Opportunities by laser joining of dissimilar materials

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Agenda

- **Laser joining of dissimilar metals**

  ✓ Aluminum-Copper

  ✓ Heat sensitive sintered metals-steel

  ✓ Micro-welding of Cu based-Nickel based alloys

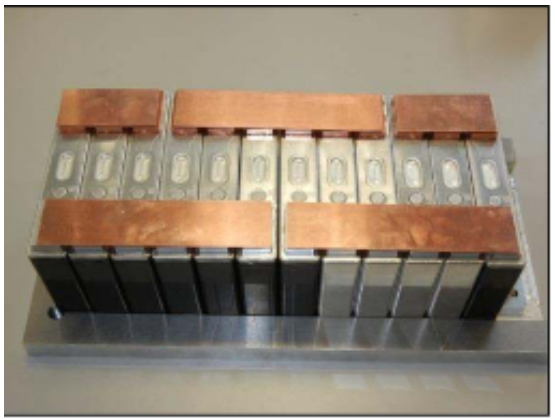
- **Laser joining of polymers**

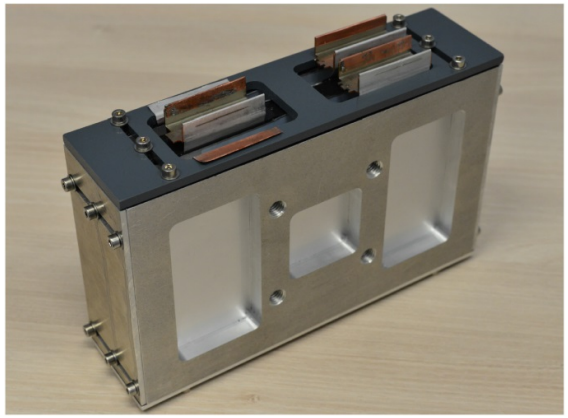
- **Laser joining of metals to polymers**

Laser joining of dissimilar metals (Al - Cu)

Aluminum-Copper

- **Advantages:** Laser enables joining of thinner materials.
  Laser delivers fast, contactless, precise energy; capable to automate.
- **Issue:** Formation of Intermetallic Compounds (IMC) due to low solubility.
  IMC deteriorate mechanical properties and electrical conductivity.
- **Method:** Overlap configuration to selectively deliver the laser energy.
  Control the reaction of Al and Cu.

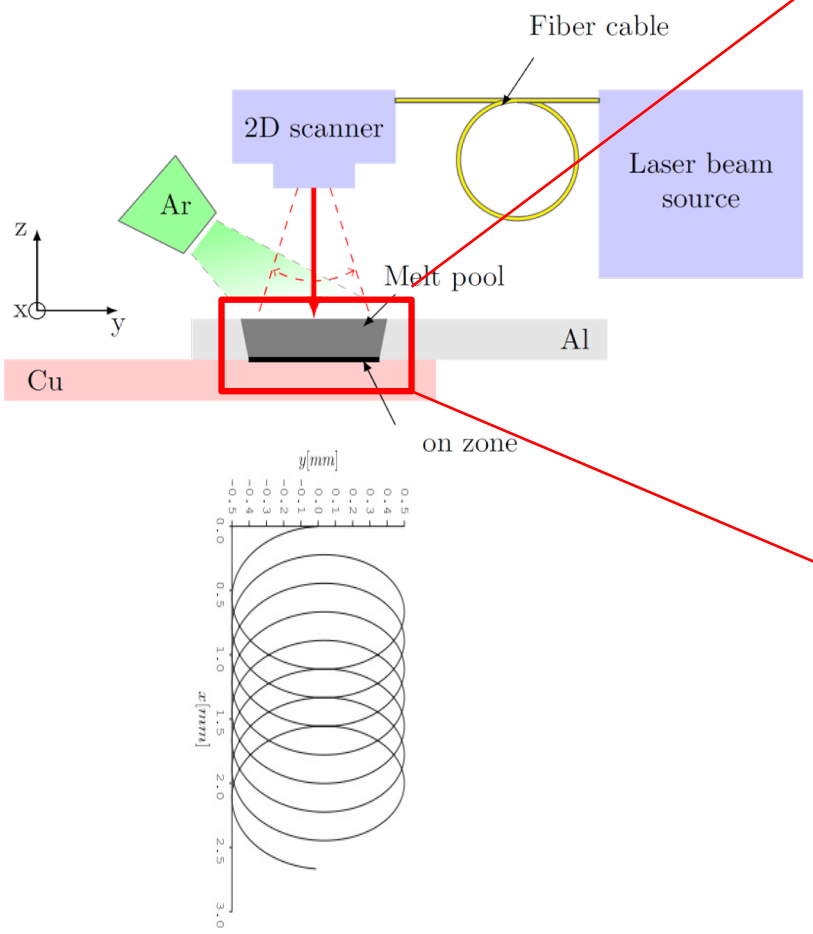


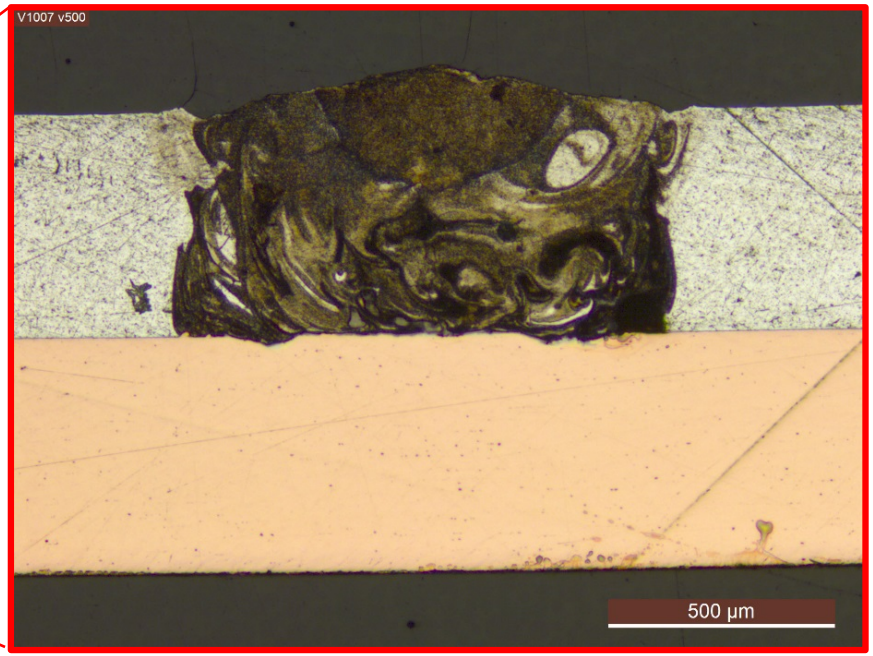


Source: J. Rudlin, P. Bono , S. Majidnia, TWI, 2014

Laser joining of dissimilar metals (Al - Cu)

