

# Substrate Free Molded Power Module

Dr.-Ing. Frank Osterwald, Danfoss Silicon Power GmbH, Germany  
Dipl. Ing. Mathias Kock, Danfoss Silicon Power GmbH, Germany  
Dipl. Ing. Tobias Nagel, Danfoss Silicon Power GmbH, Germany  
Dipl. Ing. Teoman Senyildiz, Danfoss Silicon Power GmbH, Germany  
Prof. Dr. Ronald Eisele University of Applied Sciences, Germany

## Abstract

A new kind of transfer molded package for low voltage semiconductor power modules is presented. It consists of a leadframe with power MOSFET's and other components soldered to it and it is housed using the transfer molding process. The main advantage of this new kind of package is that the leadframe is handled as a single part, even though different electrically isolated leadframe areas are provided in the package. The main features are discussed in this paper showing calculations as well as measurement results. The application of different thermal interface materials (TIM) is discussed and an outlook on isolation means for higher voltages is given.

## 1. Introduction

Volume and space limitations in automotive applications lead to more dense packages of electronic systems. If electric power is required, the choice of a power module instead of discrete packages is an option, because higher power density can be obtained. In the past the demand for power modules in 12V applications has been rapidly increasing. With respect to the power rating and to other application specific requirements the package technology will have to be carefully chosen [1]. Since robustness against vibrations and other harsh conditions is often required, the module package has to fulfill multiple challenging demands.

The package could be based on a bondable frame power module. However an extreme compact and robust solution for power semiconductor modules can be achieved, if chips soldered to DBC (Direct Bonded Copper) substrates are housed using the well known transfer molding process [2, 3, 4]. Obviously, a molded package will be mechanically robust, since the bond wires are stabilized against vibrations and other mechanical loads. It is known, that those assemblies can withstand a tremendous number of power cycles as well as reasonable numbers of temperature cycles, if the CTE of the mold compound is matched to the CTE of the DBC. This, however, requires customized mold compounds instead of off-the-shelf material.

If the electrical isolation capability of DBC's is not required e. g. in a 12V automotive application,

the disadvantages of a molded DBC solution become more and more evident: If there was no DBC, the mold compound would not have to be CTE-matched to the DBC and the solution would be more cost effective.

## 2. Substrate Free Mold Module

### 2.1. Basics

In this paper an alternative solution for molded low voltage power modules is presented. Based on leadframes instead of DBC substrates, the power modules get even more compact and simple. The excellent thermal properties of the copper lead to very good heat spreading and heat transfer. The electrical resistance of the leads can be tailored using various copper thicknesses. The mold compound can be an off-the-shelf material, since the same material combination is used in discrete components. Cost savings for a Substrate Free Mold Module (SFM) can be expected to be huge, since DBC's as well as CTE-matched mold compounds considerably contribute to the packaging cost.

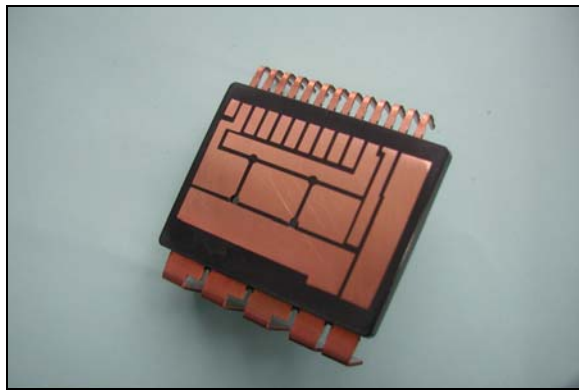
A major challenge for the substitution of the DBC by a leadframe is its design, requiring electrically isolated areas in the center of the module. A first approach to a design solution will lead to two, three or even more parts of the leadframe, which will have to be individually handled in the manu-

facturing processes, thus adding manufacturing complexity and cost to the modules.

In the presented solution, the leadframe consists of a single part, providing excellent manufacturability, since the individual leadframe areas will be punched open after the molding process. As a consequence, there is no limitation in the design of electrically isolated areas, although the leadframe is handable in one piece.

