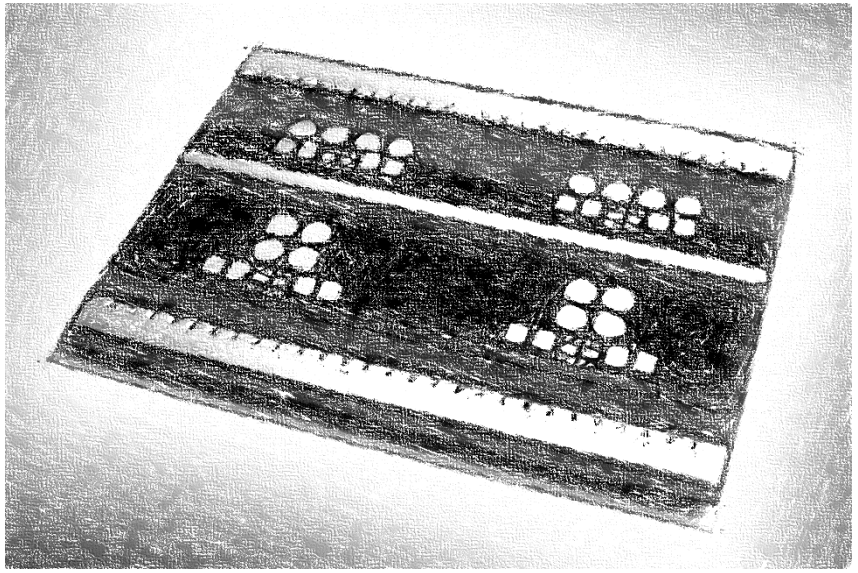
Modular Power Electronics, Realized by PCB Embedding Technology



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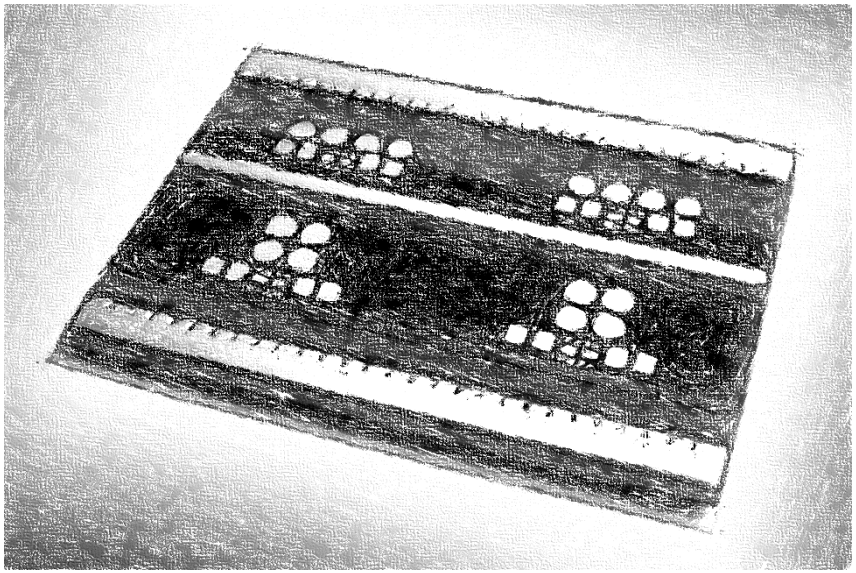
- lars.boettcher@izm.fraunhofer.de

Outline



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  - Embedding for Power Semiconductors
  - Technology
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- Applications
  - Photovoltaic Power Inverter 2.3 kW up to 125kW
  - Electrical bicycle Inverter 50kW
  - Automotive Inverter 50 kW
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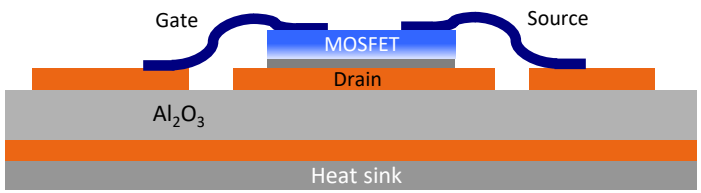
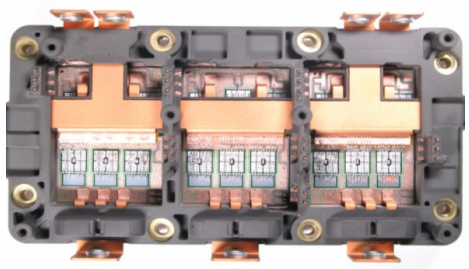
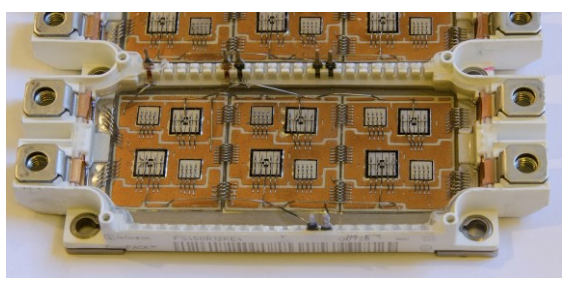
Power Chip Embedding - Opportunities

wire bonding on DCB



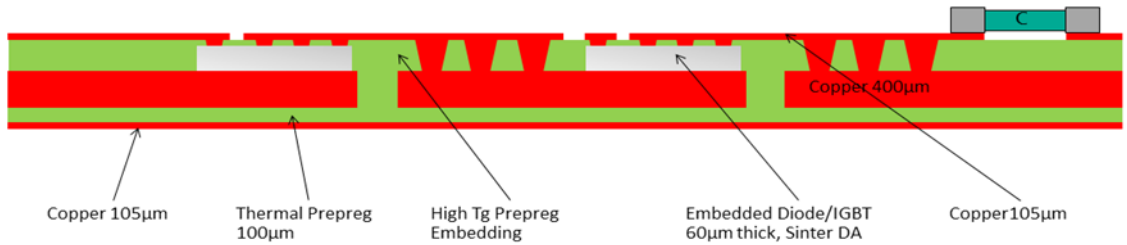


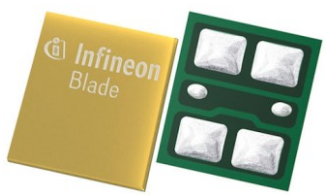


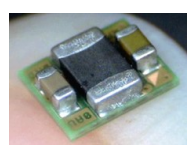
➔ strong restriction of designs by technological limits

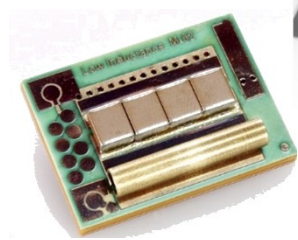
➔ Highly inductive connection by wire bonds

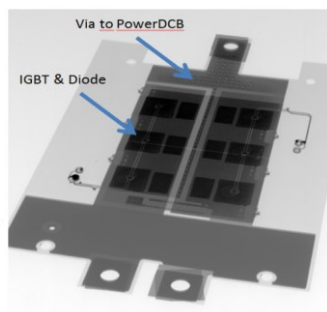
embedding











➔ Huge design space is open for exploration

➔ Improve electrical performance, low inductive connection to die

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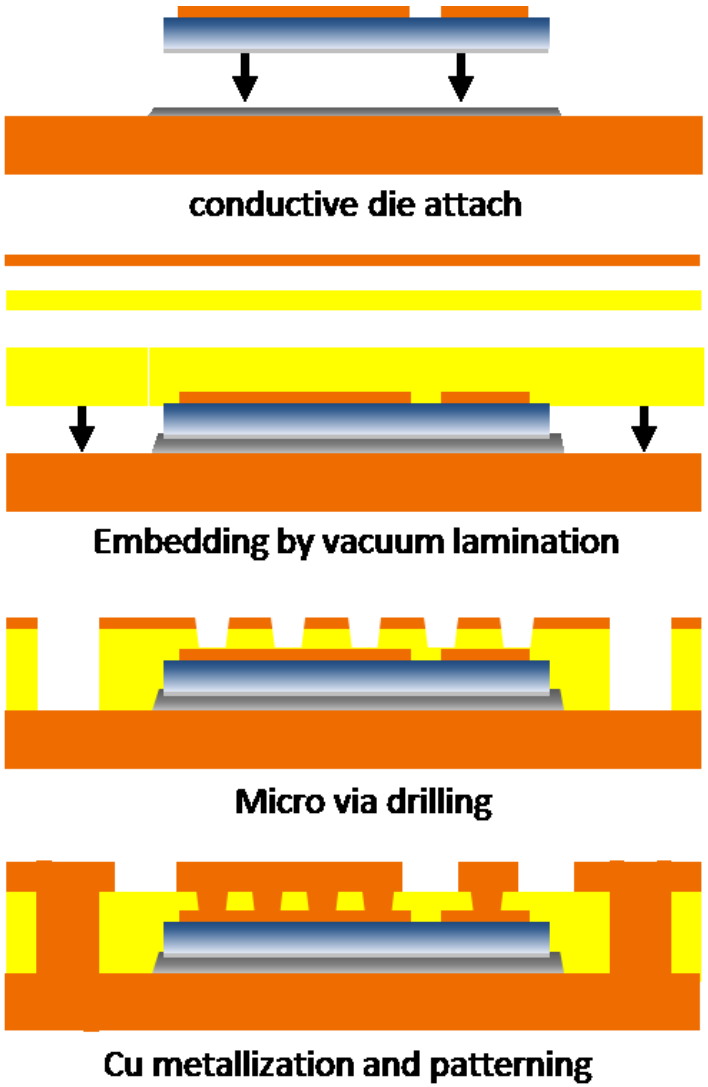
Power Chip Embedding – Process



- Substrate: leadframe, copper foil, high current PCB
- Conductive die attach: various
- Embedding in FR4 prepreg layer:
  - Structured layers for dies
  - Full layer for top side isolation
  - Cu foil
- Blind via manufacturing:
  - Laser via to embedded die
  - Laser or mechanical drilling to substrate
- Cleaning, Activation and Cu metallization
- Patterning of circuitry

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Power Embedding – Features

- Embedding of power chips into Printed Circuit Board structures
  - Multiple wiring layers
  - Very low parasitic effects
  - Flat modules → SMD assembly on top is possible
  - Top side cooling possible
  - High reliability by direct Cu to chip interconnects and embedding
  - Capablility for integrated shielding
  - Cost saving by large area process ➔ Panel Level Packaging

