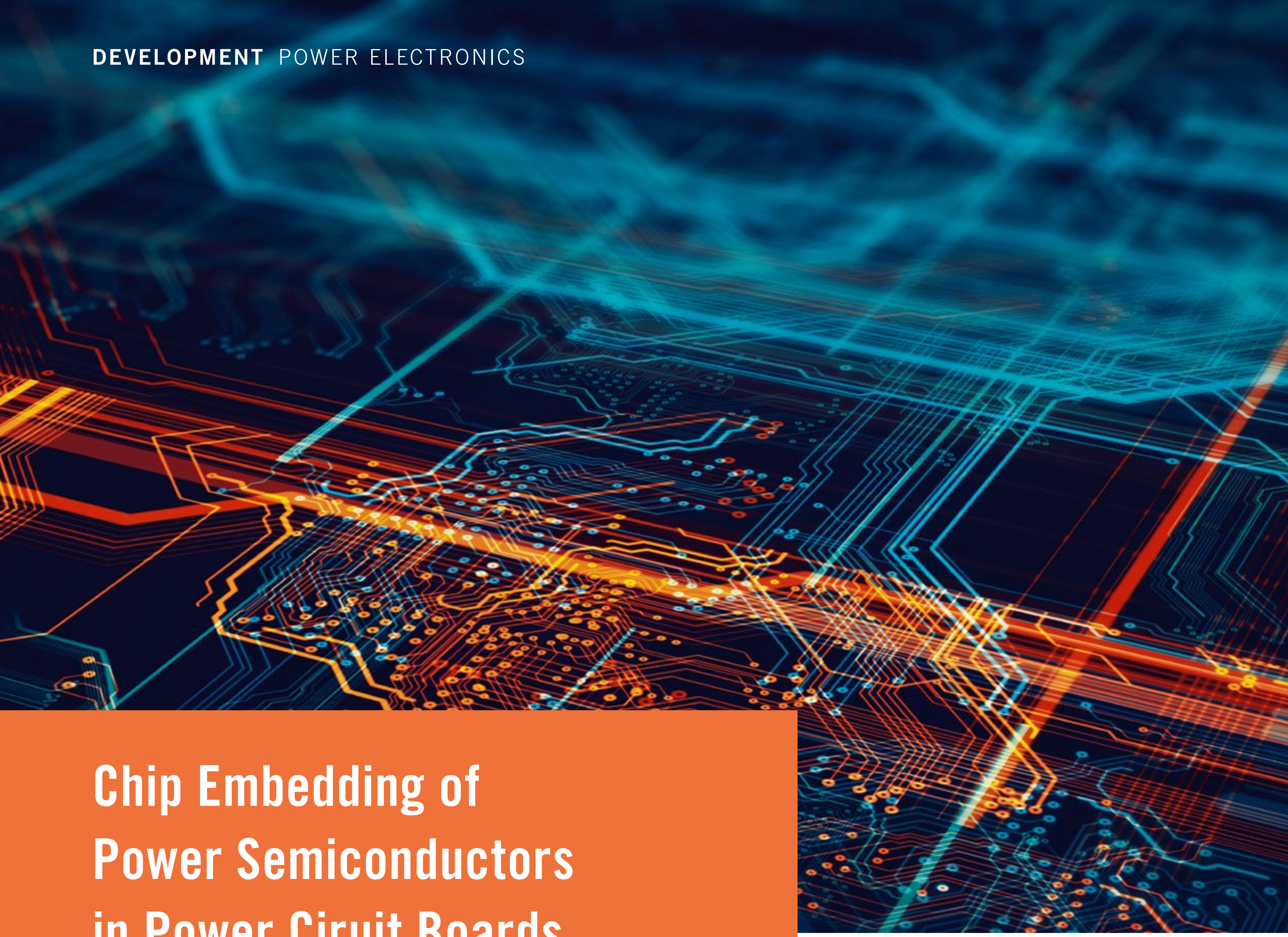

Chip Embedding of Power Semiconductors in Power Ciruit Boards

Modern power electronics for inverter controls, DC-DC converters and battery management are among the key technologies in electrified drives. The demands placed on applications in terms of power density, energy efficiency, reliability and system cost reduction are continuously increasing. The chip embedding of power semiconductors in power circuit boards, as presented by Infineon and Schweizer Electronic AG, meets these requirements. The power semiconductors are no longer soldered onto a printed circuit board as discretely packaged components, but embedded in a so-called system printed circuit board (power and logic) using chip embedding technology.

