Low temperature sinter technology
Die attachment for automotive power electronic applications

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Abstract:

New fields of high power inverter systems such like hybrid cars, hybrid trucks, and off road vehicles require new ways of power electronics integration and packaging. The stringent requirements in size and 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 125°C.

In this paper the authors will discuss how the environmental conditions of automotive 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 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.

Keywords:
«Packaging», «Power cycling», «Reliability»,
«Thermal stress», «Sintering»,

1. Introduction

Traditional power electronics packages and modules, which are limited to operating temperatures below 150°C, cannot meet the requirement of next generation 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. 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°C), which is much higher than typical solder reflow. General investigations about the use of pressure to lower the sintering temperature of silver powder compounds for attaching power semiconductor devices have been performed by independent organizations. The studys confirmed that pressure assisted low temperature sintering of silver pastes is a feasible alternative die attach process to solder.

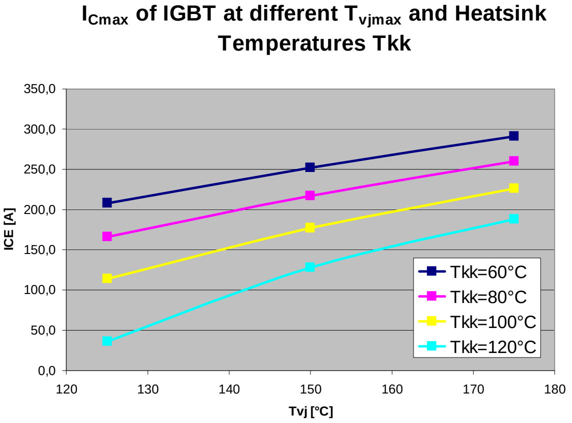

Fig 1: Increase in IGBT current with higher junction temperatures.

In automotive applications e.g. some parts of the electronics will move under the hood, the cooling water temperature is specified to 105°C (120°C 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°C to 175°C. Fig 1 shows how the maximum IGBT current decreases 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°C. Silicon devices for voltages up to 200V would allow junction temperatures up to 200°C. GaAs and SiC devices can be operated at junction temperatures up to 250°C and more. But the standard packaging technology is limited to junction temperatures of 125 to 150°C 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

1.1 Material properties:

In this table the advantage of the Ag sinter layer is show. The solidus liquidus of 961°C is outstanding for the reliability discussion. The thermal behaviour of 240 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]

		pure Silver	*Ag Sinter layer*	*SnAg solder*
Solidus liquidus	*°C*	*961*	*961*	*221*
Density	*gr / cm^3*	*10,5*	*8,5*	*8,4*
E-cond	*MS/m*	*68*	*41*	*7,8*
T cond.	*W/mK*	*250*	*240*	*70*
CTE	*µm / mK*	*19,3*	*19*	*28*
Tensil strength	*Mpa*	*139*	*55*	*30*

Table 1

2. SINTER Equipment

Semikron use a hydraulic press that can adjust specified pressures and temperatures. With this equipment SEMIKRON can sinter complete 5"x7" DBC card with various Silicon chips on it.

Fig. 2 Hydraulic Press

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

Fig. 3

The process parameter of pressure and temperature are well controlled in the equipment. The system is 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. Sinterlayers

SEMIKRON analysed the silver layer before and after the sinter process.

The sintered layer shows sintered flakes with porosity of ca.15%

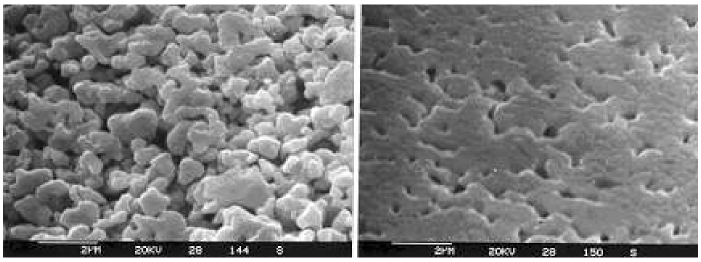

Fig .4
Screen-printed connection layer before and after pressure sintering with a connection inhibiting polished Si-wafer (REM image) [2]

One critical point for the sinter technology is to analyse the bonding force between chips and substrates. The two joning partners, substrates and chip must have a noble layer surfaces. The technology can use NiAu flash or silver layers or similar surfaces. To verify the bond strength SEMIKRON used a bending test.to evaluate the different process parameters.

Semikron specified the sinter process parameter to bring the bonding force to values where the silicon itself will break before the sintered joint will fail.. Fig. 5a,b illustrates the effect. Fig. 6 shows pictures of bending test results of a strong sinter layer.