Laser weld/brazing of Al-Cu



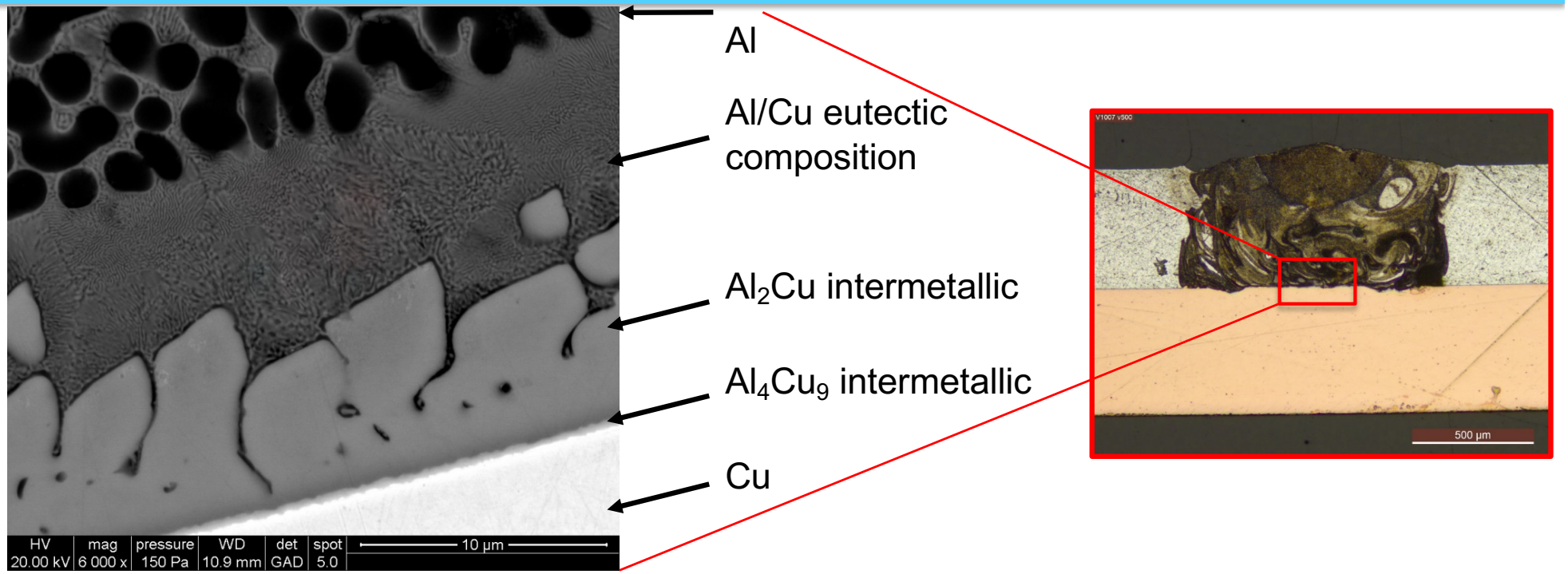


- Trumpf Trufiber 400 W
- Circular oscillation of Laser beam
- Melting of Al
- Copper stays in solid state (!!)
- Diffusion bonding of Al to Cu
- Pulse modulation of energy
- Spot diameter 30 µm
- Focus Z=0

Source: T. Solchenbach, P. Plapper, 2012

Laser joining of dissimilar metals (Al - Cu)

Laser weld brazing of Al-Cu: Intermetallic Compounds

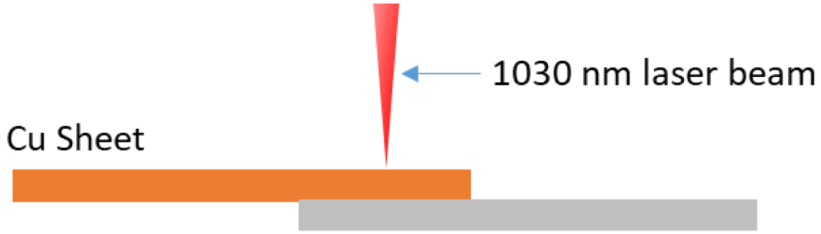


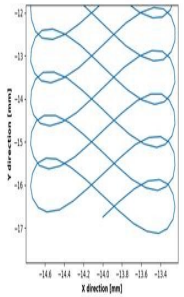
- Analysis by SEM/EDS and XRD => 2 Intermetallic Compounds (IMC): Al_2Cu & Al_4Cu_9
- Thickness of intermetallic compounds ≤ 3.2 µm
- Excellent mechanical properties (120 MPa)
- Minimized electrical resistance
- Ageing effect minimized

Source: T. Solchenbach, P. Plapper, W. Cai, 2014,

Laser joining of dissimilar metals (Cu - Al)

