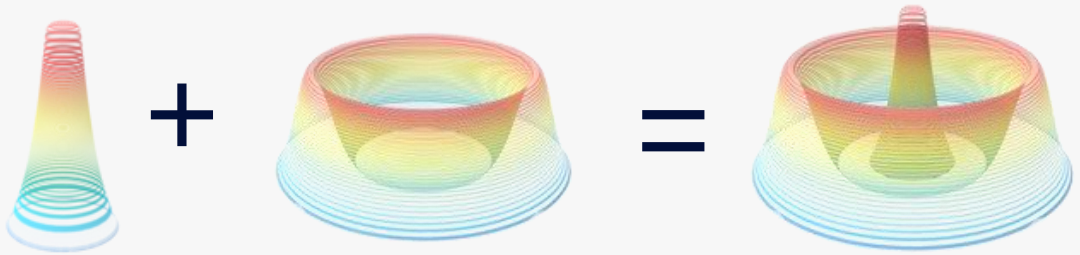
From 20 µm to 600 µm



Real-Time Weld Monitoring

Adjustable Mode Beam (AMB)

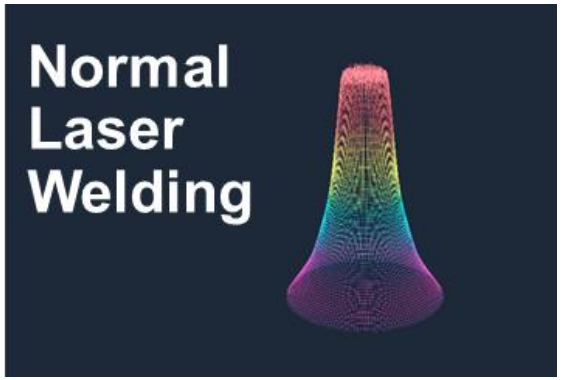
- **Broadest range of beam profile tuneability:**
  independent and dynamic control of the size and intensity of the core and ring beams enabling high-quality, high-speed, uniform welding
- **Single-mode and Multi-mode core options**
- **Virtually eliminates welding spatter:**
  molten material is deflected towards the bottom of the weld pool which is stabilized with large keyhole openings allowing molten vapor to escape
- **Increases welding quality:**
  consistent high weld seam quality, pore and crack free
- **High-speed welding for e-Mobility and automotive applications:**
  300 mm/s or higher speeds welding Al battery enclosures and drivetrains
- **Maximizes uptime:**
  less rework of parts, drastically reduces sensor contamination

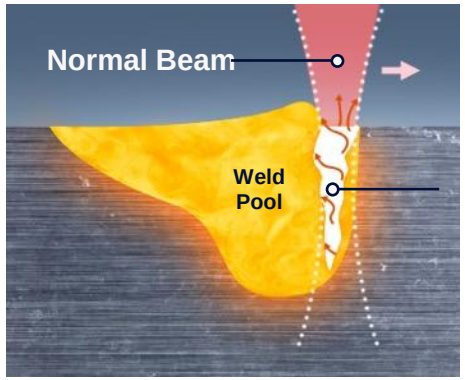


core ring AMB beam

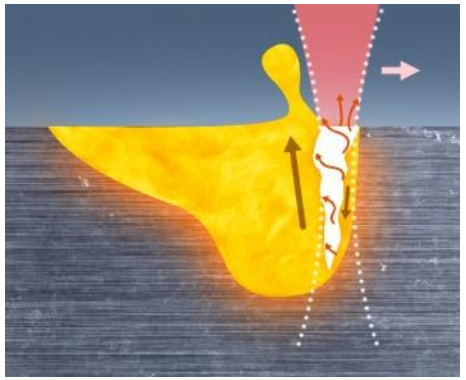
Any combination of a small-spot high intensity bright core and a larger ring-shaped beam

AMB Lasers Create Larger & More Stable Keyholes Eliminating Spatter & Increasing Quality

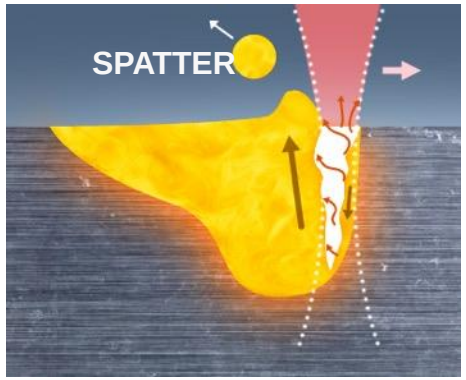




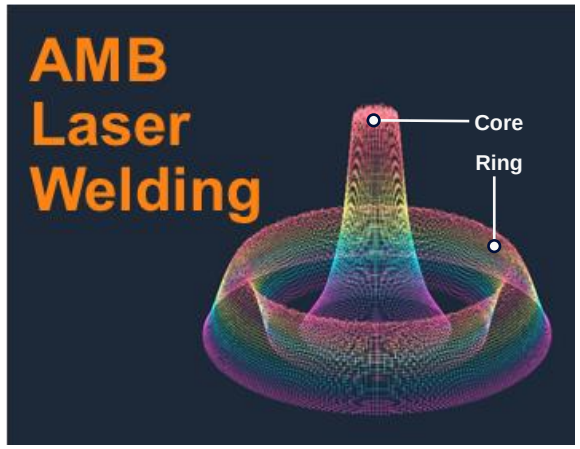
Material vaporizes and exits the keyhole quickly

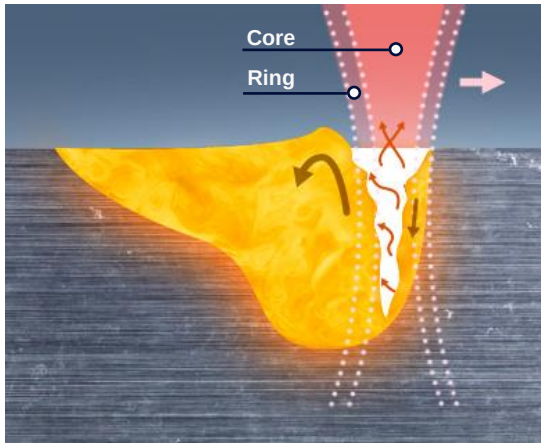


High pressure vapor pushes material to the keyhole surface



Spatter is propelled out the top of the keyhole





KEYHOLE STABILIZATION

- **AMB creates a larger and more stable keyhole**
- Ring beam minimizes the kinetic energy of the escaping vapor **minimizing spatter**

