

Application of the PCB-Embedding Technology to a 3.3 kW Power Factor Corrector

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Rémy CAILLAUD¹, Johan LE LESLÉ², Cyril BUTTAY¹,
Florent MOREL¹, Roberto MRAD², Nicolas DEGRENNE²,
Stefan MOLLOV²

¹Laboratoire Ampère, Lyon, France

²Mitsubishi Electric Research Centre Europe, Rennes, France

19 – 21 March 2019

Introduction

PCB Embedding Technology – A Review

Presentation of an embedded converter

Conclusions

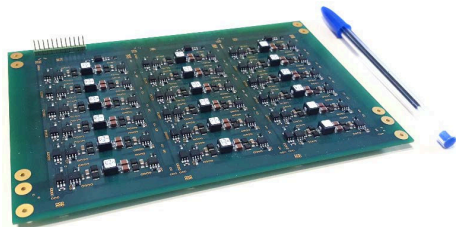
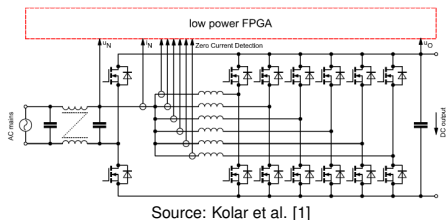
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Power electronics – Areas for Progress

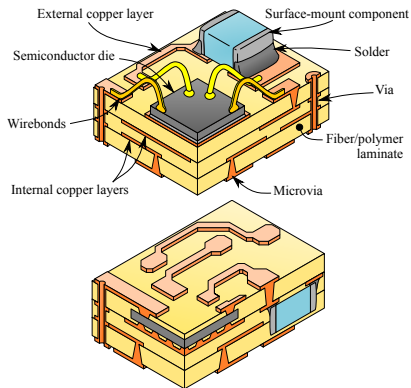


Source: Kerachev et al. [2]

- ▶ Excellent active devices are now available (SiC, GaN)
- ▶ Many topologies introduced over the years;
 - ▶ Recent changes: multi-cellular structures
- ▶ Integration and Packaging are the main areas for progress [1, 3, 4, 5]
 - ▶ Reduce size and circuit parasitics, improve thermal management. . .
 - ▶ Manage increased interconnection density

Why Embedding?

- ▶ Optimize thermal management
 - ▶ Heat sources closer to heatsink
 - ▶ Dual side cooling
- ▶ Improve performance
 - ▶ Shorter interconnects
 - ▶ Lower inductances
- ▶ Reduce size
 - ▶ Use substrate volume
- ▶ Manage complex interconnects
 - ▶ Batch process
 - ▶ Take advantage of PCB design tools



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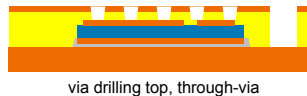
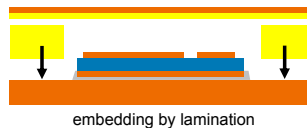
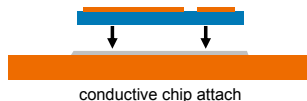
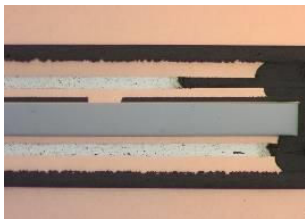
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Embedding of Power Dies – 1

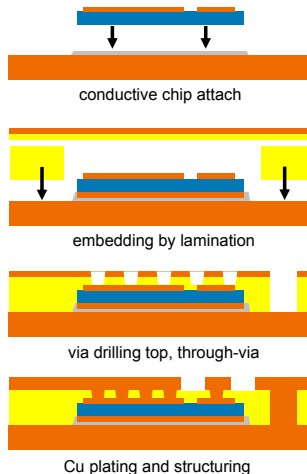
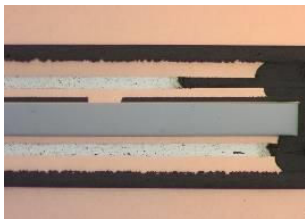
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 - ▶ Most power density
 - ▶ Fastest voltage/current transients
- ▶ Requires special finish on dies
 - ▶ 5-10µm Cu (not standard)
 - ▶ Buffer for UV laser
 - ▶ Also for microetch in plating step
- ▶ Backside connection by sintering or vias
 - ▶ Sintering compatible with standard dies
 - ▶ Vias require Cu finish and adhesive