Cu-Al: Changed stacking

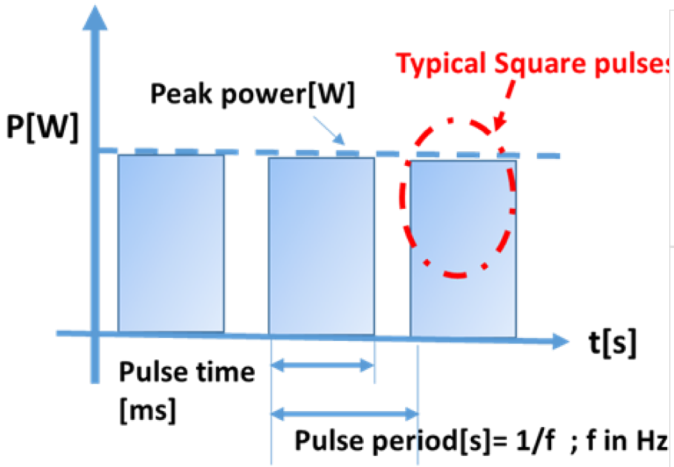


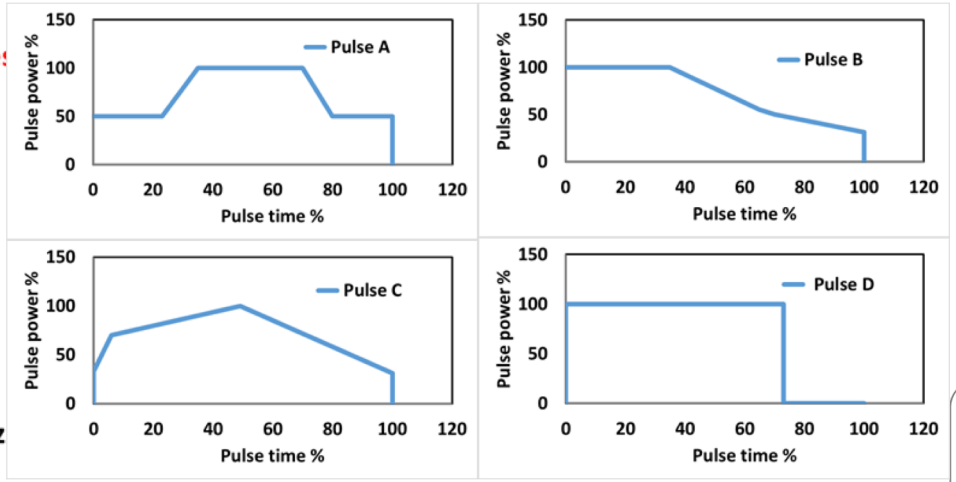


- Trumpf Trudisk 2000 W
- Combined wobbling and pulsing
- 0.4mm Cu- 0.4 mm Al

Laser beam path / Wobbling:

– Wobble width	1.5 mm
– Frequency	100 HZ
– Speed	v=30 mm/s
– Spot diameter	89 µm
– Focus	Z=0

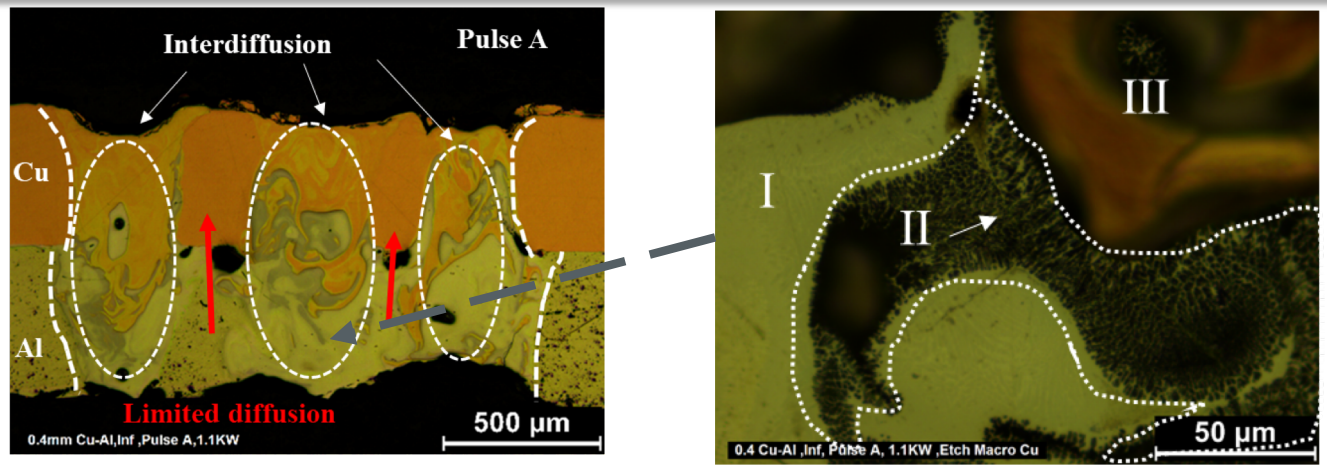




Source: K. Mathivanan, P. Plapper, 2019.

Laser joining of dissimilar metals (Cu - Al)

Cu-Al: Pulse welding of thin Cu sheet



- Good intermixing of Cu and Al
- No impact of pulse shape
- Presence of intermetallic structures
- Ⅰ) Al rich phase, Ⅱ, Ⅲ) Cu rich phase, as a result of intermixing of Cu and Al
- Stable mechanical properties, comparable to that of base Aluminum (1.23 kN)
- Both orientations are feasible => freedom for product design

Source: K. Mathivanan, P. Plapper, 2019.

Laser joining of dissimilar metals

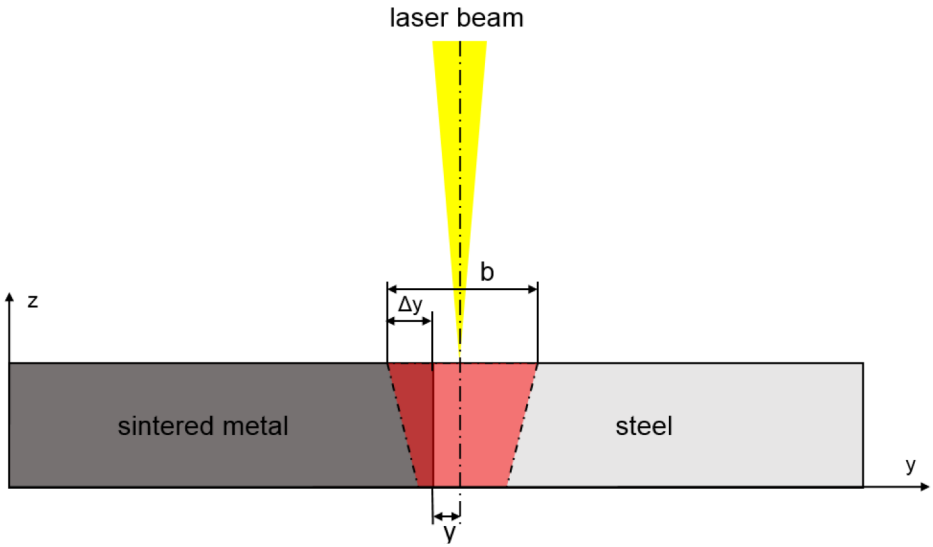
Heat sensitive sintered materials-steel

- **Issue:** Substitute brazing processes for butt geometries
- **Advantage:** Increase mechanical properties, reduce heat load, enable automation,
- **Method/result:** Laser welding in butt joint configuration,

  Optimized temperature profile in sintered part,

  Analysis of weld seam metallurgy,

  Improved weld seam strength due to favorable weld seam metallurgy.



