Laser welding of e-mobility materials with variable beam profile lasers and pulse shaping

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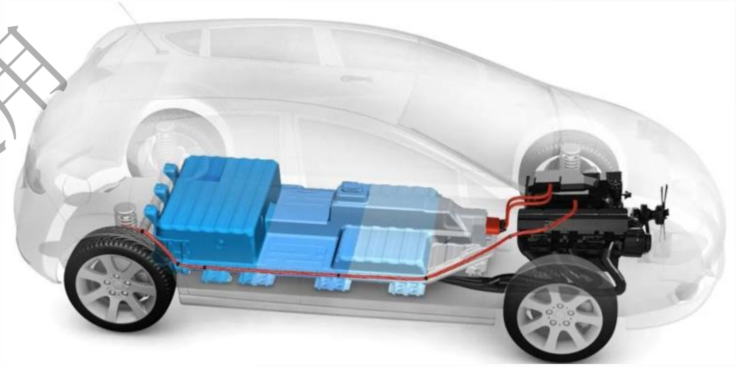
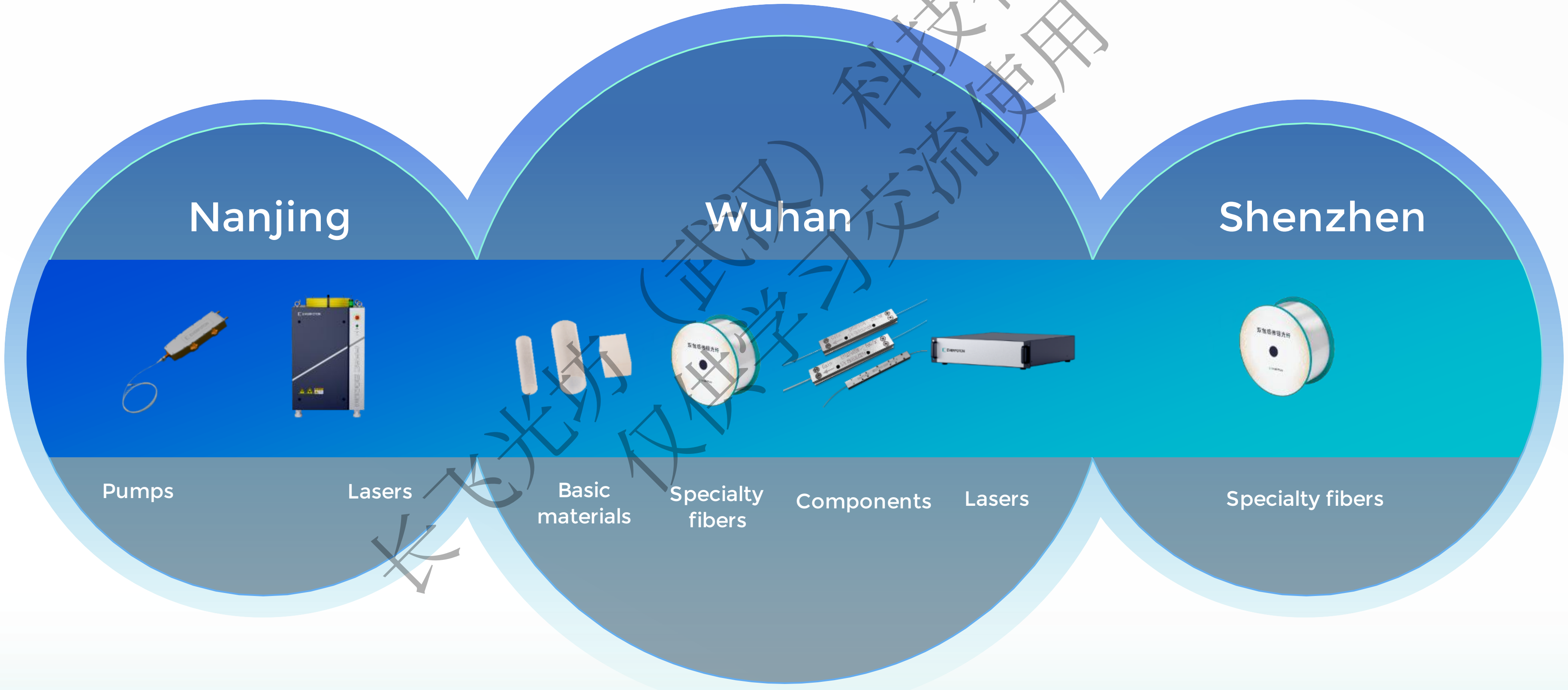


Everfoton profile

Everfoton represents a major first step by YOFC into the industrial laser field. Through critical acquisitions and integration of upstream and downstream industries, Everfoton has become one of the few industrial laser enterprises world-wide, with a complete, vertically integrated industrial chain.