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REQUIREMENTS

The automotive industry faces the major challenge of continuously reducing average fleet emissions. From 2021, an EU-wide average CO_2 emissions limit value of 95 g/km will apply to all newly registered passenger cars. The EU then aims to cut CO_2 emissions from new vehicles by a further 30 % or even more between 2021 and 2030.

This will not be possible with internal combustion engines alone. As a result, the electrification of powertrains in hybrid and electric vehicles is on the rise. This in turn raises the demands placed on electrical power management systems in automobiles.

In the past, auxiliary equipment in combustion-engine only vehicles – such as power-assisted steering, oil and water pumps, radiator fans, air-conditioning compressors etc. – was increasingly electrified so that it only had to be switched on when needed. This has already led to large reductions in fuel consumption and the associated emissions in today's motor vehicles. In the future, vehicles with electrified powertrains – mild hybrids, plug-in hybrids and all-electric cars – will further amplify and support this trend.

Modern power electronics for inverter controls, DC-DC converters, battery management systems etc. are therefore a key technology in tomorrow's automobile electronics. At the same time, the application requirements with respect to power density, energy efficiency, reliability and system cost reduction are constantly increasing.

Chip embedding power Mosfets in Power Circuit Boards (PCBs) is an ideal way to meet such requirements, and hence represents a base technology for many future automotive applications. In this process, the power semiconductors (power Mosfets) are no longer soldered onto a circuit board in the conventional way. Instead, they are integrated or "embedded" into a so-called system PCB (power and logic) using chip embedding technology.

Infineon Technologies AG and Schweizer Electronic AG are working together to bring this base technology to market. Using a 48-V starter generator inverter for a mild hybrid vehicle as an example, they have highlighted the main advantages at system level of power electronics with chip embedding of power Mosfets as compared to conventional design solutions with PCB and discrete Mosfets, or complex design solutions with DCB ceramic modules and bare die chips. These include minimized wiring losses and parasitic inductances, improved switching performance, maximum cooling of the power electronics, higher system output or power density, a reduction in the PCB surface area and system volume, increased system reliability, and lower system costs.

PROCESS CHAIN AND STEPS IN CHIP EMBEDDING POWER MOSFETS

The manufacturing process for chip embedding power Mosfets requires close cooperation between the semiconductor industry and the PCB industry, specifically in the PCB embedding of power electronics, **FIGURE 1**.

It starts with so-called Cu lead frames. With cavities for the power Mosfets, they serve as carrier elements into which the power Mosfets are embedded flat. The Mosfet chips are specially adapted for chip embedding technology and also go through a Cu metallization stage to make them compatible with the subsequent PCB embedding process steps. Once they are placed in the Cu lead frames, the power Mosfets are tested before the process continues. The scope of testing corresponds 100 % to that of conventionally packaged discrete power Mosfets. This is a major quality and cost advantage over using bare dies on DCB substrates.

In the next step, the power Mosfets on Cu lead frames are combined to form a three-layered laminate structure, and then laminated in a special process to form a homogeneous bond. Conventional bond wires are replaced by a wiring level above the chip. Gate control is implemented via tracks, and the source pads have a flat design to achieve a low-ohmic electrical connection and a favourable thermal spreading of the dissipation loss. Contacting the upper side of the chip is done galvanically by way of copper-filled Cu vias, which were previously created in the dielectric layer using a laser. After structuring of the outer layers, the power PCB is complete.

The very flat and homogeneous design of this power PCB makes these power modules perfectly suited to subsequent embedding in a system PCB, which can be ideally realized as a combination with the logic PCB (microcontrollers, drivers etc.) without additional connecting elements. This system PCB with the integrated power Mosfets can then be installed directly and in a very compact way in the respective automotive application (for example 48-V starter generator), including heat sinks. As a result, the mechatronic system as a whole is greatly simplified and its manufacturing costs can be optimized, **FIGURE 2**.