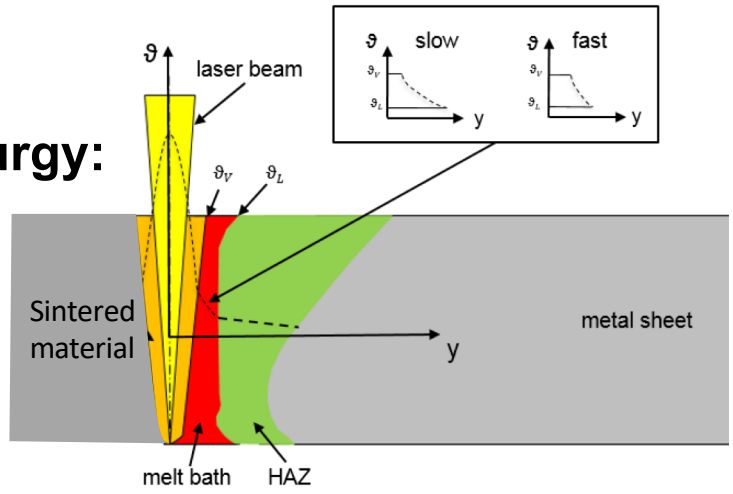
Laser joining of dissimilar metals

Heat sensitive sintered materials-steel

Influence of bead profile:

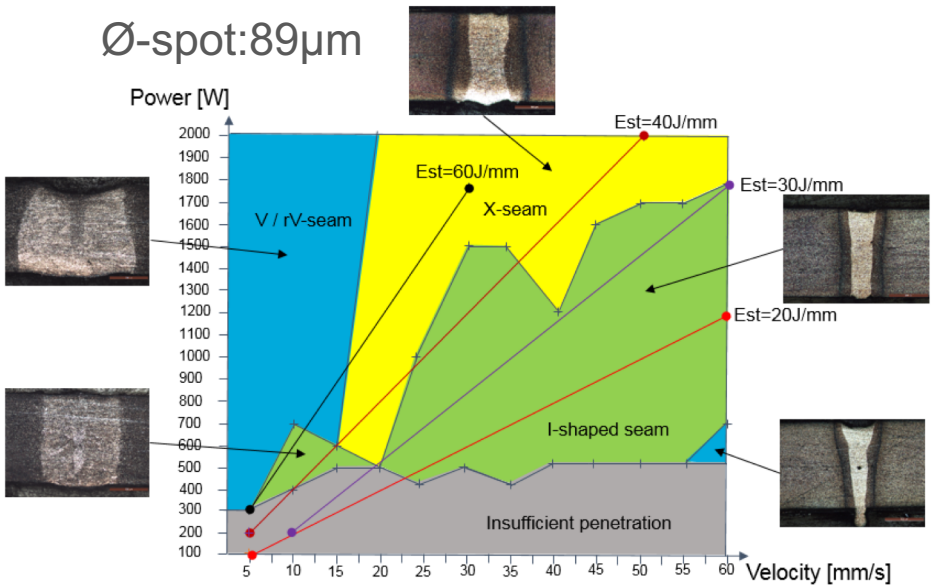
- Correlation of phase boundaries with temperature profile
- Improvement of 3-d weld seam profile
- Influence on cooling rate and temperature profile
- Low thermal load on sintered part

$$\dot{Q} = \alpha_{th} \cdot A \cdot \frac{(\vartheta_V - \vartheta_L)}{\Delta y}$$



Influence of seam volume on weld metallurgy:

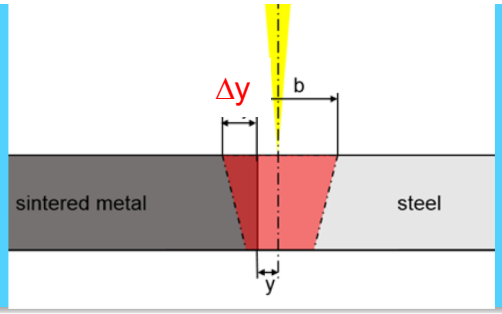
- Larger laser spot with bigger seam volume
- Smaller laser spot with lower full penetration threshold



Source: M. Schiry, P. Plapper, 2018

Laser joining of dissimilar metals

Heat sensitive sintered metals-steel

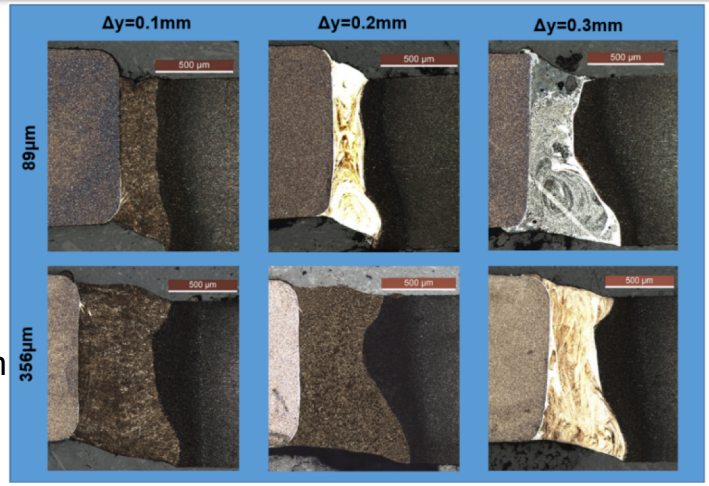


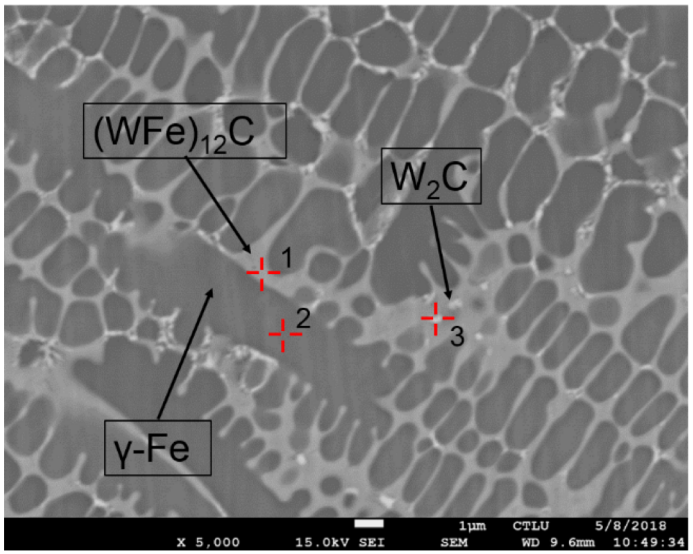
Joint properties:

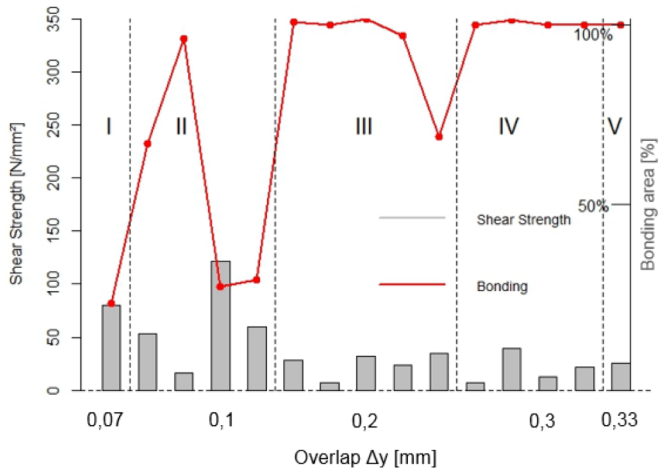
- I-shaped seam geometry provides best bonding
- Defined, limited melting of sintered material

Metallurgical impact:

- High seam volume reduces relative amount of sintered elements in seam
- Shift of “metallurgical” threshold to higher melting rates
- Metallurgical change reduces thermal stress in weld seam





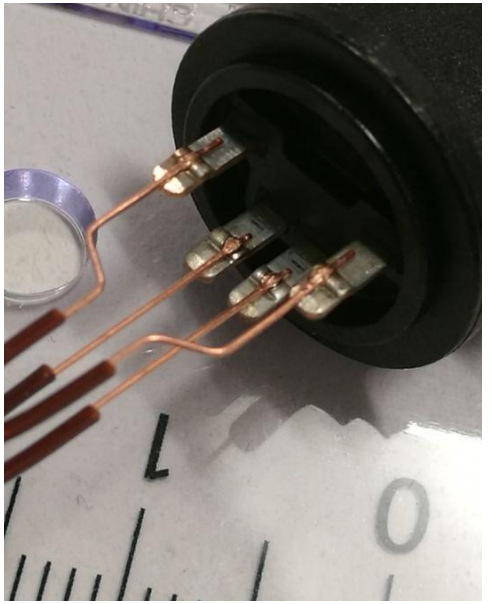


Source: M. Schiry, P. Plapper, 2019

Laser joining of dissimilar metals

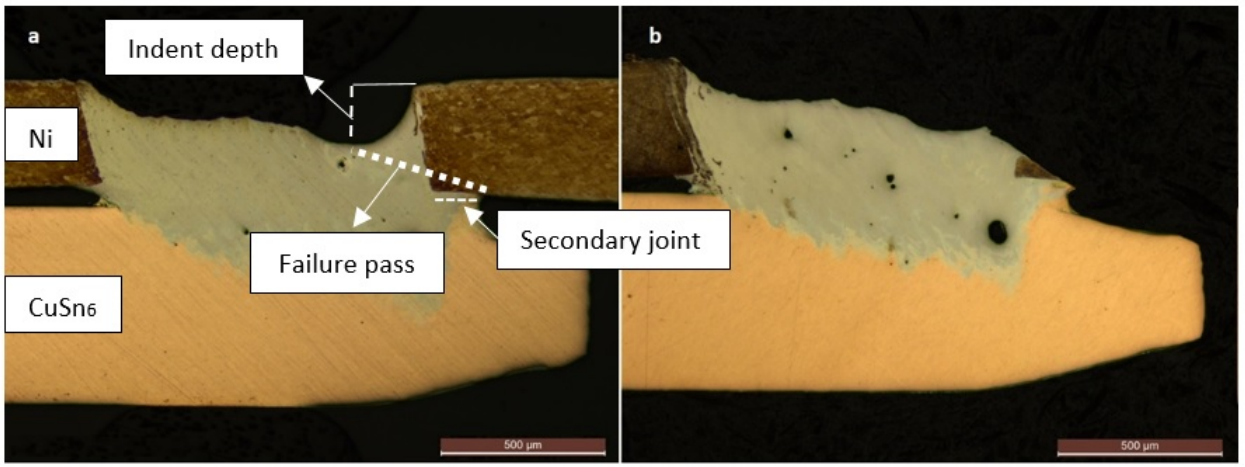
Micro-welding of Cu based-Ni based alloys

- **Issue:** Replace tactile brazing by contactless laser welding
- **Advantage:** Non-contact technique, automation potential
- **Method:** Optimization of beam oscillation path.
  Weld from both wire and terminal side,
  Simulation of temperature distribution,
  Analyze mechanism of failure



Before tensile test

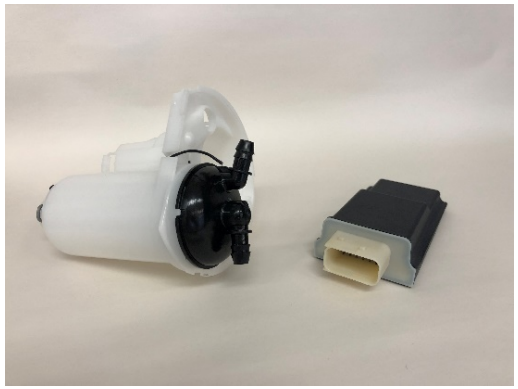
After tensile test



Source: M. Amne Elahi, P. Plapper, 2018.

Laser joining of polymers

- **Issue:** Substitute of form lock, in-mold, and gluing technology
- **Advantage:** Miniaturization, weight saving, automation
- **Method:** Welding through transparent polymer into absorbent material CO_2 laser, providing different material absorption properties.
- **Result:** Process parameter: Energy density, focus position, speed, …