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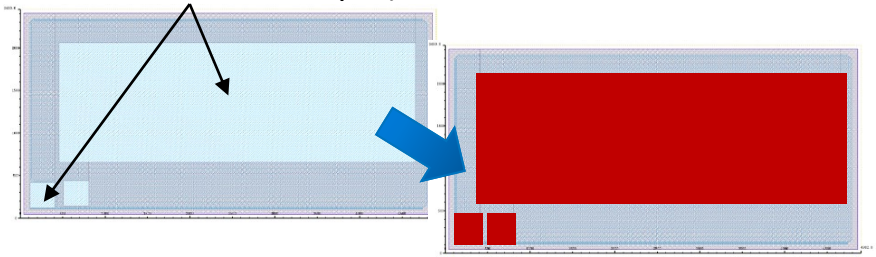
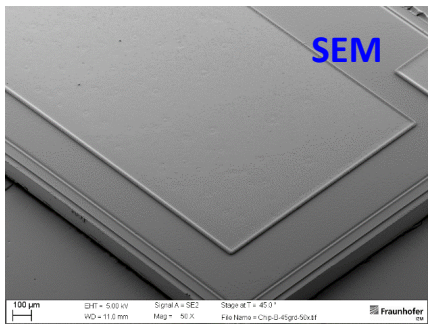
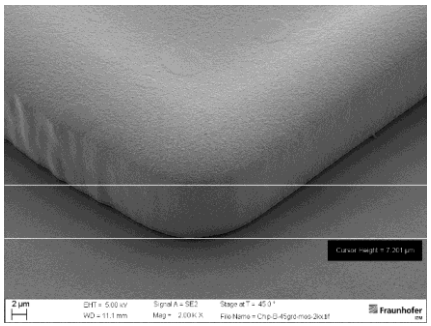
Power Chip Embedding – Special requirement

Contact Pads Al ~ 1 µm)

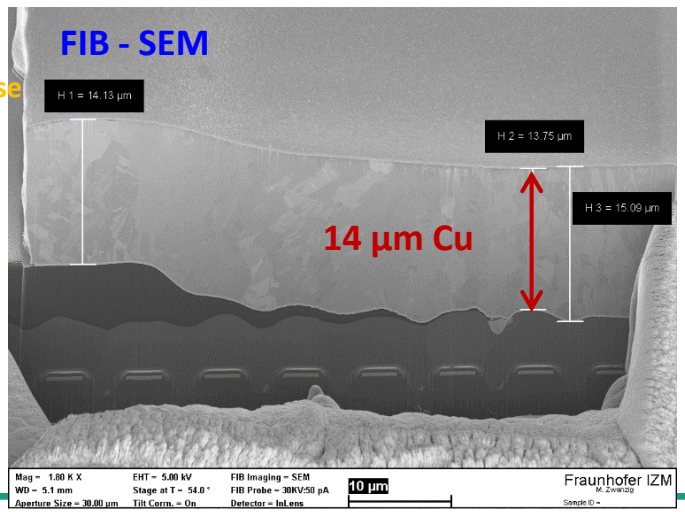


Good



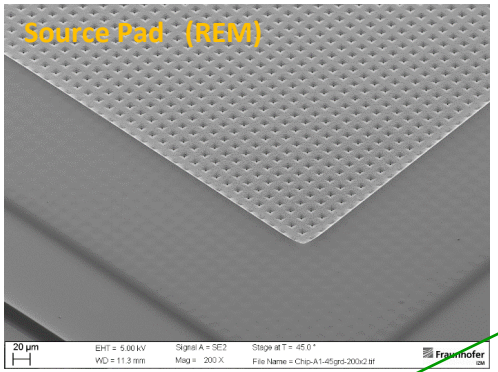


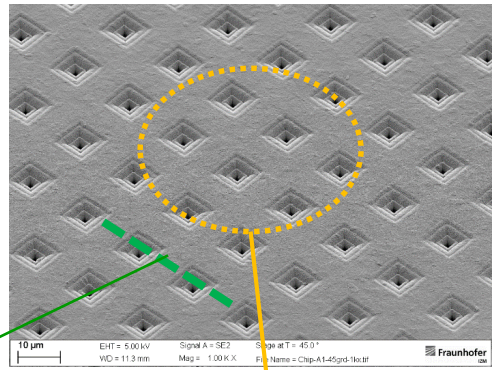
FIB Analyse



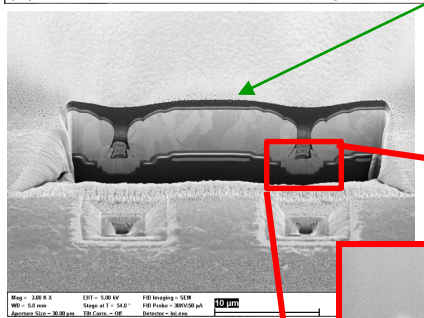
Insufficiant

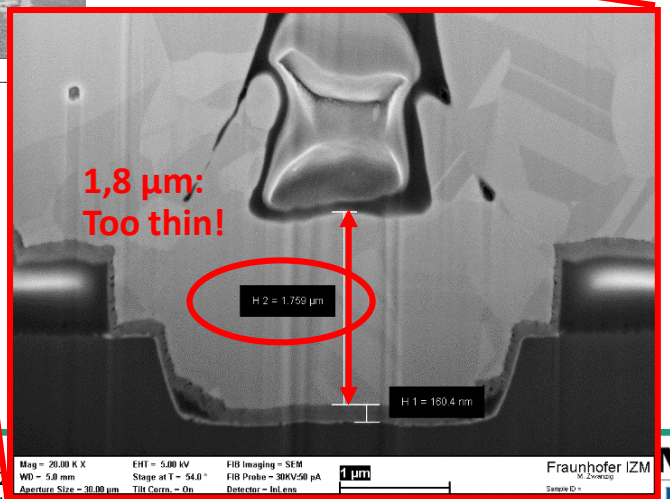
Chip provided by supplier with 5 µm Cu reinforcement





Size of a laser via





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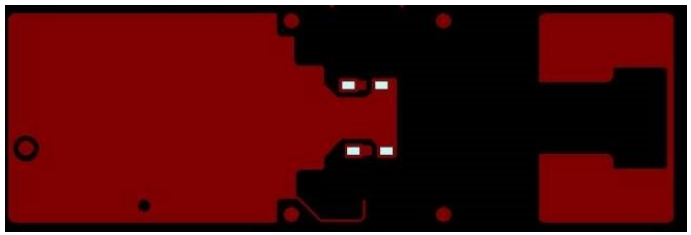
Chip Assembly and Sintering - Concept

1. Application of electroless silver on Cu



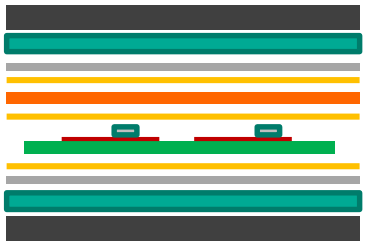
2. Positioning and „pre-sintering“

Time for bonding (due to thick copper core) 30 sek

Temperature: 200 °C

Pressure: 3 kg

3. Press stack build up and sintering



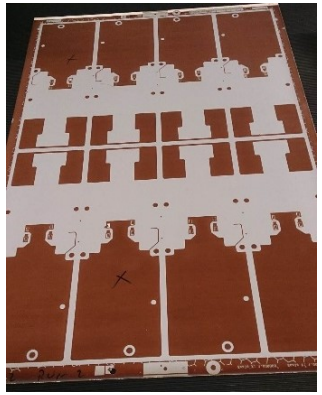
Pressure distriubtion
Steelplate
Separation foil
Reusable Press Pad
Separation foil
Substrat with chips

Press time 90 min

Temperatur: 230 °C

Druck: 30 bar

4. Measurement of x-y position and components height



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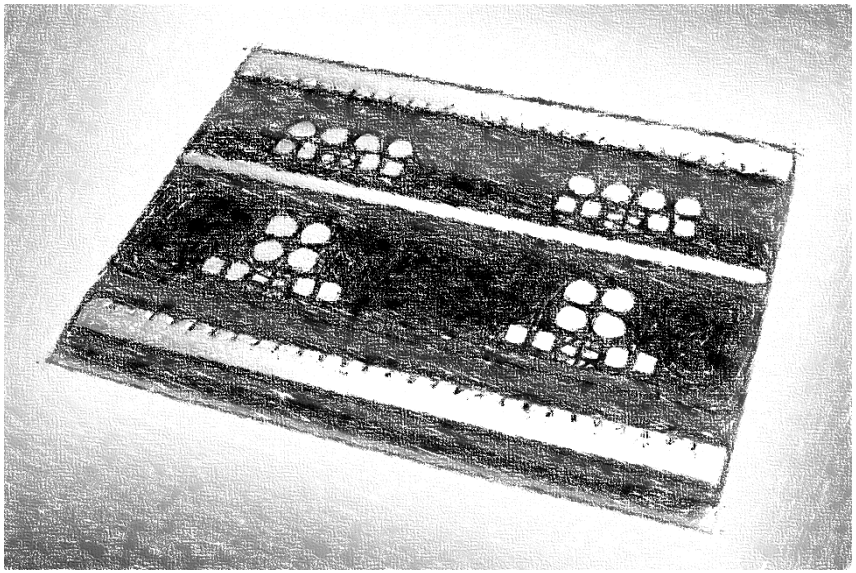

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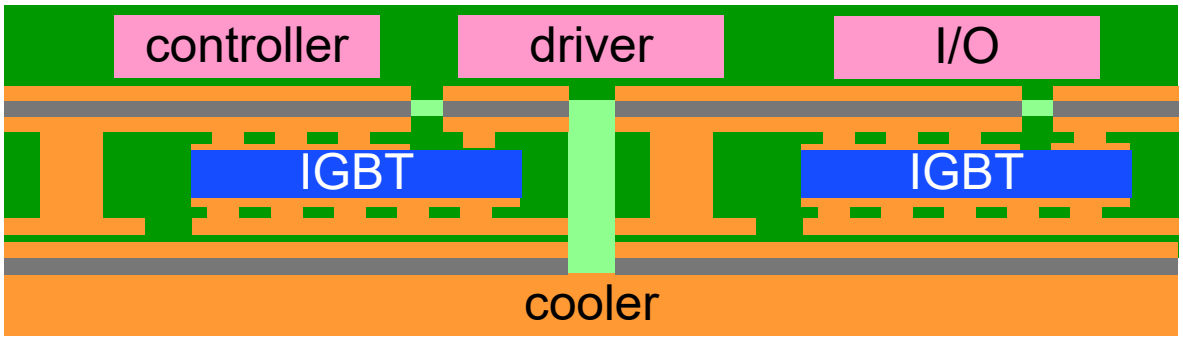
Modular Power Electronics – Concept

- Compact and modular embedded power electronics
- Use established and validated processes for
  - Building blocks with integrated logic
  - 3D stacks of blocks



- Performance benefits:
  - High reliability expected (>300 k power cycles demonstrated)
  - Very good heat spreading and vertical heat conductivity
  - 3D multiple layer interconnection architecture
  - Complete integration of switches and logic into a monolithic block
  - Integration capability e. g. direct attachment to electrical engine