WELD POOL STABILIZATION

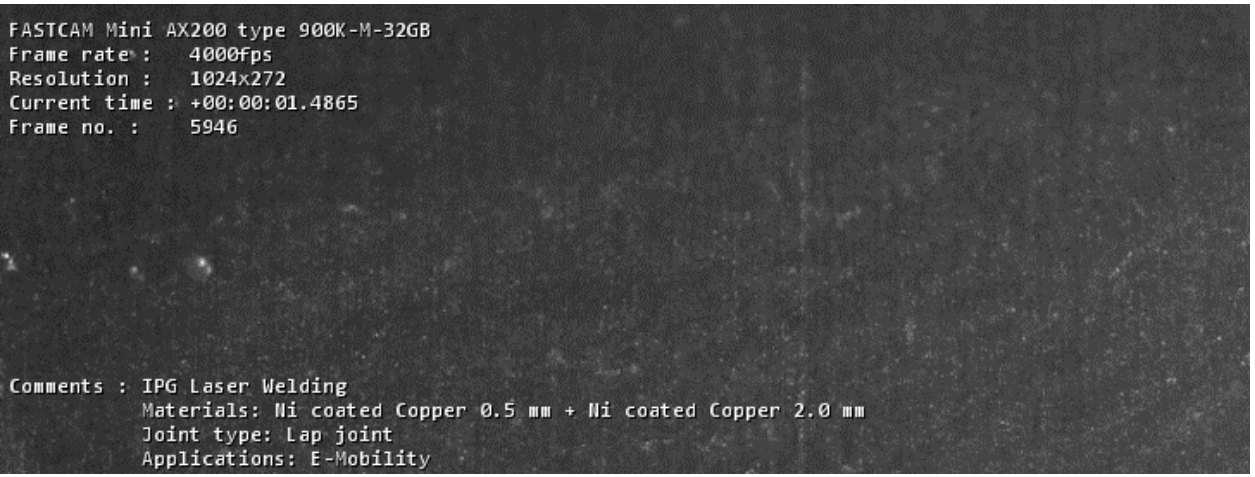
- **AMB stabilizes the weld pool** with no further melting behind the more stable keyhole
- Ring beam deflects material to the bottom of the weld pool **significantly reducing spatter**