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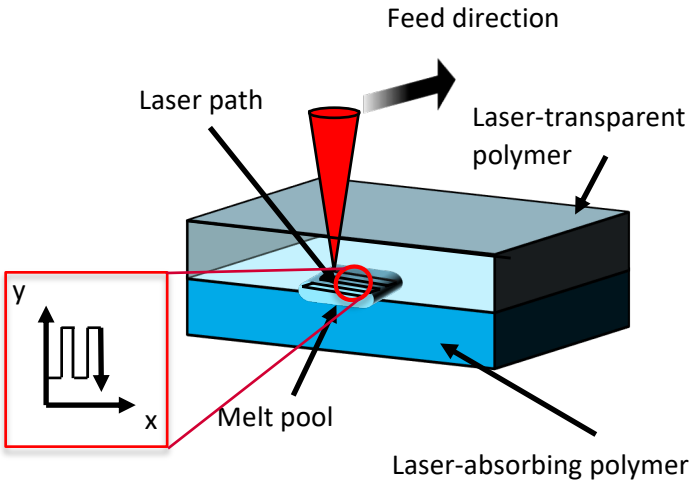
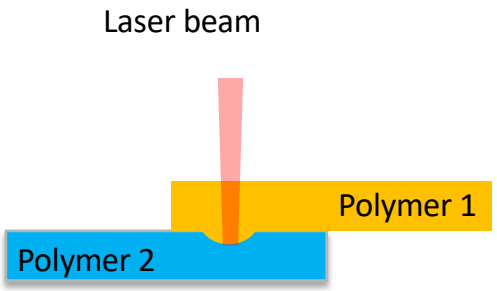
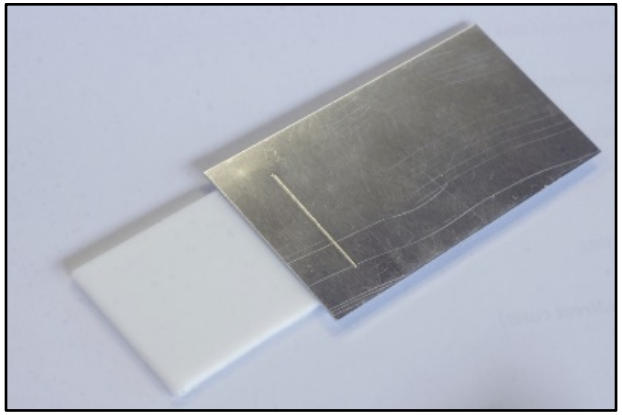


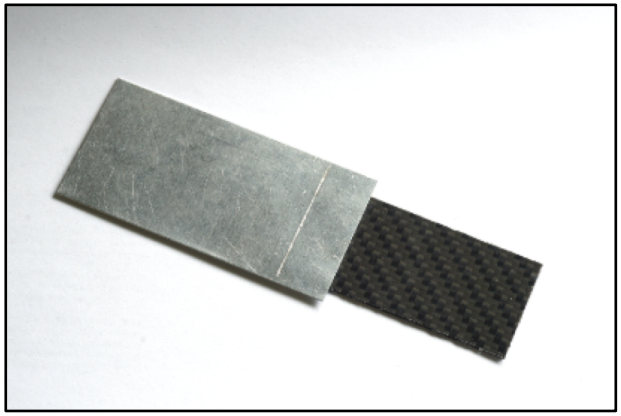


Laser joining of light weight metals to polymers

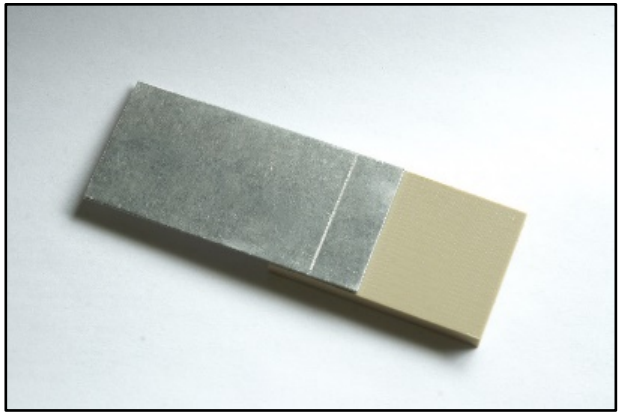
- **Issue:** Understand mechanism of joining, mechanical properties of the joint, failure mechanism and durability
- **Advantages:** Weight reduction, tight joint, light weight components
- **Method:** Apply different pre-treatments on metal/polymer
  Improve physico-chemical bonding.
- **Status:** Impact adhesion failure to cohesion and t base material failure
  Ongoing research projects



PBT and Aluminium



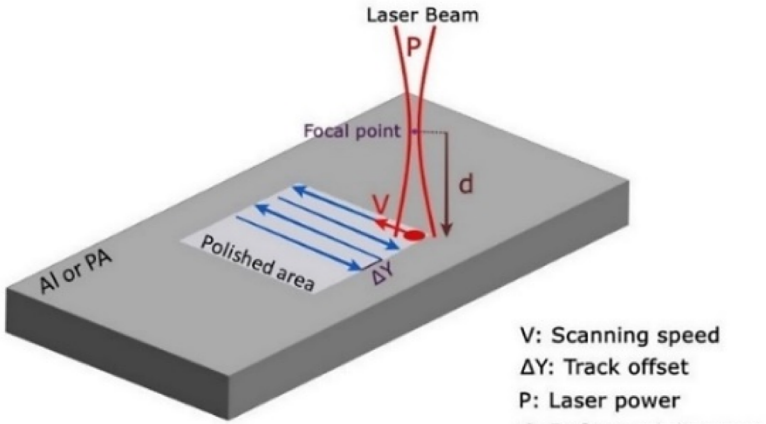
CFRP PA-6 and Aluminium



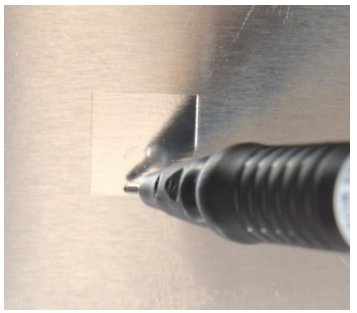
PEEK and Al.

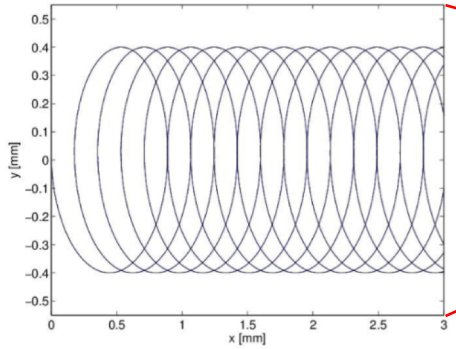
Laser joining of light weight metals to polymers

