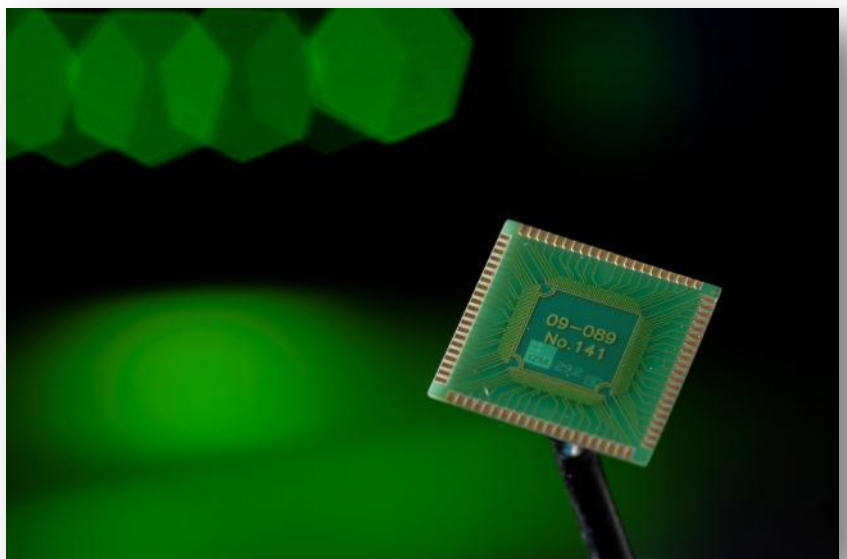
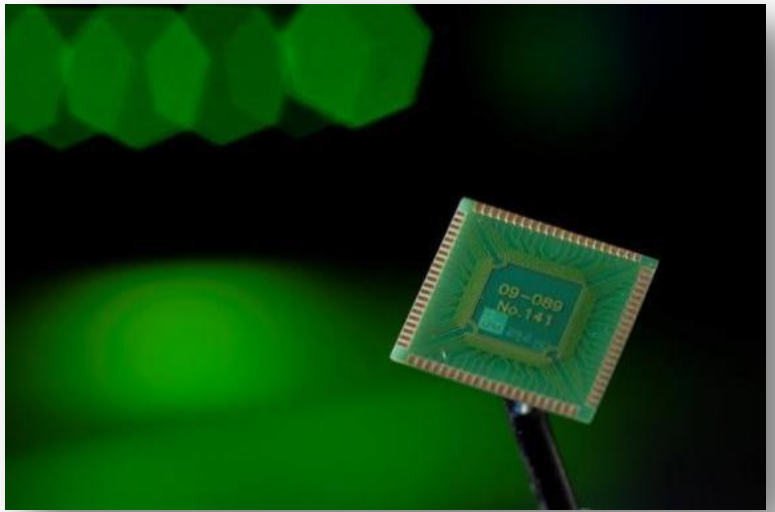
Embedded Power Modules – A new approach using Power Core and High Power PCB



- Lars Böttcher
- Fraunhofer IZM Berlin
- lars.boettcher@izm.fraunhofer.de

Outline



- Introduction
- Embedding for Power Semiconductors
- Automotive Power Systems – Project “**Hi-Level**”
- Power core embedding concept – Project “**EmPower**”
- Conclusion
- Acknowledgements

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Power Chip Packaging

Power Packages

- Single chip packages for MOSFETs, IGBTs or diodes
- Use in lower power applications

Power Modules

- Use for mid and high power applications
- Include e. g. IGBTs and diodes in half bridge configuration
- Electrical isolation to backside

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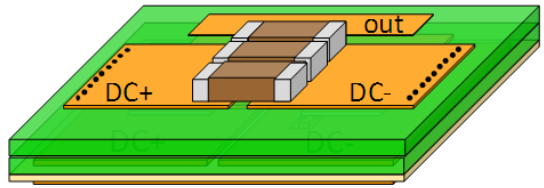
Power Chip Embedding - Opportunities

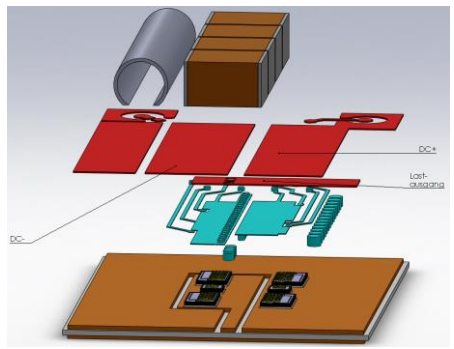
wire bonding on DCB

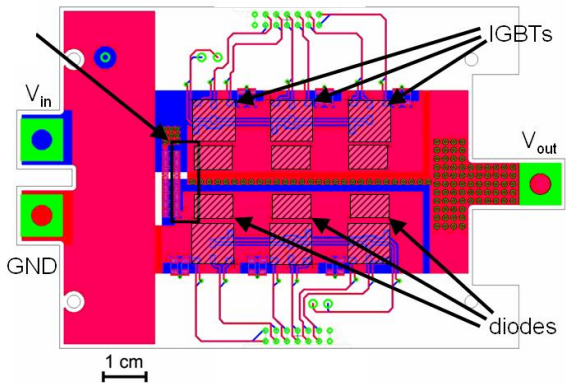
➔ strong restriction of designs by technological limits

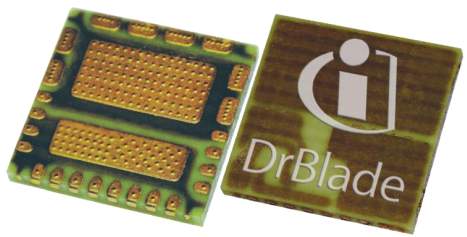
➔ Highly inductive connection by wire bonds

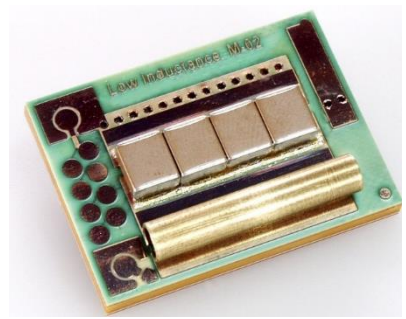
embedding











➔ Huge design space is open for exploration

➔ Improve electrical performance, low inductive connection to die

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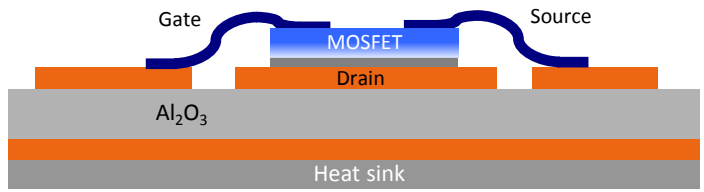
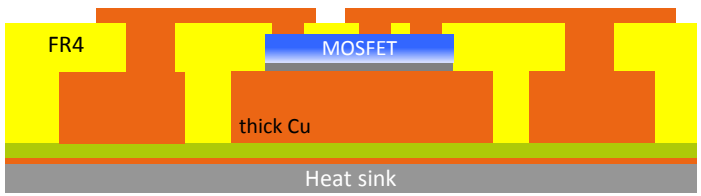
Fraunhofer IZM

Embedded Power Modules

traditional power module



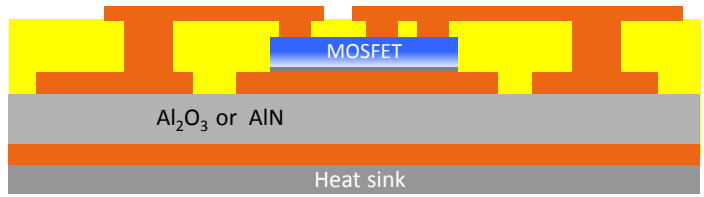
embedding on PCB substrate



- Production panel 610x456 mm² (18”x24”)
- Isolation and thermal conduction by high-λ laminate

→ Low to medium power modules

embeding on ceramic substrate



- Production panel 125x175 mm² (5”x7”)
- Isolation and thermal conduction by Al2O3 or AlN DCB

→ High power modules

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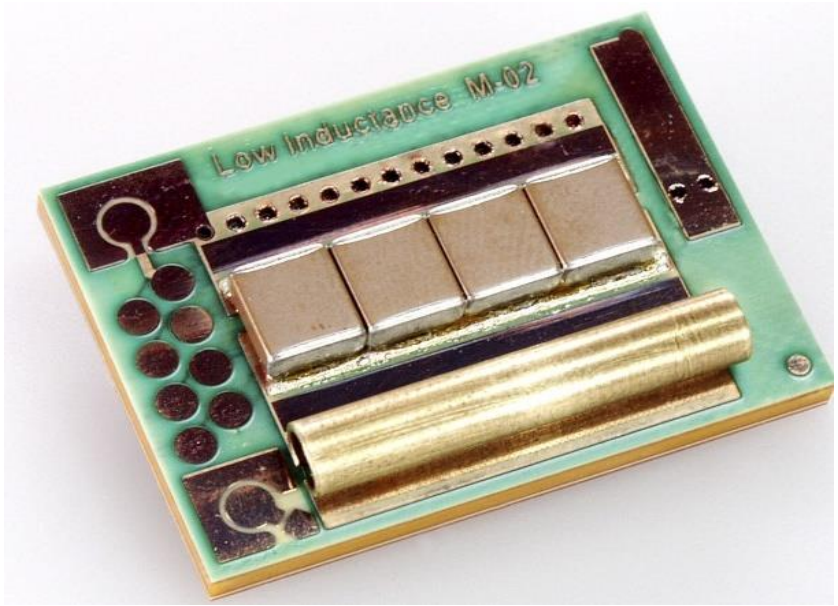
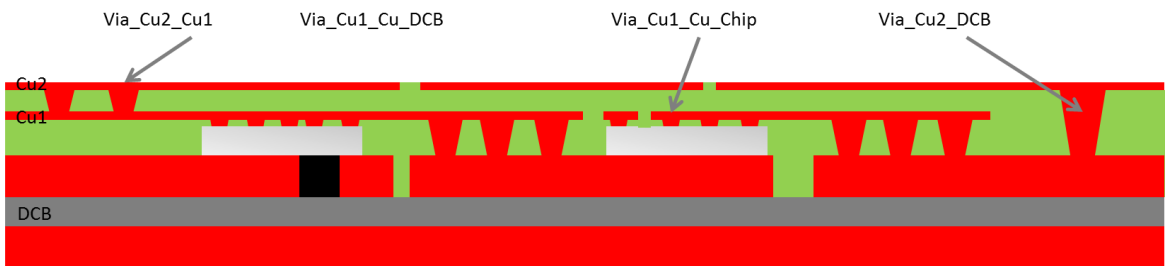
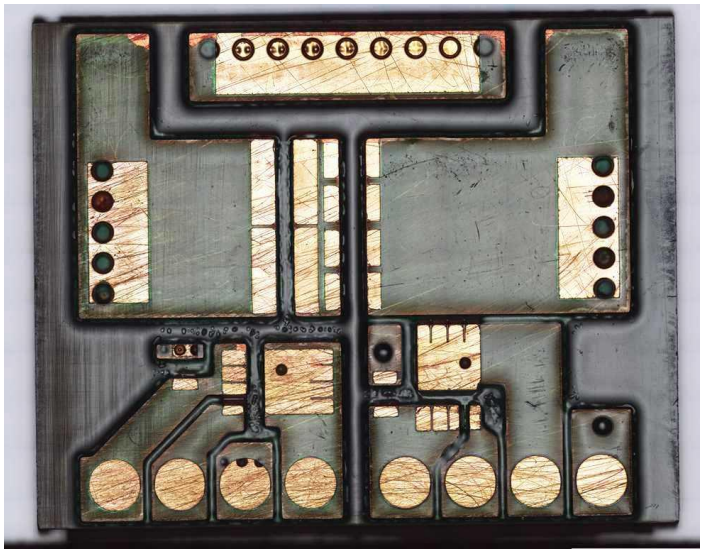
DCB based, ultra low inductance module