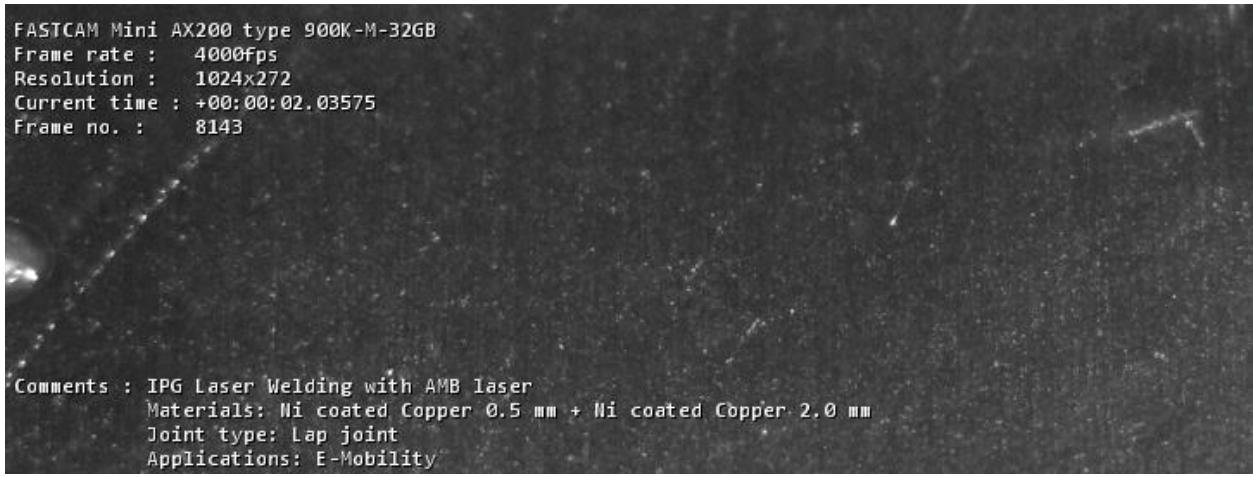
COPPER TO COPPER WELDING - SPATTER-FREE WITH AESTHETIC FINISHES

High Speed Video Analysis
AMB vs Normal Welding

2.5 mm Lap joint

*Material: 0.5 mm **Ni coated Copper** + 2.0 mm **Ni coated Copper***





Normal Welding

HIGH SPATTER

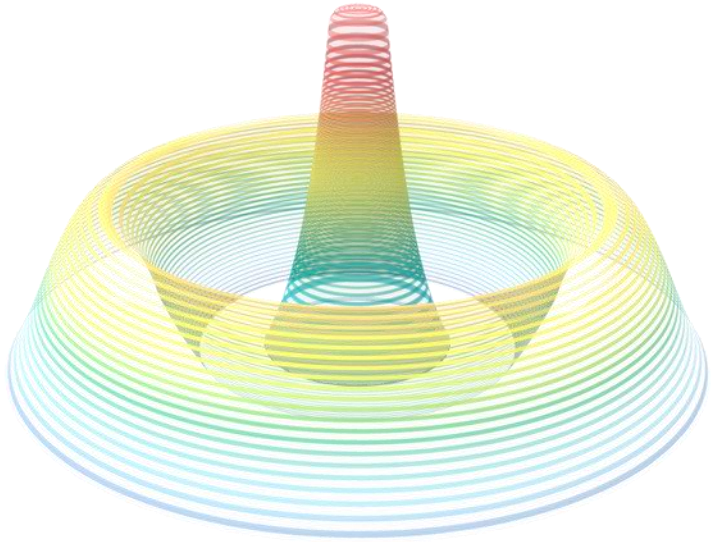
POOR VISUAL FINISH

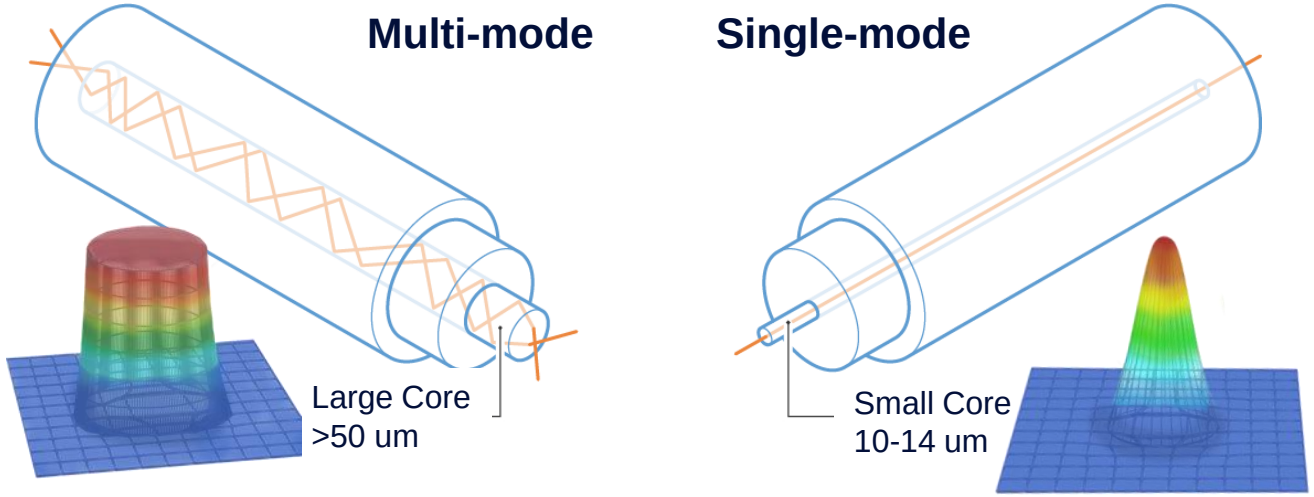
AMB Welding

SPATTER-FREE

HIGH-QUALITY FINISH

Single-mode Lasers provide Higher Power Density





Single-mode IR lasers offer:

- the **best beam quality**
- the **highest energy density**
- the **fastest keyhole creation**

AMB Laser Parameters:

- Power availability in ring and central core
- Independent beam control in real-time

High power density with a small beam
allows use of lower power laser
- **More cost effective equipment and processing**

AMB Welding Advantages

Characteristic	Adjustable Mode Beam (AMB) Fiber Lasers	Green and Blue Lasers
Initial Absorption Rate	**SLOWER**	**FASTER**
Post-Keyhole Absorption Rate	**STANDARD**	**STANDARD**
Cost (Initial and Operating)	**LOWER**	**HIGHER**
Field-Proven Reliability	**HIGHER**	**LOWER**
Power Scalability	**HIGHER** **up to 25 kW** total power	**LOWER** **< 2 kW** total power
Welding Speed	**FASTER**	**SLOWER**
Penetration Depth	**DEEPER**	**AVERAGE**
Interface Width Control	**WIDER**	**AVERAGE**
Standard Laser Component Availability	**EXTENSIVE SELECTION**	**SPECIALIZED AND COSTLY**

→ AMB OFFERS GREEN/BLUE CAPABILITIES ←

HIGHER RELIABILITY and MORE FLEXIBILITY at LESS COST

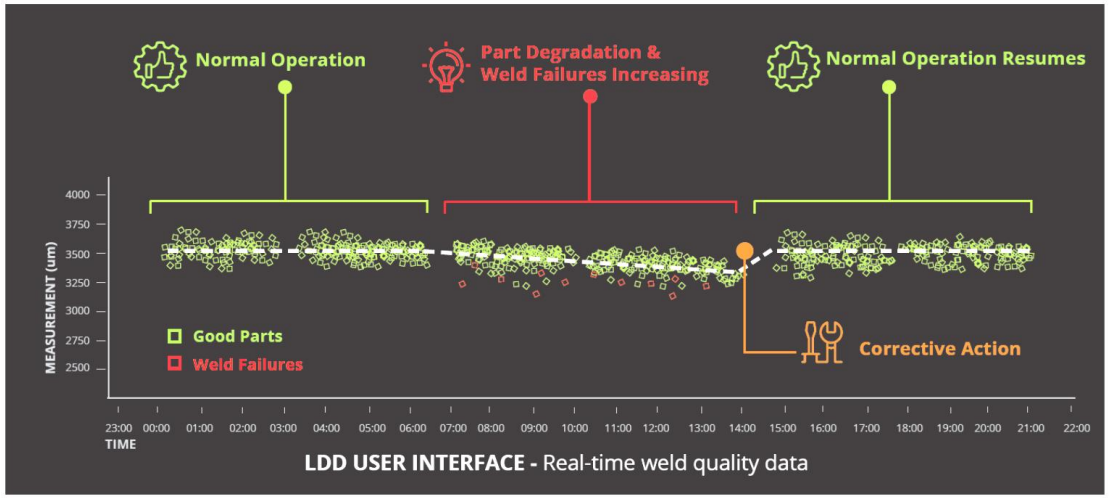
Real-Time Weld Monitoring and Control

Pre-weld monitoring **identifies problems before processing begins**
In-weld real-time monitoring and control for **optimal welds**
Post-weld inspection **assures quality**