Left and above, source: Ostmann [6]

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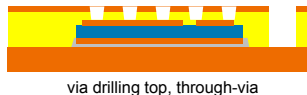
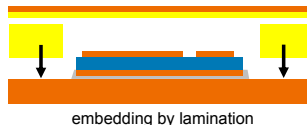
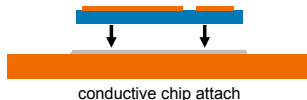
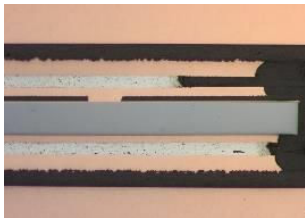
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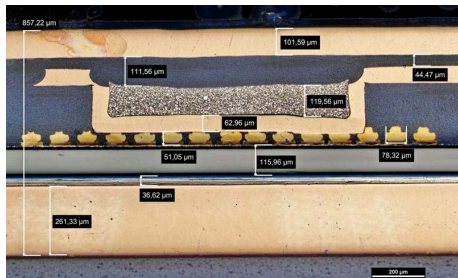


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Embedding of Power Dies – 2

Some alternative techniques

- ▶ Stud bumps and machining
- ▶ Foam interposer
- ▶ Mechanical drilling

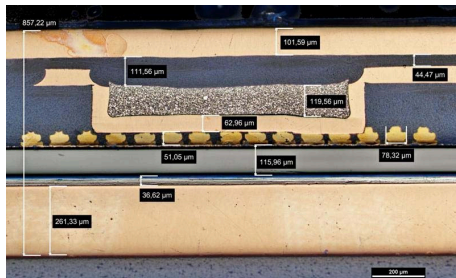


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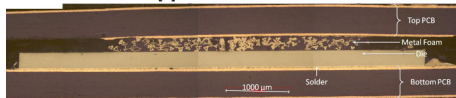
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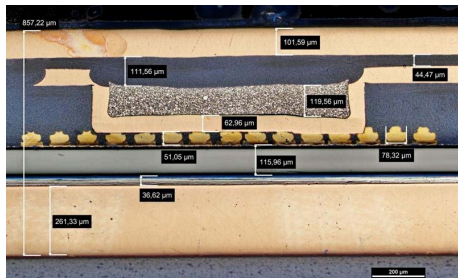


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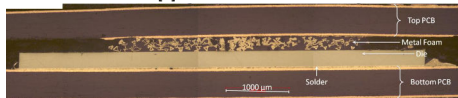
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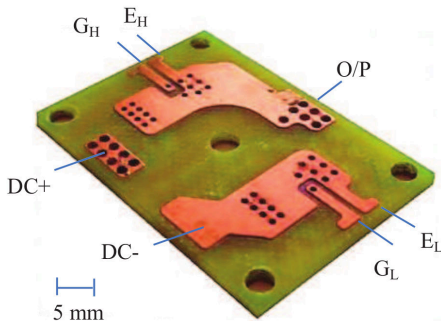
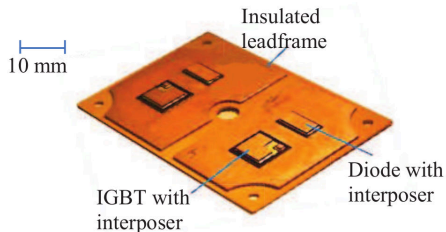
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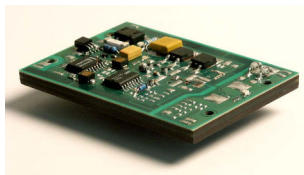


Source: Sharma et al. [9]

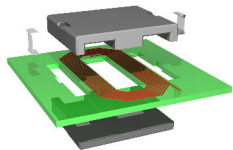
Embedding of Formed Components – Inductors