The leadframe does not require any additional metallization layers, as e. g. terminals or pins of bondable frame modules do. The SFM simply consists of the absolute minimum of ingredients to ensure performance fulfilling all application specific requirements.

The feasibility study will be rounded up by discussing the application of thermal interface materials providing sufficient electrical isolation, and thermal conductivity.



**Fig. 1.** View on the backside of the SFM

## 2.2. Layout and Design

The layout of an SFM consists of a structured single part leadframe. Since the leadframe will have to be transfer molded afterwards, the outline of the housing is defined by a so called dam bar. The dam bar is taking over different functions:

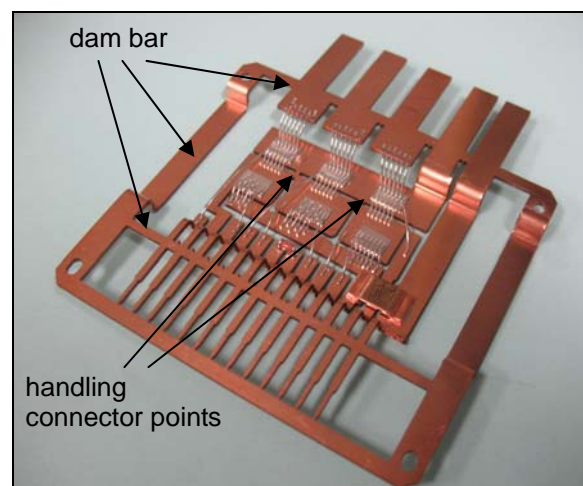
- To simplify the handling of the un-molded leadframe the dam bar keeps together the different copper parts.
- In the transfer moulding process it serves as a gasket (dam) between the upper and lower mold tool, making sure, that the mold compound is not squeezed out of the mold tool.

After the transfer molding process, the dam bar is removed by a punching step. It is no longer a

part of the layout. Instead, individual copper parts are left, taking over electrical and thermal functions, mainly.

Creating a leadframe layout for e. g. a six pack power module requires electrically isolated copper areas in the center of the leadframe. Obviously, it is not possible to connect those areas to the dam bar in order to open these connections later by cutting them off from the dam bar. Even if there were no layout constraints, this would be very space consuming.

The alternative for the SFM is to connect the electrically isolated areas with each other in a way that every single part is connected with its neighbours. To obtain electrical isolation, these connectors will have to be removed after molding in the same way as the dam bar has to be removed (see fig. 2).

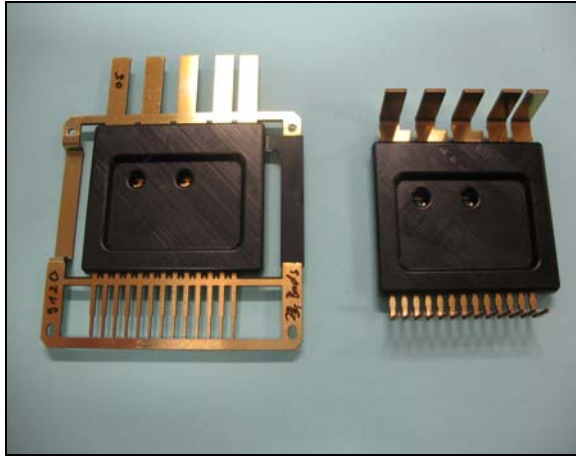


**Fig. 2.** Leadframe layout, dam bar and handling connector points

These “handling connector points” are an uncommon and very elegant layout specialty to overcome the necessity of having diverse individual metal parts, which would lead to comparably high manual handling cost during volume manufacturing.

The other leadframe elements are to be designed according to the application specific requirements.

The top view of an SFM shows the two openings in the mold body that provide access to the handling connector points (see fig. 3). The module on the left side still contains the dam bar and the handling connector points. The module on the right side is shown after removing the dam bar and the handling connector points. The leadframe terminals are already formed according to the design requirements (trim & form).