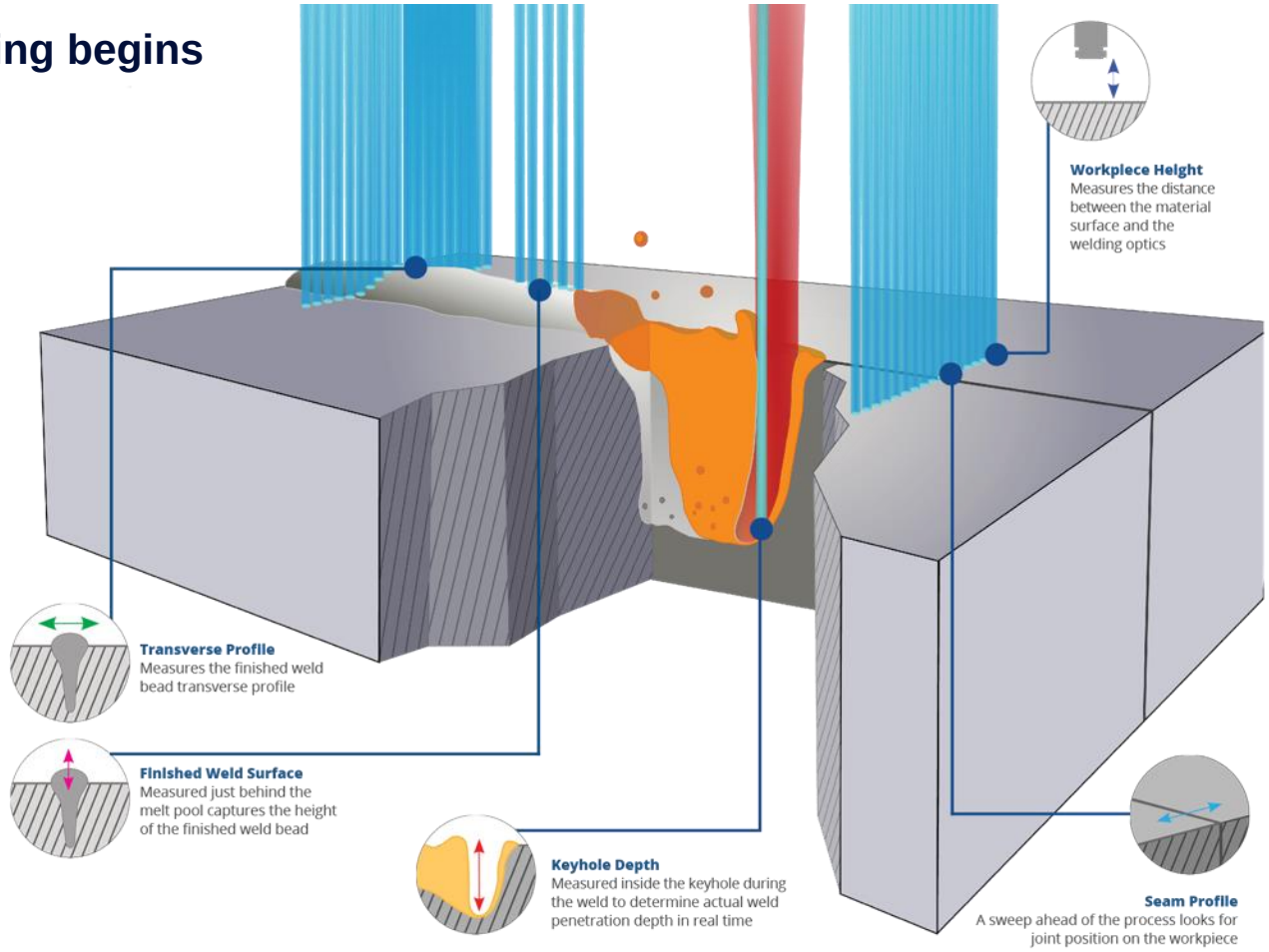
20 weld metrics

- Weld penetration depth
- Lateral weld profiles
- Joint position
- Process stability
- Surface quality

LDD-700 INLINE WELD
MONITORING and CONTROL SYSTEM



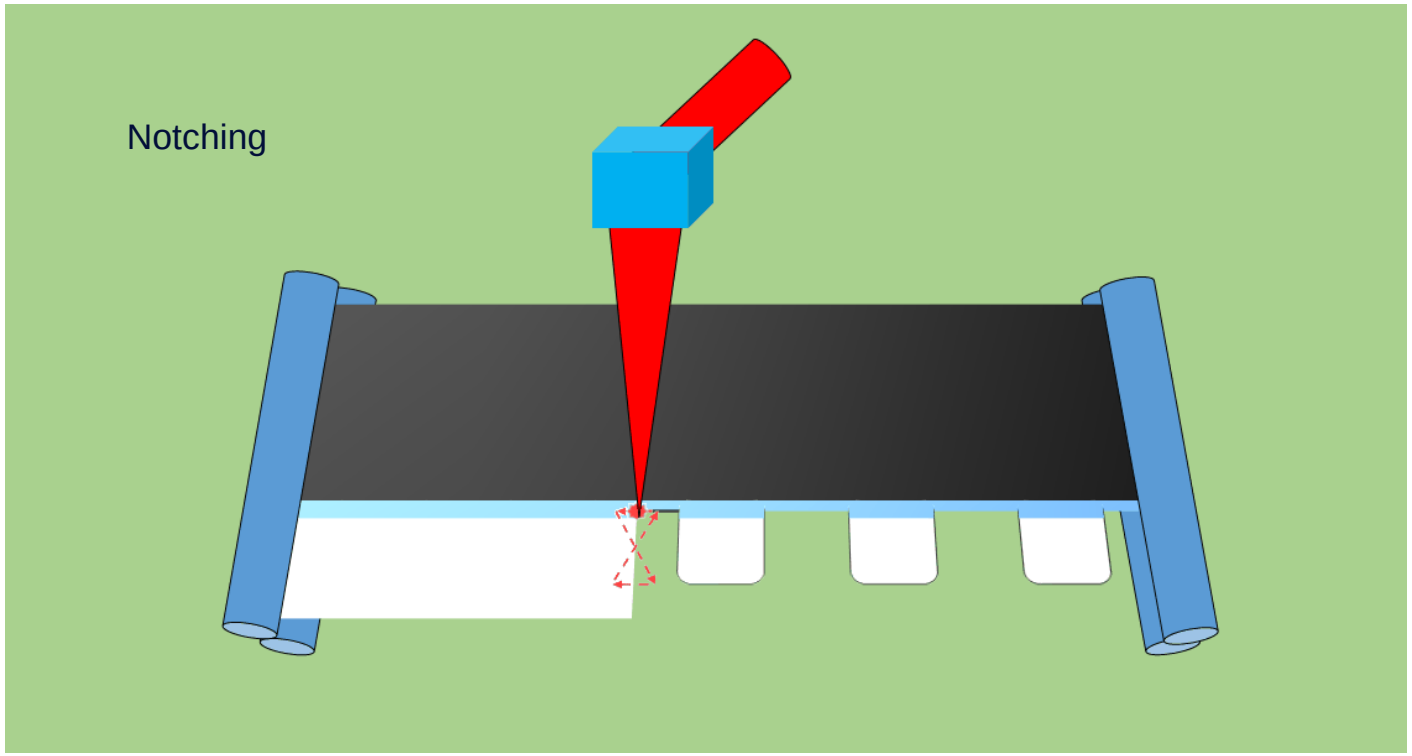
LDD USER INTERFACE - Real-time weld quality data

