Low temperature sinter technology
Die attachment for power electronic applications

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Abstract:
New fields of high power inverter systems such like windmills, hybrid cars, hybrid trucks, and off road vehicles require new ways of power electronics integration and packaging. The requirements in size, weight, reliability, durability, ambient temperature, and environment are driving the operation temperatures of power electronics beyond the limits of today's industrial applications. In industrial power modules solder and bond wires are still the standard joining technologies of power dies. These technologies are reaching their reliability limits if die temperatures are pushed above 135℃.
In this paper the authors will discuss how the environmental conditions of applications drive silicon power device selection and packaging technologies. Extreme cooling conditions and ultra high power densities require a package design that needs to work on the thermal and electrical limits of the components without making any compromise in reliability and durability. The low temperature sinter technology can extend the power and thermal cycling capabilities of modern power modules to the values that are required for industrial and automotive applications. Next to the reliability data also a proposal for a high volume manufacturing process of the low temperature sinter technology of multi chip modules will be presented.

1. Introduction

Traditional soldered power electronics packages and modules, which are limited to operating temperatures below 150℃, cannot meet the requirement of next generation of industrial and automotive electric drive systems. Currently, solder is the material of choice for attachment and interconnection of semiconductor die to the substrates. Solder alloys are unable to withstand the relatively high operating temperature of the devices because of their low melting points of 220℃. Silver is a desirable material for high temperature packaging application because it is substantially cheaper than gold and palladium but is not susceptible to the oxidation problems like other metals. It has significantly better electrical and thermal conductivity and is more reliable than solder during temperature cycling. Its melting point is more than sufficient to withstand the high operating temperature of the devices. So far a major drawback is that silver paste normally must be processed or sintered at higher temperature (>600℃), which is much higher than typical solder reflow. General investigations about the use of pressure and temperature to sintering the silver powder compounds for attaching power semiconductor devices have been performed by independent organizations. The studies confirmed that pressure assisted low temperature diffusion sintering of silver pastes is a feasible alternative die attach process to solder. [1,2,3,4]

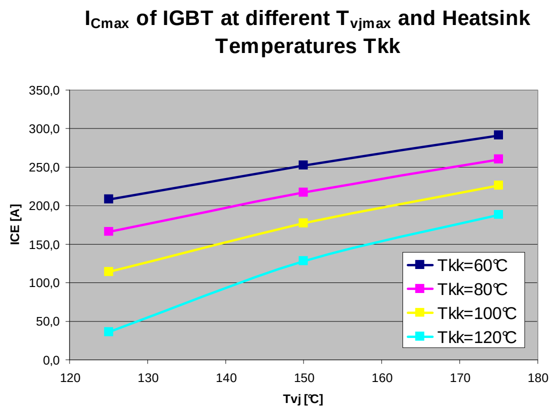
1.1 Material properties:

In figure 1 the advantage of Ag sinter layers are shown. The melting point of 961℃ is outstanding for the reliability discussion. The thermal behavior of 250 W/mK with the opportunity of a CTE value of 19 make the sintered Ag layer a good choice to combine power devices Chips to DBC Substrates.[1]

			Ag pure silver	Ag sinterlayer	SnAg solderlayer	factor
1	Liquidus	℃	961	961	221	4
2	Electric conductivity	MS/m	68	41	7,8	5
3	Thermal conductivity	W/mK	429	250	70	4
4	Density	gr / cm³	10,5	8,5	8,4	1
5	CTE	µm / mK	19,3	19	28	1
6	Tensil strength	Mpa	139	55	30	2

Fig . 1 material properties

In automotive and industrial applications e.g. some parts of the electronics will move under the hood, the cooling water temperature is specified to 105℃ (120℃ with derating), in order to keep the footprint of the power electronic components small it becomes necessary to increase the maximum junction temperature from 150℃ to 175℃. Figure 2 shows how the maximum IGBT current decreases