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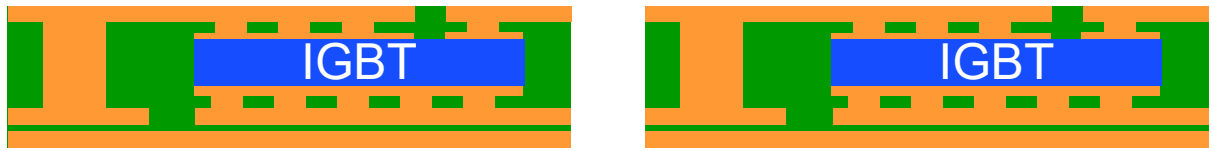
Modular Power Electronics – Requirements

Embedding of **logic** chips

+

Embedding of **power** chips



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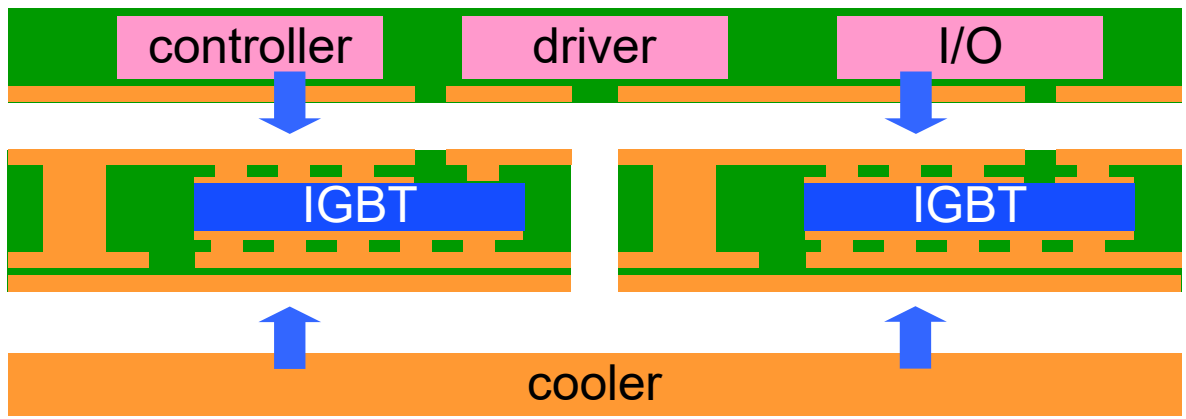
Joining Technology ➔ Sinter/lamination Technology (SLT)



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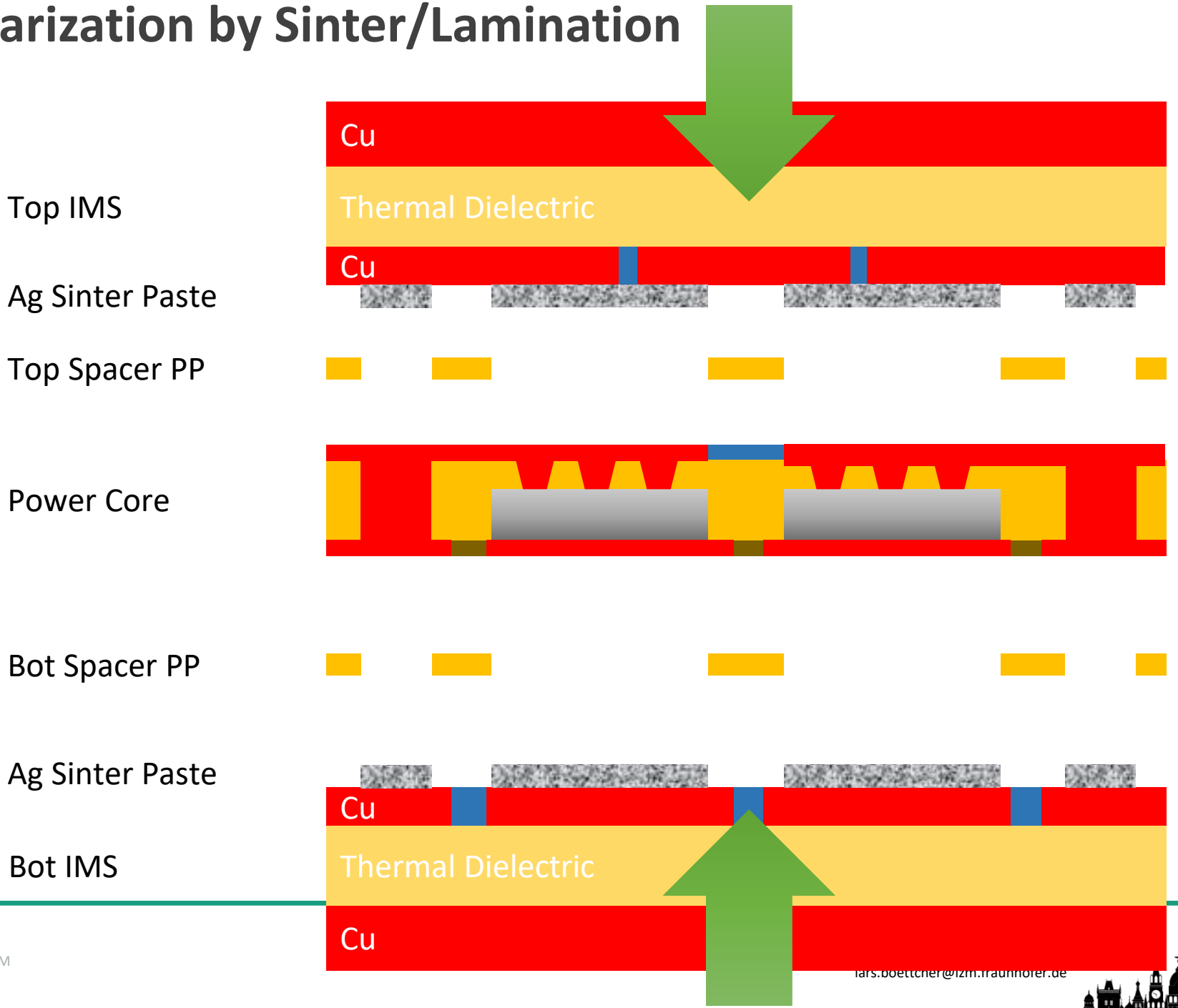
Modularization by Sinter/Lamination



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Modularization by Sinter/Lamination

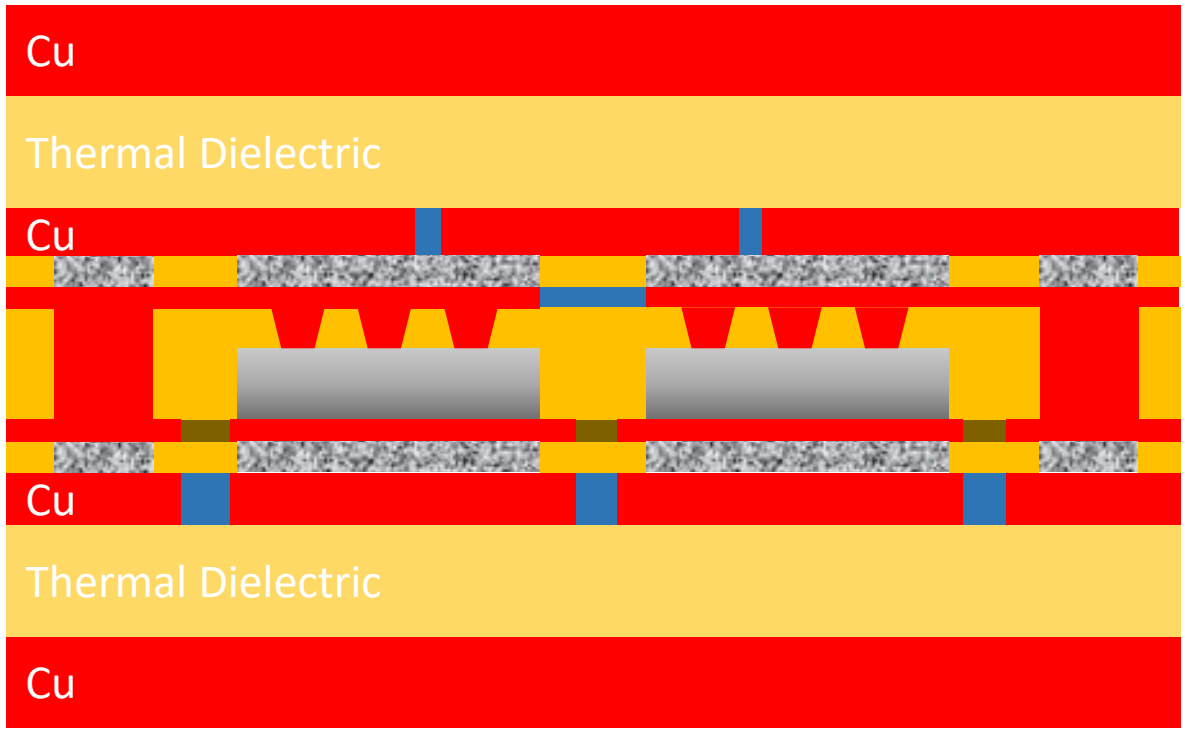
Top IMS

SLT Layer

Power Core

SLT Layer

Bot IMS



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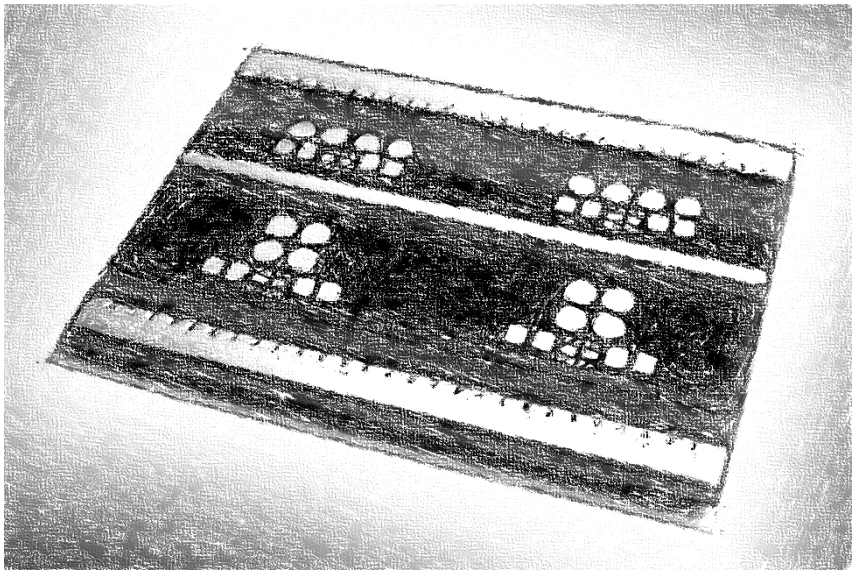

