

Motivation for pressure-assisted metallic sintering in Power Electronics

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Abstract (Preliminary Summary)

This technical paper explores the compelling motivations behind the alternative of pressure-assisted metallic sintering in the realm of power electronics. As the demand for more efficient and reliable Power Modules grows, this approach proves to be a high-quality solution, especially for silicon carbide SiC applications. The paper delves into the underlying principles, benefits, and potential applications of pressure-assisted metallic sintering and why it is a key technology to unleash the potential of SiC devices. The paper aims to provide a comprehensive understanding of the motivations and practical implications of pressure-assisted metallic sintering in the context of power electronics. By embracing this innovative technique, we pave the way for more robust, efficient, and reliable power electronic modules.

Introduction

When performing sintering, the chip is bonded to a substrate using sintering powder with the aid of heat and pressure. Typically, copper or silver sintering powders are used. During the actual sintering process, the metal particles are bonded together by diffusion processes. The advantage over soldering processes is an outstanding thermal and electrical conductivity, longer service life due to the high thermomechanical stability. These properties are particularly important in electromobility and power electronics.

Costs vs. performance

For Power Modules, the packaging technology is key to lower costs and increase performance of power semiconductors (such as IGBTs, SiC MOSFETs, GaN HEMTs). A typical value ratio of power per Euro you will achieve with a certain technology mix.

When selecting a packaging technology four key aspects must be considered:

1. Costs (material + assembly + yield)
2. Thermal performance (maximum device temperature, cooling effort, energy consumption of water pump to lower EV range)
3. Thermo-mechanical properties (lifetime, reliability)
4. Electrical properties (Operation temperature, integration density)

Costs

In terms of costs, this equation is key:

$$\text{Chip costs} \propto I \cdot \frac{R_{th}^{(A)}}{\Delta T}$$

I : required current

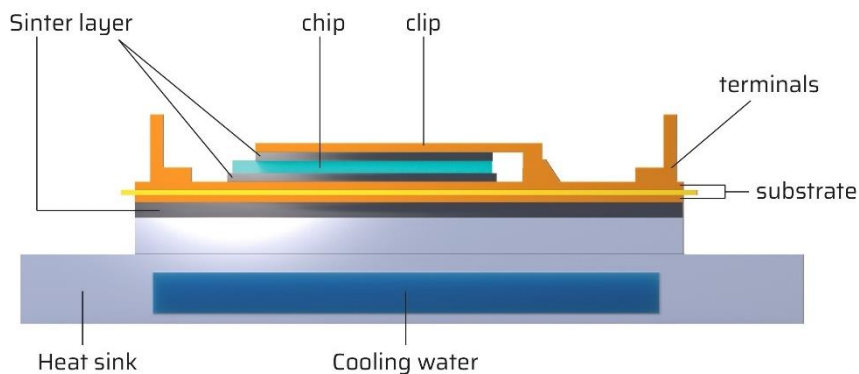
$R_{th}^{(A)}$: Thermal resistance of the packaging technology,
chip area related

ΔT : allowed temperature rise of the chip

The costs can be reduced by:

1. Lowering thermal resistance
2. Increasing maximum temperature / reliability
3. Having more current/power per chip (using less chips to convert a certain current)

However, the additional expenditure required for substrate and connection technologies should not overcompensate the chip cost savings!



Pic 1. Schematic assembly of a power module sintered onto a heat sink

Considering this formula, pressure sintering of power semiconductors and pressure sintering of substrates on baseplates / heat sinks offers some benefit to the application.

- Outstanding reliability: 20x better power cycling capability compared to SAC solder
 - Higher yield strength (Higher dT)
 - Lower CTE mismatch (Higher dT)
 - Lower creep fatigue (Higher dT)
- Lower thermal resistance compared to solder
 - Higher thermal conductivity of silver
 - Thinner bond line thickness
- Higher application temperature of semiconductors possible
 - Much higher melting point: 961°C instead of 220°C (SAC solder) (Higher dT)

Thermal performance

The thermal performance of sintering and soldering processes differs in their applications and outcomes. In summary, while both processes involve heat, sintering is more about forming a solid structure from powder particles, potentially yielding materials with good thermal properties. Soldering is a joining process in electronics, and its thermal performance is influenced by the solder alloy and joint quality.

Sintering:

Sintering involves heating the material below its melting point, result in materials with good thermal conductivity, as the particles fuse to form a solid structure.

