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

PCB Embedding Technology – A Review

Presentation of an embedded converter

Conclusions
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Conclusions
Power electronics – Areas for Progress

◮ 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
Outline

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Most embedding effort on power dies:
- Most power density
- Fastest voltage/current transients
- Requires special finish on dies
  - 5-10 µm 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]
Embedding of Power Dies – 1

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Embedding of Power Dies – 2

Some alternative techniques

▸ Stud bumps and machining

▸ Foam interposer

▸ Mechanical drilling

Source: Hoene et al. [7]
Embedding of Power Dies – 2

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Source: Pascal et al. [8]
Embedding of Power Dies – 2

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Source: Hoene et al. [7]
Source: Pascal et al. [8]
Source: Sharma et al. [9]
Embedding of Formed Components – Inductors

Magnetic Layer

- Relies on magnetic/polymer film → Low $\mu_r$
- Limited to 10 – 100 W

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)
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)

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For power electronics
► Embedding of “large” capacitors (1 µF 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 (1–7 W m$^{-1}$ K$^{-1}$ vs 150 W m$^{-1}$ K$^{-1}$ for AlN)
- In theory better breakdown field ($\approx$ 50 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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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!
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Source: Randoll et al. [14]. Superimposition of reliability data for dies in PCB on Infineon’s results for standard power modules

Source: Perrin et al. [15]. Left: standard FR4, right: low-CTE. Magnetic core embedded, after 1000 thermal cycles (-50/200 °C)
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Bidirectional, 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

- Inductor PCB (4.5 mm-thick)
- Driver PCB (4.5 mm-thick)
- Dies PCB (0.7 mm-thick)
- Heatsink (25 mm-thick)
- TIM (0.2 mm-thick) x 3

3-PCB structure

- Magnetic component on top
- Heatsink on bottom (natural convection)
- Power chips close to heatsink
Manufacturing of the PCBs

Two board structures are used:

**Thin** PBC (1 mm)
for bare dies
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for SMD devices and inductors
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Converter Cell Assembly

- PFC inductor (Thick)
- TIM
- Gate driver (thick)
- TIM
- Power devices PCB (thin)
- 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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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
    - 500×800 µm²

- Good electrical perf.
  - Consistent $R_{DS_{on}}$ (80 mΩ)
  - No change in $V_{th}$
  - Low leakage current
    - (max 1.6 nA @ 1200 V)
  - Very good yield
    - (97% on 44 dies)
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For SMD components:

- Test on:
  - Ceramic capacitors (3.3 µF, 25 V up to 330 nF, 500 V)
  - Packaged diodes (4.7 V Zener up to 600 V rectifier)

- Characterization:
  - No failure detected

Example: 600 V diodes for bootstrap driver
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
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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.

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