Laser polishing process

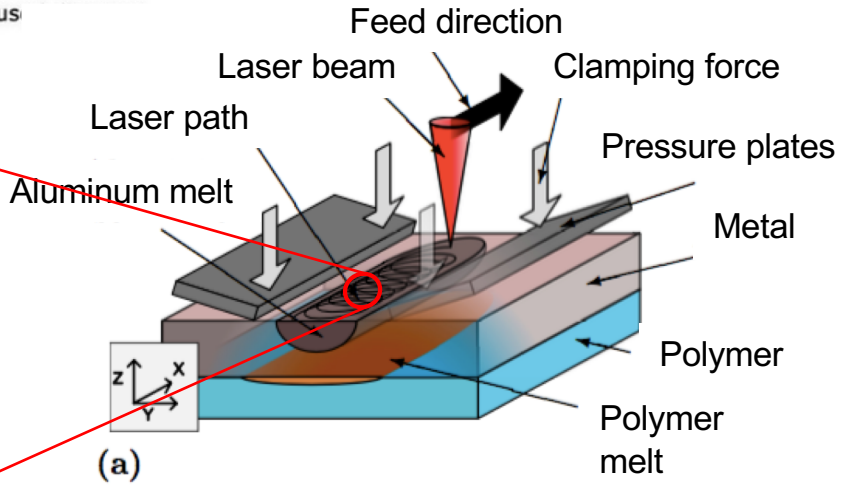


V: Scanning speed
ΔY: Track offset
P: Laser power
d: Defocus





Laser beam trajectory



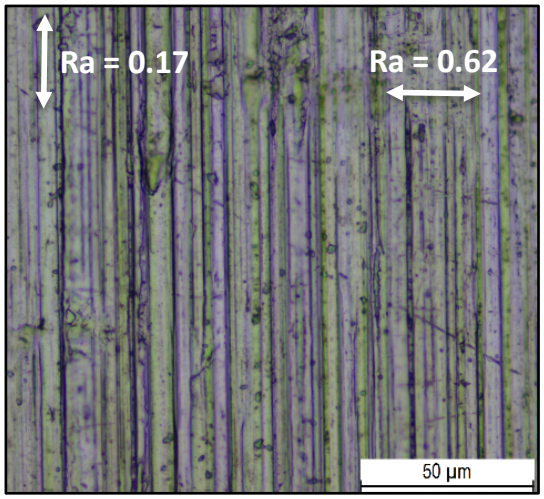
Clamping fixture to join metals to polymer

Source: M. Amne Elahi, P. Plapper, 2019.

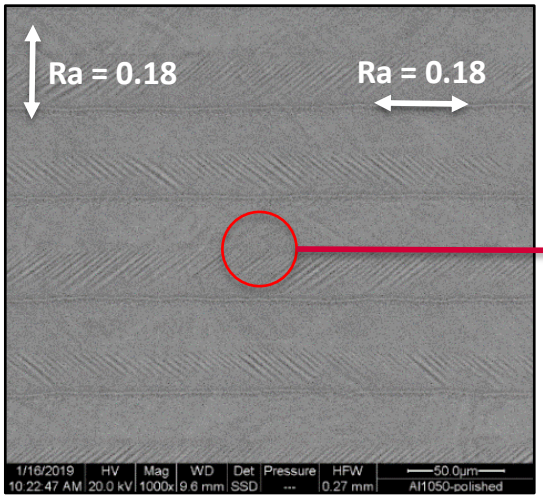
Laser joining of metals to polymers

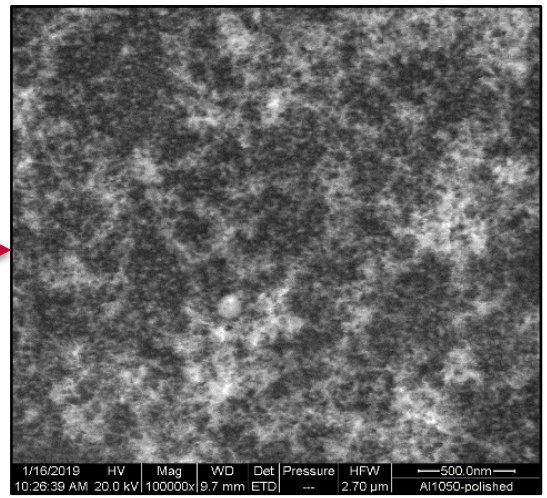
Laser polished surface

As-received



Laser-polished



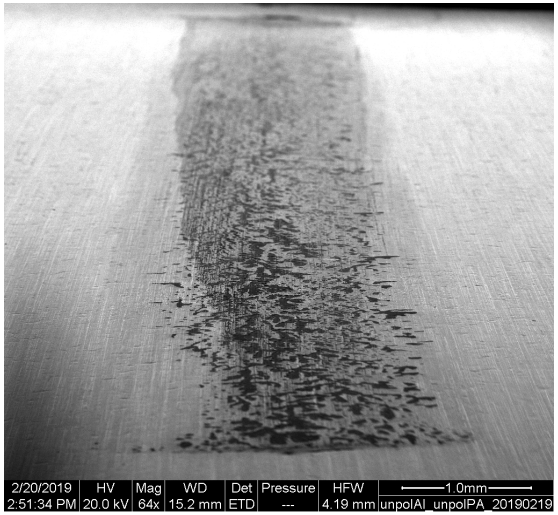


Laser Polishing on Al surface

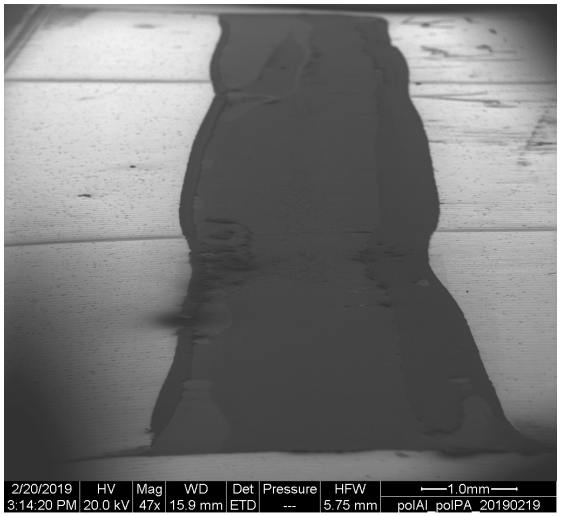
- Reduce roughness orthogonal to rolling direction
- Eliminate direction of roughness => isotropic surface
- Formation of nano-structured oxide layer on aluminum surface

Source: M. Amne Elahi, P. Plapper, 2019.