Soldering:

Soldering is the process of joining two or more metals (such Ag, Sn, Bi, Cu, Flux...) using a lower melting point metal alloy. Soldered joints may not provide as high thermal conductivity as sintered materials. The thermal performance depends on the solder alloy used and the quality of the joint.

Thermal resistance can be calculated by this formula. A is the area of the dies and will be constant.

$$R_{th} = \frac{T_2 - T_1}{P} = \frac{d}{\lambda_{th}A}$$

- Thickness d
 - Solder die attach: 100...130µm
 - Sinter layer: 20...40µm ☞ Factor of 3 compared to soldering
- Thermal conductivity λ_{th}
 - SnAg3 solder: 30 W/mK
 - Pressure sintered Ag: 240 W/mK ☞ Factor of 8 compared to soldering

In conclusion, the outstanding thermal properties of silver or copper sintering material compared to solder alloys, lower the thermal properties significantly. Additionally, the sinter layer is roughly three times thinner than solder layers. In combination with the higher application temperature and increased peak temperatures, the better thermal performance helps to increase the current per die.

Thermo-mechanical performance

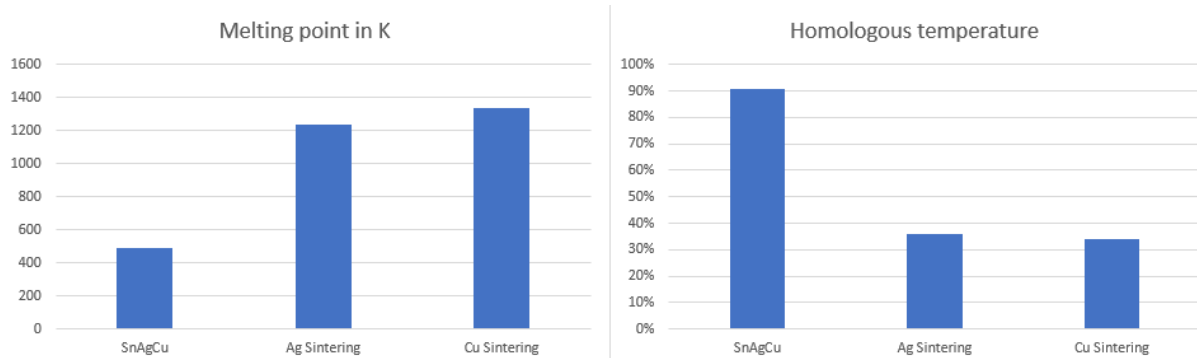
The advantage of Ag or Cu sintering is its ability to achieve an even distribution of silver particles. This creates a homogeneous, metallurgical connection between the materials that offers improved mechanical strength and stability. In comparison, soldering can result in uneven joints that may be more susceptible to mechanical stress. When sintering, higher temperatures are avoided than when soft soldering, which leads to lower thermal stress on the materials. This is particularly important to protect sensitive semiconductor components from damage caused by extreme temperatures. Sintering allows a controlled shrinkage during the bonding process. This controlled shrinkage helps ensure the thermal and mechanical properties of the components remain consistent and predictable.

The creep resistance and yield strength of Ag sintering is much higher compared to soft solders. In this context, homologous temperatures come into play as well. The homologous temperature is the aspect ratio of application temperature to melting point in Kelvin. A rule of thumb states, that metals that are used at homologous temperature higher than 30%, tend to creep fatigue.

- Yield strength SAC solder: 30 MPa
- Yield strength sintered Ag: 120 MPa

Homologous temperature at 175°C application temperature:

	SnAgCu	Ag Sintering	Cu Sintering
Homologous temperature	91%	36%	34%
Melting point in K	493	1234	1334



Both properties result in a much higher thermos-mechanical stress capability, such 20x higher active power cycling lifetime. Especially for SiC devices, this thermos-mechanical properties are needed, as SiC shows a much higher stress onto the packaging materials due to the better thermal conductivity and higher elastic modulus compared to Si semiconductors. To increase the current per die as well the max. temperature on the die, the thermomechanical performance of Ag and Cu sintering material helps to economically use SiC devices.

Electrical performance

Same as the thermal conductivity, the electrical conductivity of sintered silver or sintered copper is 3 – 4x higher compared to soft solders. Sintering allows materials to be directly connected at a microscopic level, resulting in lower electrical resistances. In comparison, soldered connections can have higher resistances because the solder is present as additional material in the connection. It allows a controlled microstructure in the connections, resulting in a homogeneous distribution of materials and uniform electrical performance. This is particularly important for power electronic applications. Therefore, an outstanding electrical performance is given and needed to make use of fast switching SiC devices.