- Full bus bar structure using PCB Process on a DBC
- DC capacitors on the module
- DC link current measurement included





DC-link inductance of 0.8 nH
Lowest possible inductance of conventional package: 10nH

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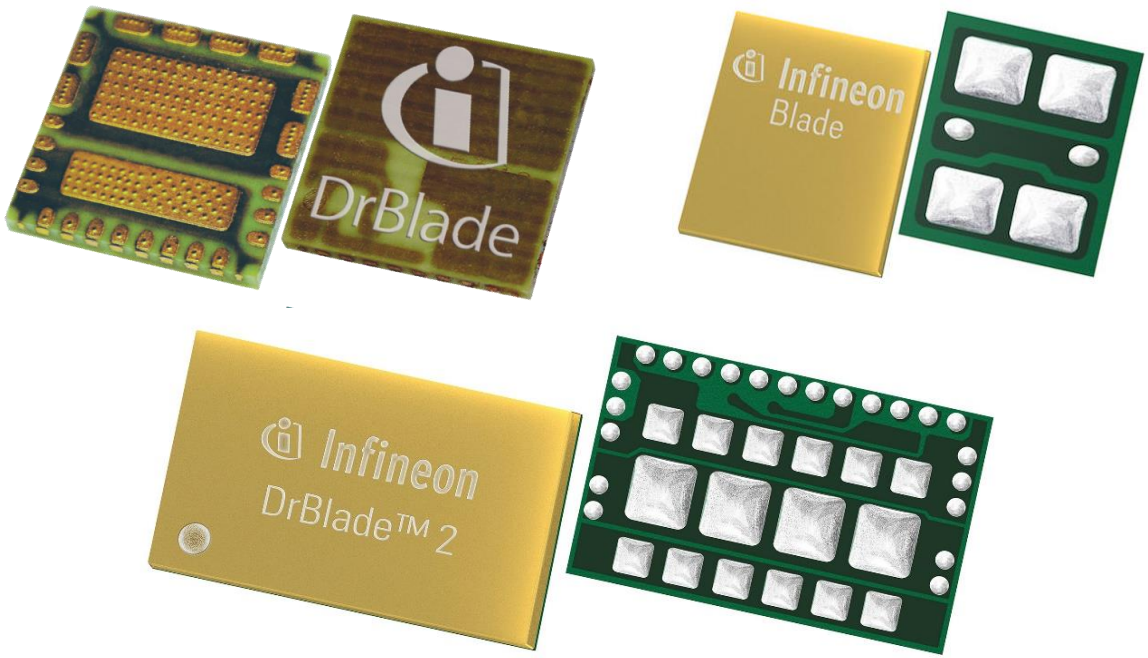
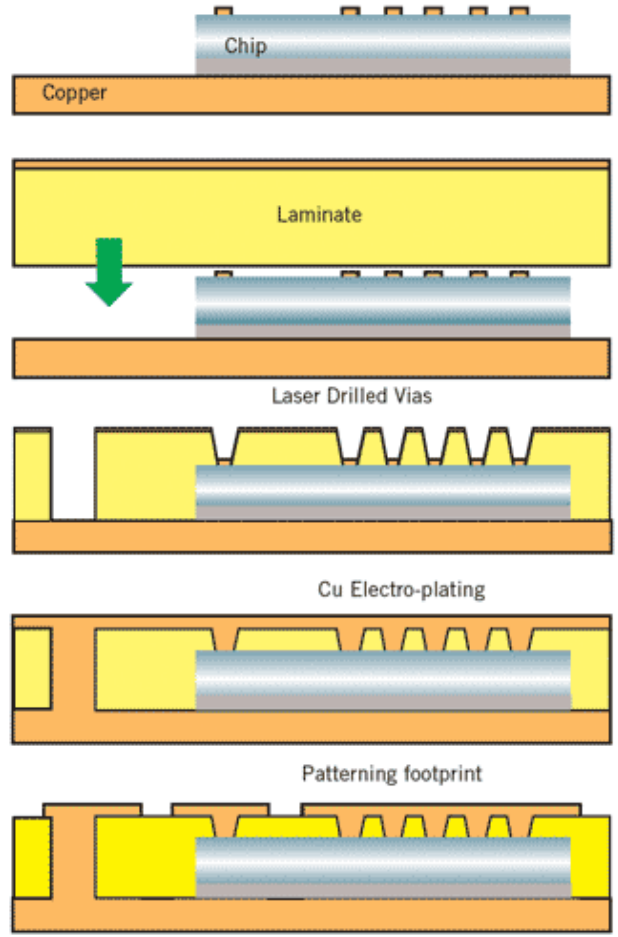
Products – Power Chip Packages & SiPs

Blade power package

- Embedded MOSFET / Driver MOS
- Manufacturing on PCB format





Licensing and process transfer from Fraunhofer IZM

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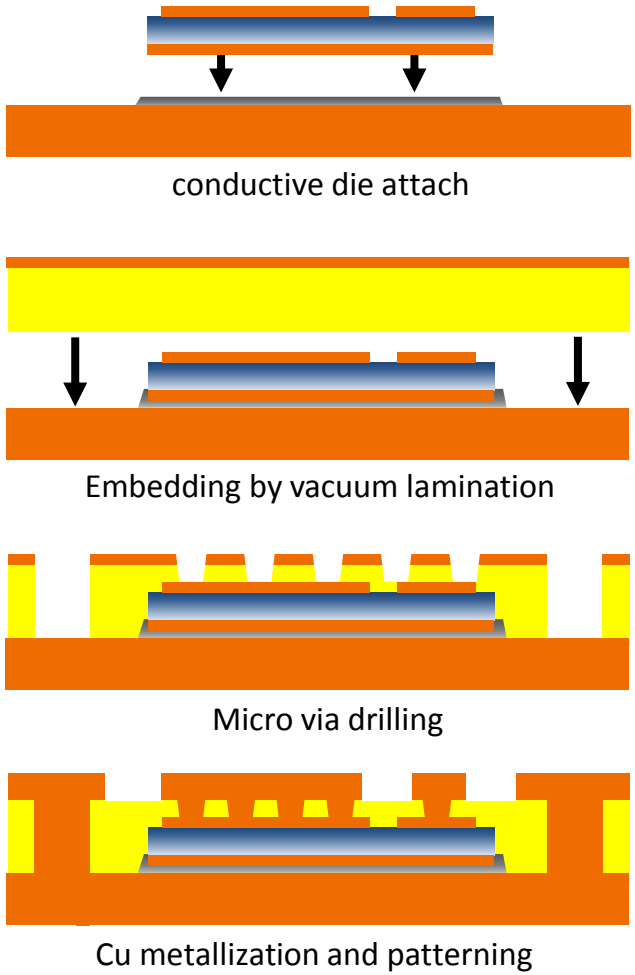
Power Chip Embedding – Face-up Process



- 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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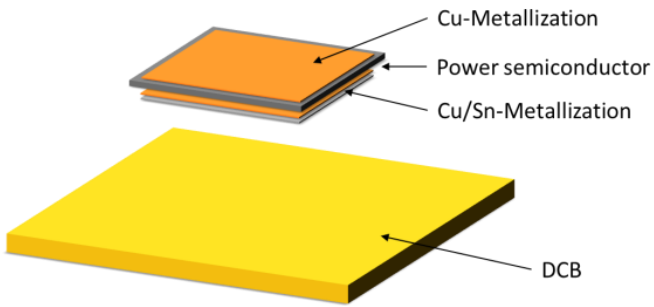
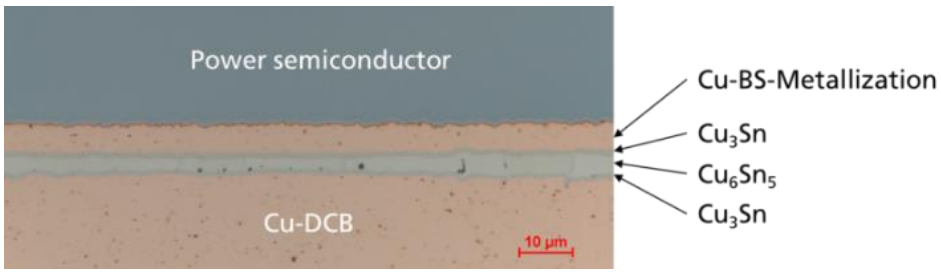
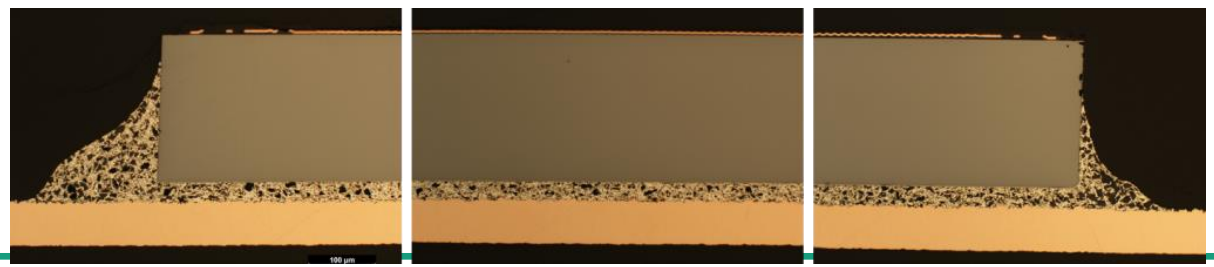
Power Chip Embedding – Die assembly