A 48-V starter generator for mild hybrid vehicles is used as an example. Beginning with a power Mosfet on Cu lead frames, the result is an integrated system circuit board consisting of power

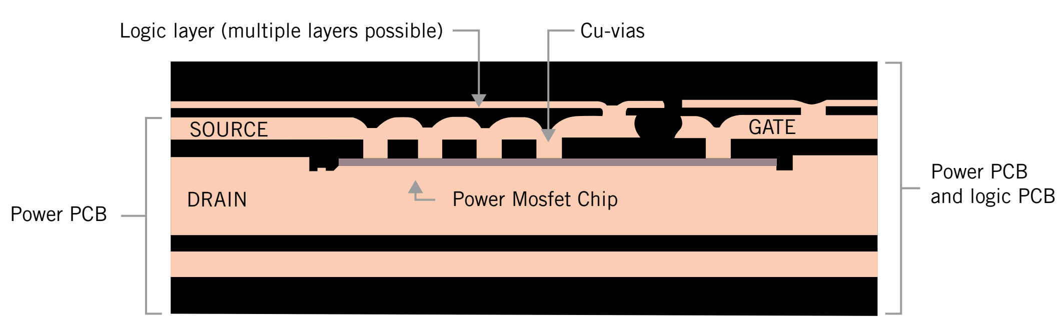
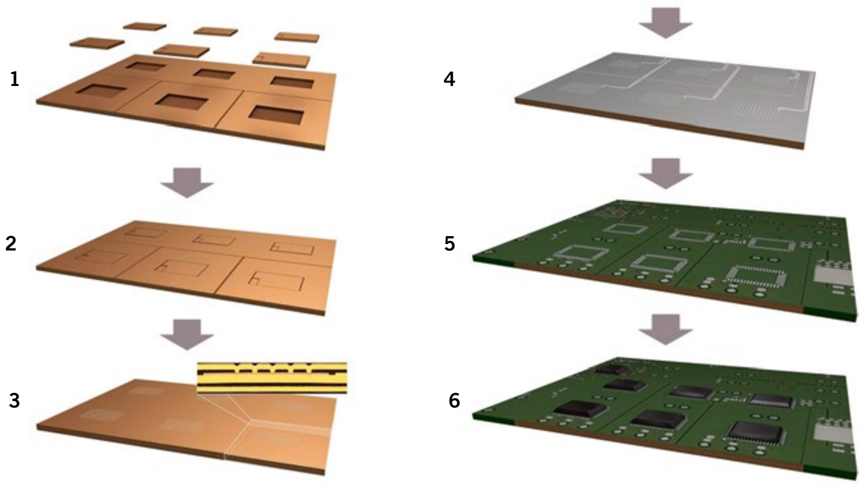


FIGURE 1 Micrograph: chip embedding technology with power Mosfets as a system circuit board (power and logic) (© Infineon)



1. Cu lead frames with cavities as carriers for power Mosfets with Cu metallization
2. Embedding and testing of power Mosfets in Cu lead frames
3. Cu lead frames are laminated to form a three-layer bond
4. Outer layers are structured and the power PCB is completed
5. Power PCB is laminated into the logic PCB and structured to produce a finished system circuit board (power and logic PCB)
6. System circuit board (power and logic PCB) fitted with microcontrollers, driver components etc. in the conventional way

FIGURE 2 Process steps for chip embedding power Mosfets in power PCBs (© Infineon)

PCB layers (underside) and logic PCB layers (top side), **FIGURE 3**. This system PCB with integrated power Mosfets can then be fitted very compactly, reliably and cost-efficiently onto the housing of the 48-V starter generator. In addition, the large surface area and direct connection of the system PCB maximizes the cooling capacity against the housing. This revolutionary approach of chip embedding power Mosfets in PCBs produces an integrated mechatronic system that achieves the best values in respect of power density, energy efficiency, reliability and system cost reduction, **FIGURE 4**.