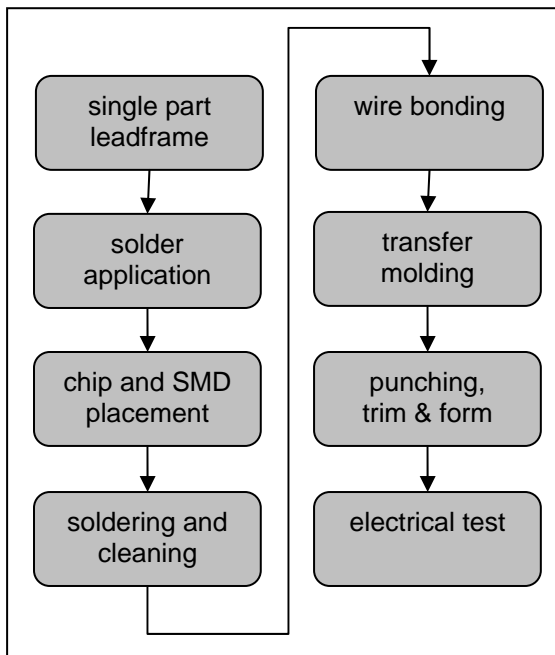
**Fig. 3.** Top view of an SFM before and after trim & form

- Die bonding is performed. Optionally, SMD pick & place might be added.
- Soldering is done in a vacuum soldering process.
- The fully equipped leadframe is cleaned from flux.
- Wire bonding is done, using Al large wire.
- The unit undergoes a transfer molding process.
- The following trim & form process is combined with the opening of the handling connector points.
- After the final electrical test, the module may be marked, optionally.

The result is a module with as few as possible ingredients, which can be manufactured applying well known processes and materials.

### 2.3. Process

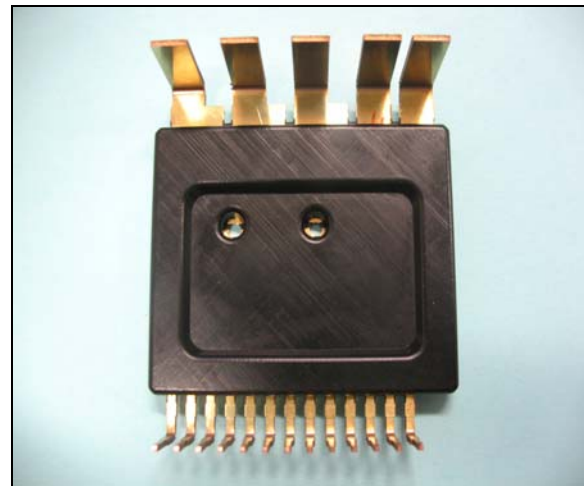
The manufacturing process flow is shown in fig. 4.



**Fig. 4.** Manufacturing process flow of SFM

The manufacturing process of an SFM can be summarized as follows:

- The manufacturing process flow is started based on a single part leadframe.
- Solder paste is applied to the die bonding and SMD positions. Solder paste application may be done by screen printing or dispensing.



**Fig. 5.** Top view of a fully processed SFM

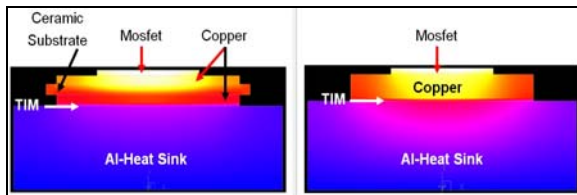
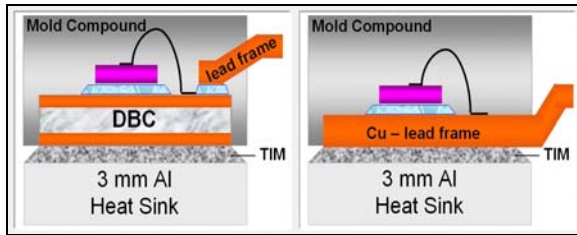
## 3. Calculations