Motivation

- The motivation is driven by the market to weld e- mobility materials used in Lithium-ion batteries. These batteries are used in a number of applications, including automobiles, buses, trucks, off-road vehicles, ships, ferries, and other seagoing vessels.

- EverFoton have been carrying out extensive R&D work to address some of welding issues associated battery welding
  - Laser sources
  - Process development

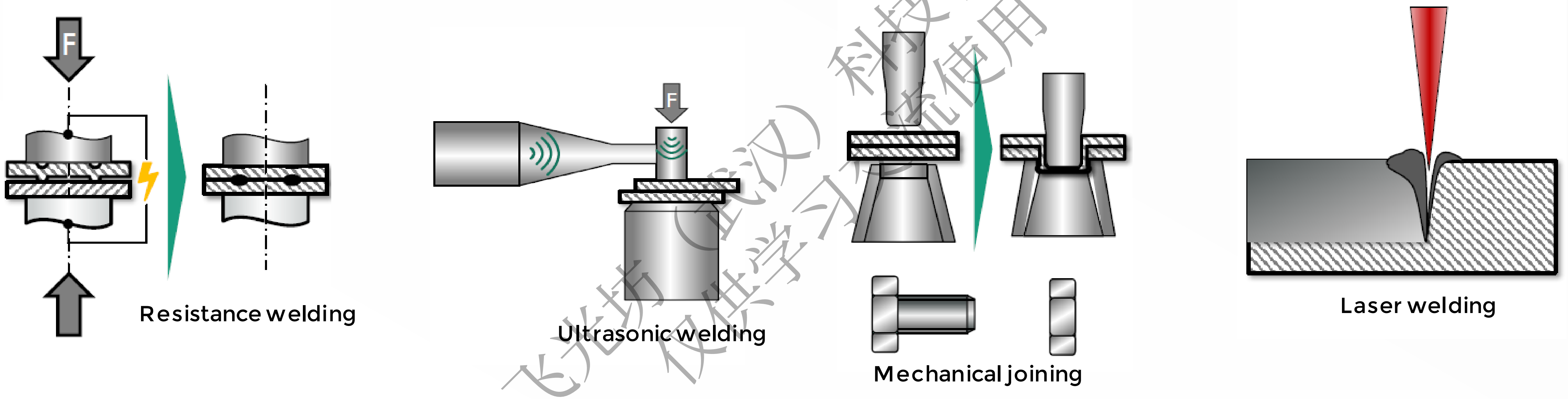
Lithium-ion batteries

- According to an observer of the 2018 CES (Consumer Electronics Show), “automakers are reallocating and prioritizing their research and development budgets toward electrification of vehicles.

- Lithium-ion batteries have increasingly been used due to their high voltage, high power density and low weight compared to competing for battery chemistries (nickel–metal–hydride)

Industry status for joining

- Lithium batteries (battery cell and pack) are complex assemblies of multiple layers of several materials (copper, aluminium, nickel, and nickel-plated copper) in a wide range of thicknesses (100μm-6mm)



- No single joining process dominates this application. No one seems to agree on which process to use for each material-geometry combination

Types of batteries

Prismatic cell

Al/Al, Cu/Cu and Al/Cu lap joints, Sub-mm and thicker materials (1-2mm) involved.

Cylindrical cells

Sub-mm thicknesses, Commonly Ni-plated Cu to Ni-plated steel lap joint corrosion, also improve the coupling of IR radiation.