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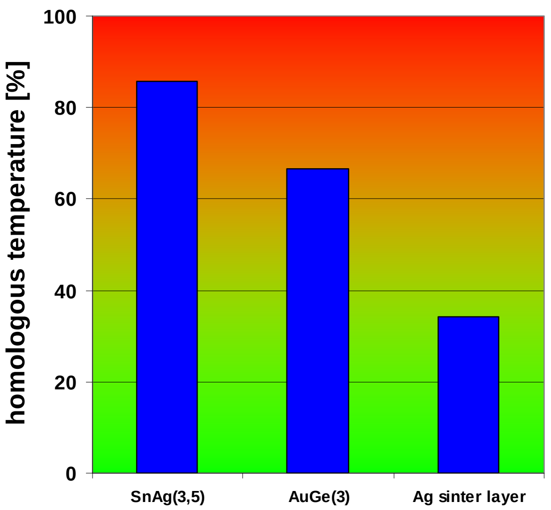
with rising heat sink temperatures. In order to keep the same power densities known from systems with dual cooling loops it is obvious that the maximum junction temperature need to go up. The latest generation of IGBT and freewheeling diodes are rated up to 175℃. Silicon devices for voltages up to 200V would allow junction temperatures up to 200℃. GaAs and SiC devices can be operated at junction temperatures up to 300℃ and more. But the standard packaging technology is limited to junction temperatures in the range of 125 to 150℃ in order to achieve the desired power and thermal cycling requirements. The automotive standard AEC-Q101 stipulates that power components must withstand 5000 temperature cycles at temperature swings higher than 100K and the vehicle mission profiles require 3 Mio active power cycles of 40K on top of that. The restricting factors in today's power modules are solder fatigue and bond wire lift-off to withstand these cycling requirements. The existing packaging limits increase exponentially with higher operating temperatures. In general it can be assumed that power cycling capabilities can be halved with a temperature increase of 20K . The Low Temperature Sinter Technique promises to be a cogent solution to these problems. [3,6]

Applying the concept of homologous temperature, the real advantage can be illustrated: Fig. 3



material		SnAg(3,5)	AuGe(3)	Ag sinter layer
solidus temperature	[℃]	221	363	961
solidus temperature	[K]	494	636	1234
operation temperature	[℃]	150	150	150
operation temperature	[K]	423	423	423
homologous temperature	**[%]**	**86**	**67**	**34**

<40%: considered mechanical stable
40-60%: creep range, sensitive to strain
>60%: unable to bear engineering loads

Sinterlayers reach a value of 34 % under this view. This value is state of the art for mechanical stabile joining technology. [2,6]

2. SINTER Equipment

Semikron is using now two sinter production lines with an maximum capacity of 1600 DCB cards / day. The hydraulic press can adjust specified pressures and temperatures. With these equipments, SEMIKRON can sinter complete 5"x7" DBC card with various Silicon chips on it.

Fig. 4 Hydraulic Press

The sinter tool is designed to bring a homogenous pressure up to 40 Mpa to the silicon chips and the pre applied silver layer.

The process parameter of pressure and temperature are well controlled in the equipment. The systems are fully automated and can be use in a series production process.

The entire DBC card's can be sintered in continuous process for high volume output of sintered 5"x7" DBC card's.

3. Sinter layers

SEMIKRON analyzed the silver layer before and after the sinter process. The individual silver flakes (Fig. 4 left) are sintered to a relatively dense silver layer with certain porosity (Fig. 4 right).

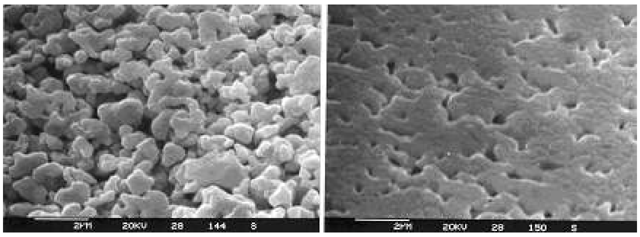


Fig. 4: Screen-printed connection layer before and after pressure sintering (REM images) [1].

It's possible to adjust the porosity of the layer by applying different pressures during sintering. Figure 5 (left) shows a cross section, prepared by focussed ion beam, of the sinter layer processed with the high pressure used in the established SEMIKRON sinter process; porosity is in the range of 5 %. If the pressure is reduced by a factor of about 4, the porosity is distinctly increased to a value of about 20

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% (Figure 5, right). It is believed that a low porosity causes a better sinter joint.

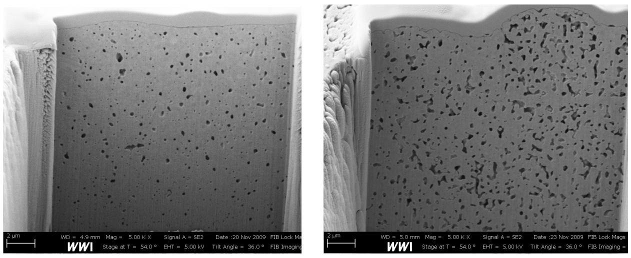

Fig. 5: Cross section (FIB) REM image of a standard SEMIKRON sinter layer and a layer processed with relatively low sinter pressure.