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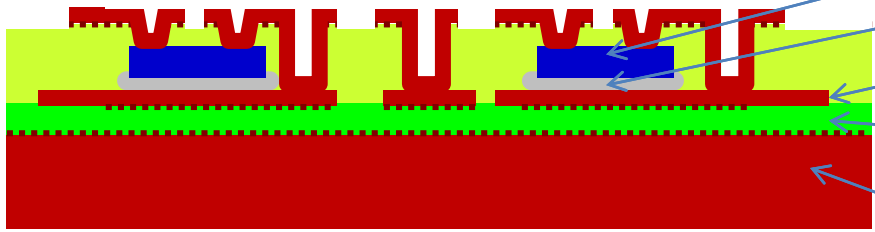
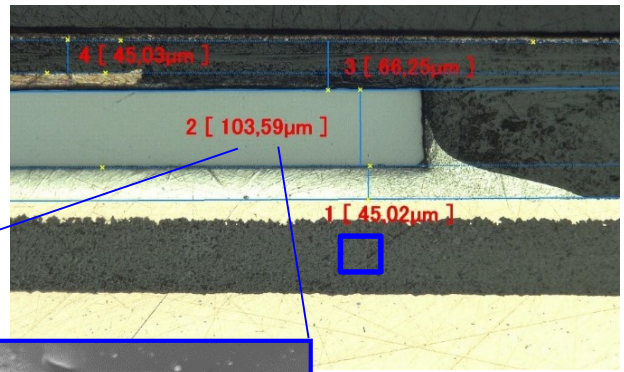
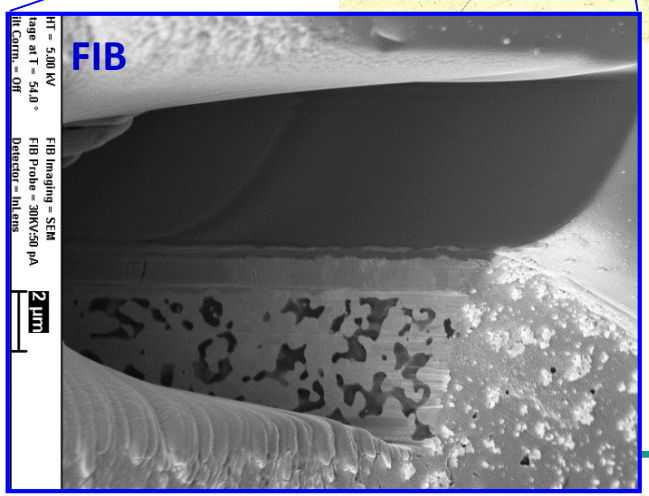
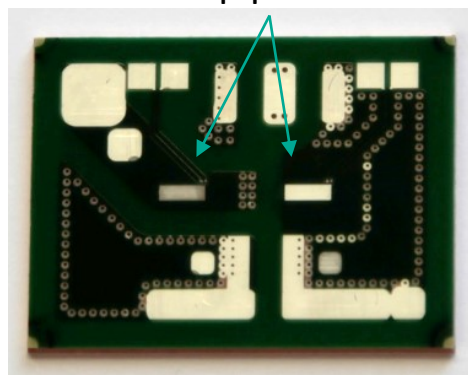
PV inverter – 1.5 to 2.3 kW switching power

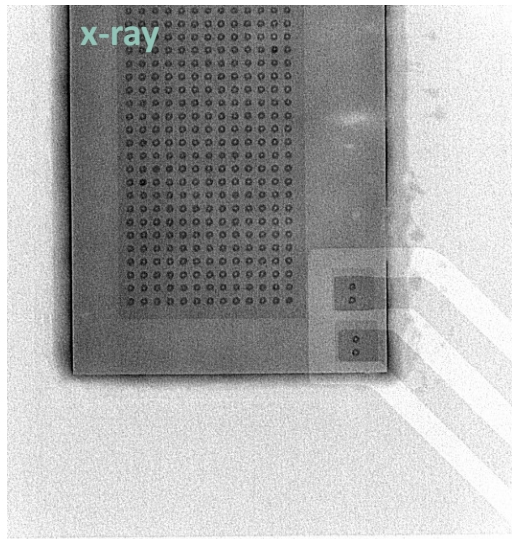






Chip positions





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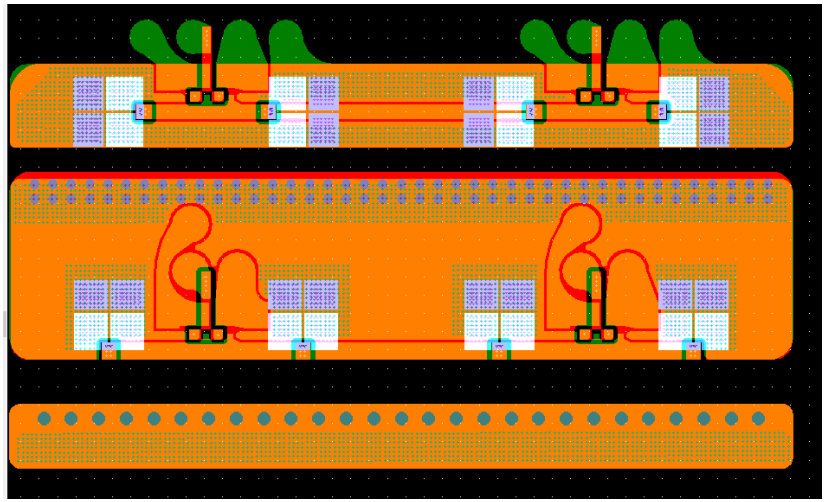
PV inverter – 125kW switching power

- Module Demonstrator for PV Inverter
  - Embedding of SiC on thick copper base 0,5 / 1mm)
  - Eight SiC per switch
  - Embedding in High Tg Epoxy prepreg
  - Two layer build up



		Top	
SM	Dynamask 5016		35
plated Cu			65
Cu foil	Cu Folie 5/35µm		5
PP	PP GEA 679FGS 1080		80
plated Cu		PP Einlege	95
	PP GEA 679FGS 2116	Teile	
Cu foil	Cu Folie 5/35µm		5
PP	PP GEA 679FGS 1080		80
PP	PP GEA 679FGS 1037		50
PP	PP GEA 679FGS 2116		120
PP	PP GEA 679FGS 2116		120
PP	PP GEA 679FGS 2116		120
Cu Substrat			500

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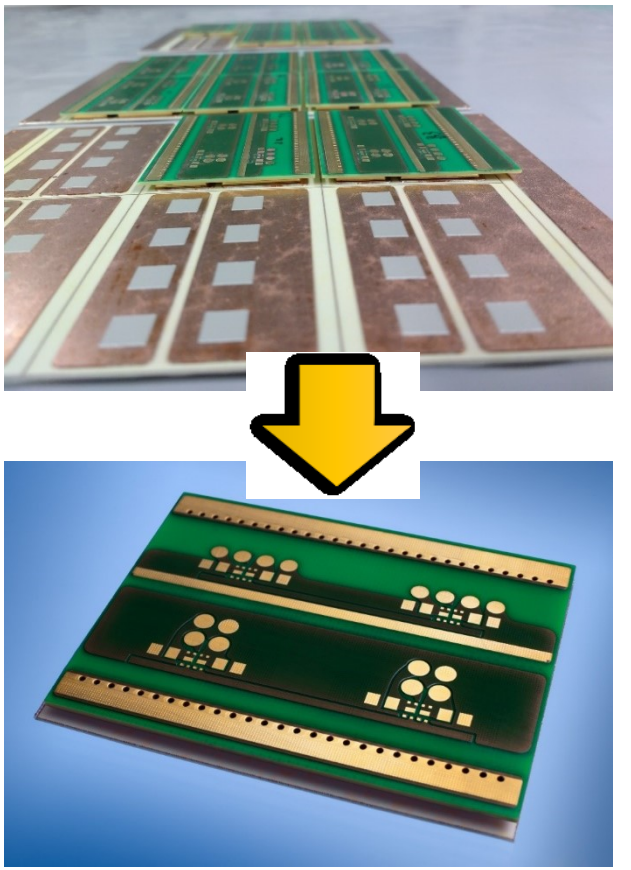
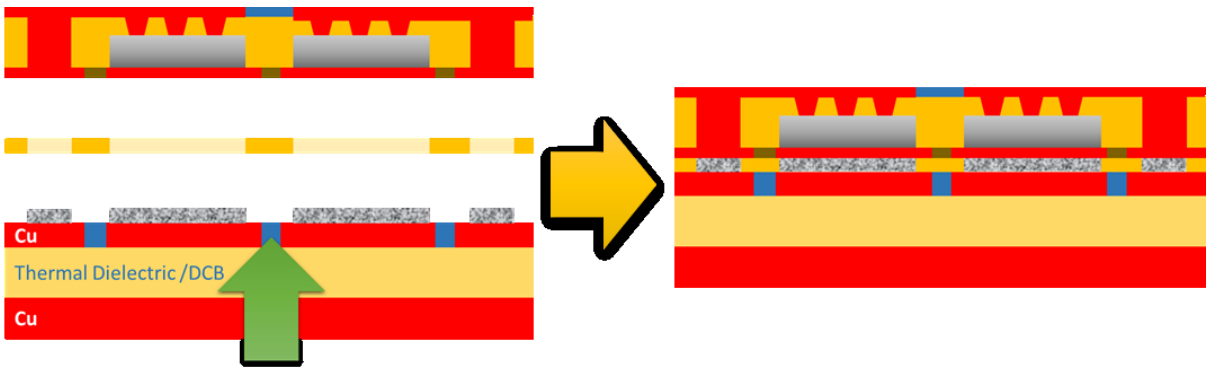
PV inverter – 125kW switching power

- Thermal management of module
  - Ag sintering to ceramic substrate
  - Layup and sintering in large panel format
  - Possibility to fill air gaps with epoxy resin → sinter-laminate-technology (SLT)