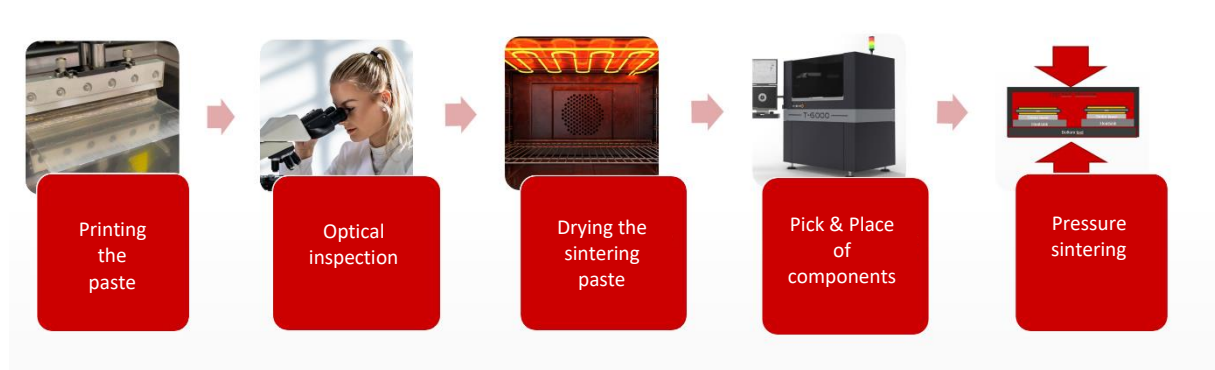
Key for pressure-ag sintering

Due to the 10...20x higher material cost of Ag sintering material compared to soft solder, and the higher costs of SiC to Si semiconductors, the production yield is key for sintering.

Besides the sintering process itself, the pre-processes are important. All issues and variations occurring during printing and place or dispensing and placing of components will stay in the sinter layer due to the missing liquid phase. During the sintering process itself, the silver or copper will not melt but just sinter to reduce surface energy. The liquid phase of soldering can sometime be beneficial for self-alignment and compensation of tolerances. This is not the case with sintering. Therefore, the pre-processes are extremely important.

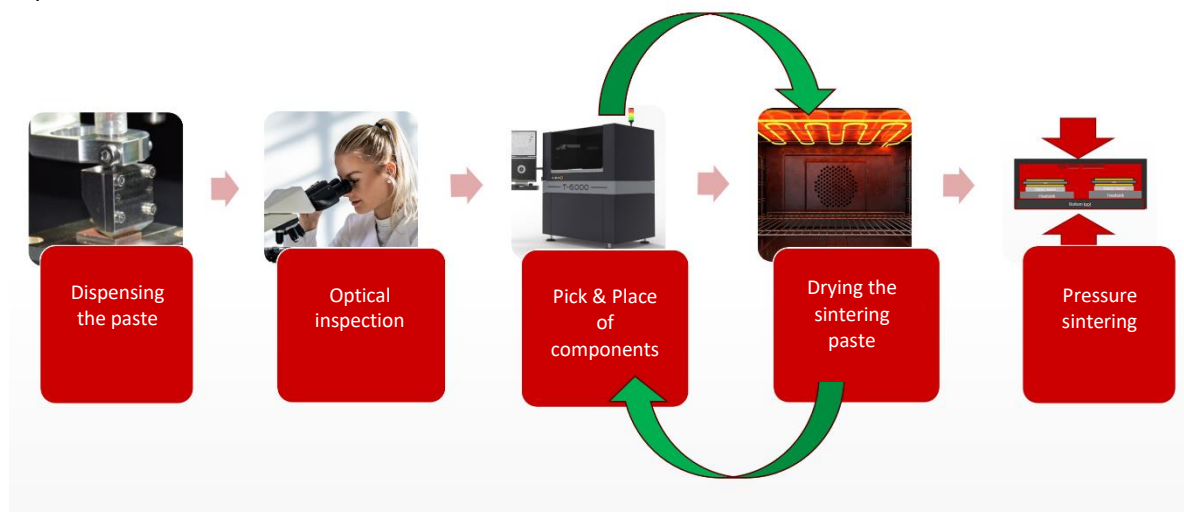
A typical process overview is shown in the following figure.

Dry process:



The “dry” process is the most common process for DIE Attach. In this case the paste is printed, inspected and dried. After that the pick & place of the dies will be performed. Finally, the parts will be sintered.

In contrast, the wet process switches the pick & place and drying process. The components will be placed into the wet paste and the drying will be done with components on it. Finally, the parts will be sintered as with the dry-route.