One critical point for the sinter technology is to analyze the bonding force between chips and substrates. The two joining partners, substrate and chip must have a noble layer surface. The technology can use Ni/Au flash, silver layers or similar surfaces. To verify the bond strength SEMIKRON uses a bending test to evaluate the different process parameters. SEMIKRON specified the sinter process parameters to bring the bonding force to values where the silicon itself will break before the sintered joint will fail. Fig. 6a and b illustrate the effect. Fig.7 shows pictures of bending test results of a strong sinter layer [1,6,7].

Bending test for the SINTER technology

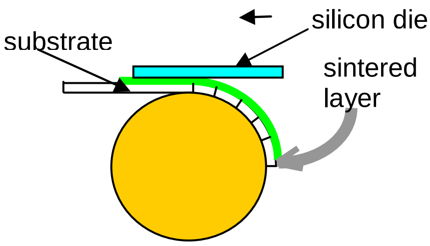

Fig. 6a: Low bonding strength.

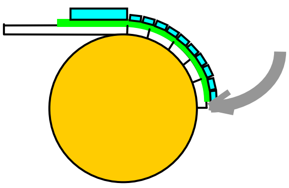

Fig. 6b: High bonding strength.

Fig. 7: Samples of well sintered chips with high bonding force.

4. Semikron sintered modules SKiM / SKiiP 4

The Semikron intregrated intelligent Powermodules SKiM`s and SKiiP`s are the first products on the market that will utilize the new sintered die attachment method. These modules are especially designed to meet the size, reliability and cost requirements for vehicle and industrial applications. These modules are pure pressure contact modules for electrical and thermal contacts. The assembled DBC substrates are directly pressed to the heat sink utilizing multiple stamped and folded busbar contacts. In this way the main reliability risk, the large area solder connection from substrate to baseplate has been eliminated. Fig. 8 and 9 shows the internal design of these high voltage modules.

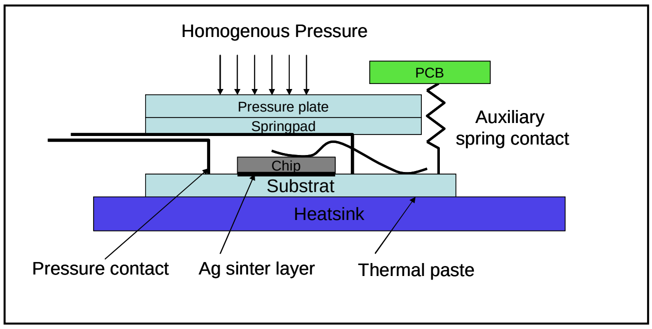

Fig.8 cross section

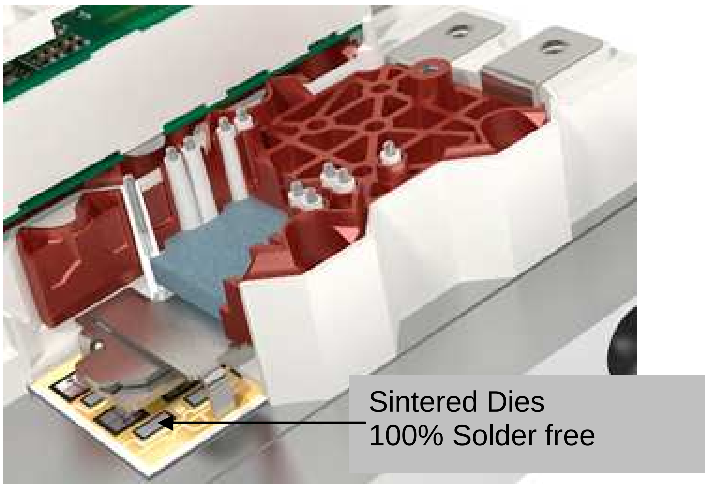

Fig.9 detailed view SKiiP 4

To achieve good thermal properties and high power levels it becomes necessary to parallel several power dies per switch. This module has 8 IGBT chips and 8 freewheeling diode chips in parallel.
Fig. 9b shows the assembled Al_2O_3 DBC substrate using the low temperature sintering die attachment process.

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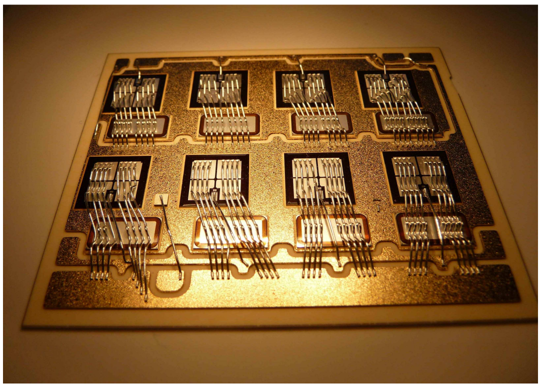

Fig. 9b SKiiP4 sintered and bonded substrate

Power modules combining the SKiiP pressure contact system and Sinter technology and show an excellent reliability in temperature cycling and power cycling. The modules do not use any solder connection. The behavior of these kind modules are designed for high junction temperature (175°C) and good load cycle test results.