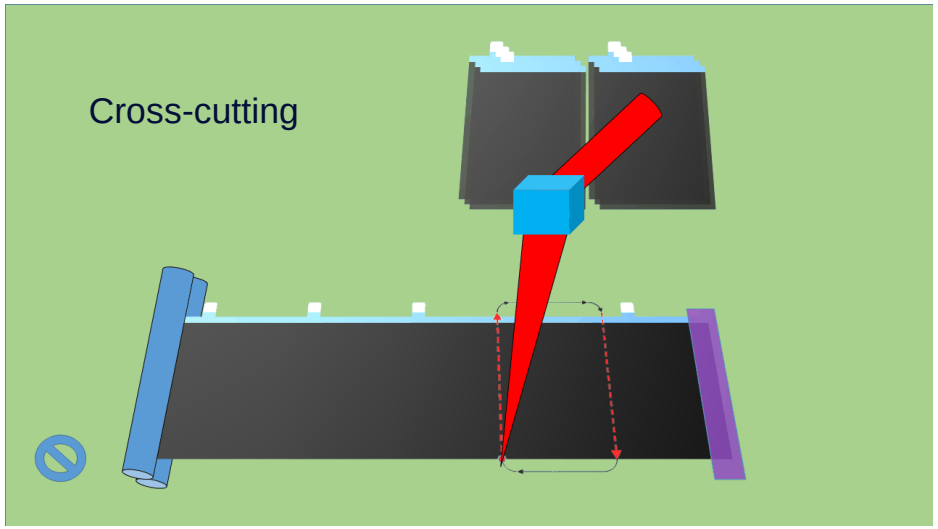


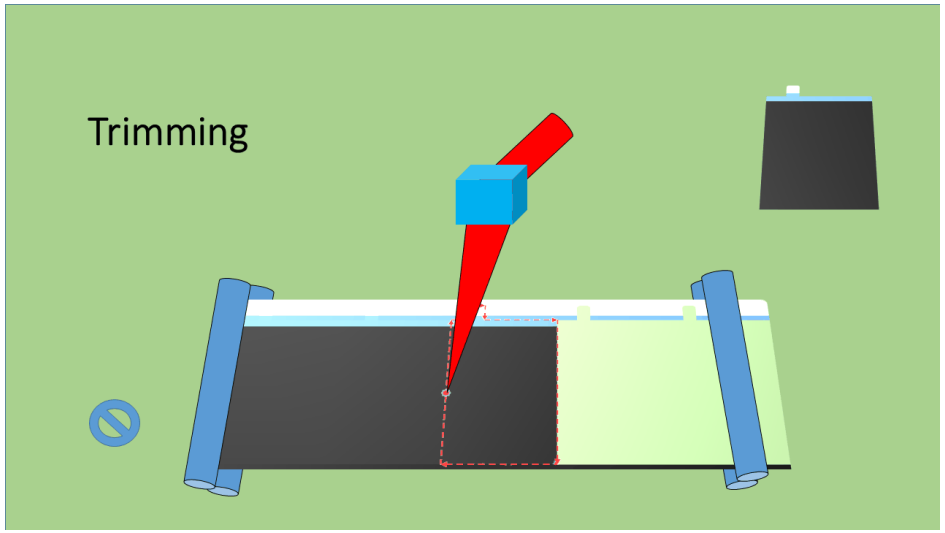
Weld Penetration Depth - Needs to be **measured** – not inferred
Best Indicator of Punch Through Risk for busbar-cell welds

Laser Cutting of Battery Foils

- **Cutting of bare (Al, Cu) and coated (with ceramic, graphite, NCM, LFP,…) foils**
- **Different processes – notching, cross-cutting, trimming, slitting**



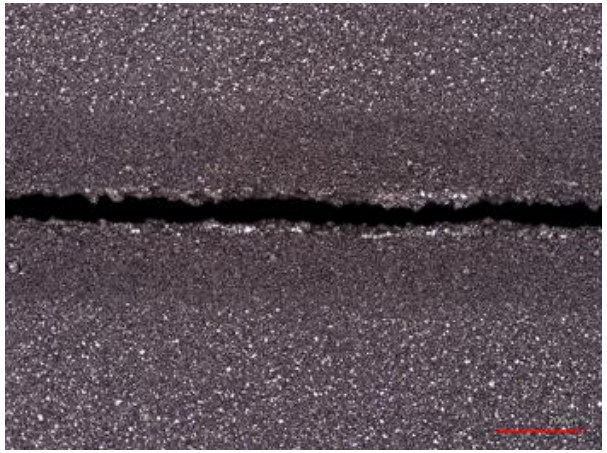




Laser Cutting of Battery Foils

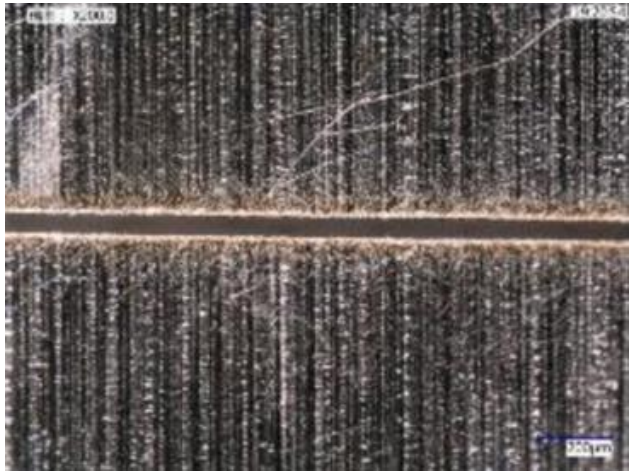
Cathode

Active material



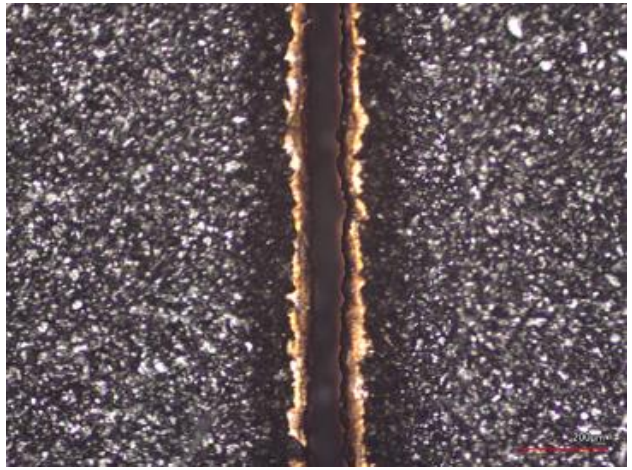
Ceramic layer

Bare foil

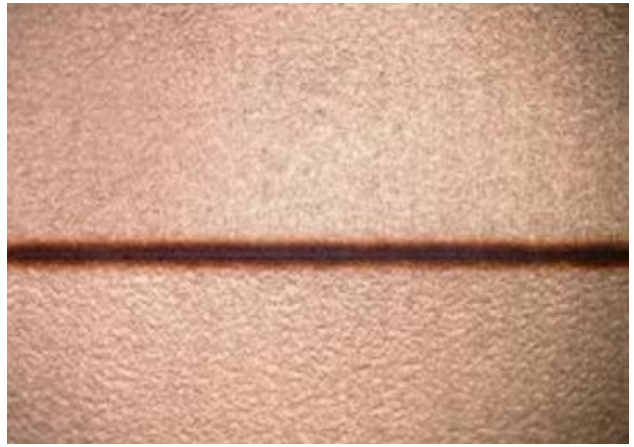


Anode

Coated material



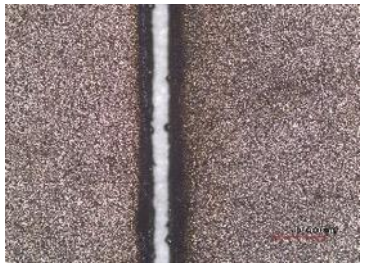
Bare foil

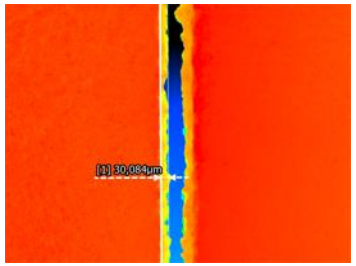


Laser Cutting Speed vs. Quality (ns Laser)

Low Cut Quality

- Higher cutting speed leads to better cut quality
- Higher cutting speeds require higher average power