Results and discussions

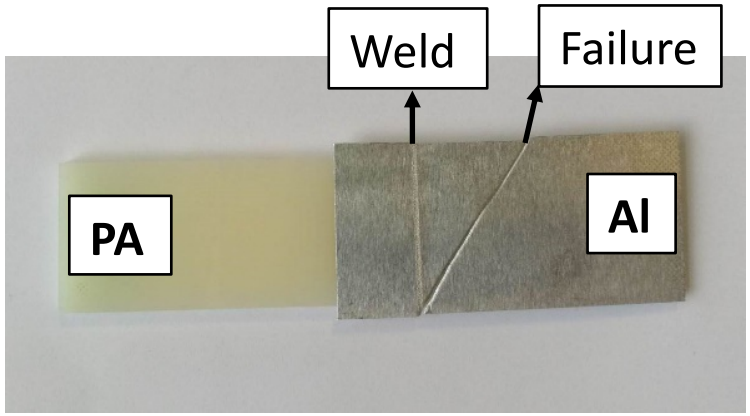


Un-treated Al fracture surface



Laser-polished Al fracture surface

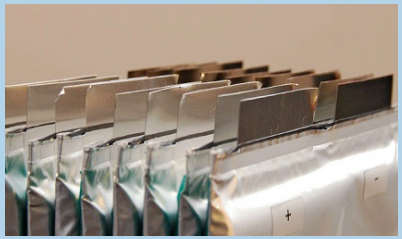
Optimized polishing and welding process



Source: M. Amne Elahi, P. Plapper, 2019.

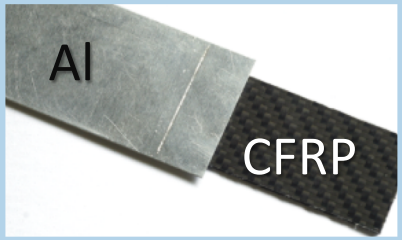
Summary
Opportunities by laser joining of dissimilar materials

Non ferrous metals



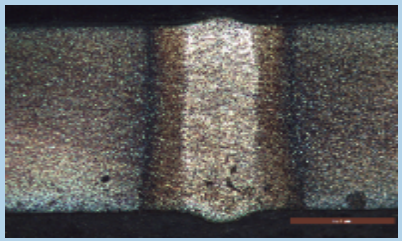
- Electro-mobility
- Al- Cu; Cu-Al
- Reduce brittleness, minimize resistance

Polymers and metals



- Joining PA, PEEK, PBT, … to Aluminum, Titanium, Steel, …
- Lightweight design
- Automotive, railway, aviation, medical, consumer, …

Sintered materials



- Different geometries
- Create defined spatial 3 dimensional temperature profile
- Impact metallurgy by cooling rate

Contact Data

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Slected Literature

For complete list of publications please refer to http://orbilu.uni.lu/

- Schiry, Marc; **Plapper, Peter**: “Elucidation of influencing parameters of the laser butt welding process of dissimilar steel to tungsten alloy sheets” in Proceedings: International Conference on Competitive Manufacturing COMA'19 (2019, January)
- Schiry, Marc; **Plapper, Peter**: “Novel Opportunities by Laser Welding of Dissimilar Materials” in Proceeding: International Conference on Competitive Manufacturing COMA'19 (2019, January)
- Amne Elahi, Mahdi; Plapper, Peter: “Dissimilar Laser Micro-Welding of Nickel Wire to CuSn6 Bronze Terminal” in Transactions of the Indian Institute of Metals (2018)
- Mathivanan, Karthik; **Plapper, Peter**: “Autogenous Laser welding of copper to aluminium” 11th International Conference on Photo-Excited Processes and Applications – ICPEPA 11, Lithuania, 2018, September
- Amne Elahi, Mahdi; **Plapper, Peter**: “Laser micro-welding of wire to flat geometry for dissimilar materials in an electromechanical application”, 11th International Conference on Photo-Excited Processes and Applications – ICPEPA 11, 2018, September
- Schiry, Marc; **Plapper, Peter**: “Influence of laser parameter on weld bead shape and process stability of laser welded steel sheets, in Proceedings of 10th Conference on Photonic Technologies LANE 2018 (2018)
- Schmalen, Pascal Guy; **Plapper, Peter**; Peral Alonso, Inmaculada, et al: “Composition and phases in laser welded Al-Cu joints by synchrotron x-ray microdiffraction” in Proceedings of 10th CIRP Conference on Photonic Technologies [LANE 2018] (2018)
- Schmalen, Pascal Guy**; Plapper, Peter**: “Spectroscopic Studies of dissimilar Al-Cu laser welding” Manufacturing Science and Engineering Conference MSEC2018, Texas USA, in proceedings of ASME MSEC 2018 (2018) June 18-22
- Al Sayyad, Adham; Bardon, Julien; Hirchenhahn, Pierre, **Plapper, Peter**, et. al.:“Aluminum pretreatment by a laser ablation process: influence of processing parameters on the joint strength of laser welded aluminum – polyamide assemblies” in Procedia CIRP (2018)
- Al Sayyad, Adham, Bardon, Julien; Hirchenhahn, Pierre; **Plapper, Peter**, et al “Influence of laser ablation and plasma surface treatment on the joint strength of laser welded aluminum-polyamide assemblies” Journées Nationales des Procédés Laser pour l'Industrie - JNPLI 2017 ; Strassbourg, France (2017, September 14)
- Schmalen, Pascal Guy; **Plapper, Peter**: „Resistance measurement of dissimilar Al/Cu laser welds“ in Proceedings of LPM2017 - the 18th International Symposium on Laser Precision Microfabrication (2017; July)
- Lamberti, C.; Peral Alonso, Inmaculada; **Plapper, Peter**: „ Influence of Material Moisture during Laser Joining of Polyamide 6.6 to Aluminum“ in Atiner's Conference Paper Series (2017), IND 2017 – 2270
- Schmalen, Pascal Guy ; **Plapper, Peter**: „Resistance Measurement of Laser Welded Dissimilar AlCu Joints“ in Journal of Laser Micro/Nanoengineering (2017), 12(3), 189-194
- **Plapper, Peter**: “Innovations enabled by laser joining of dissimilar materials” Key note speech at Conference on Industrial Laser Processing JNPLI 2016, Liege, Belgium (2016, June 29)
- Schmalen, Pascal Guy; Plapper, Peter; Cai, Wayne: “Process Robustness of Laser Braze-Welded AlCu Connectors” in SAE International Journal of Alternative Powertrains (2016), 5(1),
- **Plapper, Peter:** “Editorial“ in Cahier Scientifique - Revue Technique Luxembourgeoise (2016), 1
- Solchenbach, Tobias; **Plapper, Peter**; Cai, Wayne: “Electrical performance of laser braze-welded aluminum–copper interconnects” in Journal of Manufacturing Processes (2014), 16(2), 183-189
- Lamberti, Christian; Solchenbach, Tobias; **Plapper, Peter**; et al.: ”Laser Assisted Joining of Hybrid Polyamide-aluminum Structures” in Physics Procedia (2014), 56(0), 845-853
- Solchenbach, Tobias; Plapper, **Peter; Greger**, Manfred; et al.: “Thermal and electrical aging of laser braze-welded aluminum–copper interconnects” in Translational Materials Research (2014), 1(1), 015001