Pouch cells

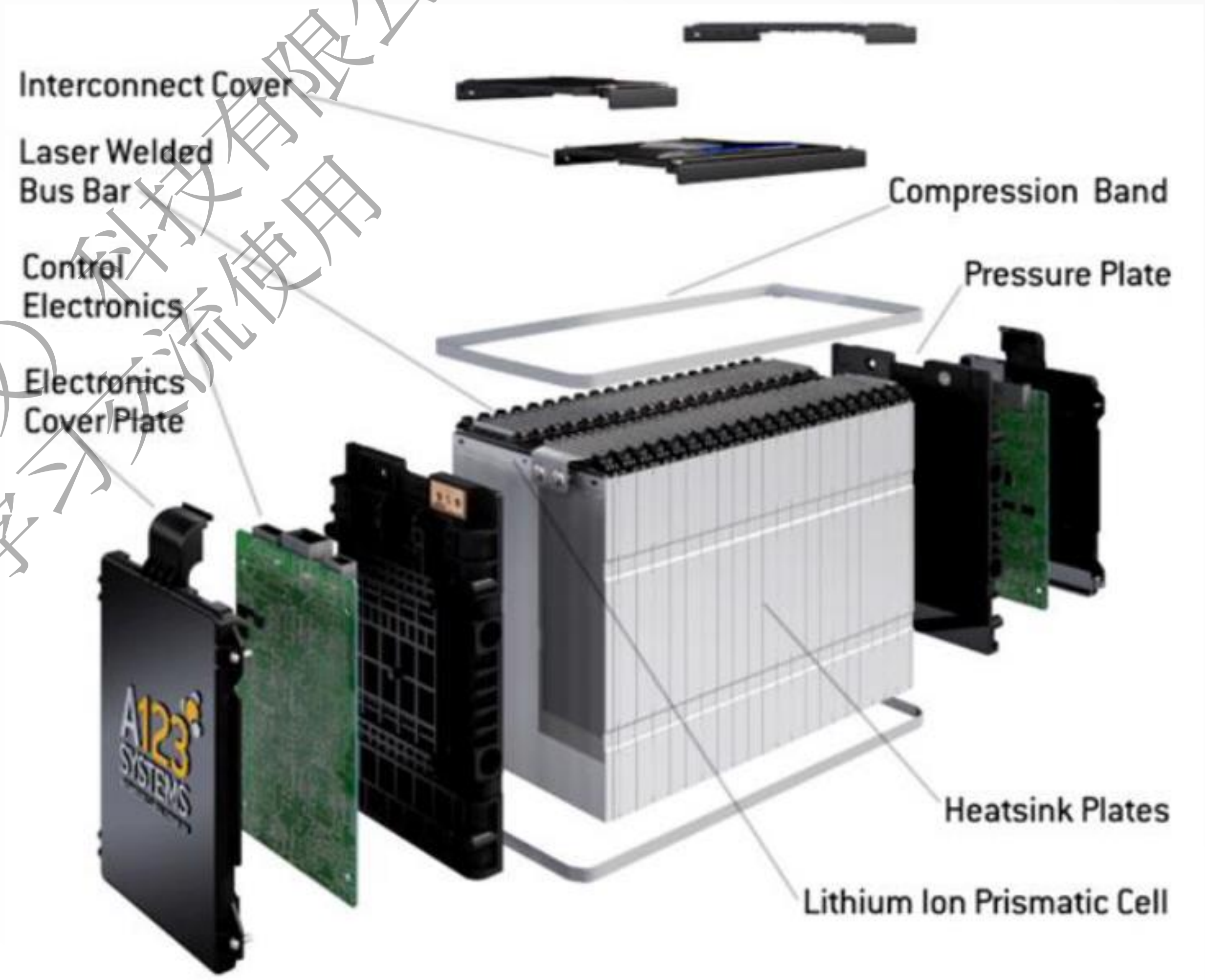
Similar sub-mm thicknesses Multiple stacks possible Commonly Al/Al, Cu/Cu and Al/Cu lap joints

Voltage 2.5-4.0V; Capacity 50-400mAH, Charging 0-45 deg C; Discharging -20- +55 deg C

Lithium- ion batteries materials

- These new batteries present new joining challenges and typical material combinations are:
  - Aluminium alloys
  - Pure copper
  - Aluminium- Copper
  - Copper- Aluminium
  - Copper - stainless steel
  - Stainless- copper
  - Copper to pure nickel
  - Aluminium to pure nickel
  - Nickel coated steels