High Cut Quality

Example 150 µm NCM Cathode Foil

Fiber Lasers for Battery Foil Cutting

Single mode models with spot size on work piece 20-60µm

Process	Lasers
Anode and cathode notching (up to 150m/min web speed)	Air-/water- cooled 100-500W YLPN lasers
Anode cross-cutting (up to 5 m/s cutting speed)	Water-cooled 500-1000W YLPN lasers
Anode trimming (up to 10m/s cutting speed)	Water-cooled 1-2kW YLPN lasers
Cathode trimming (up to 1m/s cutting speed) (up to 5m/s cutting speed)	Water-cooled 50-200W YLPP lasers Water-cooled 1-2kW YLPN lasers

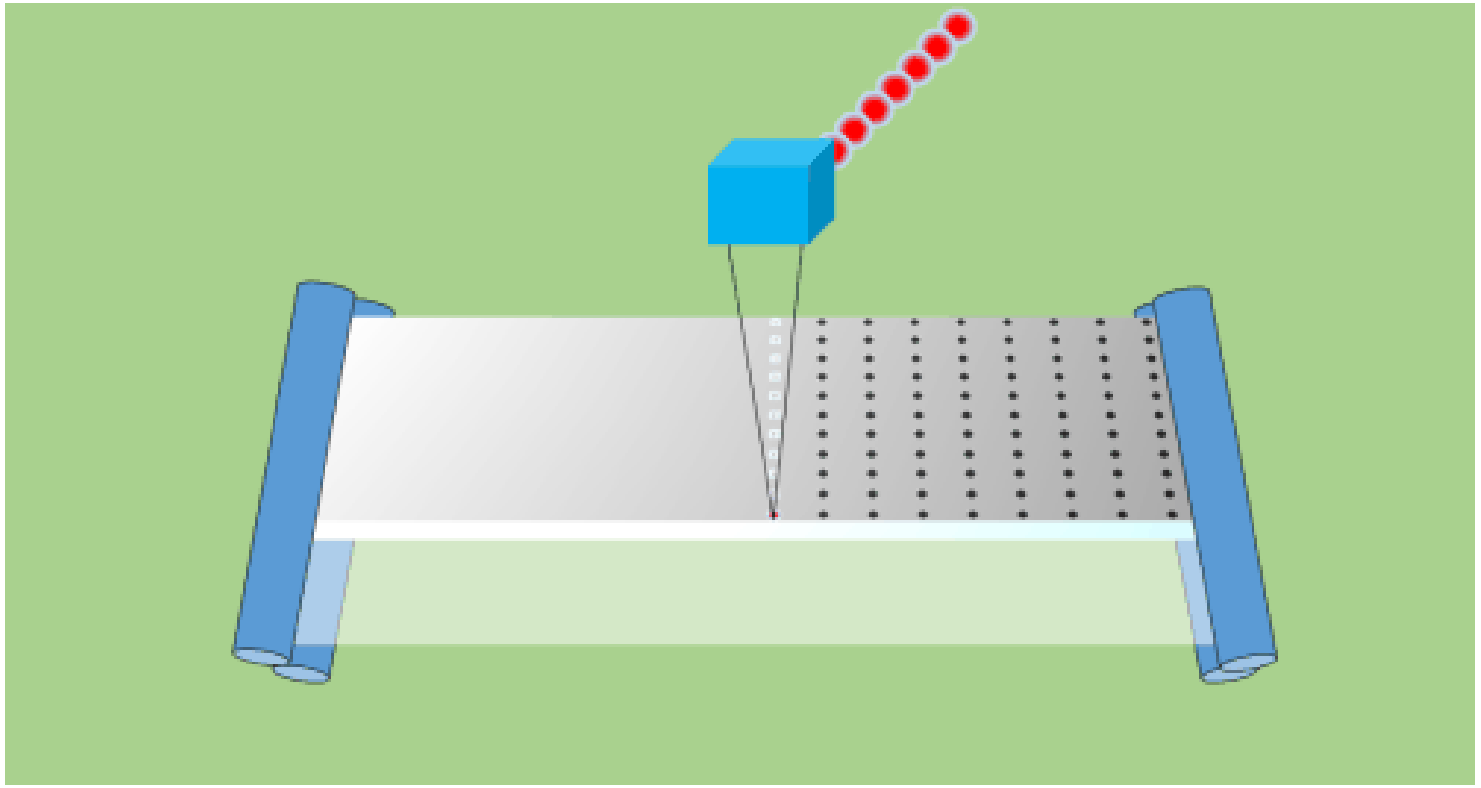
YLPN air-cooled lasers

YLPN water-cooled lasers

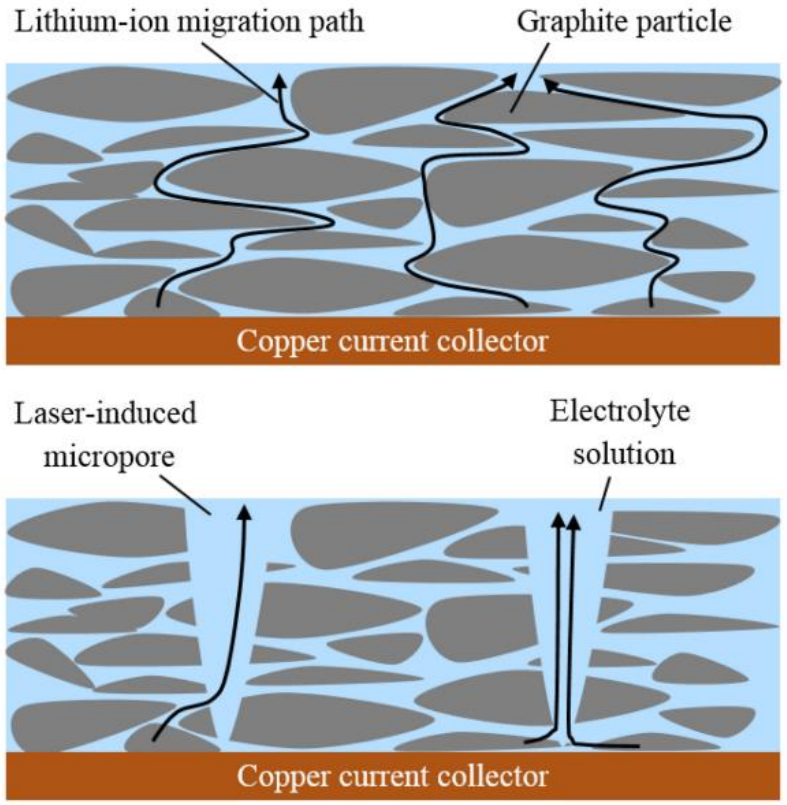
YLPP lasers

Laser Structuring of Battery Foils

Creating of laser-induced structure (pattern of craters) on anode coating for fast charging of batteries