### 3.1. Thermal Stack

Comparing the thermal stacks of a module with DBC (fig. 6a, left) and an SFM reveals reasonable advantages of the SFM. The principle of "reduce to the max" leads to a powerful thermal stack (fig. 6a, right), which is capable to directly spread the heat under the chips and ideally hand it over to the heatsink via the thermal interface material (TIM). The very good heat spreading properties of the copper leadframe reduce the thermal resistance of the TIM layer (see fig. 6b), because of a wider area of heat transfer. Thus the temperature of the power semiconductors is

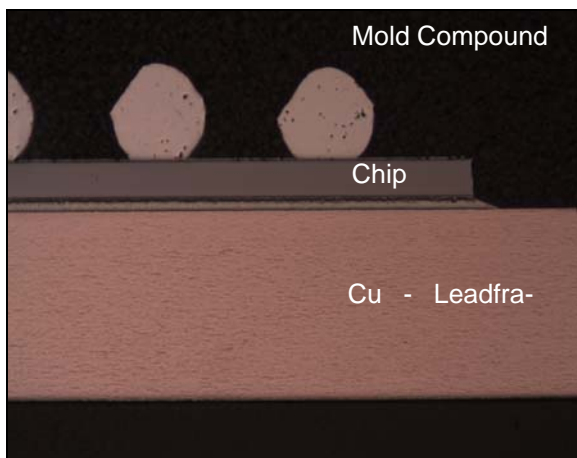
kept as low as possible. The thickness and the layout of the copper leadframes can be modified in order to tailor the thermal properties of the SFM.

Even in the case of a DBC based module with a base plate, the heat spreading effect of substrate and base plate is less effective, so the thermal resistance of the overall thermal stack is worse compared to the SFM. Calculation results are shown in fig. 8.



**Fig. 6.** a) Illustration of the thermal stack and b) Illustration of heat spreading effect in a DBC based module (left) and an SFM (right)

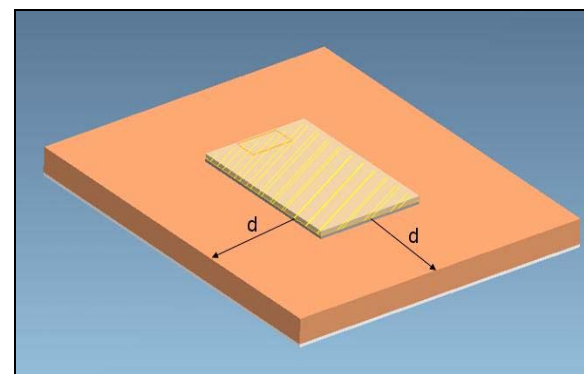
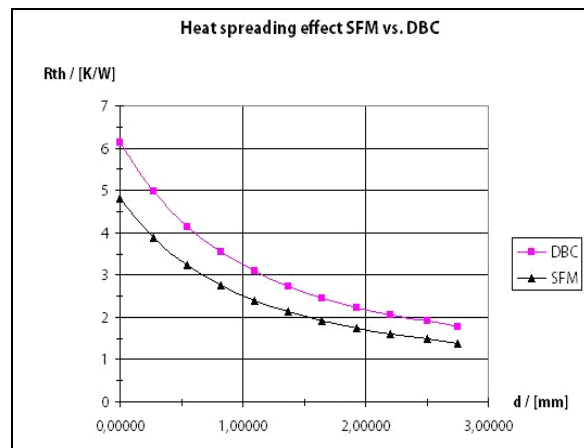
The following cross section (see fig. 7) shows the Cu leadframe with a power semiconductor soldered to it. Al-wire bonds are bonded to the front metallization of the chip. Leadframe surface, chip and wire bonds are surrounded by mold compound. The TIM layer and the heatsink are not shown.



**Fig. 7.** Cross section of SFM module

In fig. 8b it is depicted how the heat spreading area around the power semiconductor is defined by the parameter “d”. The thickness of the copper leadframe in this calculation is 800µm. The DBC layer structure is assumed to be 300µm Cu, 380µm Al<sub>2</sub>O<sub>3</sub> and 300µm Cu. The DBC is soldered to a 2.5mm thick Cu base plate.