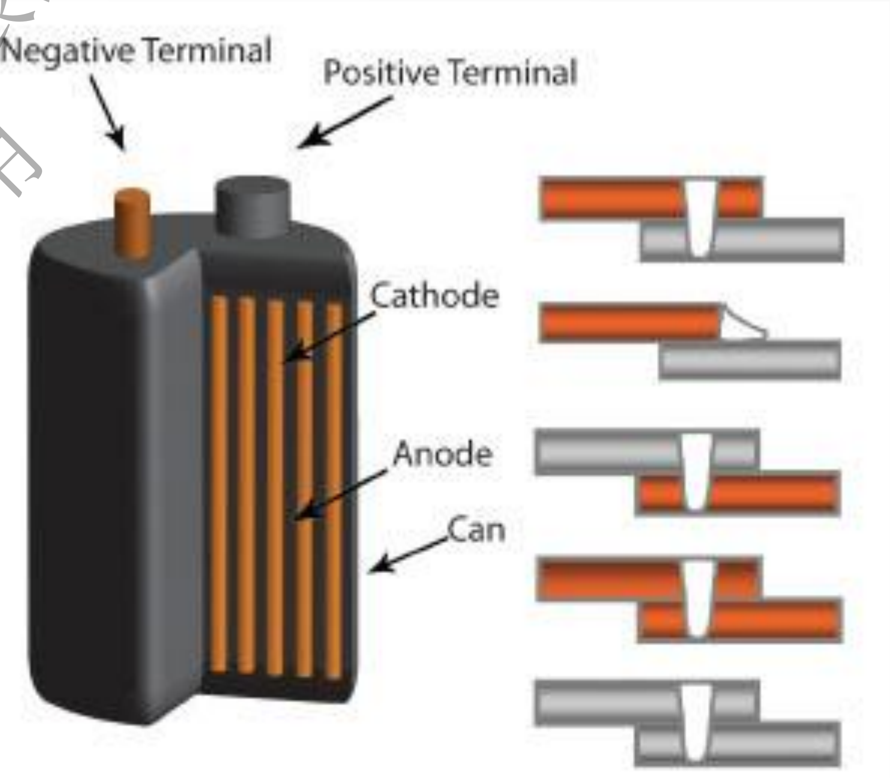
Electric current carrying components



Weldability of EV materials

- One of the most notorious, crack prone, weld metal combinations is copper to aluminium, which also happens to be one of the most wanted metal combinations in lithium-ion batteries.

- The final welding steps in the cell assembly are seam sealing of cans, which creates a barrier for the internal electrolyte and welding of tabs material to negative and positive terminals. It also creates the electrical contacts for the pack. These materials are:
  - Stainless steels
  - Aluminium alloys (3000 series)
  - Magnesium alloys



Welding requirements

- Successful laser welding requires intimate contact between the substrates being welded. This requires careful fixturing of the parts for best results. This can be difficult to achieve with thin tab substrates that are easily bent out of alignment especially when the tabs are recessed in a large battery module or pack structure

- Mechanical performance is evaluated using both lap shear and t-peel tests

- Electrical performance of the joints is assessed by measuring electrical resistance of the tabs

Weldability of dissimilar materials

- Potential Issues with dissimilar materials laser beam welding
  - Physical material properties
    - Differences in absorption/reflectivity of laser beam
    - Differences in heat conductivity
  - Metallurgical material properties
    - Solubility of material/alloying elements
    - Differences in melting temperatures and
    - Thermal expansion
    - Formation of inter-metallic phases

	Al	Ag	Au	Cu	Pt	Ni	Fe	Ti	W
Al	-	C	X	C	X	X	X	X	X
Ag	C	-	S	C	S	C	D	C	D
Au	X	S	-	S	S	S	C	X	N
Cu	C	C	S	-	S	S	C	X	D
Pt	X	S	S		-	S	S	X	X
Ni	X	C	S	S	S	-	C	X	X
Fe	X	D	C	C	S	C	-	X	X
Ti	X	C	X	X	X	X	X	-	X
W	X	D	N	D	X	X	X	X	-

C: complex structures may exist
X: intermetallics compounds formed; undesirable combination
S: solid solubility exists in all alloy combination
D: insufficient data for proper evaluation
N: no data available

Weldability

- In the welding of dissimilar metals, good solid solubility is essential for sound weld properties.
- This is achieved only with metals having compatible melting temperature ranges.
- If the melting temperature of one material is near the vaporization temperature of the other, poor weldability is obtained and often involves the formation of brittle intermetallic.

	Al	Ag	Au	Cu	Pt	Ni	Fe	Ti	W
Al	-	C	X	C	X	X	X	X	X
Ag	C	-	S	C	S	C	D	C	D
Au	X	S	-	S	S	S	C	X	N
Cu	C	C	S	-	S	S	C	X	D
Pt	X	S	S		-	S	S	X	X
Ni	X	C	S	S	S	-	C	X	X
Fe	X	D	C	C	S	C	-	X	X
Ti	X	C	X	X	X	X	X	-	X
W	X	D	N	D	X	X	X	X	-