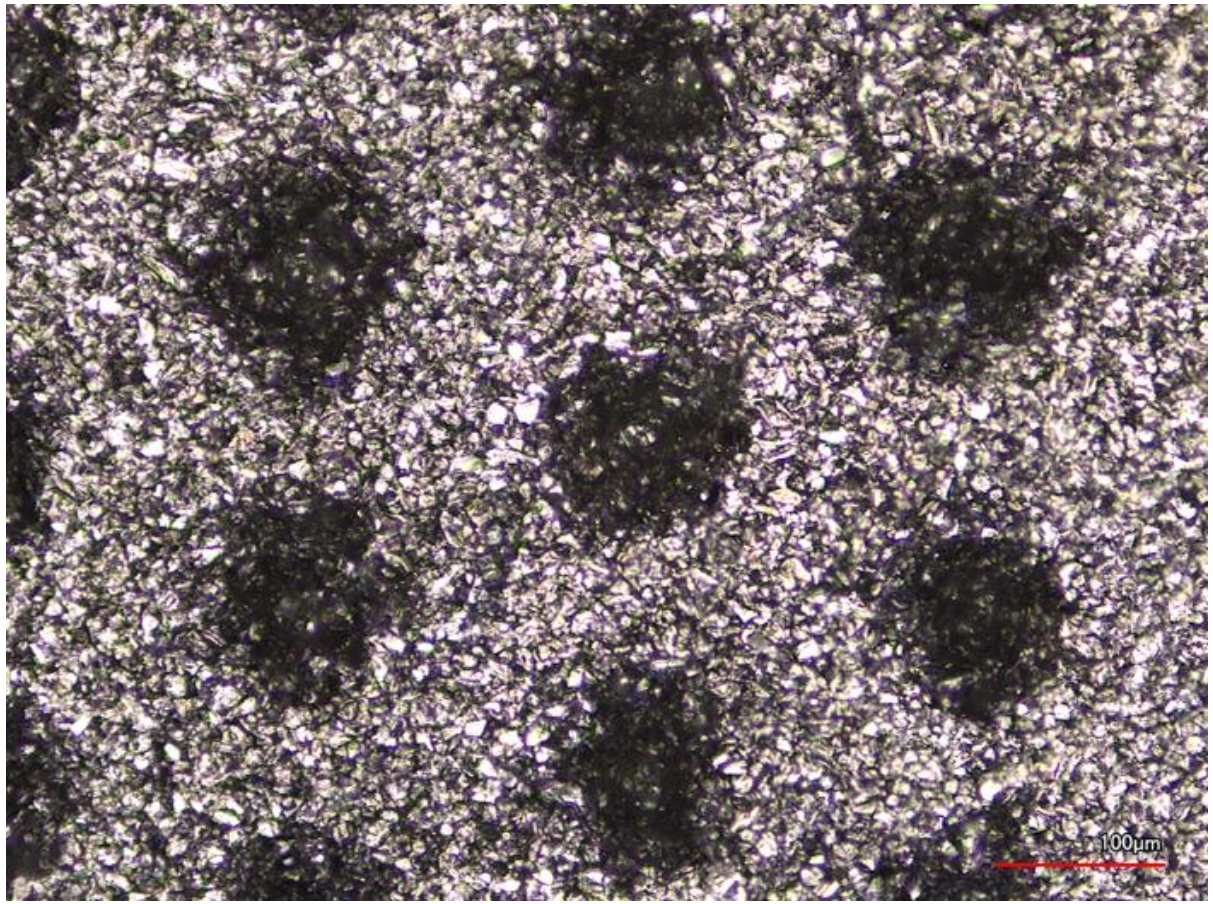
Lasers	**Water-cooled 1-2 kW YLPN lasers** **One pulse per crater, pulse prepetition rate 2-4 MHz**



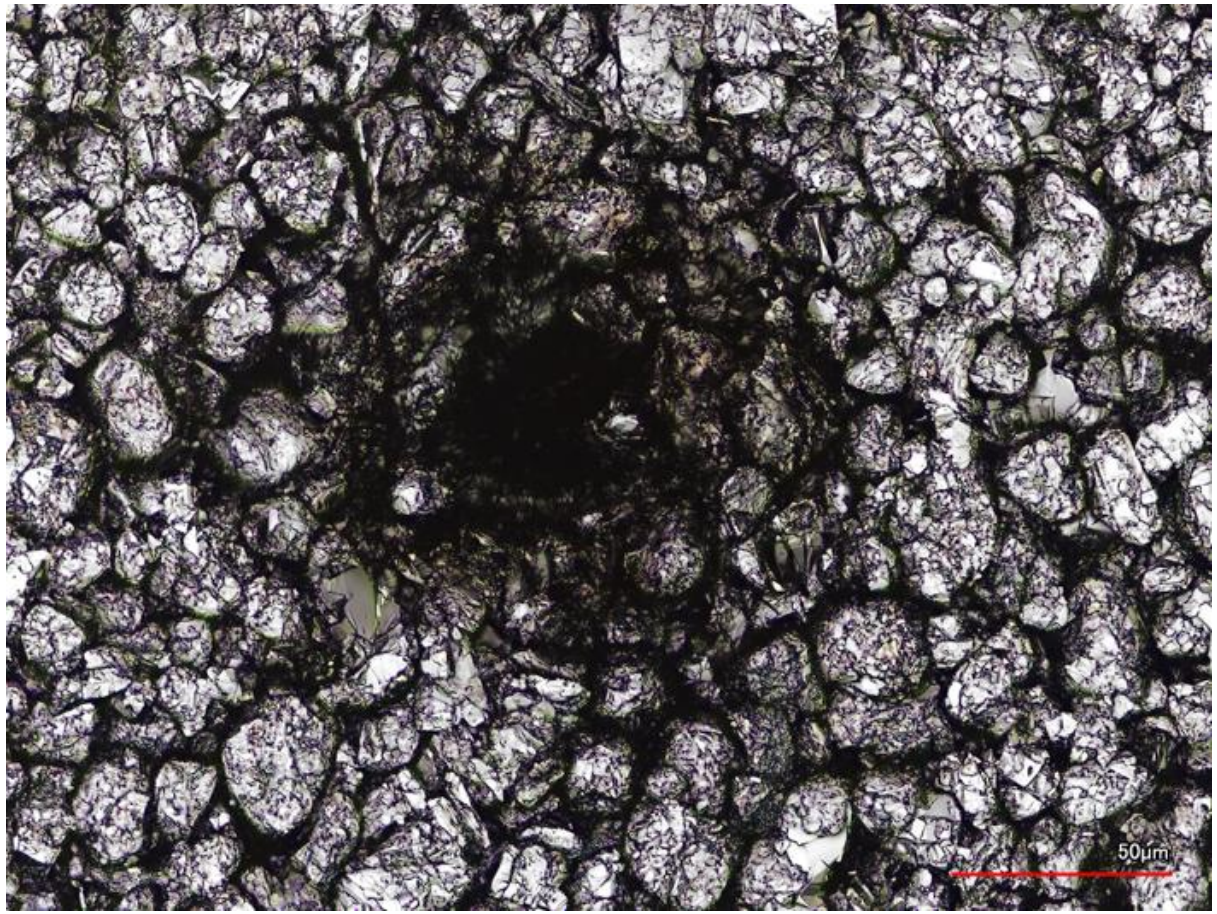
Source: Femtosecond laser structuring of graphite anodes for improved lithium-ion batteries: Ablation characteristics and process design Journal of Laser Applications 30, 032205 (2018)