Magnetic Layer

- ▶ Relies on magnetic/polymer film \rightarrow Low μ_r
- ▶ Limited to 10 – 100 W



Source: Waffenschmidt et al. [10]

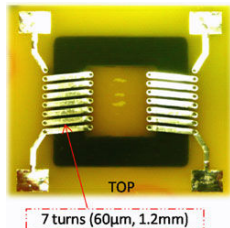


Planar magnetic components

- ▶ Very common, but not really embedded
- ▶ High performance
- ▶ Compatible with low (W) or high power (kW)

Embedded core

- ▶ Strong industrial development (Murata, AT&S, Würth)
- ▶ Currently limited to low power (W)



Source: Ali et al. [11]

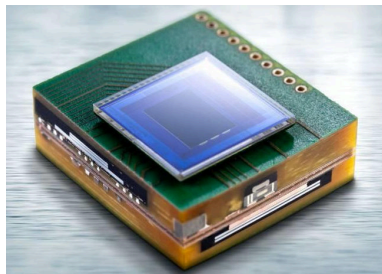
Embedding of Inserted Components

Soldered components:

- ▶ Suits most Surface-Mount Devices
- ▶ Connections with regular vias

Vias to components:

- ▶ Requires components with Cu finish
- ▶ More compact (vias on components)



Source: Ostmann [6]

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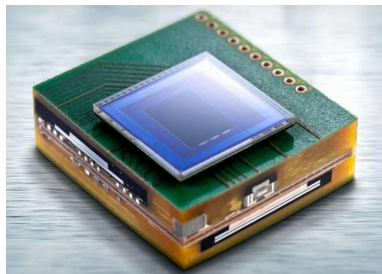
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For power electronics

- ▶ Embedding of “large” capacitors (1 μ F range)
- ▶ Embedding of gate driver ICs and peripheral components, control



Source: Ostmann [6]

Thermal Management of Embedded Components

- ▶ Poor thermal conductivity of FR4 compared to ceramics ($1\text{--}7\text{ W m}^{-1}\text{ K}^{-1}$ vs $150\text{ W m}^{-1}\text{ K}^{-1}$ for AlN)
- ▶ In theory better breakdown field ($\approx 50\text{ kV mm}^{-1}$ vs. 20 kV mm^{-1})

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To improve through-plane heat conduction:

- ▶ Micro-vias (electrically conductive), Filled cores (e.g. alumina)

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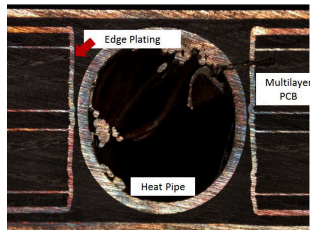
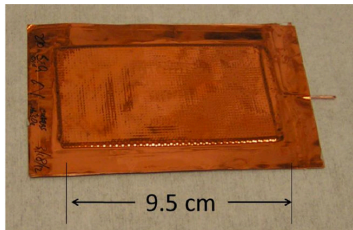
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To improve through-plane heat conduction:

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To increase in-plane heat conduction:

- ▶ Thicker copper, Anisotropic layers (Graphite), Dual-phase

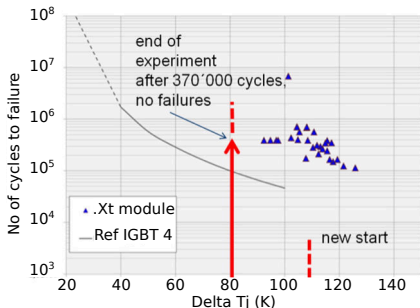


Source: left: Liew et al. [12]; right: Silvano et al. [13]

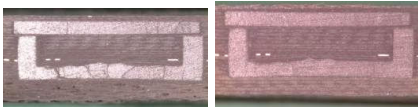
Reliability of PCB with Embedded Components

- ▶ Temperature-related issues
 - ▶ Rapid degradation above 190 °C
 - ▶ Hydrocarbon, polyimide-based PCBs resistant up to 250 °C
- ▶ Thermal cycling issues
 - ▶ CTE of PCBs much higher than ceramic or semiconductor
 - ▶ Availability of low-CTE materials
 - lacks data on large components
- ▶ Other PCB-specific issues
 - ▶ moisture absorption
 - ▶ conductive anodic filaments
- No showstopper identified yet!