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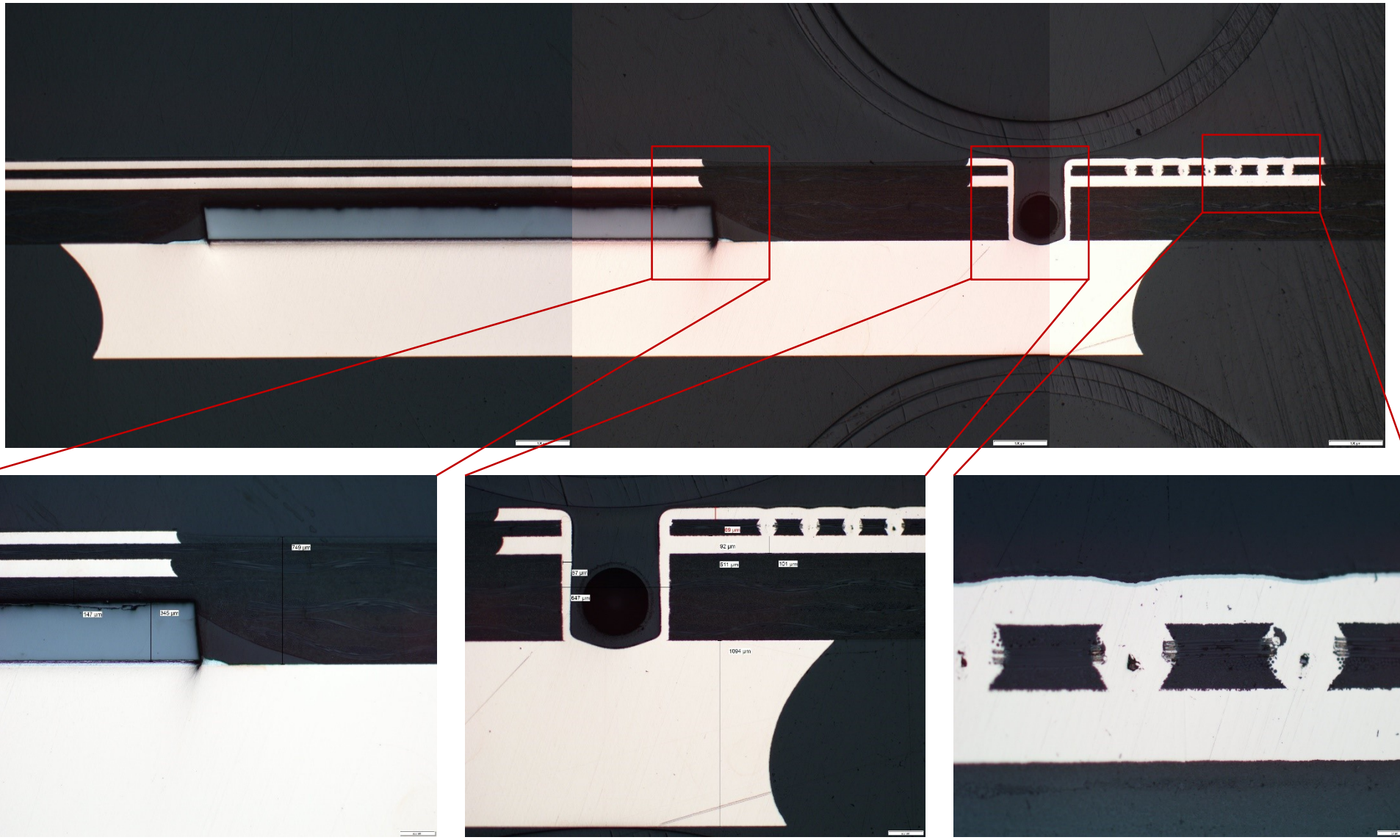

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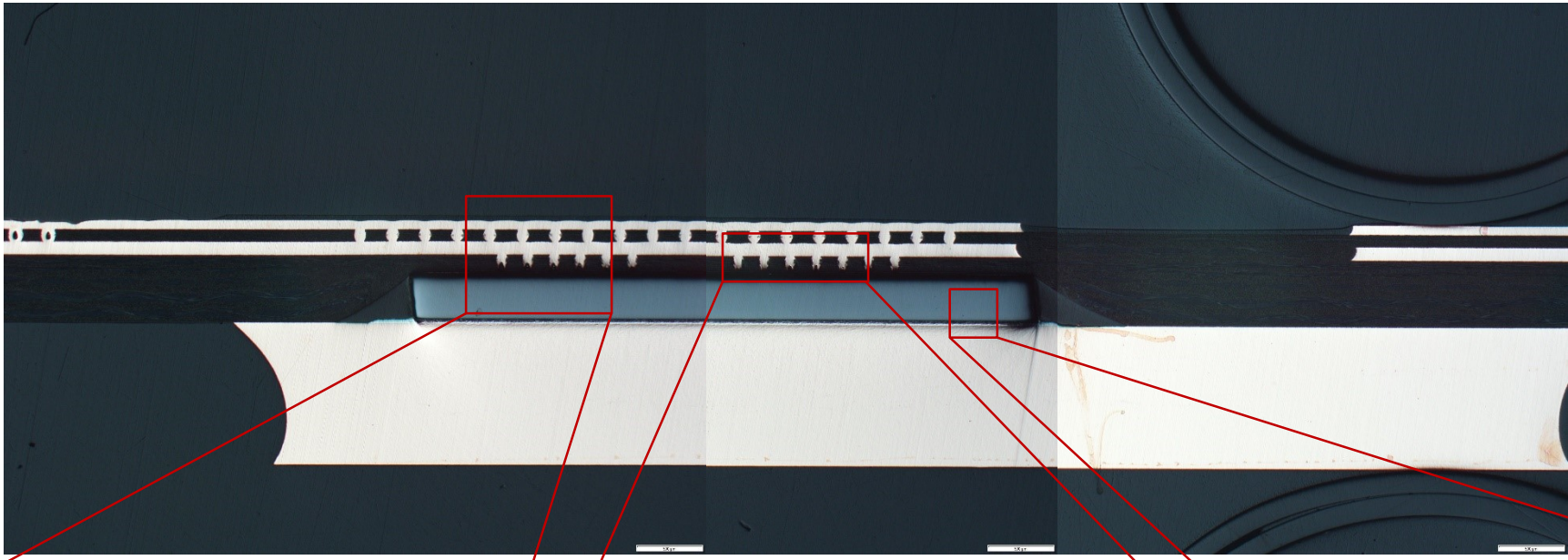

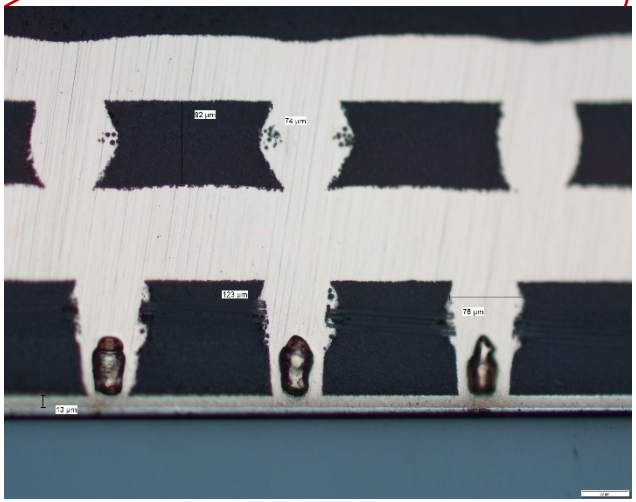

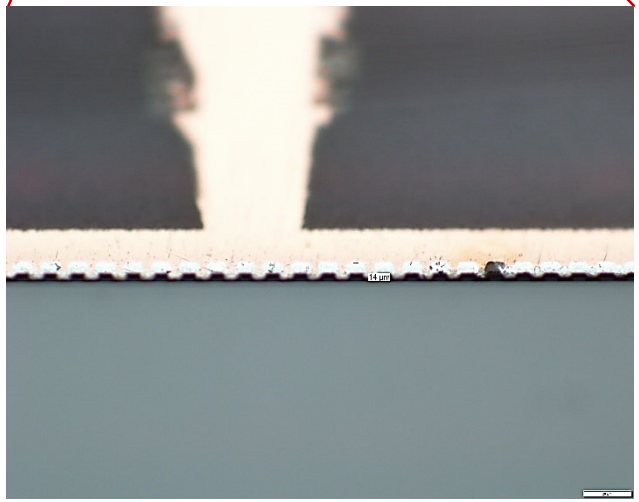

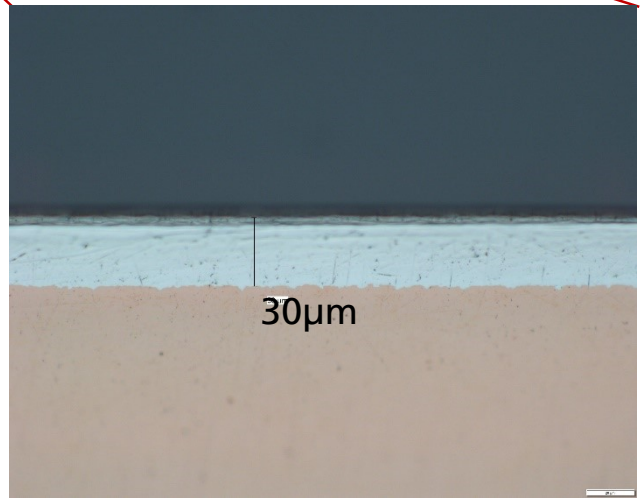

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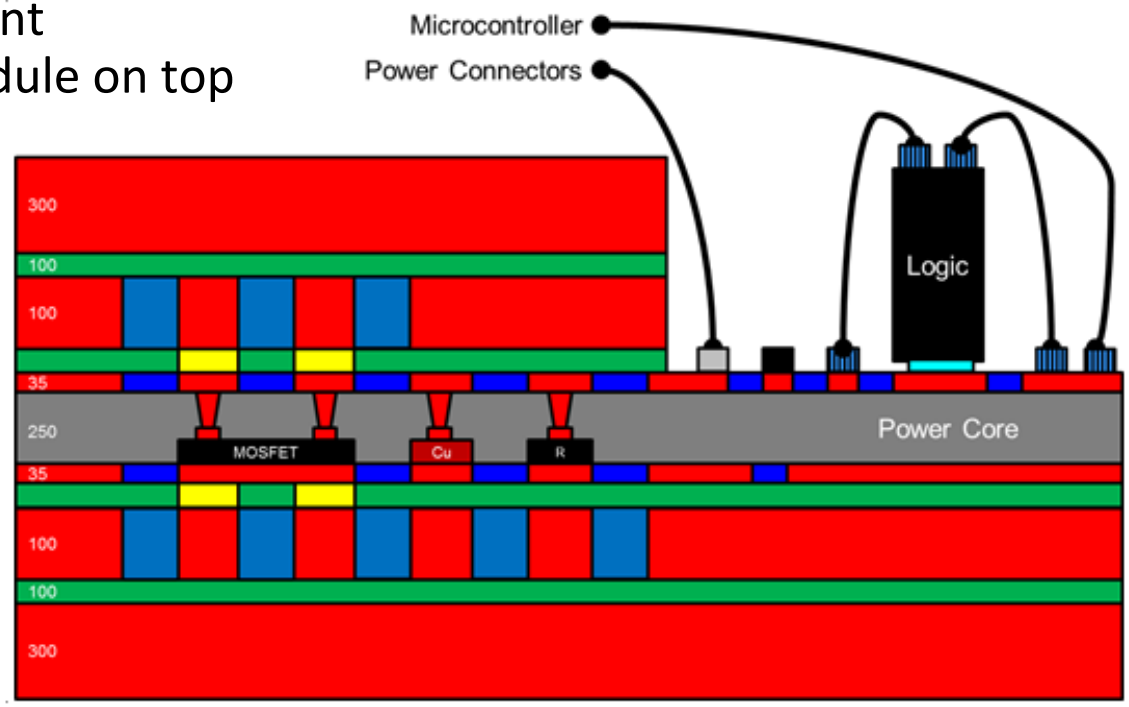
Application – 500W Inverter for Pedelec

- Module concept for 500 W Inverter:
  - IMS substrate 300µm Cu / Thermal dielectric / 100µm Cu
  - Full area bottom IMS
  - Smaller Top IMS, Access to high current connectors and assembly of logic module on top