Laser Structuring of Battery Foils

Pattern



Single crater

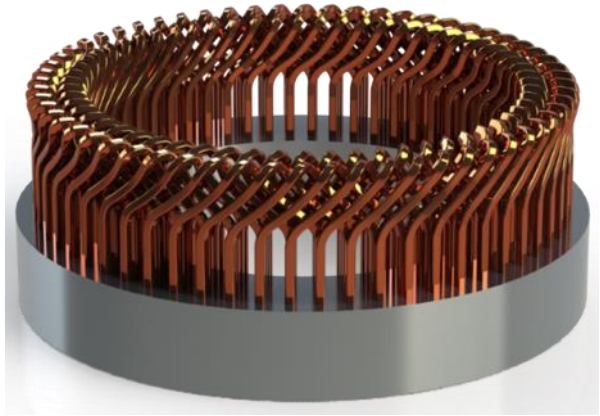


Fiber Laser Solutions

Hairpin & Battery Welding

EV Laser Solution Example - Hairpin Welding Module

Simplifies line integration. Makes welding projects possible by non-experts



LASER + SCANNER + VISION + CONTROLLER

Integrated **L**aser **W**elding **S**ystem (ILWS)

Hardware Deliverables:

- YLS 2000 AMB Multi-mode Laser
- 2D High-Power Scanner (with smart Vision)
- ILWS Rack Controller with HMI

Solution Deliverables:

- Vision programming and Integration
- Process Developed by IPG
- Part Programing by IPG
- Full ILWS Welding Module Integration

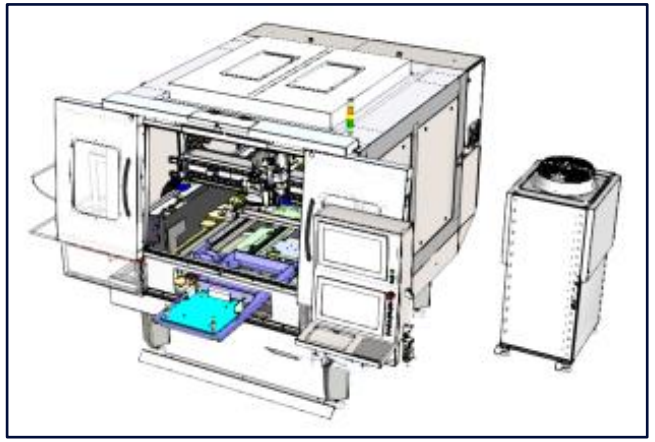
EV Laser Solution Example - Welding R&D Workstation

Laser Welding Workcell with Precision Motion Systems, Controller and Software

- Standard work volume: 500 x 300 x 300 mm
  - Optional cabinet extension for load of heavy parts
- Any IPG Laser.
  - CW, QCW, Pulsed, Single Beam, AMB MM, AMB SM
- Any IPG Beam Delivery
  - Fixed / Wobble, Scanning, Shaped Beams
- Real-Time Weld Measurement
  - Penetration Depth, Surface Area, Profile
- Simple G/M code programming for easy learning

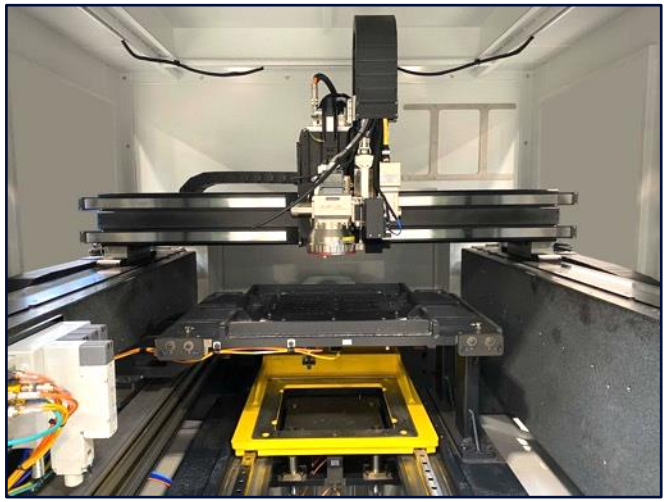
Ideal for process development, process and material qualification, and proof of concept parts
- Developed technologies transferrable to IPG EV Manufacturing Solutions

EV Laser Solution Example
Cylindrical Cell Weld Module



Battery Welding Workcell with Controller and Software

- X-Y-Z motion system for large part coverage (1250 x 1000 mm)
- YLS 3000 AMB Single-mode Laser
- High Power Scanner
- Integrated real-time weld measurement
  - Penetration depth & Quality
- IPG supplied tooling
- IPG Process Development (Optional)



Manual load gantry motion platform with flexibility for part prototyping

EV Laser Solution Example
Robotic Weld Cell for Pouch and Hairpins

Welding Workcell, Robot, Controller and Software, IPG Welding Process

- 6-axis robot, 1 or 2 fixture nests,
- 850 x 1900 mm max part size
- Laser Power: Typically 3000 W, AMB
- High Power Scanner with Integrated Vision
- Integrated Real-Time Weld Measurement

- **Conveyor I/O with robotic motion for prototypes and pilot production**
- **Loading and Process Flexibility for Compatibility with Many Different Part Types**

Battery Module Weld & Test Production Solution

Automated low-mid volume welding of cylindrical cells to busbars

- With integrated real-time weld depth measurement and post-weld electrical test

- X-Y-Z gantry motion system for large part coverage (1250 x 1000 mm)
- IPG proprietary “intelligent tooling” part holding
- Laser Power 3000 W
- 2-D High Power Scanner, Integrated Vision
- Integrated weld depth and profile measurement
- Optional integrated flipping station for 2-side weld
- Optional integrated electrical test station

Summary

- Science of light-material interactions is immensely complex
  IPG has application scientists in 26 locations
- IPG is the leader in fiber lasers and has the breadth of technologies to test and determine the best Solution for your application
- EV industry not homogenous – Auto companies will start to compete on their differences
  - **One size does not fit all - you need equipment tested and optimized for your individual applications**
- **IPG partners and collaborates** with customers in this rapidly evolving industry to provide the **Best Laser Processing solution** for **Your Specific Application**

THANK YOU