- TLPB: transit liquid phase bonding:
  - Good thermal and electrical conductivity
  - Requires additional metallization on Wafer backside





- Sinter glue:
  - Easy to apply
  - Limited electrical and thermal conductivity



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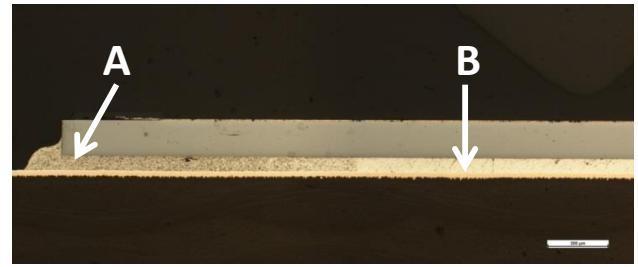
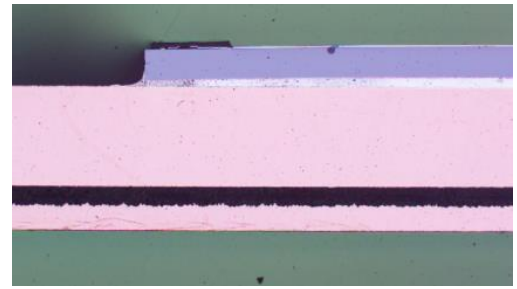
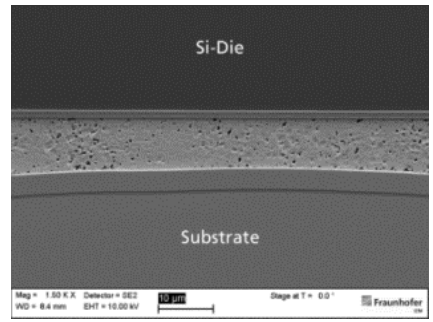
Power Chip Embedding – Die assembly

- Ag sintering
  - Good thermal and electrical conductivity
  - Sinter paste application by printing or dispensing
- Without pressure
  - Sintering in oven
  - Reliability issues in TC
- Low Pressure (≤ 30bar)
  - Sintering in Multilayer press, capable for large subtrates
  - Process under development
- Pressure
  - Sintering in press, capable for small subtrates







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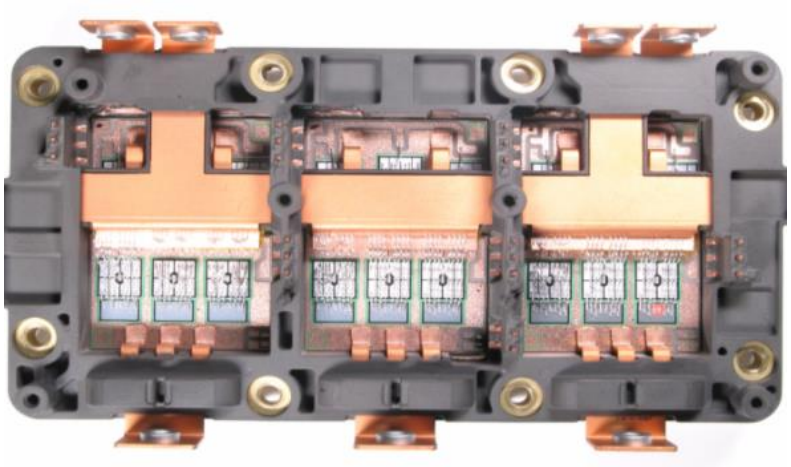
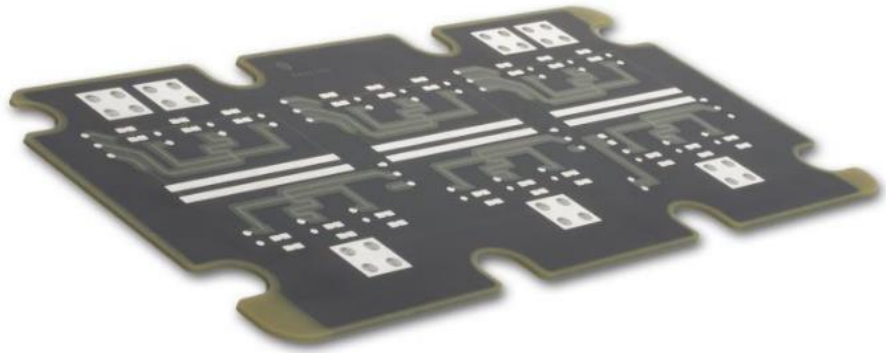
Development of planar power modules for motor inverter





p² Pack, courtesy of Schweizer Electronic

Features

- Reduction of height by 10 mm
- Cost efficient production
- Manufacturing on panel format
- Integration of control electronics

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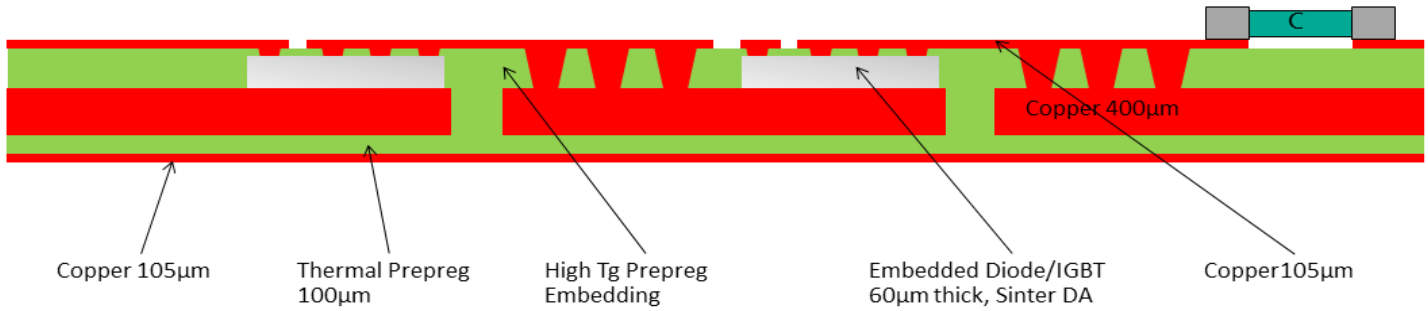
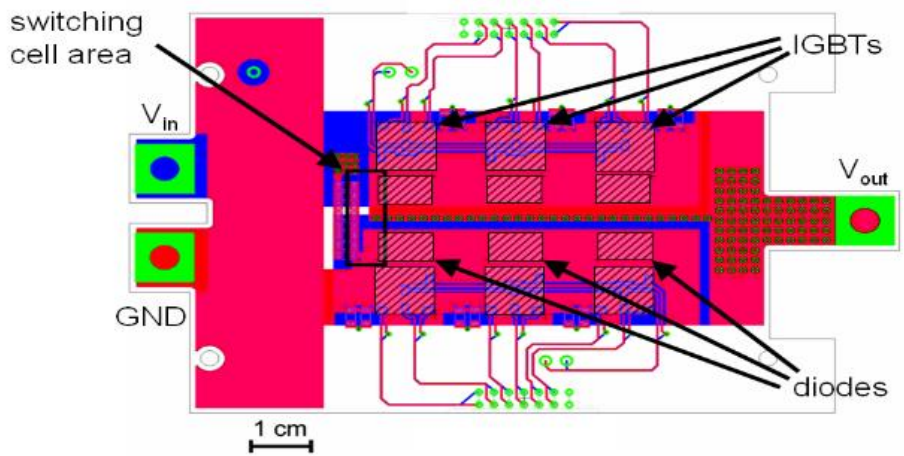
10 kW Demonstrator



- Single phase, 20 – 660 VAC
- 2 IGBTs 200 A
- 2 freewheeling diodes
- IGBT and Diode on thick copper substrate



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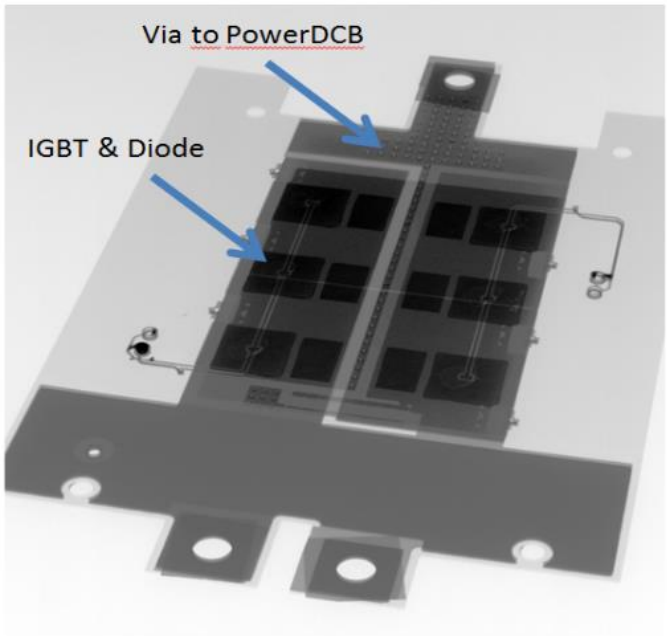
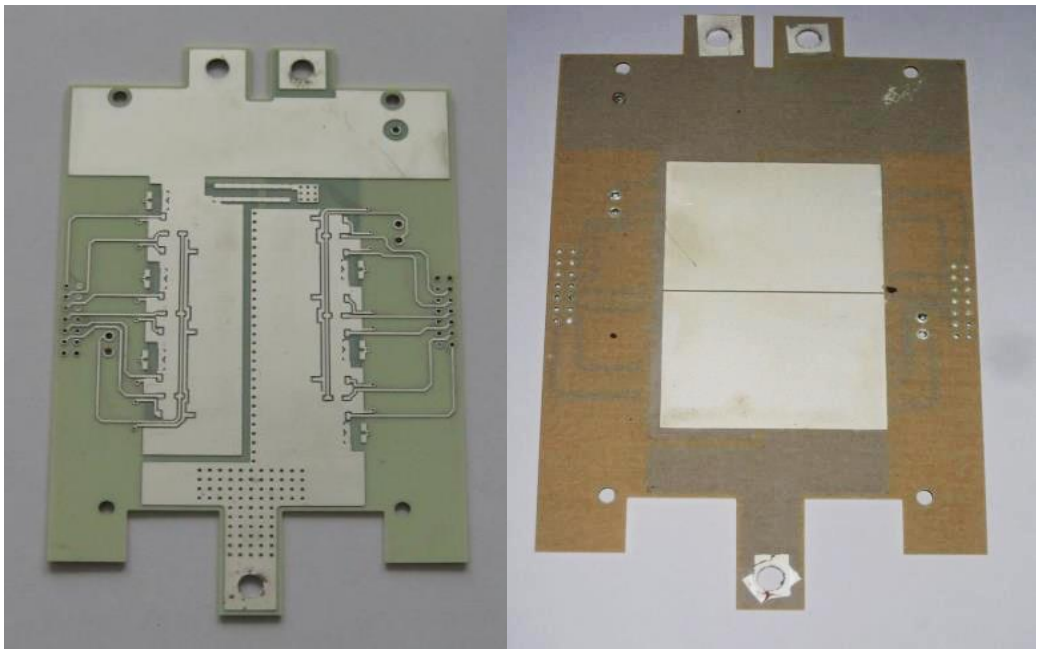
10 kW Demonstrator