Reliability of PCB with Embedded Components



Source: Randall et al. [14]. Superimposition of reliability data for dies in PCB on Infineon's results for standard power modules



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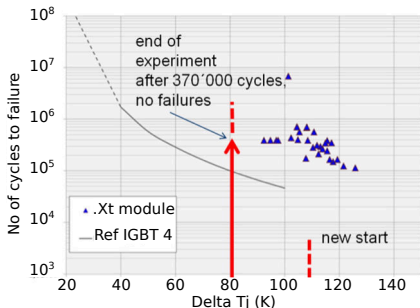
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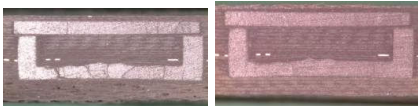
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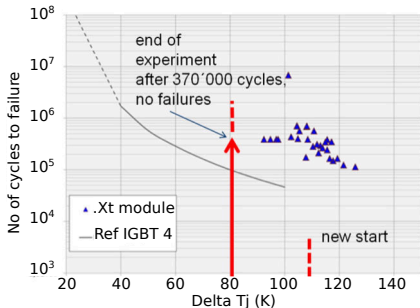


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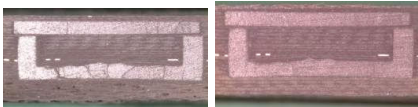
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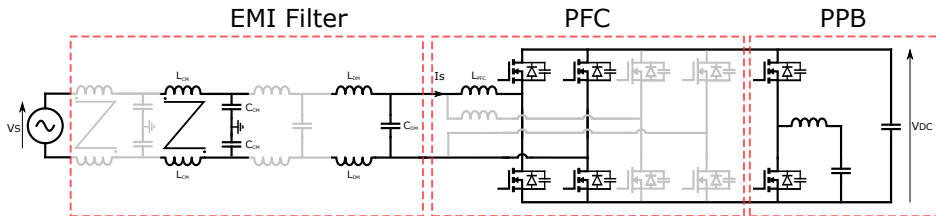
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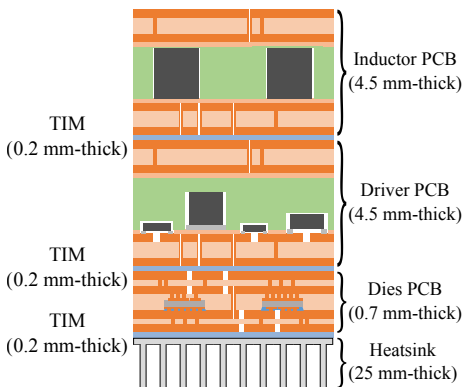
Conclusions

Converter topology



- ▶ Bidirectionnal, Power Factor Converter for 3.3 kW applications
- ▶ Designed through an optimization procedure [16, 17]
 - ▶ Based on SiC power devices
 - ▶ 180 kHz switching frequency
 - ▶ 4 interleaved cells
- ▶ Discussed here: PFC cell

Physical Structure



3-PCB structure

- ▶ Magnetic component on top
- ▶ Heatsink on bottom (natural convection)
- ▶ Power chips close to heatsink

Two board structures are used:

Thin PBC (1 mm)
for bare dies

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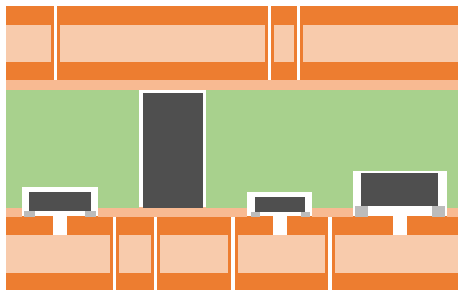
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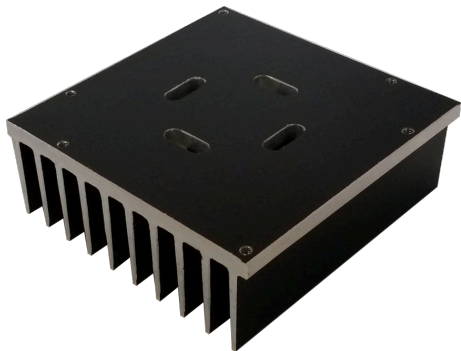