C: complex structures may exist
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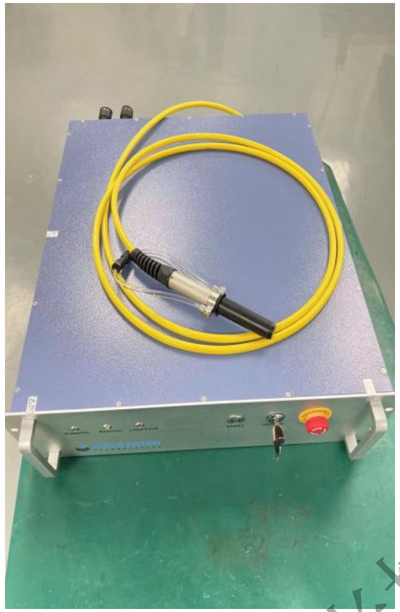
Advantages of laser welding dissimilar materials

- When joining dissimilar materials, there may be certain advantages in using laser welding even though brittle intermetallic may tend to form.
- Since the weld itself is narrow, the volume of intermetallic may also be reduced to acceptable limits.
- Again, it may be possible to offset the beam in one direction or the other, thus allowing some control over composition of the resulting alloy

EverFoton status on laser welding of e-mobility materials

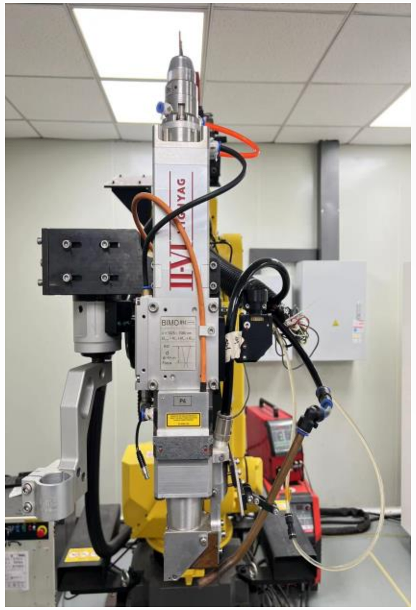
VBP lasers
Independent control of Ring and Core



SM CW lasers
Pulse Shaping Capability

QCW lasers
Pulse Shaping/Peak is ~10x Ave Power

Galvo system
Provides Flex. In moving beam about weld seam



Robot Integrated with weld head
High Average Power

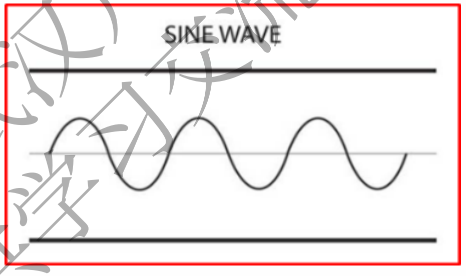
Pulse shaping

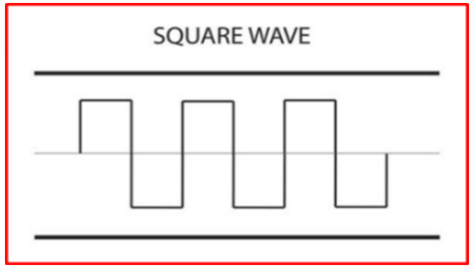
- Shaping the pulse can greatly affect the weld quality (i.e. cracking, porosity, etc.). The pulse shaping can also be optimized to improve the metallurgical properties and also has impact on the cosmetic appearance. Pulse shape is very beneficial, when welding:
  - High carbon steels
  - Crack sensitive alloys
  - Dissimilar melting points materials
  - Coated materials
  - Painted materials
  - Contaminated materials
  - Powder metallurgy parts
  - Highly reflectivity materials

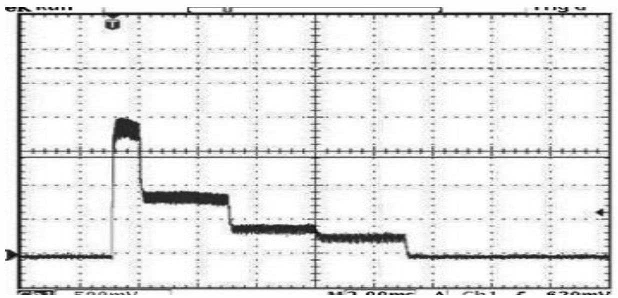
Welding tests

- Laser parameters
  - Laser out (pulse; CW)
  - Average power
  - Peak power
  - Power densities
  - Pulse shapes
  - Core & ring power
- Processing parameters
  - Shield gases
  - Focus positions
  - Welding speed
  - Weld joints
- Quality measurements
  - Metallographic analysis

- Materials tested
  - Al alloy; 1xxx & 6xxx
  - Pure copper
  - 304 stainless steel
  - Zn coated steel
  - Ni coated steels