- 900µm thick module
- Six embedded IGBT and diodes
- DC link capacitors assembled on module





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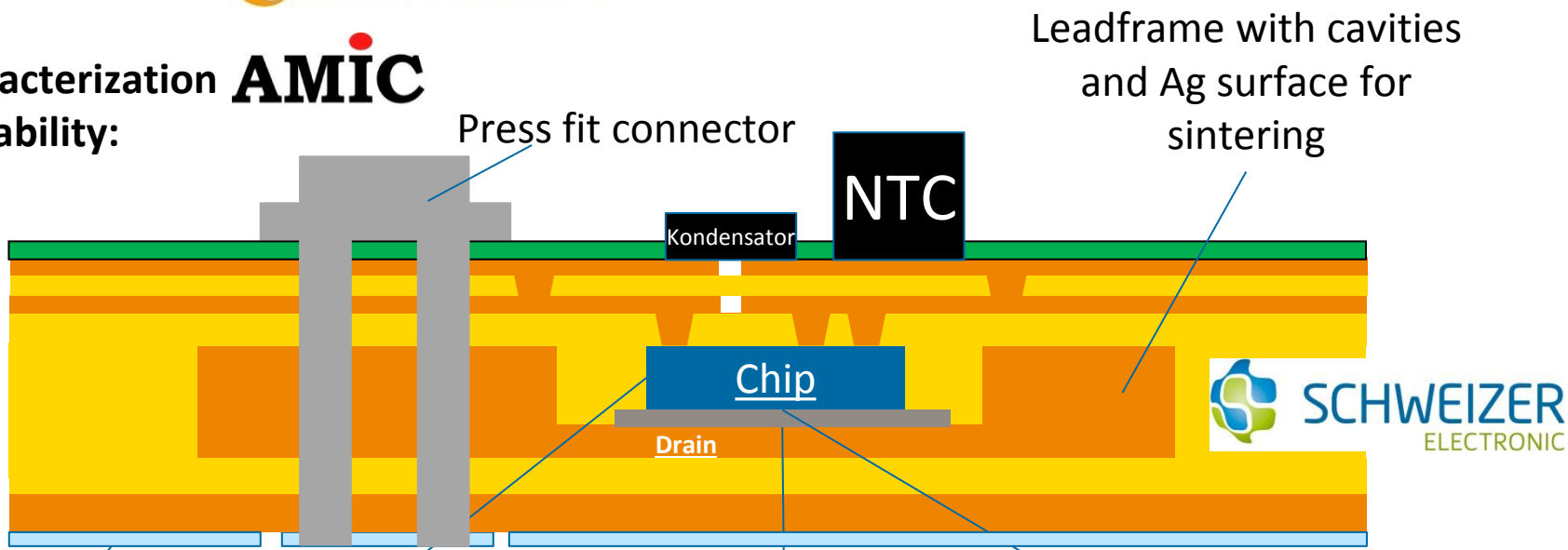
Schematic - 50 kW Demonstrator

Design/Setup/ Test: ISEA Institut für Stromrichtertechnik und Elektrische Antriebe RWTH AACHEN; Continental

Test/ End user: DAIMLER

Characterization /reliability: AMIC



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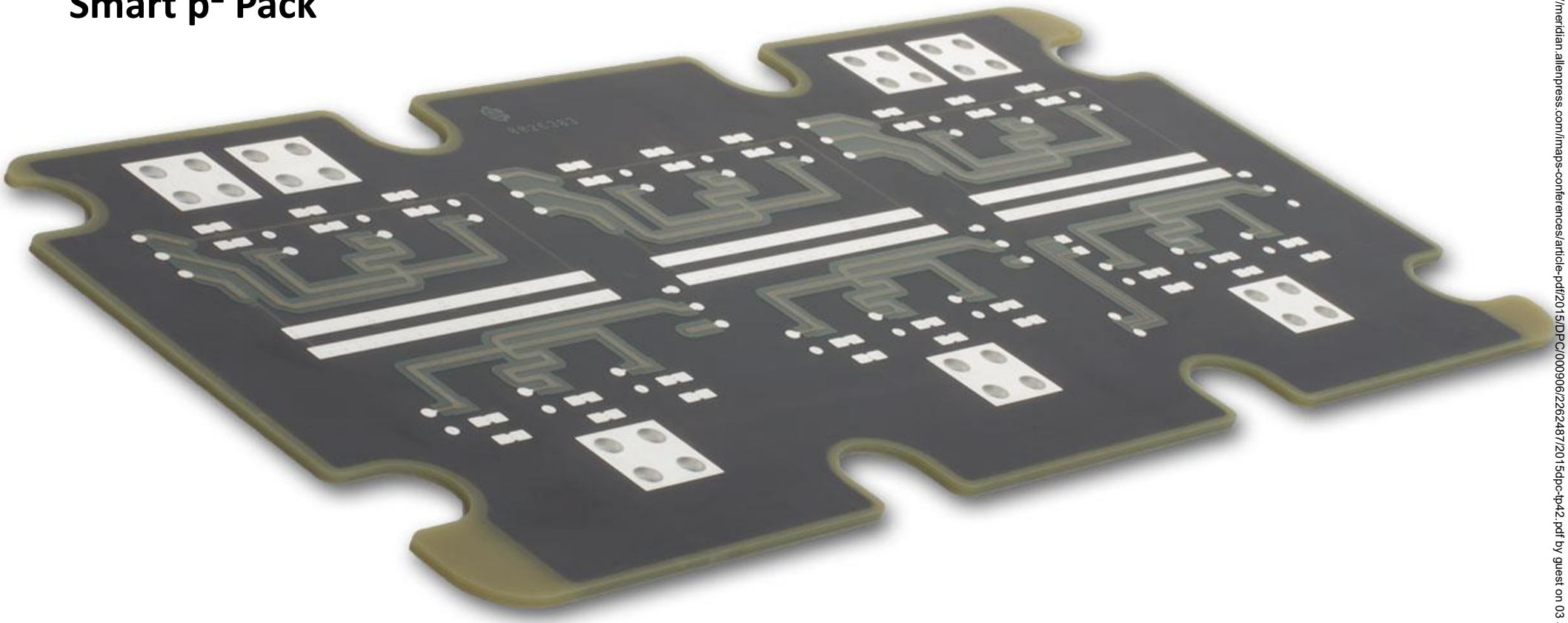
50 kW Demonstrator

PROJECT HI-LEVEL

SCHWEIZER ELECTRONIC

Smart p² Pack



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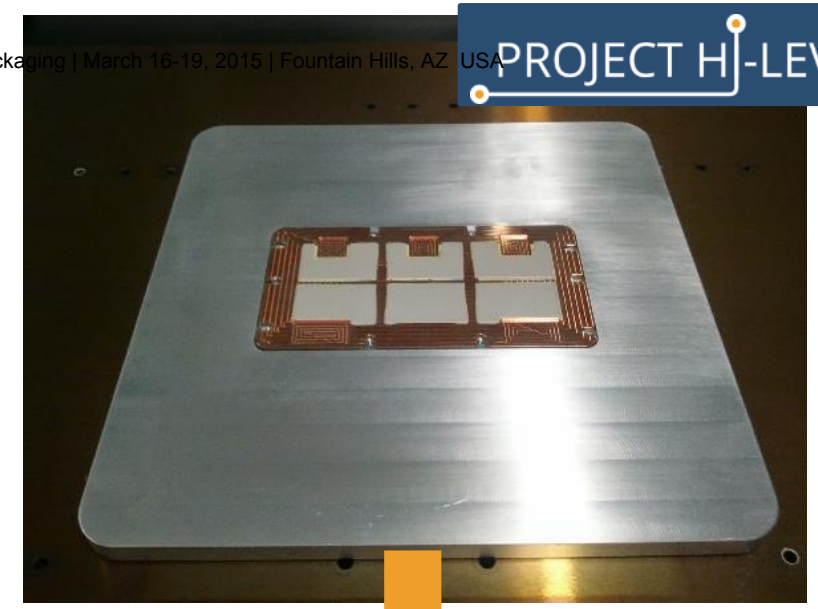
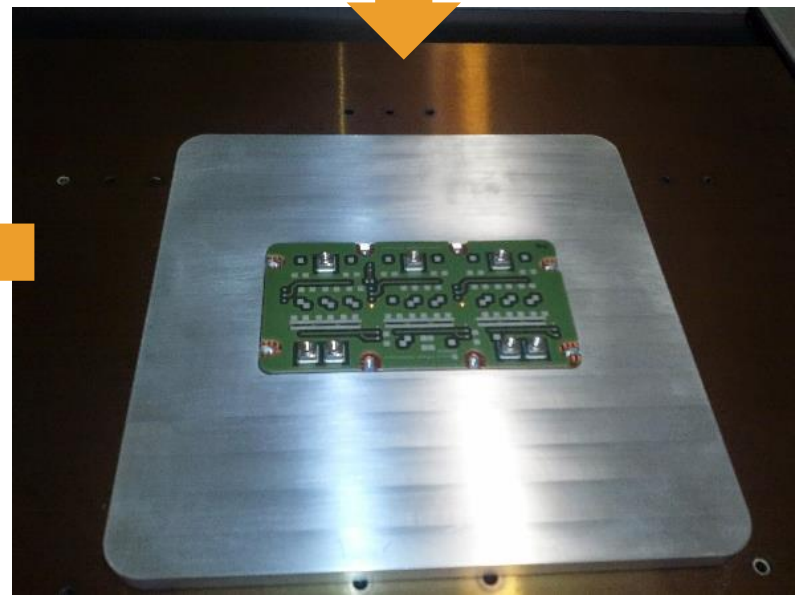
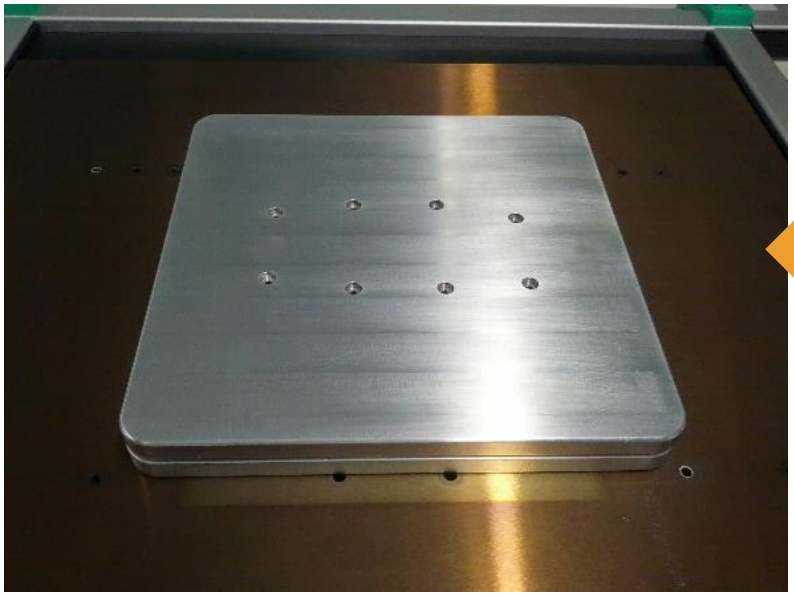
Sintering to heat sink