Bending test for the SINTER technology

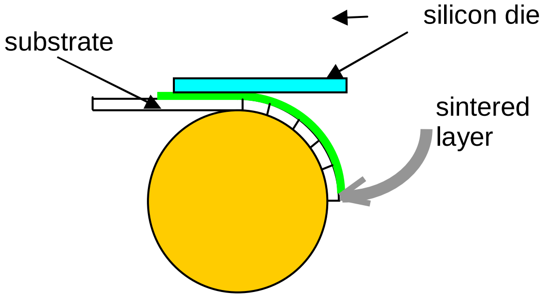

Fig. 5a low bonding strength

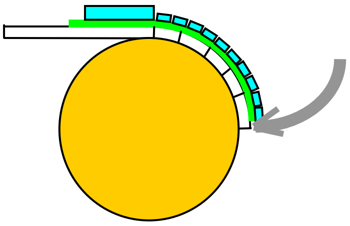

Fig. 5b: high bonding strength

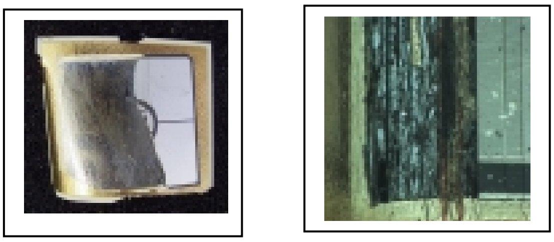

Fig 6. Samples of well sintered chip with high bonding force

4. Semikron Automotive Modules (SKAI)

The Semikron Advanced Integration (SKAI) modules are the first products that will utilize the new sintered die attachment method. SKAI modules are especially designed to meet the size, reliability and cost requirements for vehicle applications. These modules are pure pressure contact modules for electrical and thermal contacts. The assembled DBC substrates are directly pressed to the heatsink 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 completely. Fig. 7 and 8 shows the internal design of a high voltage SKAI module. suitable for 600V and 1200V IGBT applications. [3]

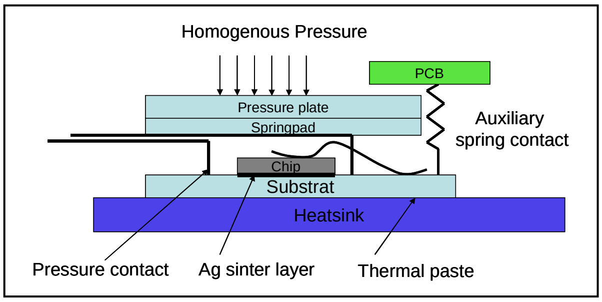

Fig.7 draft

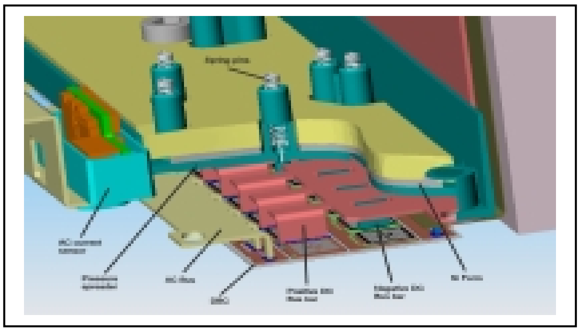

Fig.8 detailed view

To achieve good thermal properties and high power levels it becomes necessary to parallel several power dies per switch. This module has 6 IGBT chips and 3 freewheeling diode chips in parallel.
Fig. 9a shows the assembled 5"*7"ALN DBC substrate using the low temperature sintering die attachment process.