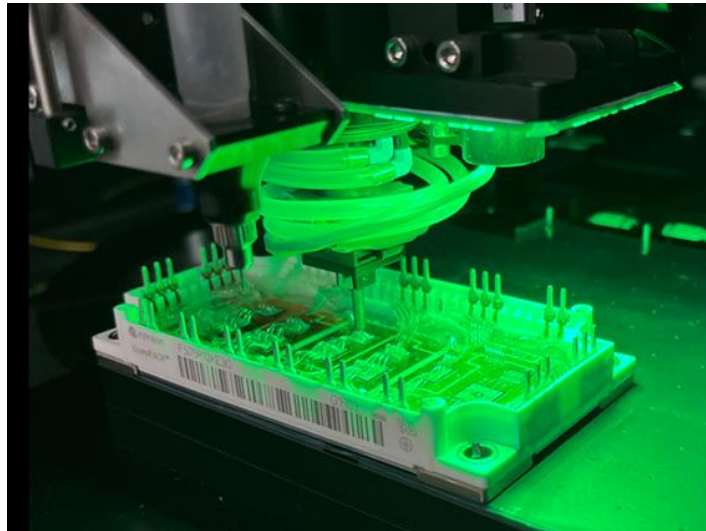
One major process that is always relevant is the pick & placement of components. For sintered DIE-Attach applications, Hot-DIE-Tacking will be done to avoid any movement of dies during travel from pick & place machine into the sintering press.

Hot pick & placement

For standard sintering processes, the sintering paste will be pre-dried and not be sticky anymore. If a DIE is placed on top of the dried paste, it will likely move during the travel from pick & place to the sintering machine and especially when a protection foil such as Teflon is placed on top of the DIE to protect it.

The Hot-DIE-Tacking requires a placing pressure of up to 1 MPa. With a 15 x 15mm DIE 22 kg of placing force are necessary. Tresky is currently the only supplier that can apply forces up to 35 kg.

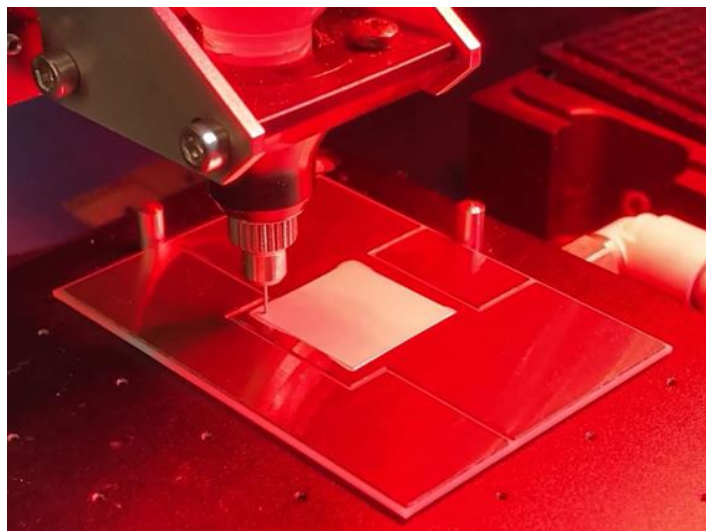
Additionally, to the force, the substrate and the DIE must be pre-heated to approx. 130°C. Tresky heated bond heat can apply temperatures up to 400°C onto the nozzle and the hotplate can apply temperature of up to 500°C onto the substrate.



Pic 2. Sintering processes for E-mobility Solutions and Power Electronics

Pick & place with tacking agent

The Hot-pick and place is a common way to place dies for sintering. Unfortunately, the heating of the substrate might cause oxidation to bare Cu substrates. Therefore, placing the DIE together with a tacking agent at room temperature is common. The tacking agent provides some stickiness until the substrates is pre-heated in the sinter press. At approx. 150°C the tacking agent evaporates without any residues. Tresky offers different ways to dispense, spray or jet the tacking agent either on top or bottom side of substrates and dies.