- Printing of Ag sinter paste
- Sintering at low pressure (3 MPa) in Multilayer press
- Parallel sintering of modules possible







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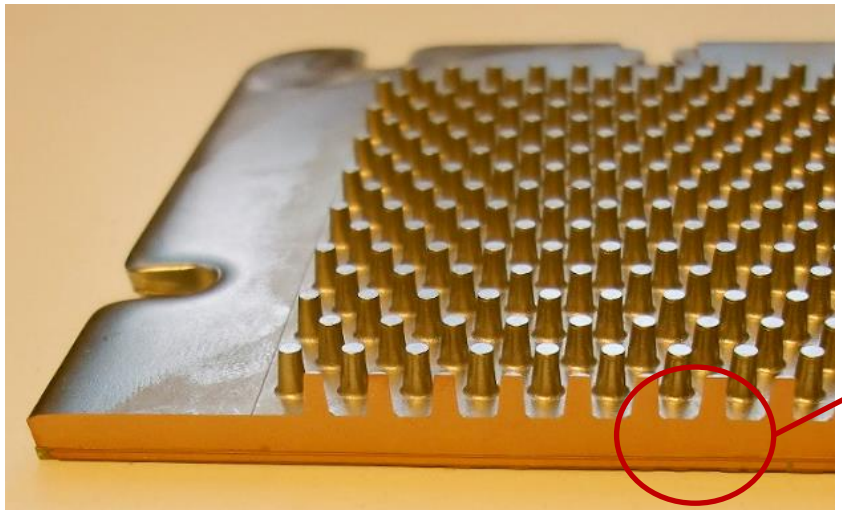
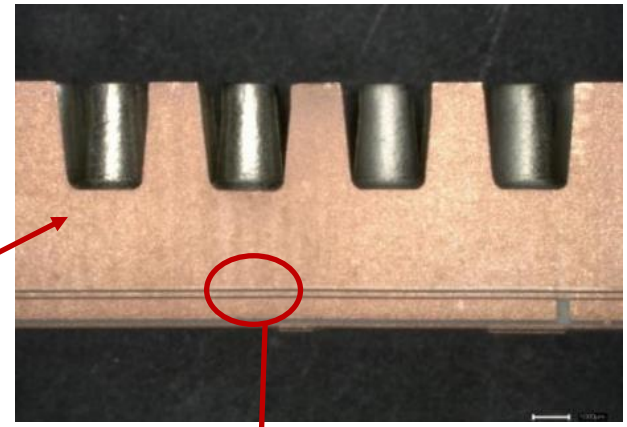
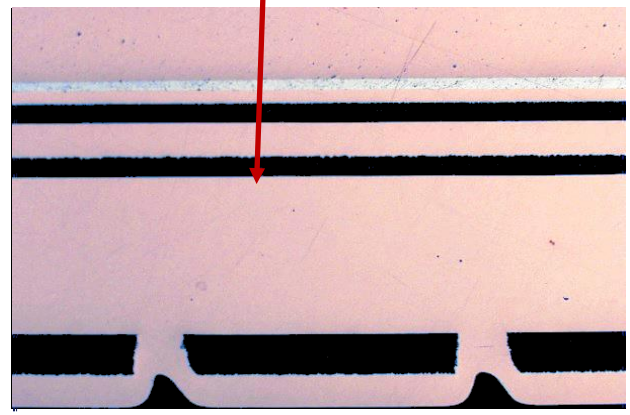
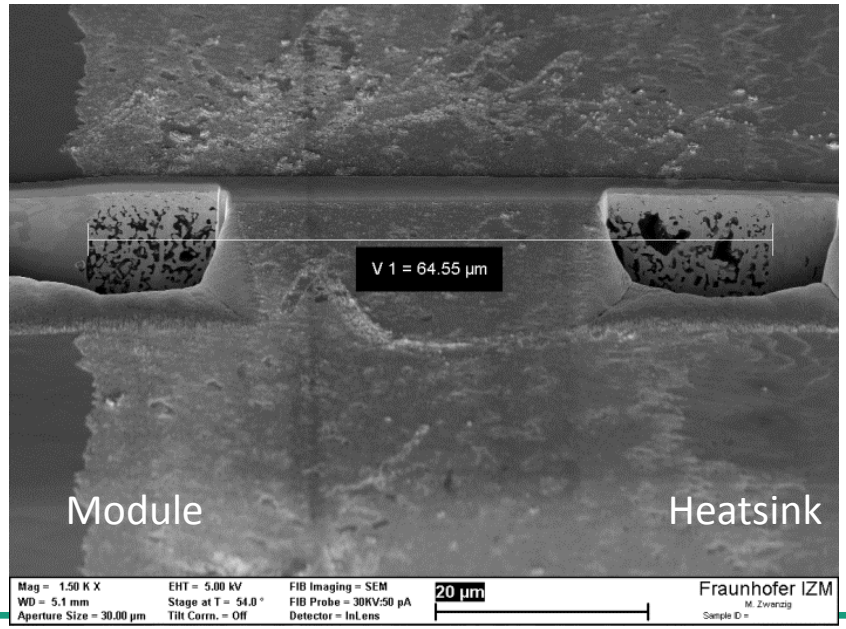
Sintering to heat sink









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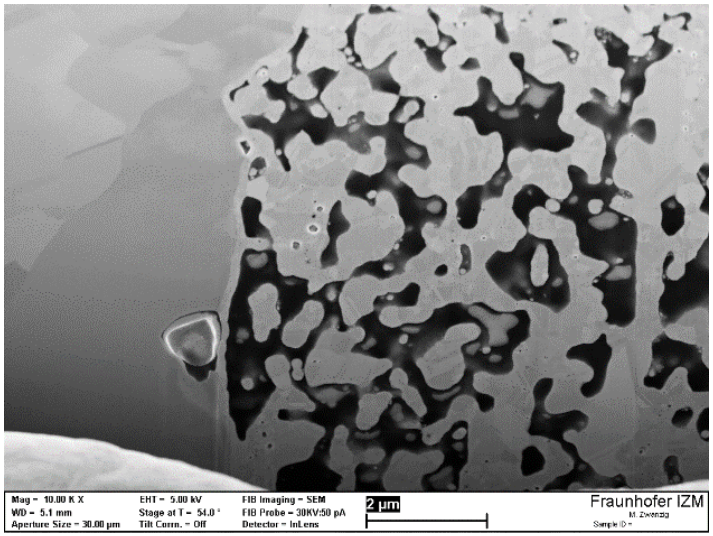
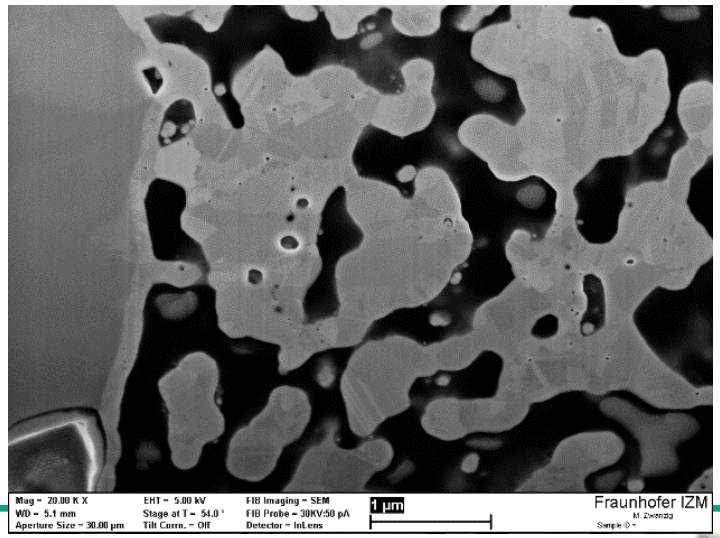
Sintering to heat sink