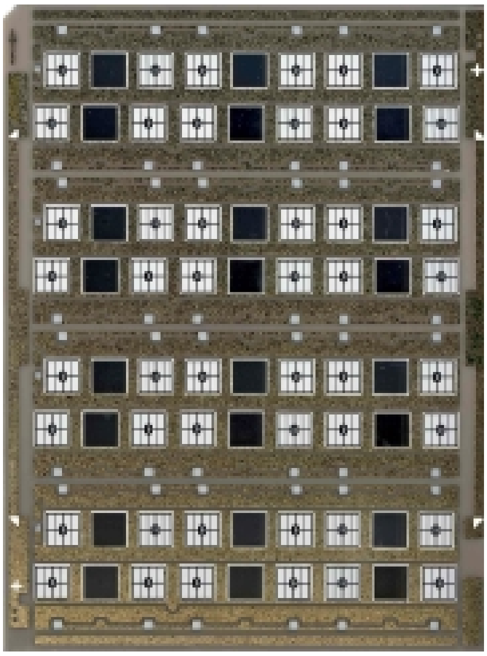

Fig..9a Sintered 5”x7” Substrate for SKAI

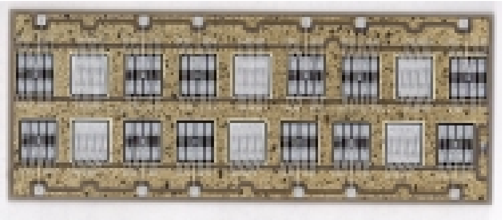

Fig. 9b SKAI sintered and bonded substrate

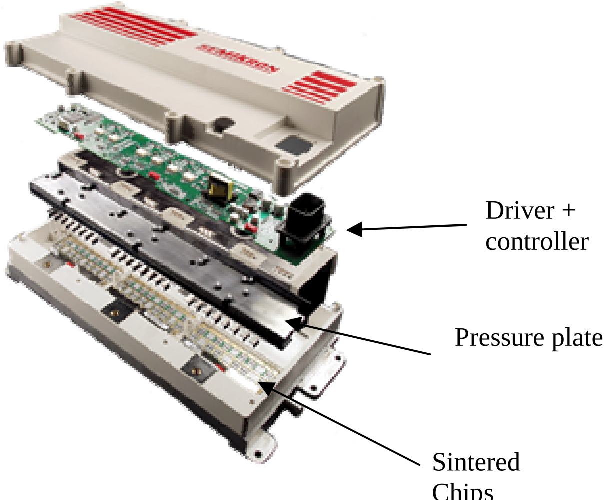

Fig.10 shows a SKAI module in a exploded view.

Power modules combining the SKAI pressure contact system and Sinter technology 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 in an automotive environment.

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. [4,5]

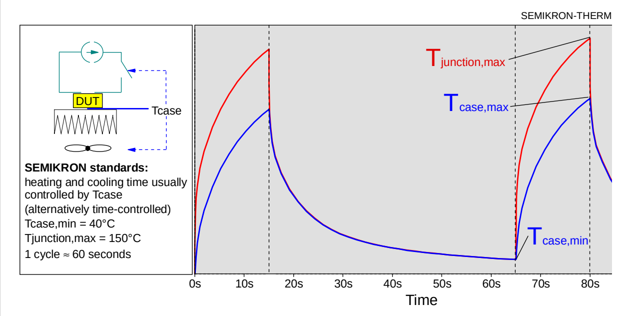

Diagram 1. Power Cycling Test Setup

Semikron specifies 20000 cycles with delta Tj 100 K The sinter technology exceeds these power cycling requirements by far.

We analyzed the sinter layers before and after the test with ultrasonic microscopy (SAM) No aging could be observed in the sinter layers. The Rth values are absolute stable over the entire test time.

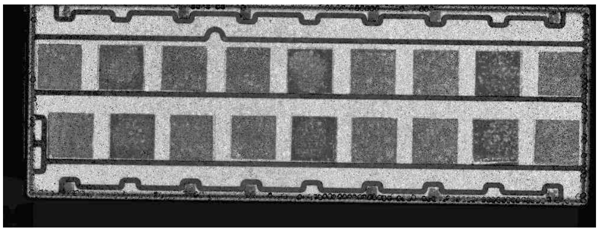

Fig. 11 SAM picture after load cycle test

7. Conclusion

SKAI modules with sinter technology are modules for high Tj temperature up to 175°C. The reliability of this package has been increased compared to standard soldered module. Semikron can use all kind of substrates in conjunction with the sinter process such as Al_2O_3, ALN, Si_3N_4 , depending on the needed thermal performance. A hydraulic press has been set up to process entire 5”x7” DBC cards in a production process. The sinter process is the ideal technology in conjunction with base plate less pressure contact modules such as the SKAI or SKiiP modules to increase the high temperature cycling and power cycling capability even further.

8. References

[1] Dipl. Phys. Christian Mertens:
"Dissertation. Die Niedertemperatur – Verbidungstechnik der leistungselektrouk ", Chapter, and Page of the quote, Publisher, 2004.

[2] Dr. Scheuermann / Wiedl: "low temperature joining technology a high reliability alternative to solder contacts", Workshop on metal ceramics composites for function applications Vienna 4/5. June 1997

[3] P. Beckedahl, W. Tursky, U. Scheuermann: "Packaging conciderations of an integrated inverter module for hybrid vehicles*r*", PCIM Nuremberg, 2005

[4] Double-Sided Low-Temperature Joining Technique for Power Cycling Capability at High Temperature AMRO Raed
EPE 2005 - Dresden ISBN : 90-75815-08-5 P.1

[5] M. Thoben, R. Bayerer Infineon Technologie
Potential and limits of powerDevice for inverters in hybrid vehicles
Automotive advanced Electronic System for the Car of Tomorrow April 2006

8. Glossary

APE	Automotive Power Electronics
PDF:	Portable Document Format