If  $d = 0$ , the thermal resistance from junction to heatsink ( $R_{th}$ ) is defined by the thermal path through either pure copper or through DBC and base plate with a heat spreading angle of 0 degree. The advantage of the good thermal properties of pure copper leads to an  $R_{th}$  of 4.8 K/W for SFM and of 6.1 K/W for DBC and base plate. For bigger heat spreading area (growing “d”) the  $R_{th}$  is rapidly decreasing, as expected.  $R_{th}$  is dropping to about 1.4 K/W for SFM and 1.8 K/W for DBC and base plate, respectively. Note that the results are also subject to other boundary conditions like thermal materials and heatsink.



**Fig. 8.** a) calculated  $R_{th}$  comparison of DBC and base plate module vs. SFM  
b) calculation parameter: heat spreading distance “d” around power semiconductor

To obtain the same good  $R_{th}$  with a DBC as with an SFM, the area around the power semiconductor

tor on a DBC must be about 4x larger ( $d_{DBC} \sim 2 \times d_{SFM}$ ). Thus, the power density in an SFM can be much higher.

### 3.2. Module resistance

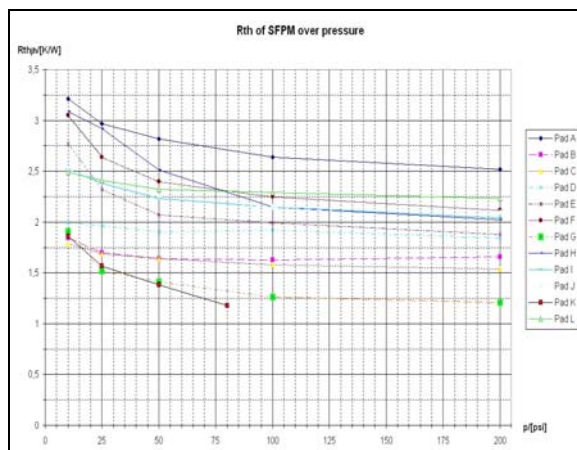
The electrical resistance of an SFM can be minimized in comparison to a bondable frame module. The reason is that one level of wire bonded contacts can be eliminated. This is because of copper leads are directly leading out of the mold package, instead of using terminals with wire bond contacts to the DBC.

Measurements of the electrical resistance of comparable designs, implemented in an SFM and a bondable frame module revealed that about 10 to 15% decrease of ohmic resistance can be achieved with an SFM.

Furthermore, the current carrying capability of an 800 $\mu$ m thick copper leadframe is significantly higher than of 300 $\mu$ m Cu tracks on a DBC. This may also lead to less space consuming layouts.

## 4. Verification of the Thermal Properties of SFM

Measurements of the thermal properties of different setups with SFM and various thermal pads have been carried out. The result is that the calculation (see fig. 8) could be confirmed for large "d".



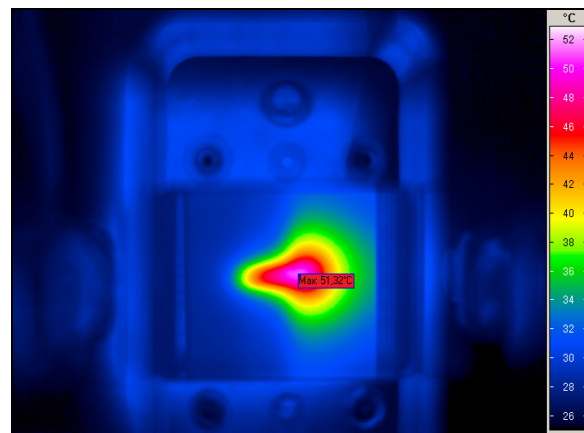
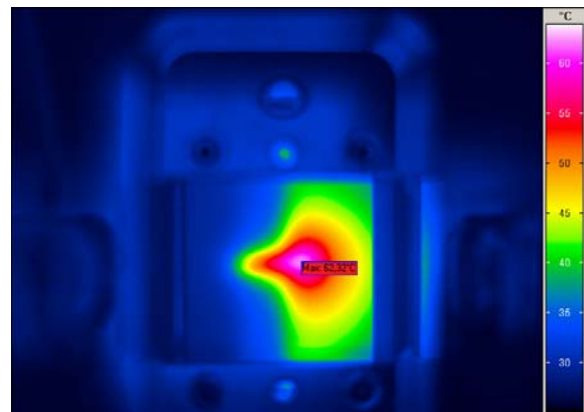
**Fig. 9.**  $R_{th}$  comparison with different thermal pads dependent on contact pressure

Out of the calculation and further measurements, it can be concluded, that if "d" is in the order of the thickness of the copper leadframe, the heat spreading effect should be near the optimum.