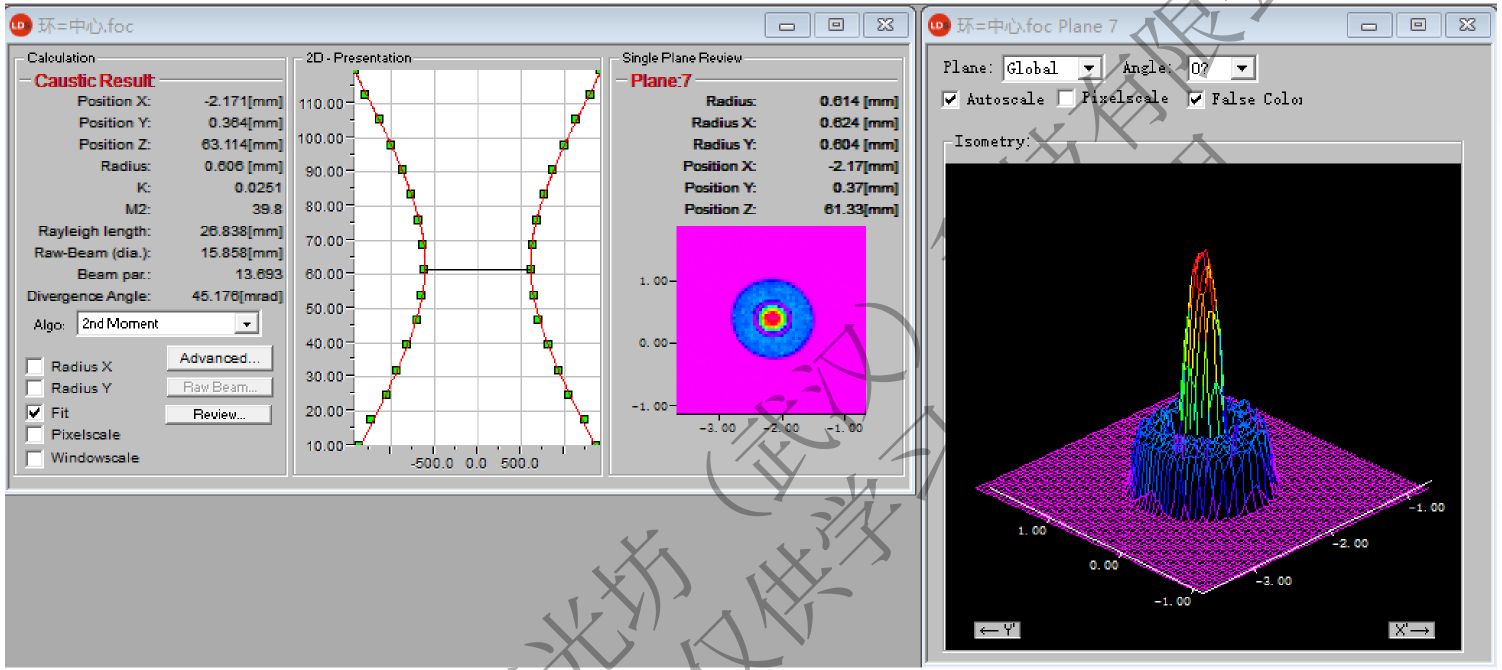






Example of pulse shapes

Welding data (6+6kW VBP laser)



Core size 100μm, ring size 600μm. The welding tests were carried with both galvo system fitted with a 330mm FL lens and with welding head fitted with a 200mm FL lens .

Weld quality comparison between traditional and VBP laser

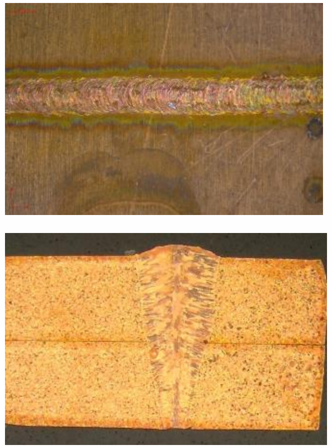
(a) Weld made with traditional fiber laser, 6kW fitted with 100µm fiber, 4mm thick pure copper, 2.5m/min, inconsistent top bead with blow holes and spatter.

Welding pure copper with a standard high power (6kW) CW fiber laser, the welding process was volatile regarding inconsistent weld penetration but more importantly, the formation of melt ejections

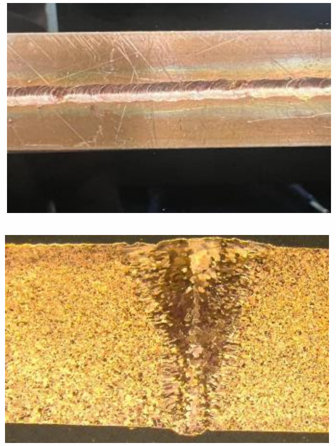
(b) Weld made with 6+6kW VBP laser, 4.5kW core, 1.5kW ring, 4mm thick pure copper, 2.5m/min, very consistent and spatter free weld.