500 W concept

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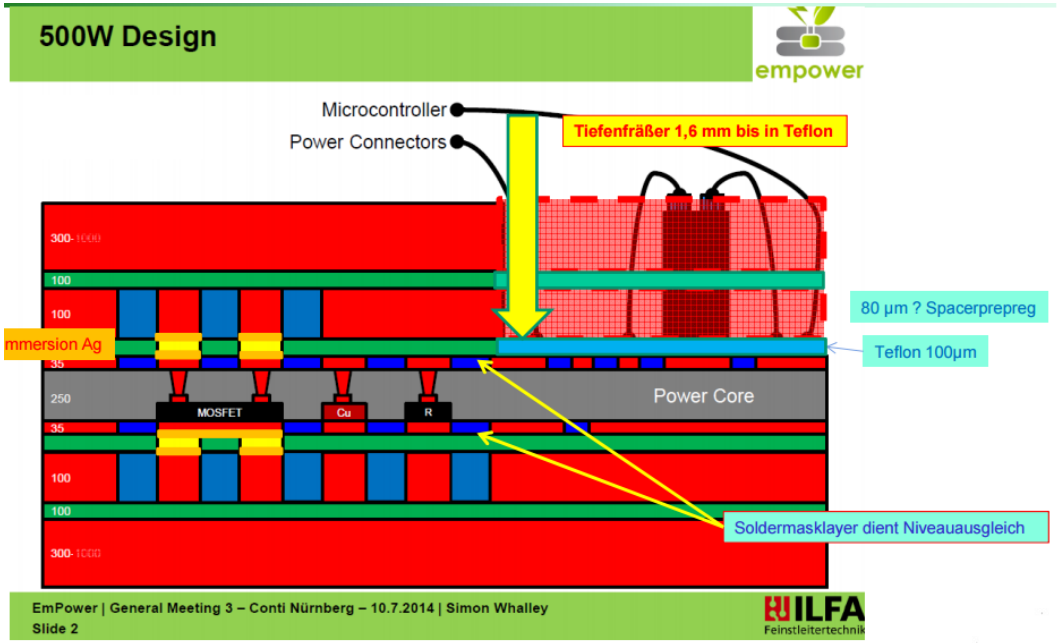

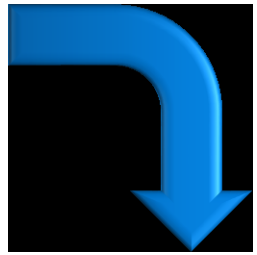

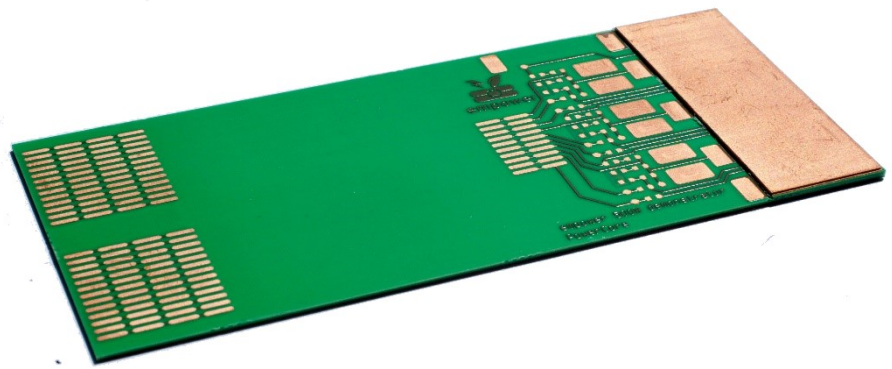

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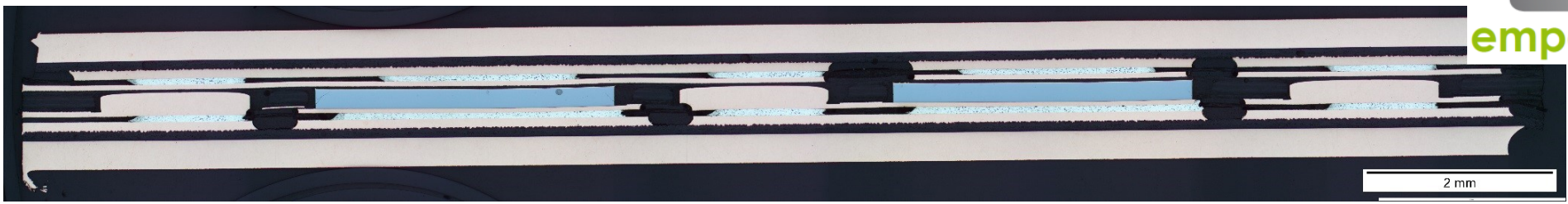
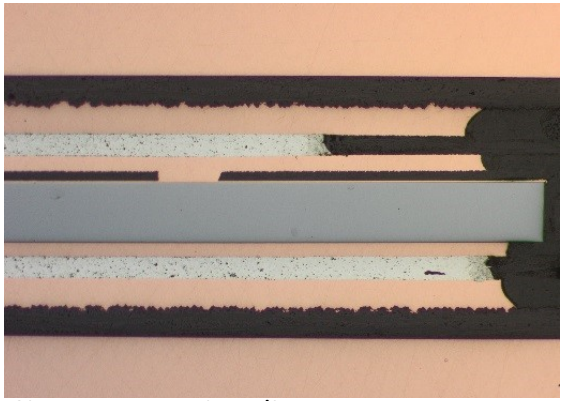
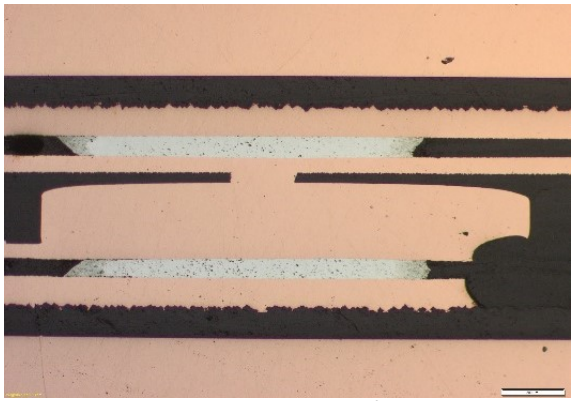
500W Demonstrator Power Core / IMS Sintering