The first target applications for chip embedding power Mosfets for production use in automobiles are medium to high-power applications (3 to 35 kW) – for example 48-V starter generators, 48-V auxiliaries, 12-V/48-V DC-DCs – where the system advantages described above bring particularly large benefits.

In partnership with leading Tier 1 suppliers in the automotive industry, 48-V starter generators with chip embedding have achieved significant increases in system performance and system efficiency, **FIGURE 5**.

BETTER ON-RESISTANCE (RON) IN POWER ELECTRONICS

With chip embedding, conventional bond wires are replaced by copper-filled vias, and practically the whole surface of the chip's upper side is contacted. The part of the package resistance associated with the bond wires is virtually eliminated with chip embedding. The exact value depends on the respective semiconductor technology generation, the voltage class, and the comparison semiconductor package.

BETTER THERMAL RESISTANCE

Excellent heat spreading in chip embedding significantly improves the system's overall Rth. Demonstrators even show advantages over DCB ceramic substrates.

Moreover, Zth – i.e. thermal impedance – is around 40 % lower than with conventional technologies owing to the solid Cu substrate under the chip. This is a particular benefit as a stabilizing element when intense heating occurs during brief current spikes.

The low power losses of the system as a whole, combined with better heat dissipation, result in lower heat development in the electronics compared to conventional design solutions.

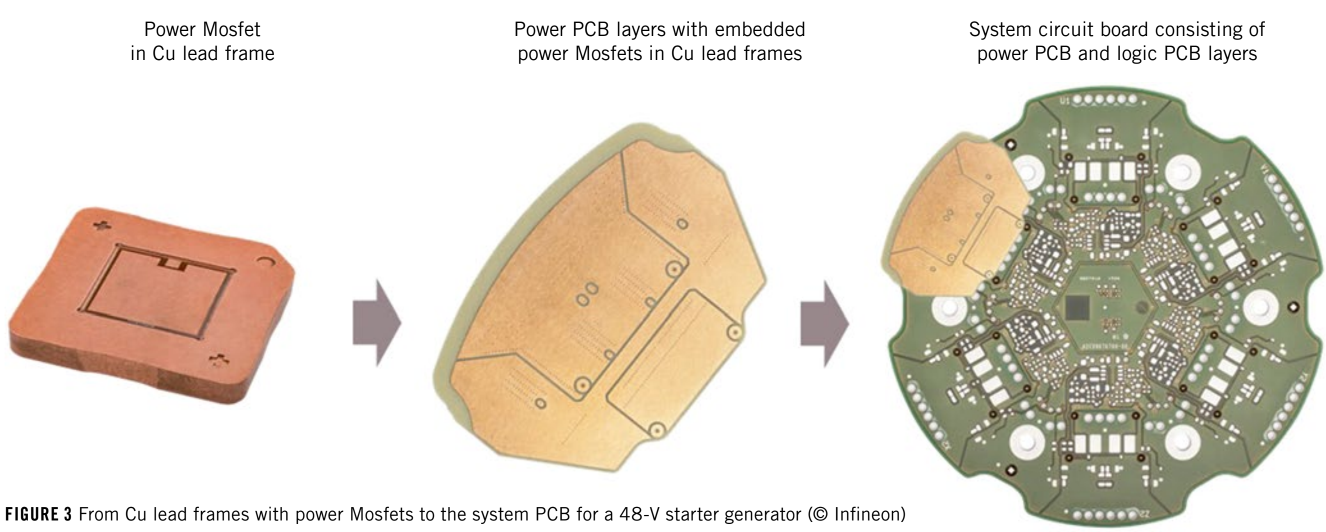


FIGURE 3 From Cu lead frames with power Mosfets to the system PCB for a 48-V starter generator (© Infineon)