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Converter Cell Assembly

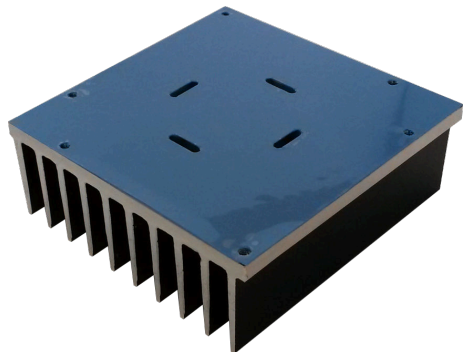
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- ▶ TIM
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- ▶ Thermal Interface Material (TIM)
- ▶ **Heatsink**



- ▶ Board-to-board interconnects using wires soldered in through-holes
- ▶ Final cell dimensions: $7 \times 7 \times 3.5 \text{ cm}^3$

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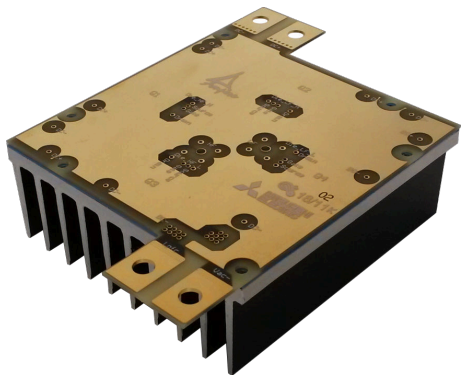
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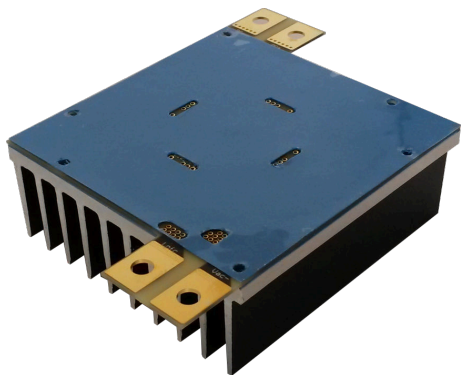
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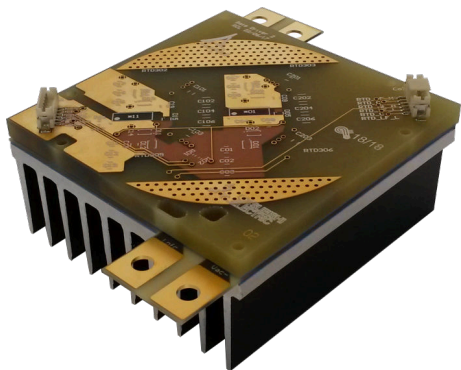
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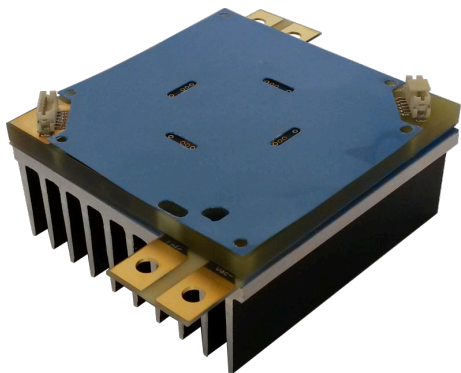
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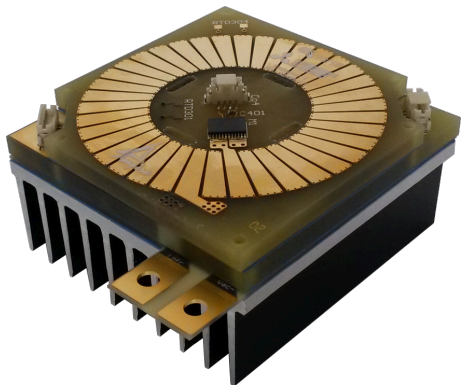
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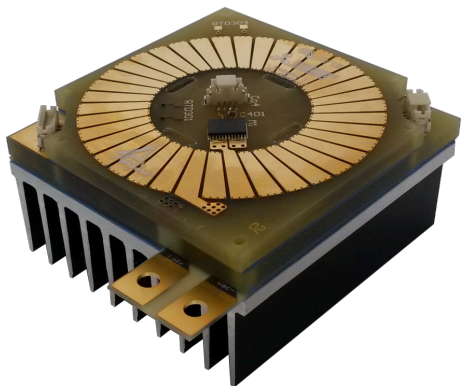
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 - ▶ Final cell dimensions: $7 \times 7 \times 3.5 \text{ cm}^3$