Much better values might not be expected, if "d" is larger. Of course this rule of thumb is depending on the properties of the TIM and the heatsink, as our measurements have shown (see fig. 9).

In fig. 9  $R_{th}$  measurements with different thermal pads are shown. The contact pressure is varied from 10 to 200 psi, according to data sheet recommendations. Most of the materials need about 75 psi to provide optimum thermal contact.

These investigations are rounded up by thermal imaging with an IR camera. Fig. 10 shows a power semiconductor under load, placed on the 0.8mm thick Cu leadframe of the SFM. The IR images have been taken through the mold body.



**Fig. 10.** IR measurements showing the temperature distribution with:  
a) low contact pressure and  
b) optimal contact pressure

Fig. 10a shows an SFM mounted to the heat-sink with low contact pressure, leading to insufficient thermal contact and heat conduction. The power loss of the semiconductor heats up the surrounding copper area. Fig. 10b demonstrates very good thermal properties of an SFM mounted to

the heatsink with ideal contact pressure. Direct heat conduction to the heatsink can be observed.

Besides the thermal properties of the TIM, the electrical isolation has to be considered. Both requirements can be fulfilled by using a thermal pad between heatsink and SFM. Another advantage of thermal pads is the easy handling.

Using thermal grease as TIM requires so called "Stand-Offs" to provide sufficient electrical isolation (for 12V applications). Stand-Offs can be designed to be integral part of the mold body. Thus, they are not leading to additional cost.

## 5. Conclusions

A new kind of substrate free molded package for power semiconductor modules has been introduced and its features and performance have been discussed. The solution is suitable for low voltages like in e. g. 12V automotive applications.

The manufacturing process steps have been explained and their simplicity has been highlighted. The "reduce to the max" principle and the combination with a smart single part leadframe setup lead to an optimized solution.

The thermal calculations and measurements revealed very good thermal and electrical properties of the package compared to other common solutions.

## 6. Outlook

The current design of the SFM is suited for low voltages, like in automotive 12 V applications.

High voltage solutions e. g. for automotive traction applications required better electrical isolation, like a ceramic layer can provide.

A sprayed ceramic layer under the SFM can be used to obtain good high voltage isolation properties. The spray coating process will cover the blank copper surfaces of the leadframe as well as the mold compound surface between the copper areas.

Fig. 11 shows a cross section of an SFM with a sprayed ceramic layer with a thickness of 150 $\mu$ m.

The thermal and electrical limits are currently under investigation. Early results are promising

to use the ceramic insulation layer up to more than 1000V.

Insulation tests before and after 500 temperature cycles provide evidence of the stability and integrity of the sprayed ceramic layer.

Currently, further reliability tests with SFM are carried out.

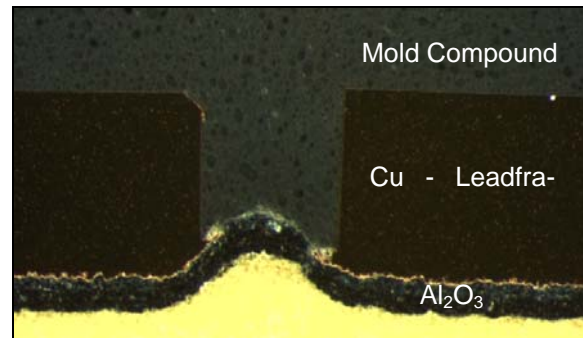


Fig. 11. Cross section of SFM module with sprayed ceramic layer

## 7. Literature

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