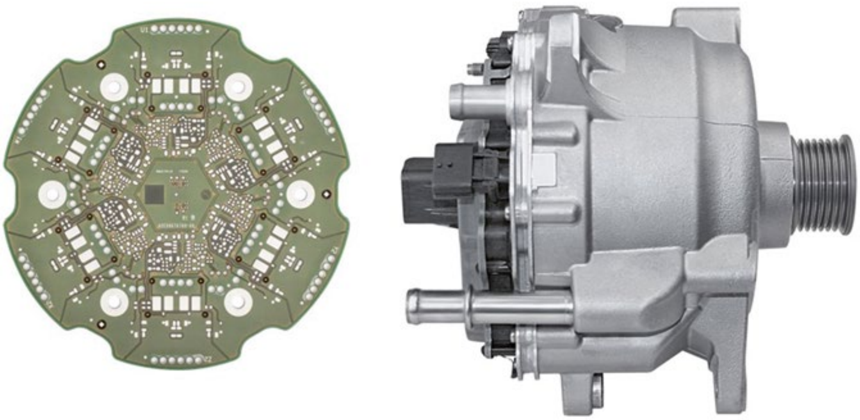


FIGURE 4 48-V starter generator with system PCB and integrated power Mosfets (© Infineon)

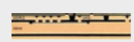
	Improvement of chip embedding	Discrete package  Toll and inlay	Chip embedding  Smart p^2 pack
Power stage	R_{DSON}	100 %	-30 %
	R_{TH}	100 %	-30 %
	Z_{TH}	100 %	-40 %
	L	100 %	-80 %
	Power capability	100 %	+35 %
System inter-connect	Loop-resistance	100 %	+++
	Compact design	100 %	+++
Quality	Reliability	100 %	+++

FIGURE 5 Performance comparison of chip embedding against discrete solutions for 48-V starter generators (© Infineon | Schweizer)

As a result, for example, the 48-V starter generator's activation times for power generation/recuperation or acceleration (boost) can be extended, where they are currently limited by thermal factors.

IMPROVED SWITCHING PERFORMANCE

Low switching inductance is achieved as a result of the almost flat connection between the top of the chip and the vias, and short distances between the intermediate circuit capacitors and power semiconductors. This enables quicker switching, which means that smaller passive components are required, leading to system cost and space savings.

In addition, systems with chip embedding show practically no voltage overshoots anymore during switch-on and switch-off. This means that, for example, 48-V systems today can be used with 80-V Mosfets, and no longer require a 100-V junction voltage. 80-V Mosfets have a 20 % lower R_{DSon}. A smaller R_{DSon} and lower switching losses result in lower overall power loss. This significantly reduces the maximum chip temperature for any given mode of operation. It is up to users whether to utilize this advantage for longer life, lower cooling system costs, or a reduction in the chip size.

MINIATURIZATION

Many systems for current and future applications have to keep getting smaller while simultaneously providing additional functionality. Chip embedding can save valuable space at the PCB solution stage.

GREATER RELIABILITY

Replacing bond wires or DCB ceramics substantially increases reliability. In thermal cycle tests with a temperature differential dT of 120K, designs were able to withstand more than 700,000 active cycles.

SYSTEM COST REDUCTION

With savings on plug connectors and cables, optimized cooling, reductions in required chip surface areas for power components, smaller passive components, fewer EMC issues, the insulation already in place and overall space savings, system cost savings are considerable.

Chip embedding power Mosfets rearranges the traditional supply chain of semiconductor manufacturers and PCB manufacturers to Tier 1. In other words, from now on Tier 1 will get a finished system circuit board processed to its requirements, comprising a power PCB with integrated power Mosfets on the underside plus a logic PCB layout on the top side. Tier1 is therefore spared the work, costs and risks involved in conventional power PCB assembly and installation, as well as all system costs for plug connectors or lead frames in conventional connection and mounting technology for power electronics.

In order to operate smoothly this newly organized supply chain requires clear responsibilities, defined risk transfers and test strategies on both sides – from the semiconductor industry and from the PCB industry. The smartphone industry has impressively demonstrated that semiconductor embedding in PCB substrates, including modified supply chains, works very well in high volumes.

Manufacturers like Infineon Technologies AG and Schweizer Electronic AG are already working together today to roll out this base technology for global series production use in the automobiles of tomorrow. Chip embedding technology for power Mosfets in PCBs is an ideal way to increase the efficiency of future automotive power electronics, and it will contribute to simpler, more environmentally friendly and higher-performance mobility in the future.