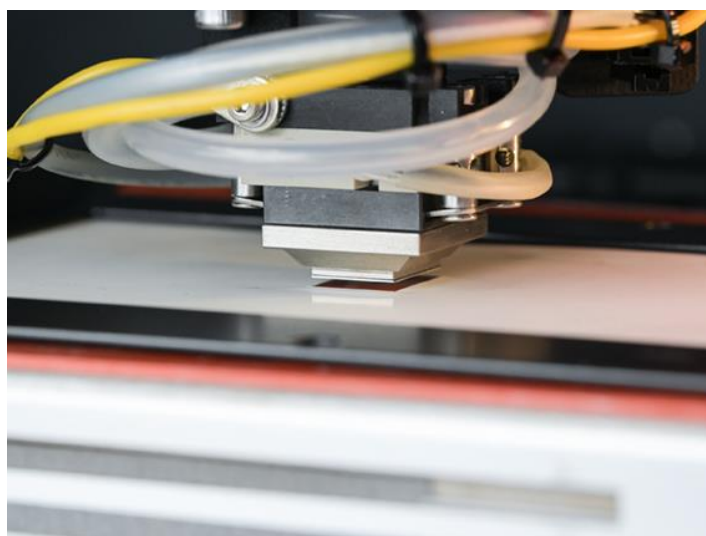
Pic 3. Dispensing of tacking agent

Sintering with the DTF Process

Another alternative to printing and drying, is to use an already pre-dried sinter film. This sinter film will be applied to the semiconductor dies during pick & place. This process is named DIE-Transfer-Film process DTF. A thin silver sinter layer, a so-called transfer film, is first picked up with the DIE. The nozzle of the pick & place machine is pre-heated, while the film remains at room temperature. The picked chip is pressed into the film with a defined force and temperature. When the component is subsequently lifted, a uniformly thick, defined layer is released from the film. Due to the good adhesion the layer remains adhered to the underside of the chip. The chip coated in this way is then placed on the substrate process with similar hot-placing parameters. Pre-heated nozzles, substrates and the possibility to apply force onto the die in the range of up to 1 MPa is key for this process. Tresky provides all necessary tools and functions to apply DTF films.



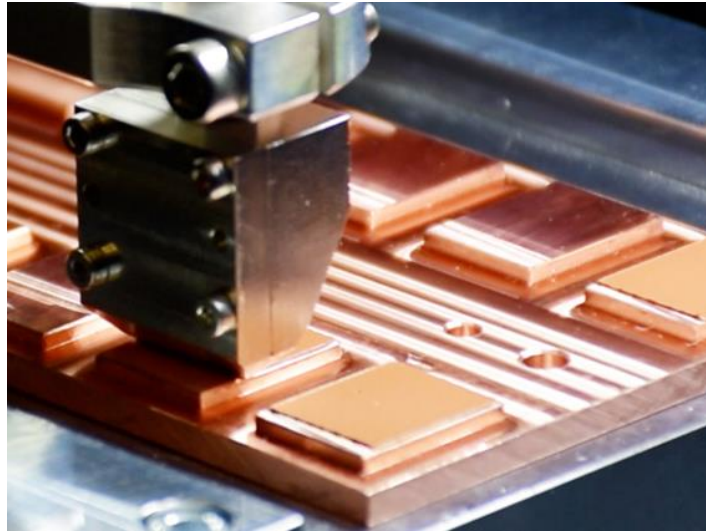
Pic 4. DIE Bonder in DTF-configuration



Pic 5. Tresky's sinter bonders enable the use of DTF films

Sintering with the wet-process

For sintering with the wet-process, instead of printing the paste is often being dispensed. This can be done with a so called slot nozzle and flat dispense process. Tresky provides this process route as well. The key actions in this case is to measure the heights of the substrates or heatsinks and to measure the height of the wet sinter paste before placing. This can be done by the Tresky machine and an even and precisely controlled bond line can be achieved.



Pic 6. Dispensing of copper sinter past with SQ-Nozzle

Conclusion

The electrical performance of SiC power modules that are sintered with silver (Ag) or copper (Cu) offers several benefits. Firstly, Ag or Cu sintering allows for lower electrical resistance compared to traditional soldering methods. This leads to reduced power losses and improved efficiency in power transmission.

Secondly, Ag or Cu sintering provides excellent thermal conductivity, which helps in efficient heat dissipation. This is particularly important in power modules, as high temperatures can negatively impact their performance and reliability. The improved thermal management offered by Ag or Cu sintering helps to keep the module cool and ensures stable operation.

Additionally, Ag or Cu sintering offers better reliability and durability compared to soldering. The sintered joints have higher mechanical strength and are less prone to fatigue and failure under thermal cycling or mechanical stress. This enhances the overall lifespan and reliability of the SiC power module.

In summary, the electrical performance of Ag or Cu sintered SiC power modules provides lower electrical resistance, improved thermal conductivity, and enhanced reliability, making them a preferred choice for high-performance power applications.

By Tresky GmbH in cooperation with Bond Pulse GmbH



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