The welding tests carried out a VBP laser show that high intensity, high power centre beam is needed to provide the energy required to readily melt the material, while the ring beam helps stabilize the keyhole. The result is that the welding process is initiated and maintained consistently without formation of metal ejections, regardless of surface variations in the work piece.

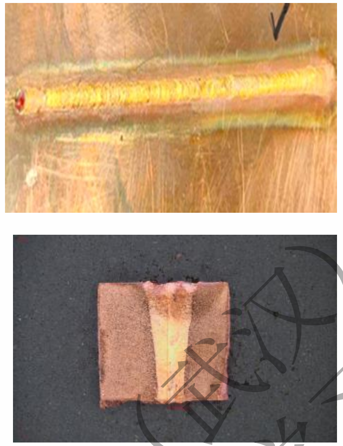
Examples of Cu welding with VBP laser



(a) 2+2mm overlap joint,
2.5m/min.



(b) 4mm butt joint,
2.7m/min.



(c) 6mm butt joint,
1.5m/min.

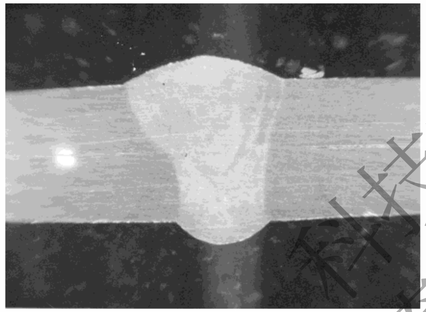
(d) 2+6mm overlap joint,
1.2m/min.

Hairpin terminal for electrical motor

Currently EverFoton have various VBP lasers with different core/ ring fiber sizes beam qualities and average power
14/100 (2+2kW); 14/400 (2+2kW) ; 50/100 (4+2kW); 100/600 (6+6kW)

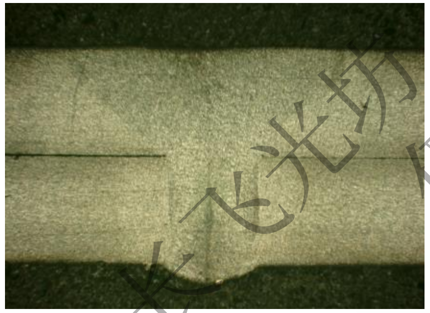
Examples of Al-based alloy welding with VBP laser

Consistent topbead, no spatter or blowholes



Fusion zone, no solidification cracking

2mm thick 6061 T6 aluminium based alloy, butt joint, 3m/min, 1.5kW+2.5kW

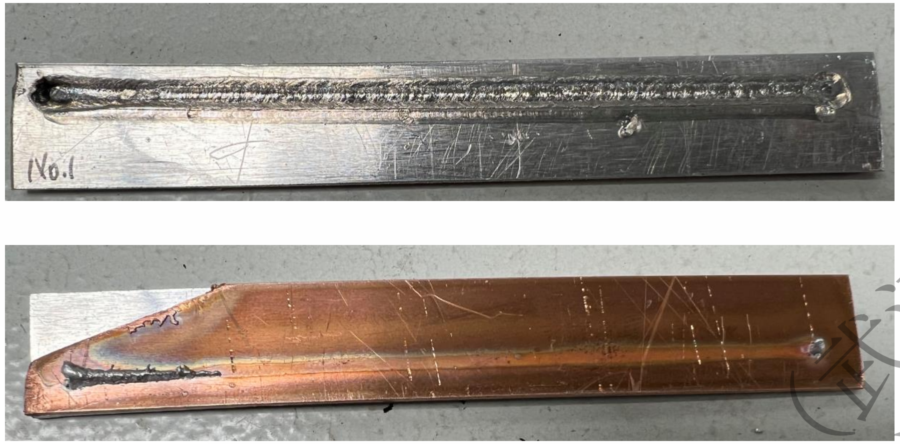


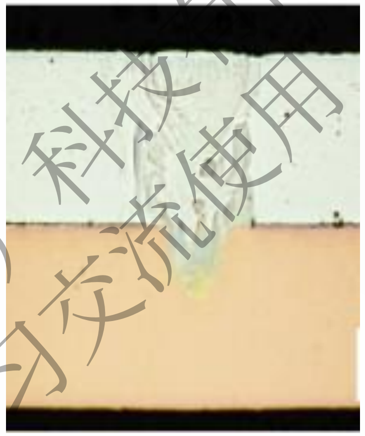
2+2mm overlap joint, 2.5m/min, 1.5kW+2.5kW