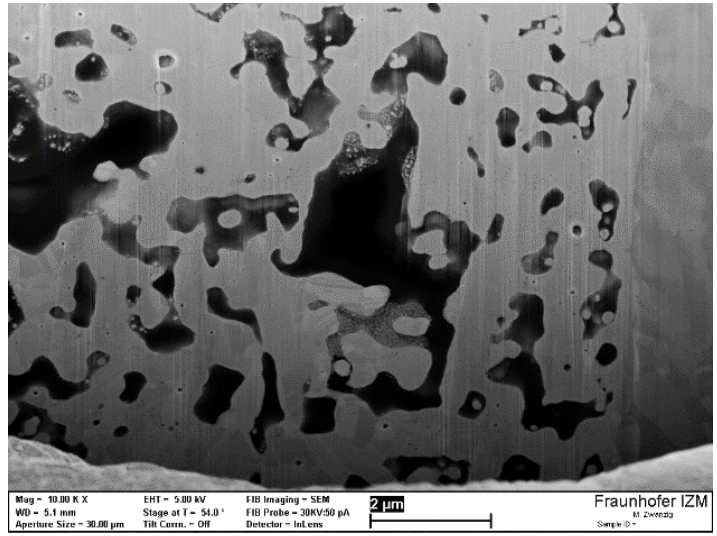
PROJECT HI-LEVEL

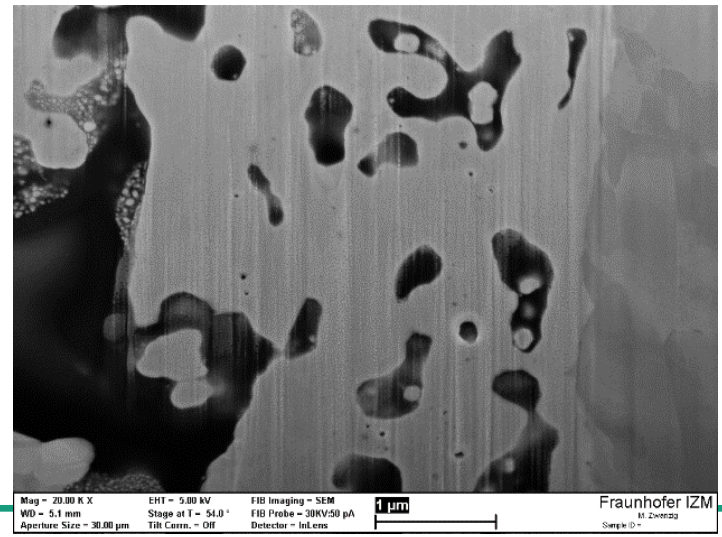
- Interface Modul





- Interface heat sink





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EmPower Project

empower

- **Em**bedded **pow**er components for electric vehicle applications
- Started in September 2013, duration 3 years
- Project goals:
  - Industrialize double sided copper plating on wafer level
  - Industrialize next generation automotive power modules
- Benefits:
  - High performance power products with embedded MOSFET, IGBT, GaN, etc.
  - Smallest form factor power supplies
- Partners:

AT&S, ILFA Feinstleitertechnik, ATOTECH, Continental, TU berlin, TU WIEN, ST

http://catrene-empower.ats.net

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Fraunhofer IZM

EmPower Project

empower

EmPower Consortium

AT&S

empower

Duration: Sept. 2013 – Aug. 2016
Project Coordinator: AT&S
Project budget: 5,6 Mio €

ILFA Feinstleitertechnik

TU berlin

ATOTECH

AT&S

ILFA Feinstleitertechnik

Continental

Wafer supply | Wafer plating | Wafer back end | Die embedding | Power module | End user

System development | System simulation

TU berlin

TU WIEN

EmPower – CATRENE | Bayern Innovativ 27.1.2015 | Hannes Stahr 10

Source: Hannes Stahr, AT&S, Bayern Innovativ Jan 2015

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Fraunhofer IZM

EmPower - Demonstrators

- Power class 50W:
  - Power package for fast rectifier diode
  - Demonstrator for embedded power core (AT&S and IZM/TUB)
- Power class 500W
  - Power module for pedelec application
  - Demonstrator for double sided cooled power module
  - Benchmark with excisting concept
- Power class 50kW
  - Power module for HEV / EV application
  - Benchmark with existing module

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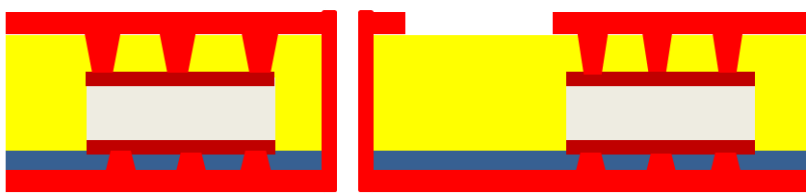
Power core concept – process

empower

(1) Die Placement

(2) Layup and lamination of PP

(3) Via formation to embedded die



(4) Cu metallization and patterning

- Epoxy coated foil or prepreg and Cu foil used
- No use of sintered or soldered die attach
- Direct micro via connection from top and bottom side
- Requires double sided Cu metallization of semiconductor

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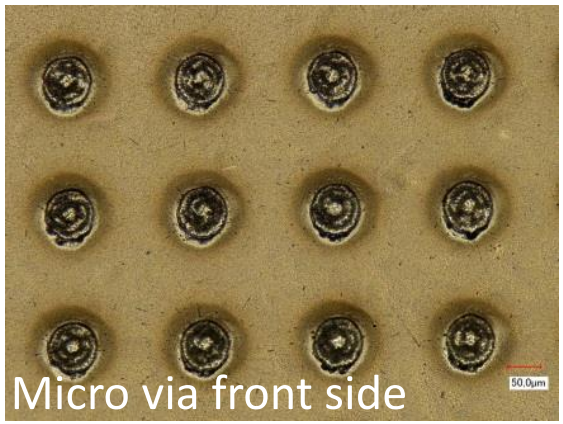
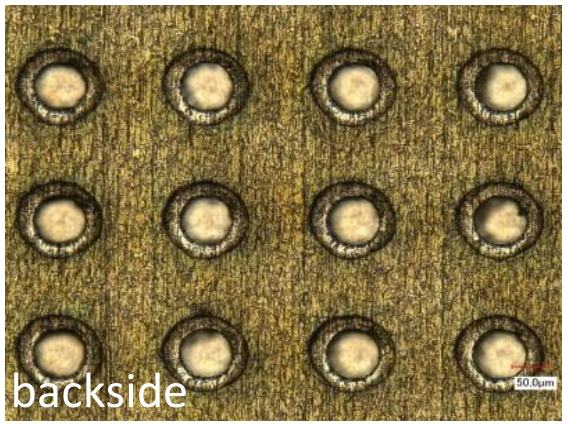
Power core concept - process

empower

- Substrate
  - Cu foil with B-stage epoxy resin
  - Cu foil and thin prepreg
- Die attach with heated tool
  - Die at fixed position
  - But resin still needs to be reactive to bond to additional layers during embedding
- Laser drilling to embedded die top and back





000928

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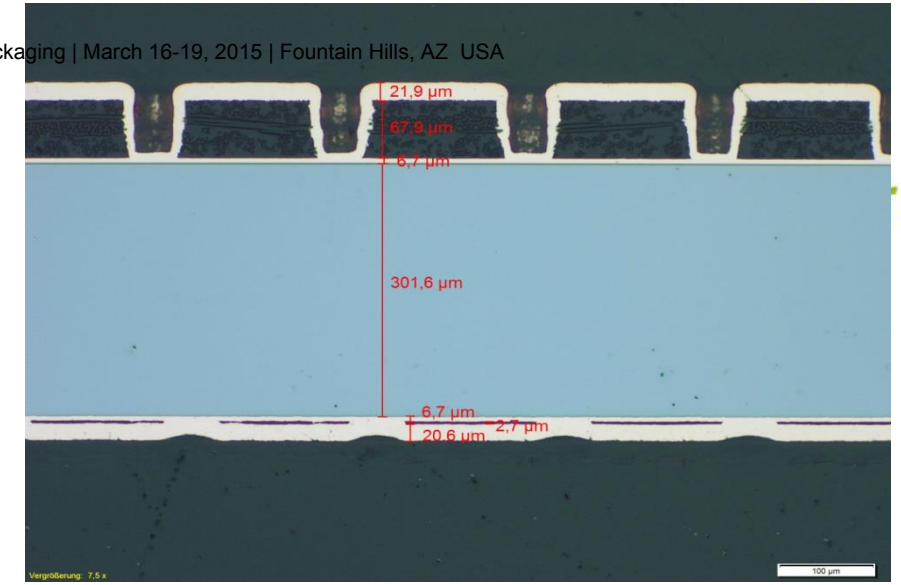
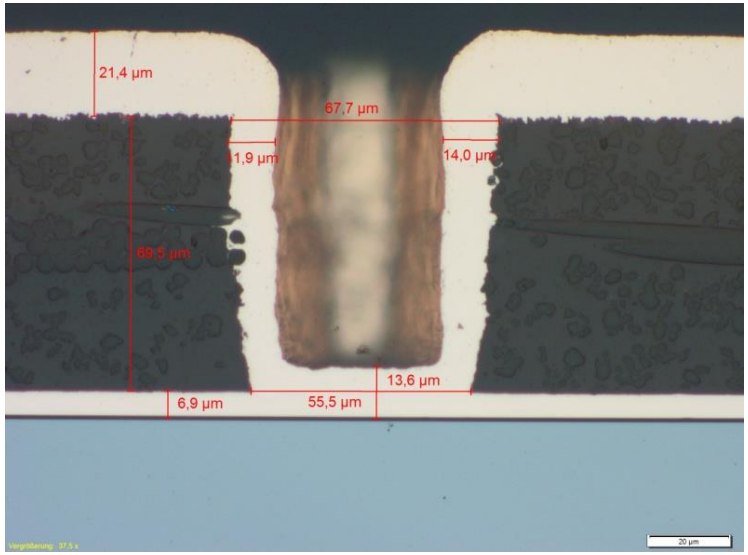
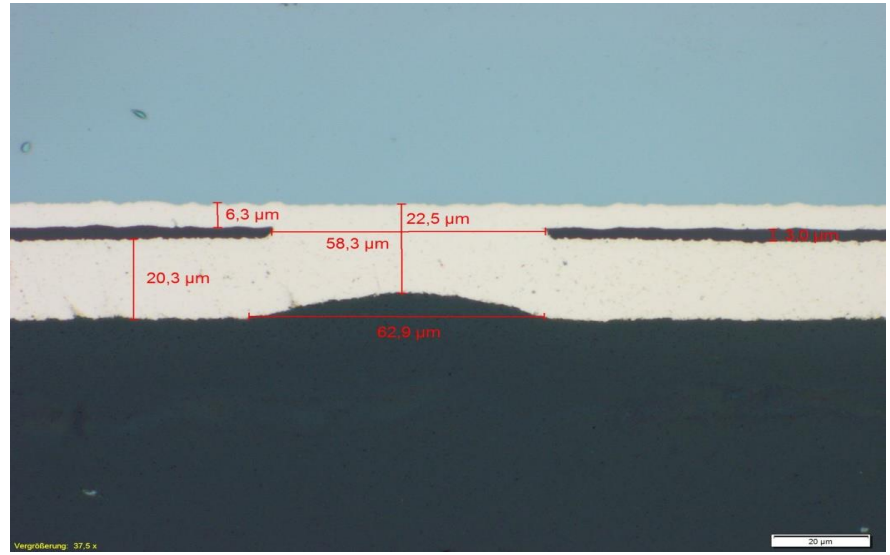
Power core concept - results