Full converter assembly

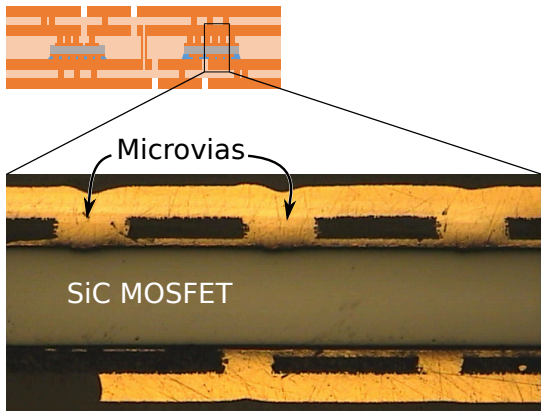


- ▶ 4 PFC cells for a full converter
- ▶ DC capacitor bank for test only
- ▶ 4-stage EMC DM filter
- ▶ 28x7x5 cm³

Test Coupons – power devices

For SiC dies

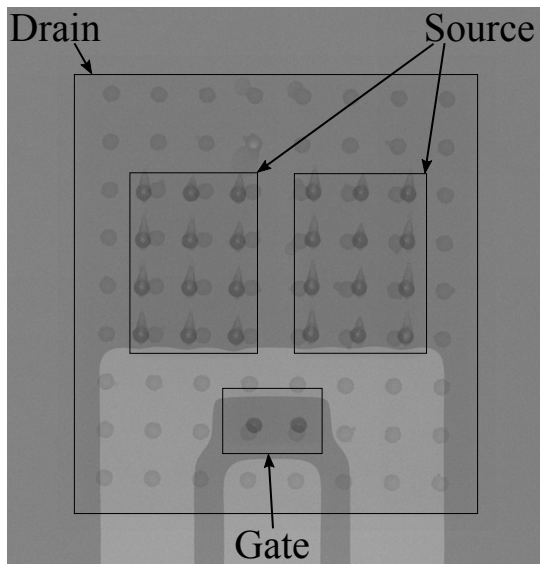
- ▶ good quality of microvias
 - ▶ No damage to dies
 - ▶ Uniform thickness
- ▶ Good alignment
 - ▶ Gate contact
 - ▶ $500 \times 800 \mu\text{m}^2$
- ▶ Good electrical perf.
 - ▶ Consistent $R_{\text{DS(on)}}$ (80 mΩ)
 - ▶ No change in V_{th}
 - ▶ Low leakage current (max 1.5 nA @ 1200 V)
 - ▶ Very good yield (97% on 44 dies)