6mm, butt joint, 2.0m/min, 2.0kW+1.5kW

6061 T6 aluminium based alloy

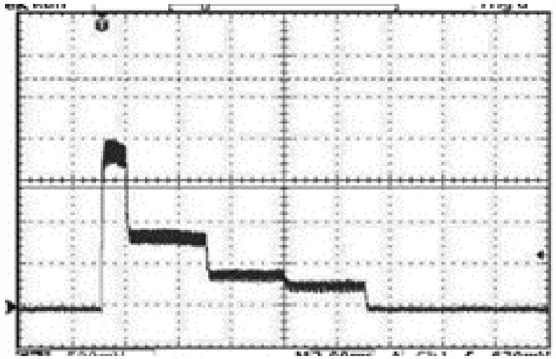
Example of dissimilar joints



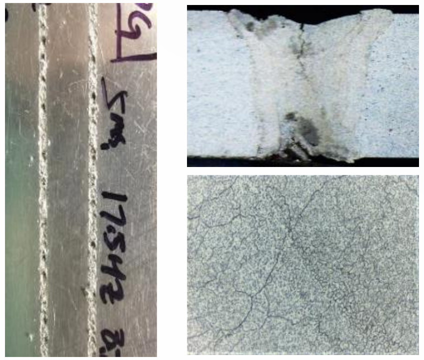


Overlap joint between Al and Cu, partial penetration weld, reduced formation of intermetallics.

Examples of pulse shaping with low SM CW & QCW lasers

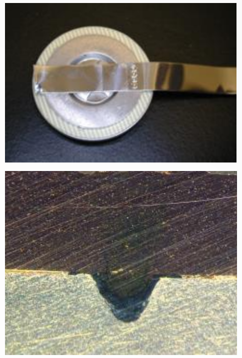


Ramp- down shape, for welding crack sensitive aluminium based alloy (6061) and for dissimilar materials (Al + Cu)

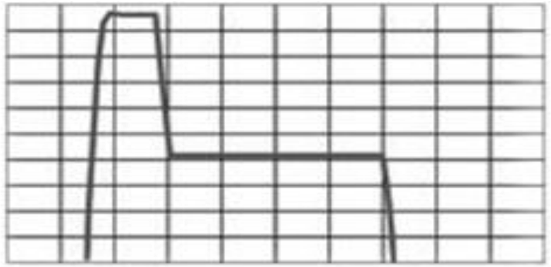


1mm 6061 T6 Al alloy, BOP, without pulse shape

1mm 6061 T6 Al alloy, BOP, with ramp-down pulse shape

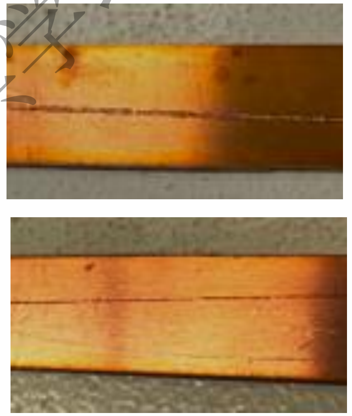


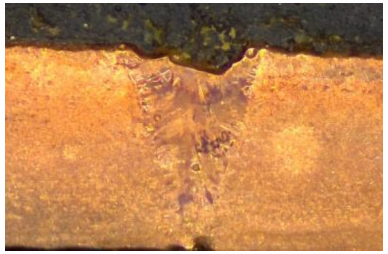
Cu/Al spot welds



Enhanced spike, for welding very reflective materials with high conductivity (pure copper

1mm pure copper, BOP, without pulse shape, no weld penetration





1mm pure copper, BOP, with enhanced spike pulse shape, full weld penetration

Pure copper battery terminals

Summary

- EverFoton has conducted comprehensive testing programs on laser welding of electric vehicle materials. These tests, which are currently in progress, covered a wide range of processing and laser parameters to study the weldability of aluminum alloys, pure copper and dissimilar materials. The results presented here for EV batteries have shown that:

  - High-quality welds of aluminum alloy, pure copper and dissimilar materials were produced with the with VBP laser and QCW laser with pulse shaping.

  - Both VBP laser and pulse shaping avoids sensitivity to surface quality and process instability issues that have restricted the use of traditional fiber lasers for welding highly reflective materials (Cu & Al).

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