- Plated copper connection to top and backside contact





cross section micro via front side



back side

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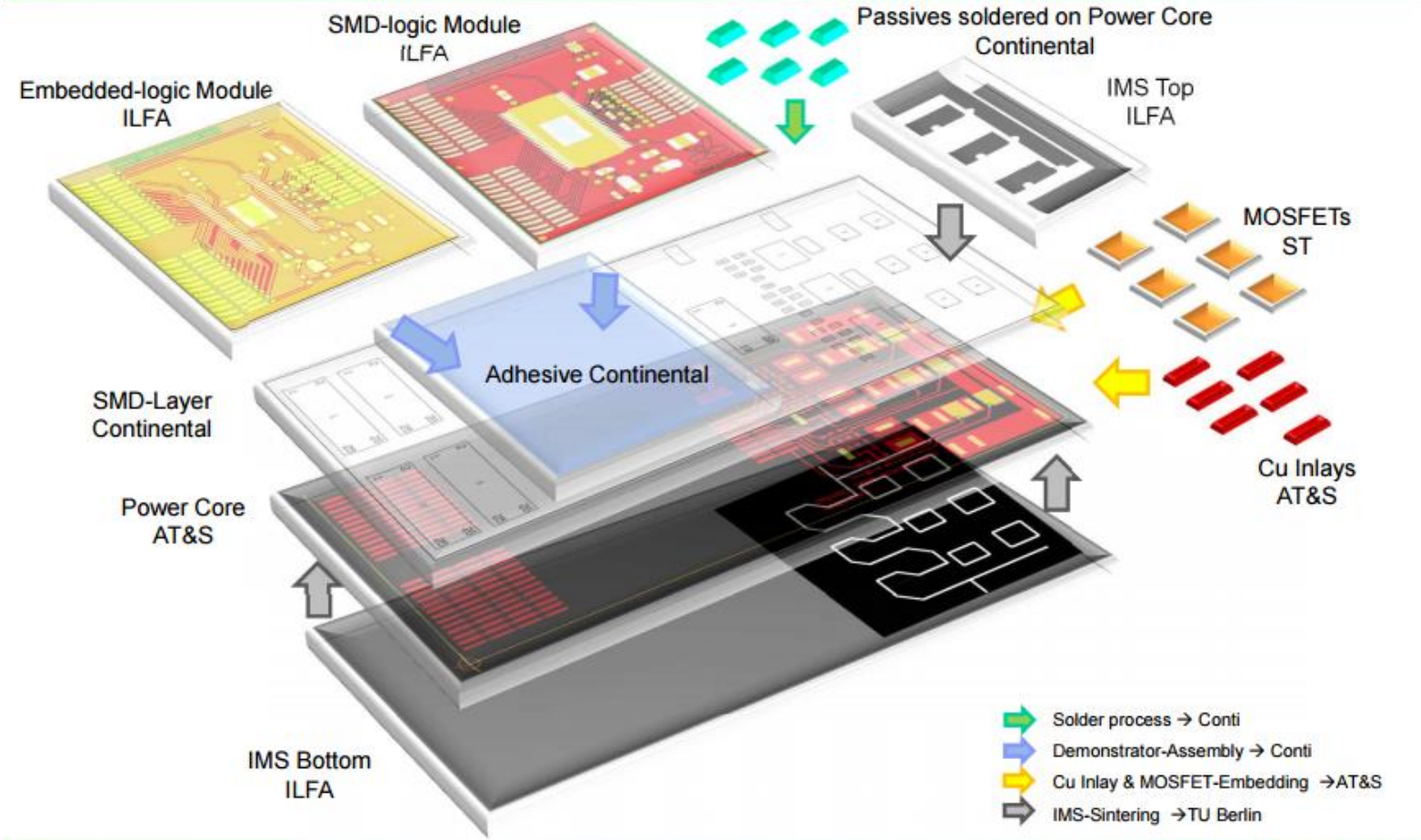
500 W Demonstrator

empower

WP5 D5.5 / Task 5.3
Power module development



EmPower | GM4 / WP5 Status | Berlin 10.-11. March 2015 | M. Morianz

AT&S
www.ats.net

Source: Mike Morinanz, AT&S, EmPower Konsortium

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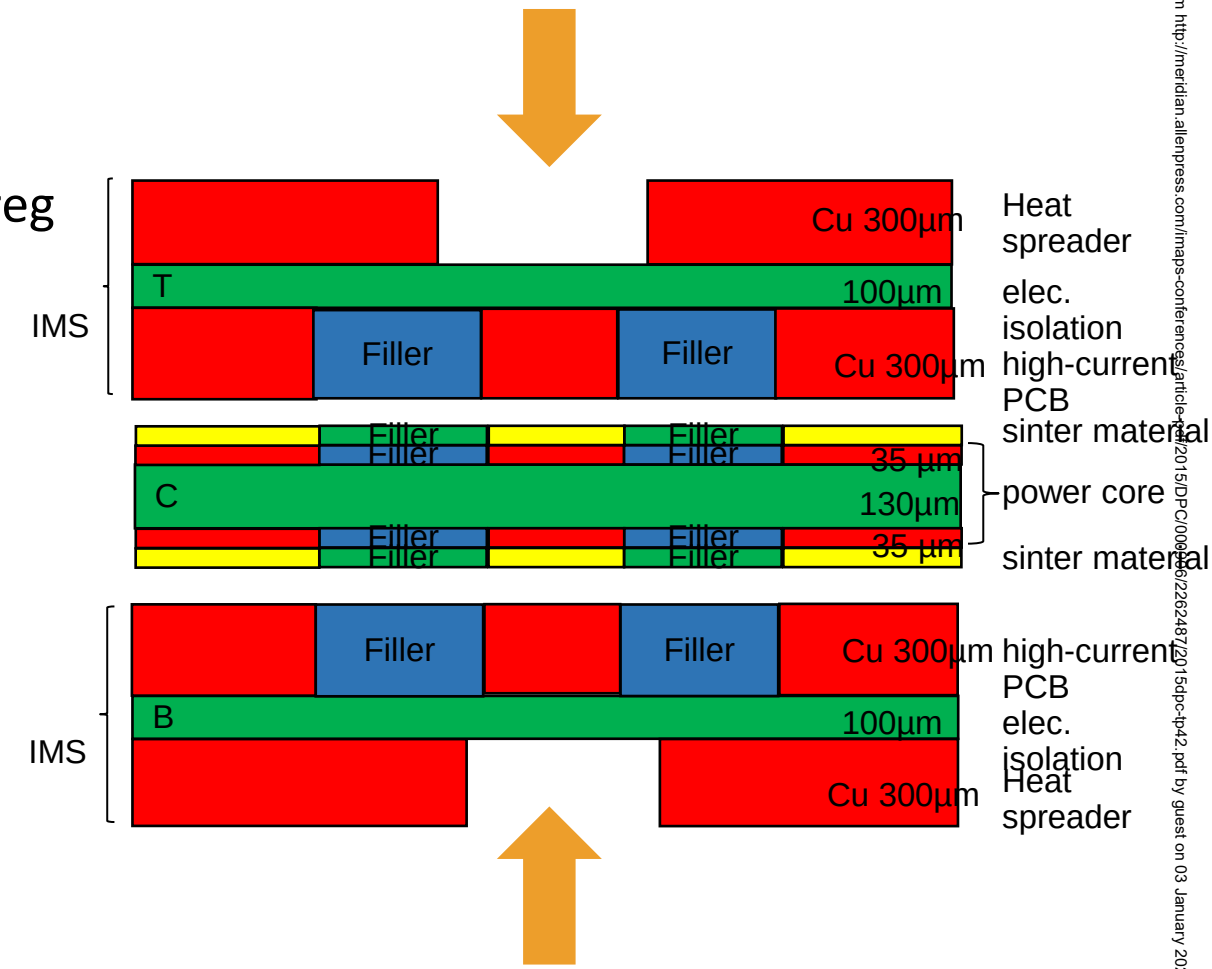
High current connection

empower

- Connection of power core to IMS substrate
  - Organic substrate with 300µm Cu layer
  - High thermal conductive prepreg
- Connection of power core to IMS substrate
- Ag sintering on substrate level



000931

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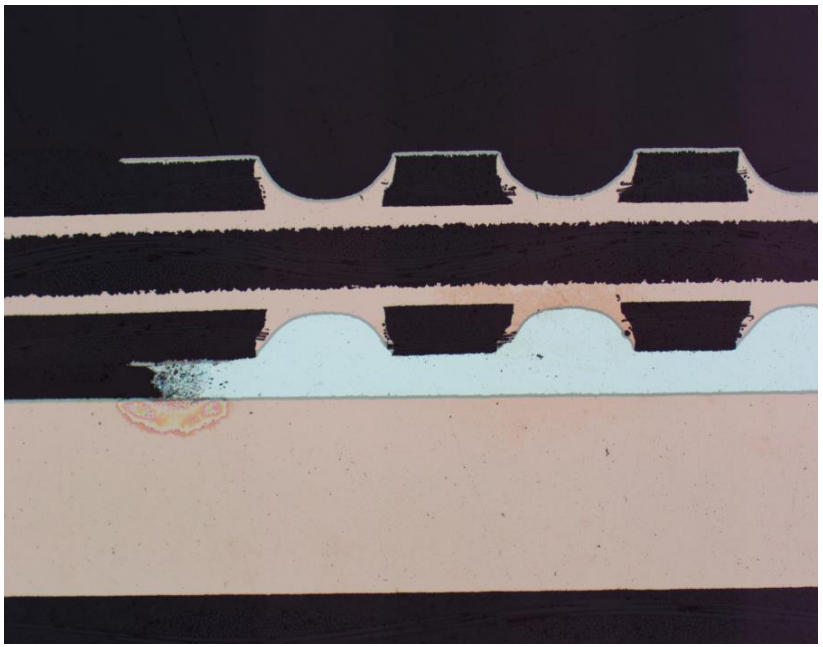
High current connection

empower

- Printing of Ag sinter paste
- Structured prepare layers for filling gap between power core and IMS
- Sintering in multilayer press
  - Void free sintering of power core and IMS
  - Void free filling of gap with epoxy resin
  - Sintering and curing in the same process