5. Test Results

One of the main advantages of the sinter technology is the power cycling capability even at high average temperatures. The power cycling test method is specified in IEC 60749-34. Fig. 10

Standard module technology, like modules SKM 145, pass this test with 30000 cycles. see figure 11a

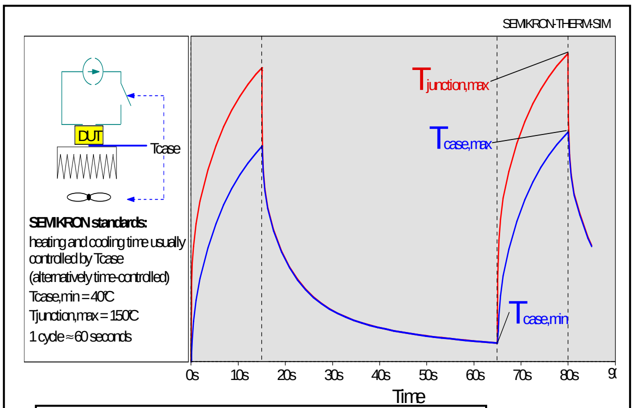

Fig. 10. Power Cycling Test Setup

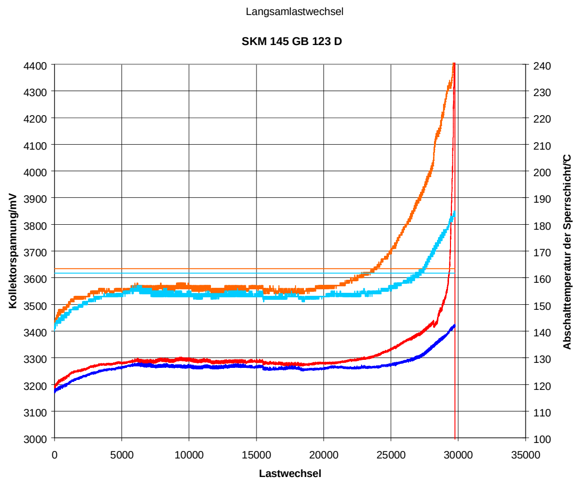

Fig. 11a Load cycle diagram SKM 145

The sinter technology exceeds these power cycling requirements by far. SKiiP 4 systems reach more than 90000 cycles. So it is a factor of 3 in the load cycle reliability. (fig.11 b). [5,6,7]

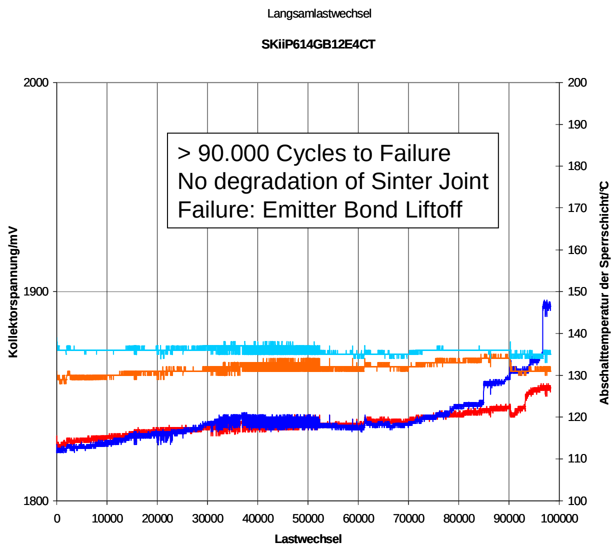

Fig. 11b Load cycle diagram SKiiP 4

After the test the sinter layers are analyzed with ultrasonic microscopy (SAM). There can not be detect any aging in the sinter layers. The Rth values between Chip and Substrate are stable over the entire test time.

6. Conclusion

SKiiP 4 and SKIM 63,93 are modules with sinter technology for high Tj temperature up to 175°C. The reliability of this package has been increased compared to standard soldered modules up to factor 3 under the same conditions. Semikron can use all

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kind of substrates in conjunction with the sinter process such as Al_2O_3, ALN, Si_3N_4 , depending on the needed thermal performance. Sinter production lines has been set up. to process entire 5”x7” DBC cards. The sinter process is the ideal technology in conjunction with base plate less pressure contact modules such as the SKiM and SKiiP 4 modules to increase the high temperature cycling and power cycling capability even further.

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