Test Coupons – power devices

For SiC dies

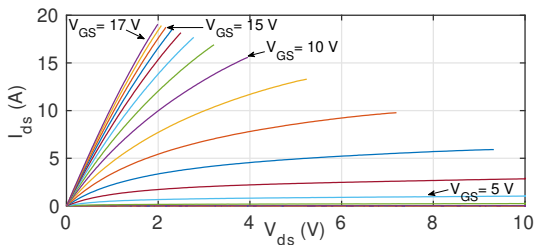
- ▶ good quality of microvias
 - ▶ No damage to dies
 - ▶ Uniform thickness
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 - ▶ Gate contact $500 \times 800 \mu\text{m}^2$
- ▶ Good electrical perf.
 - ▶ Consistent $R_{DS(on)}$ (80 m Ω)
 - ▶ No change in V_{GS}
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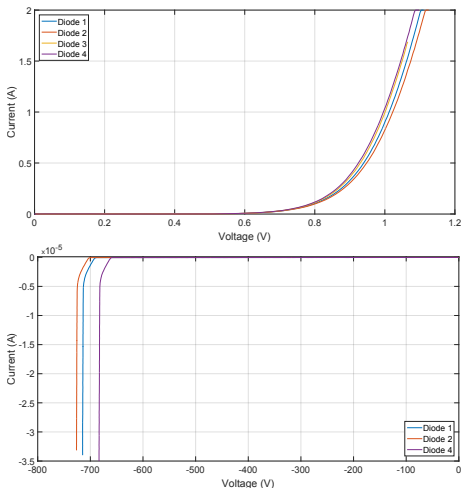
Test Coupons – power devices

For SiC dies

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 - ▶ No damage to dies
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- ▶ Good electrical perf.
 - ▶ Consistent R_{DSon} (80 m Ω)
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 - ▶ Low leakage current
(max 1.6 nA @ 1200 V)
 - ▶ Very good yield
(97% on 44 dies)



Test Coupons – 2

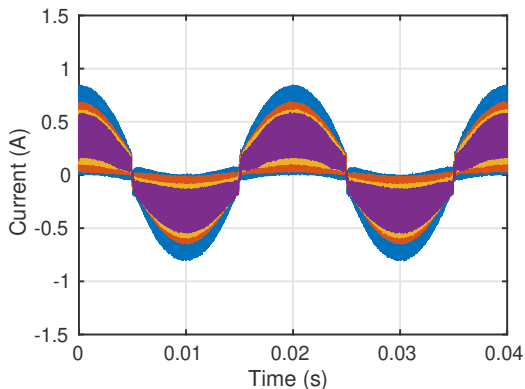


Example: 600 V diodes for bootstrap driver

For SMD components:

- ▶ Test on:
 - ▶ Ceramic capacitors (3.3 μ F, 25 V up to 330 nF, 500 V)
 - ▶ Packaged diodes (4.7 V Zener up to 600 V rectifier)
- ▶ Characterization:
 - ▶ No failure detected

Operation of the PFC converter



- ▶ 4 interleaved PFC cells (target power $4 \times 825 \text{ W} = 3.3 \text{ kW}$)
- ▶ Operation at reduced power because of losses in inductors
 - ▶ Current unbalance because of differences in inductor values

Introduction

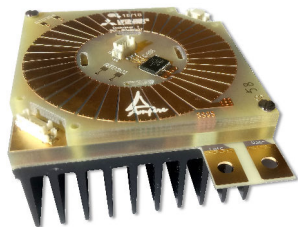
PCB Embedding Technology – A Review

Presentation of an embedded converter

Conclusions

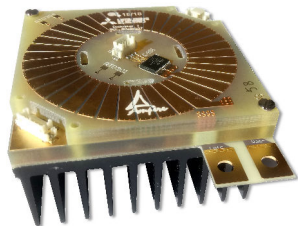
Conclusions – Exploiting the PCB Embedding

- ▶ “All-embedded”, interleaved PFC designed
 - ▶ includes dies, driver, inductors
 - ▶ Very good production yield
 - ▶ Only issue: embedded inductors
- ▶ Full power tests ongoing
 - ▶ Tested at 400 V with planar inductors
 - ▶ Frequency behavior of embedded inductor under investigation
- ▶ Next step: better use of embedding
 - ▶ Keep some components on the surface
 - ▶ Improve design for manufacturing
 - ▶ Improve design tools



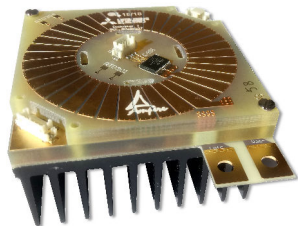
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Thank you for your attention.

cyril.buttay@insa-lyon.fr

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