000932

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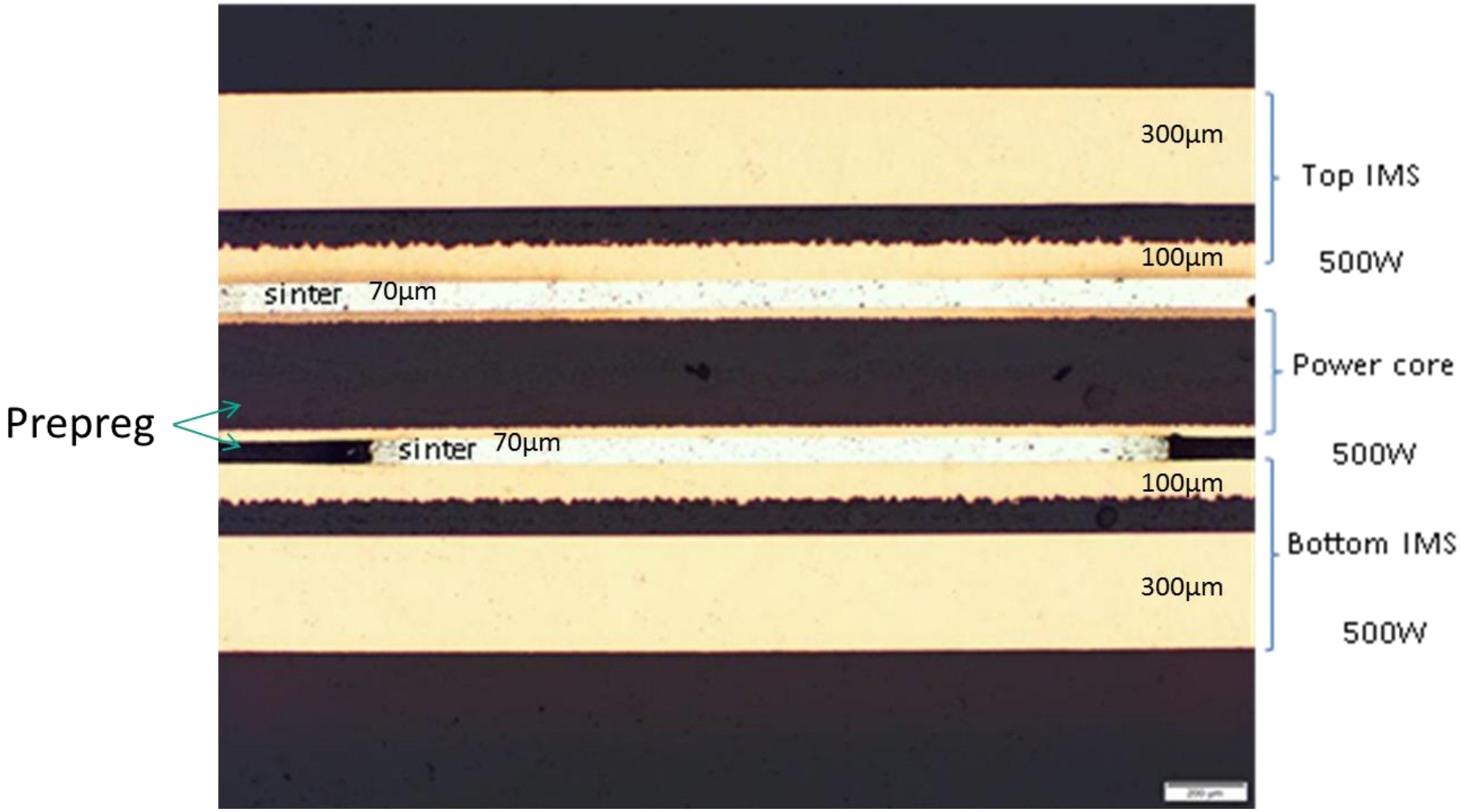
High current connection – 500 W demonstrator



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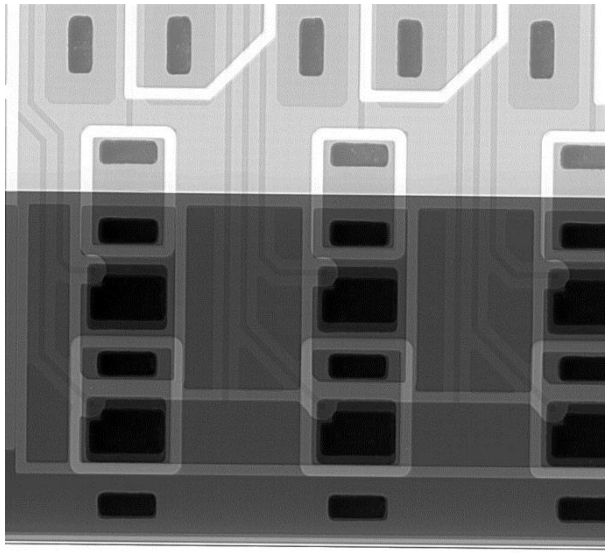
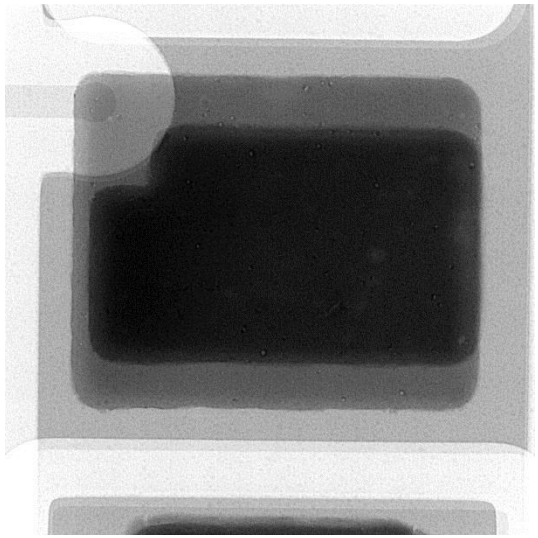
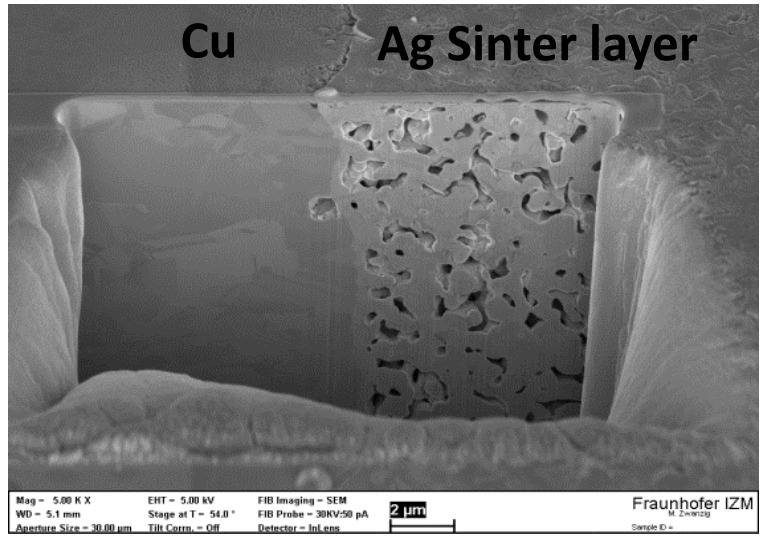
High current connection – 500 W demonstrator

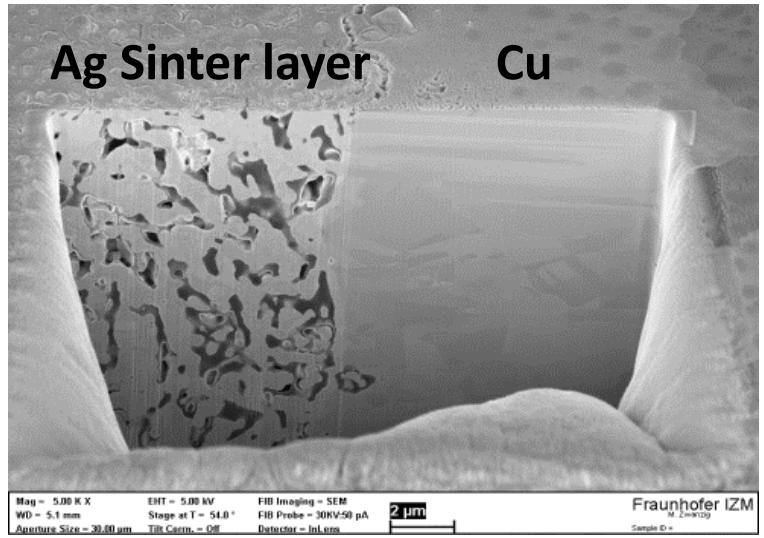
x-ray analysis





FIB analysis





000934

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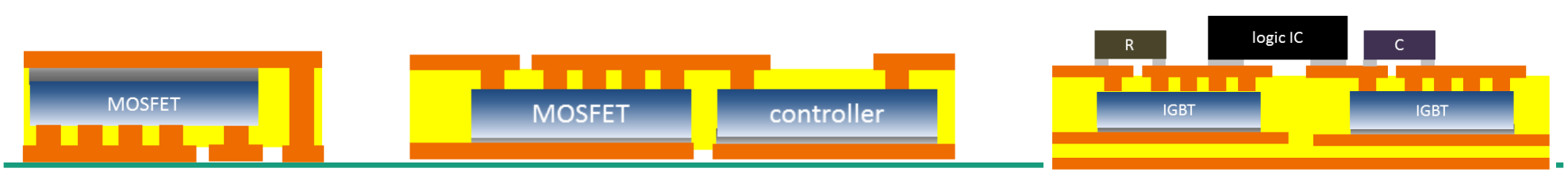
Conclusion

- The embedding of components for the realization of power packages and modules provides a flexible platform for a lot of different applications
- The Hi-Level project demonstrated the successful manufacturing and electrical test of power modules up to 50kW switching power
- The EmPower project focuses on a new approach for the embedding of power semiconductors using double sided copper connections to the embedded die (power core) and IMS substrates for high current and thermal management
- Use of power core avoids soldering or Ag sintering of the power semiconductors and the handling of thick copper substrates during the embedding process.



000935

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GEFÖRDERT VOM

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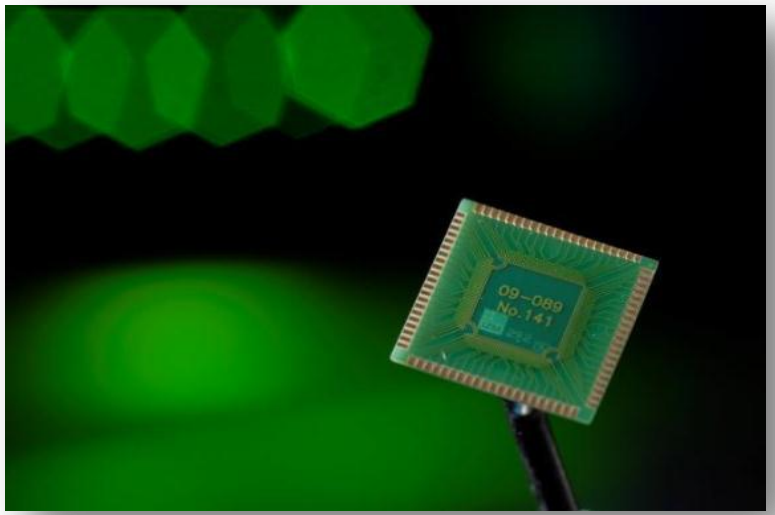

Thank you very much for your attention!

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