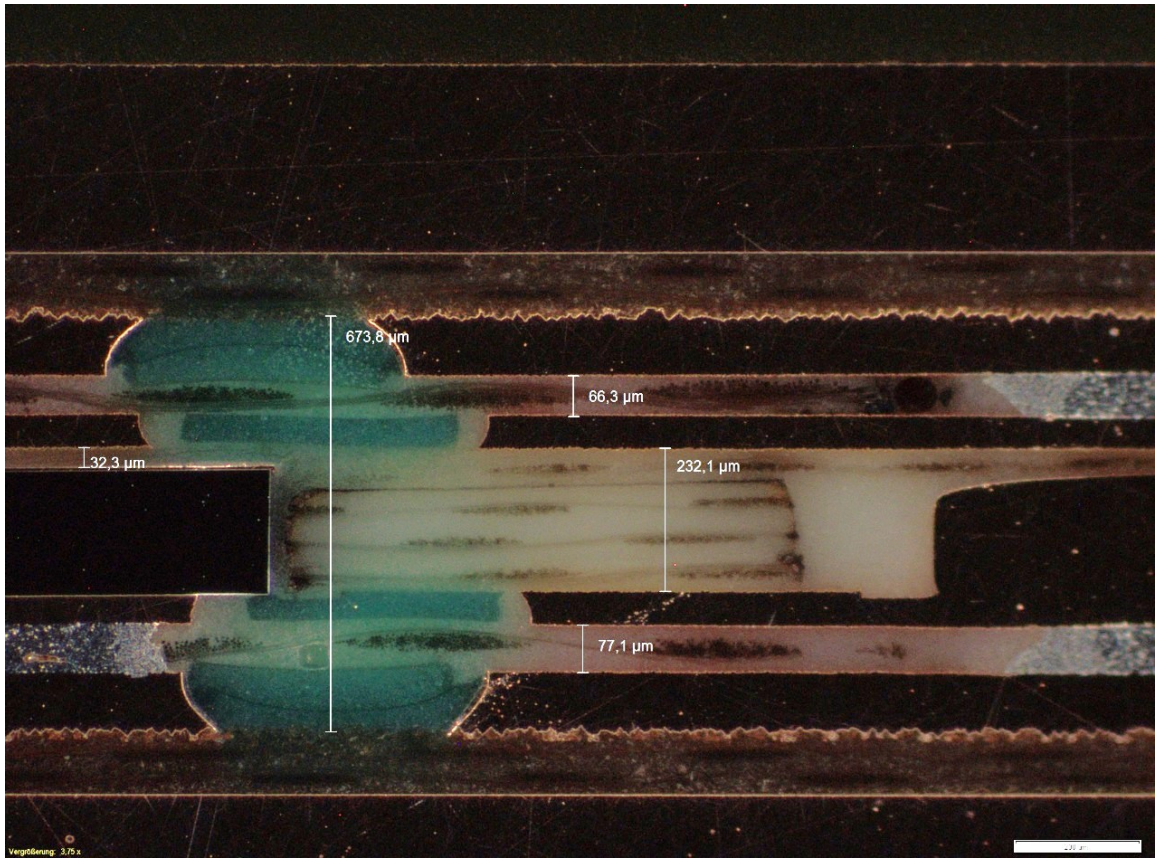




Sinter connection die area



Sinter connection copper inlay area



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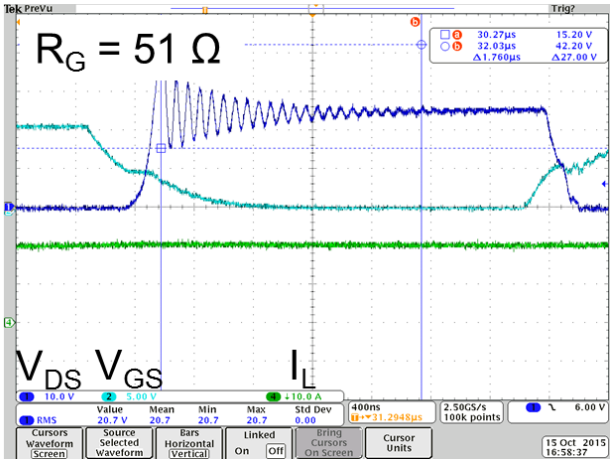
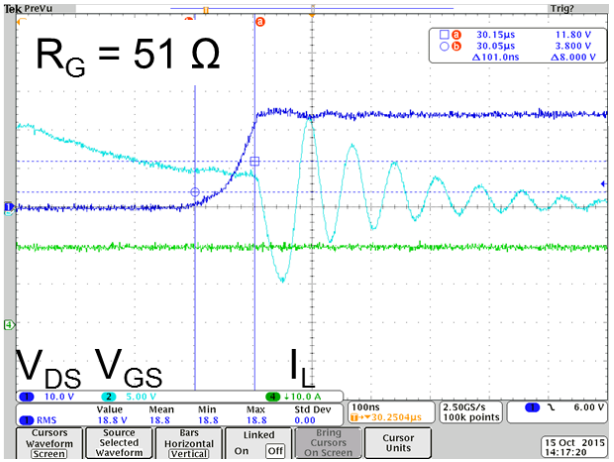
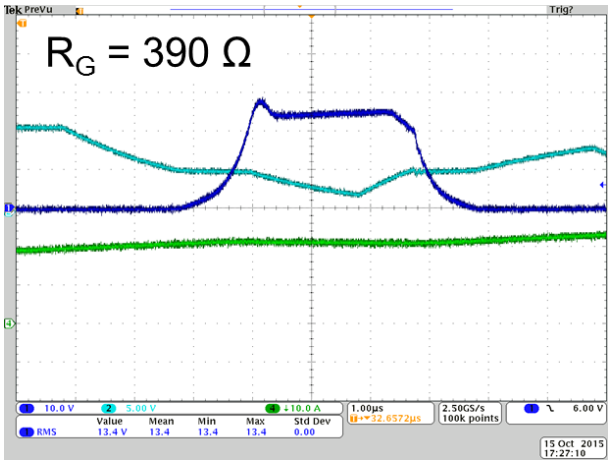
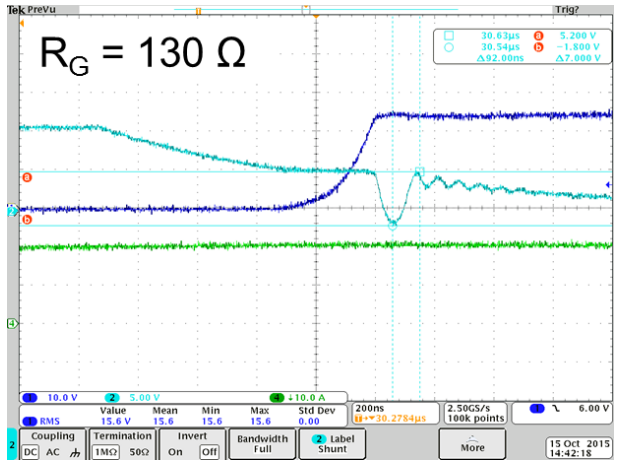
500W Demonstrator – Switching behavior

- Double pulse test with different gate resistors









- Switching-behaviour low side MOSFET SMD reference module
- Switching-behaviour low side MOSFET Embedded module

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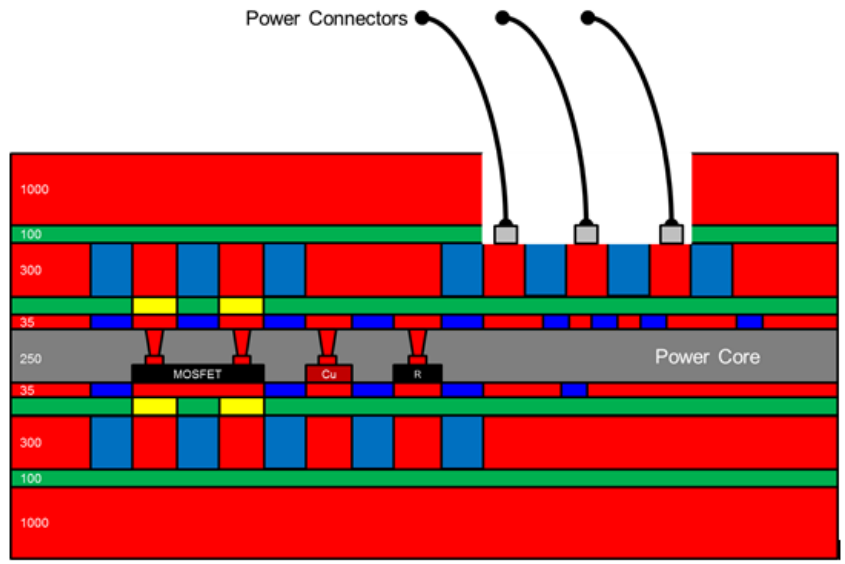
Application – 50kW inverter for HEV/EV

- Module concept for 50kW Inverter
  - Full area Top and Bottom IMS
  - 1000µm Cu / Thermal dielectric / 300µm Cu
- Power core containing embedded IGBT and Diodes
- Ag Sintering for high current connection and thermal management
- Exposure of high current connector pads by:
  - Depth milling of 1mm Cu
  - Etching of remaining (approx. 100µm) Cu
  - Laser ablation of thermal prepreg at pad positions



50 kW concept

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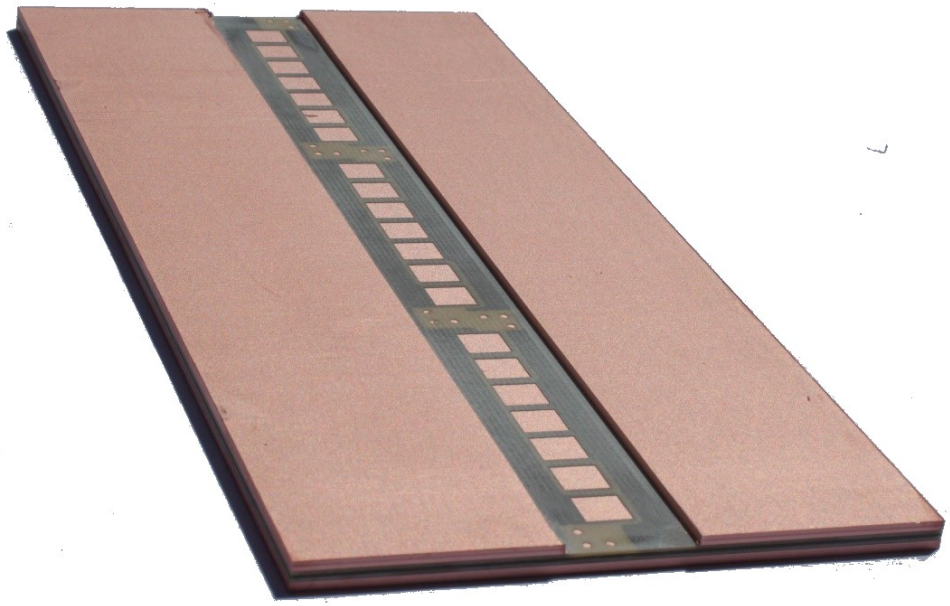
Module Manufacturing – 50kW

- Module finalization:
  - Depth milling into Top IMS Cu
  - Litho & Etch of remaining Cu
  - Opening of high current pads on bottom side of top IMS by UV laser ablation



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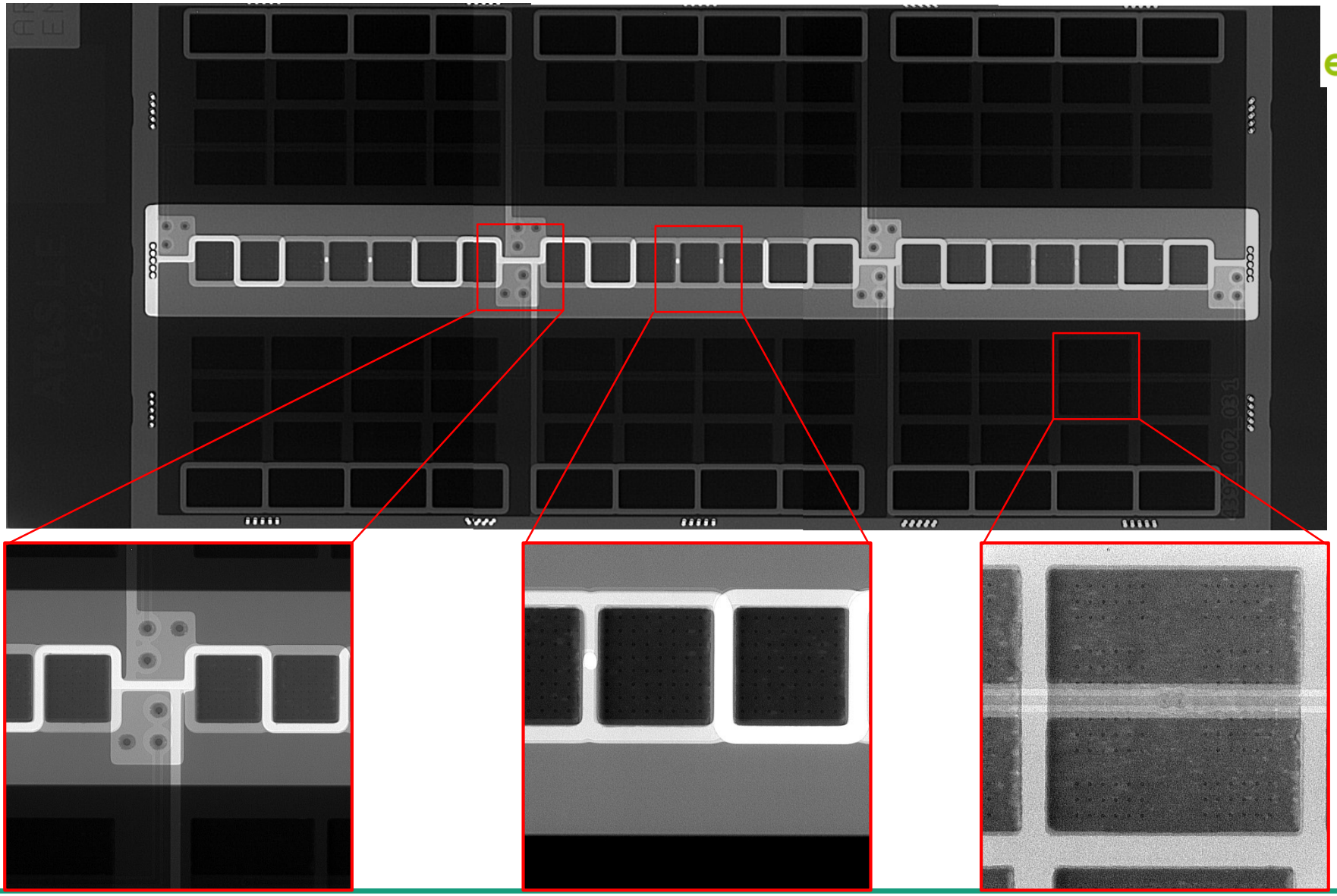
Module Manufacturing – 50kW



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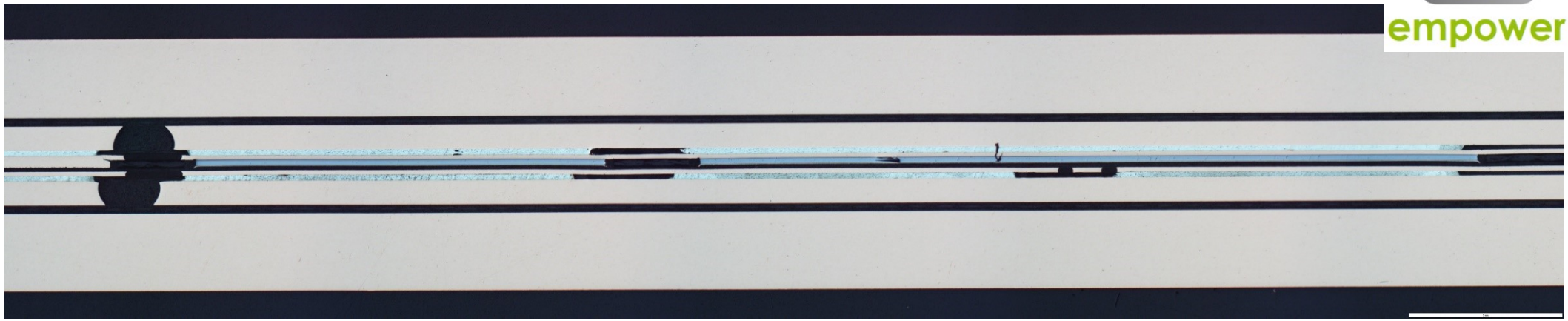
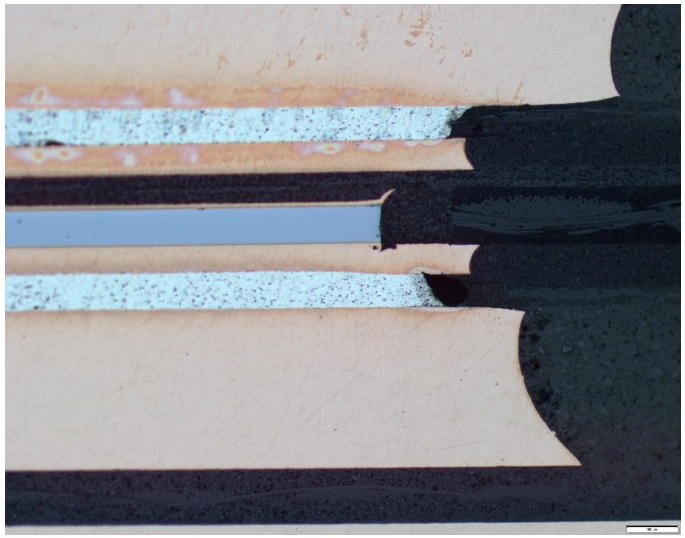
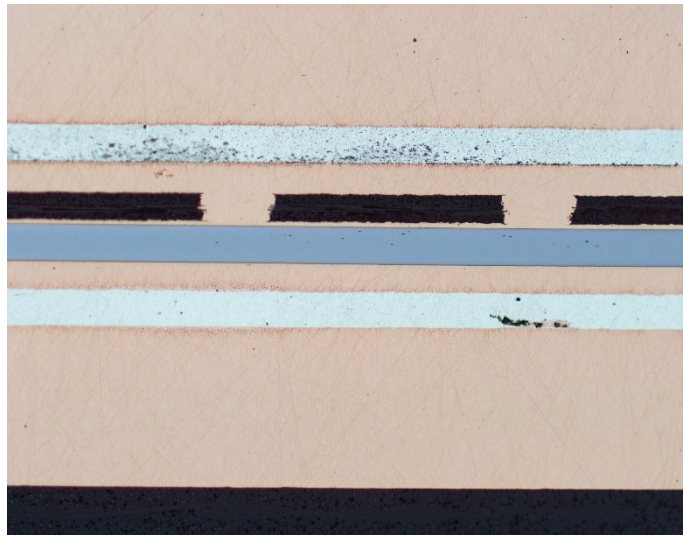
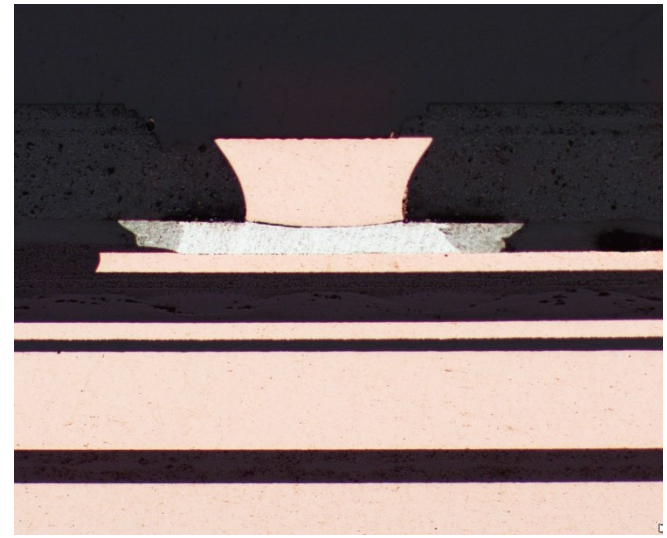
Module Manufacturing – 50kW









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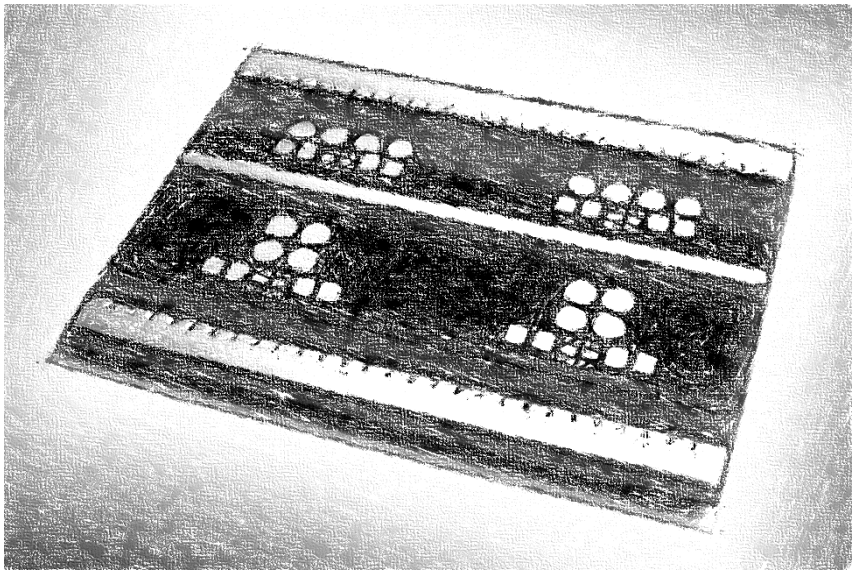
Outline



- Introduction
  - Embedding for Power Semiconductors
  - Technology
- Modularization of Power Modules
- Applications
  - Photovoltaic Power Inverter 2.3 kW up to 125kW
  - Electrical bicycle Inverter 50kW
  - Automotive Inverter 50 kW
- Conclusion
- Acknowledgements

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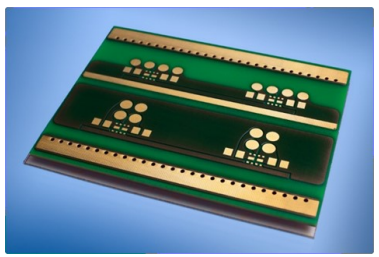
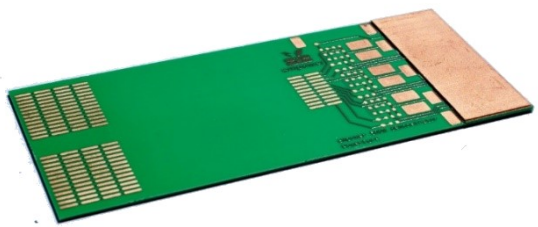
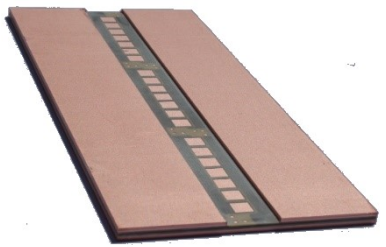
Conclusion

- Embedding of power electronic components provides a large benefit in terms of reliability and electrical performance
- Direct copper connection of power dies and short connection length lead to a significant reduction of parasitic inductance. As a result behavior and losses can be reduced.
- Compact and modular embedded power electronics can be realized by use of established processes forming
  - Building blocks with integrated logic
  - 3D stacks of blocks
- Newly development Sinter-Lamination Technology (SLT), is an important technology enabling the modular power electronics concept
- Several application examples in different power classes demonstrate the potential of embedding technologies for power electronic applications







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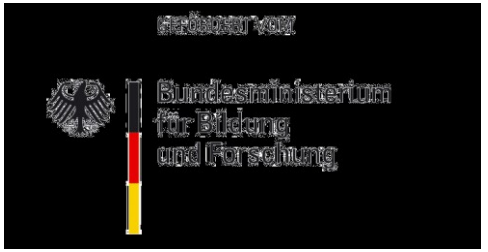
Acknowledgement

- German “Federal Ministry of Education and Research” for the financial support of the:
  - EmPower project (FKZ 16EKF0016), which is also supported in the European “Catrene” program (CT315 – EmPower)
  - LES FLIP project (FKZ 16ES0133)
  - LES HHK project (FKZ 16ES0094)

  and the partners within the projects



- Continental for providing the electrical test results for the 500W demonstrator within the EmPower project

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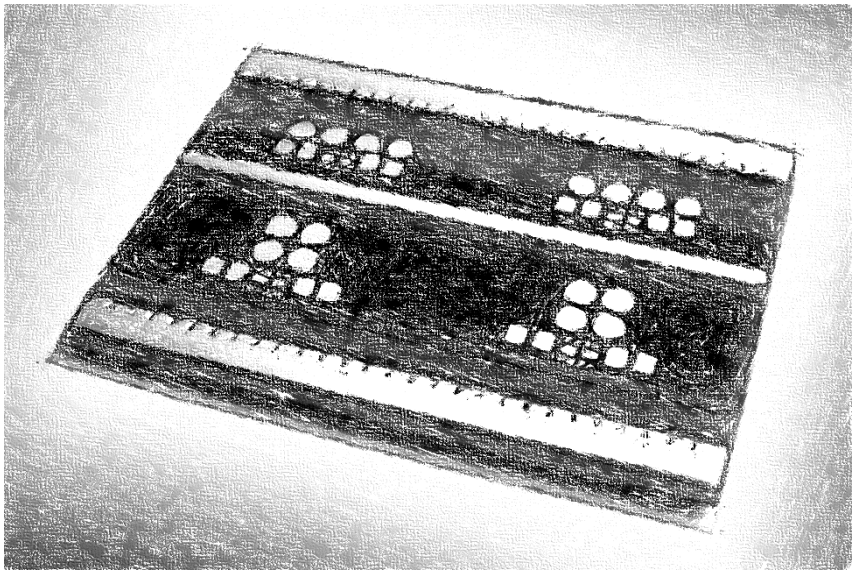

Thank you very much for your attention!

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