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BRINGING RELIABILITY TO SiC POWER MODULES

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Contents

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Bringing reliability to SiC power modules

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1 Abstract

Harnessing the unique electrical advantages of wide-bandgap silicon carbide (SiC) in commercial applications requires addressing reliability challenges caused by the material's mechanical properties. With its advanced die-attach technology, Vincotech is leading the way.

2 Introduction

First introduced over a decade ago, SiC power modules are likely to transform the power module market. By replacing the silicon used in standard semiconductors with wide-bandgap silicon carbide (SiC), they hold the potential to extend the applicability of semiconductor power modules to higher power, higher temperature use cases.

For SiC to live up to its high expectations and capture a 25% share of the power module market by 2026[1] , developers will have to overcome several challenges. First and foremost, they will have to optimize SiC module design to harness the material's full potential while delivering the reliability required for it to be viable in real-world deployments.

While SiC brings significant advantages over Si – 10 times higher breakdown voltages and 19 times lower leakage currents, it exhibits higher stress levels at the chip-substrate solder joint. In power cycling applications, this repeating stress degrades the chip-substrate interface, reducing the lifetime of SiC devices by around 70% compared to standard Si devices.

This article presents a novel design approach developed by our R&D teams at Vincotech that improves the power cycling capability of SiC power modules and, to a lesser degree, gate-oxide reliability, short-circuit ruggedness, and SIC body diode degradation. Narrowing the gap in terms of overall reliability compared to silicon-based modules has made SiC a viable, higher-performance alternative to silicon for a wide range of power module applications. We compare the performance of our improved design with standard designs and competitor products and assess its impact on electric vehicle charging poles.

[1] Yole report "Status of the power electronics industry: Market and Technology Report 2021"

3 Identifying bottlenecks

SiC is expected to play a vital role in increasing the total system efficiency of electric vehicle supply equipment (EVSE) from 95% to 98%, delivering high efficiency, higher power density, and fast charging times. To do so, it will, however, need to match the high reliability of traditional Si-based solutions in terms of their power cycling capability.

While the electrical properties of SiC are superior to those of silicon, the material's mechanical properties negatively impact its power cycling capabilities. In particular, its higher thermal expansion coefficient and three times higher Young's modulus can lead to the formation and proliferation of cracks in the solder joint.

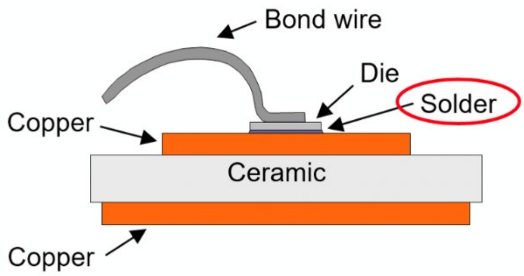

Figure 1: Power module schematic highlighting the solder joint

Moreover, the demanding mission profiles with prolonged periods of maximum power (e.g., in the case of EV chargers) and the higher temperatures generated by larger currents flowing through a smaller junction all apply additional stresses to the solder joint that need to be managed.

All of these factors point to the need to reinforce the chip-solder joint in order to improve the power cycling capability of SiC modules

4 Testing a new solder alloy for SiC power modules

In the lab, our R&D teams implemented a new solder alloy that raises SiC power module performance, making the technology viable for real-world deployments. We tested the power cycling capability of SiC power modules with respect to the technology used to connect the SiC die and the substrate. For the test, we used the VIN flowPACK E1 SiC module with the 6PACK topology featuring SiC MOSFET chip technology inside, as well as a competitor module.

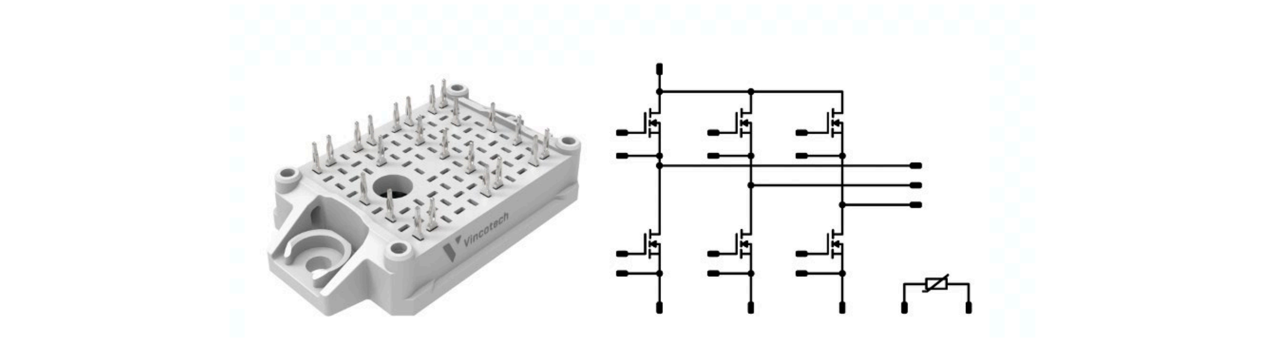

Figure 2: flow E1 housing and 6PACK schematic

To specifically trigger solder degradation, a critical failure mode, we ran accelerated power cycling tests, hitting the die at a maximum junction temperature of T_{jmax} = 150 °C and 175 °C, with a temperature difference dT = 100K and an on-time t_{on} = 1 s. This allowed us to simulate typical operating conditions encountered today (T_{jmax} = 150 °C), as well as those expected of higher-performance, next-generation solutions (T_{jmax} = 175 °C). In both cases, the failure criterion was defined as a 20% increase of the thermal resistance between the junction and the case, $R_{th(j-c)}$, indicative of the development and spreading of a crack at the chip-substrate interface.

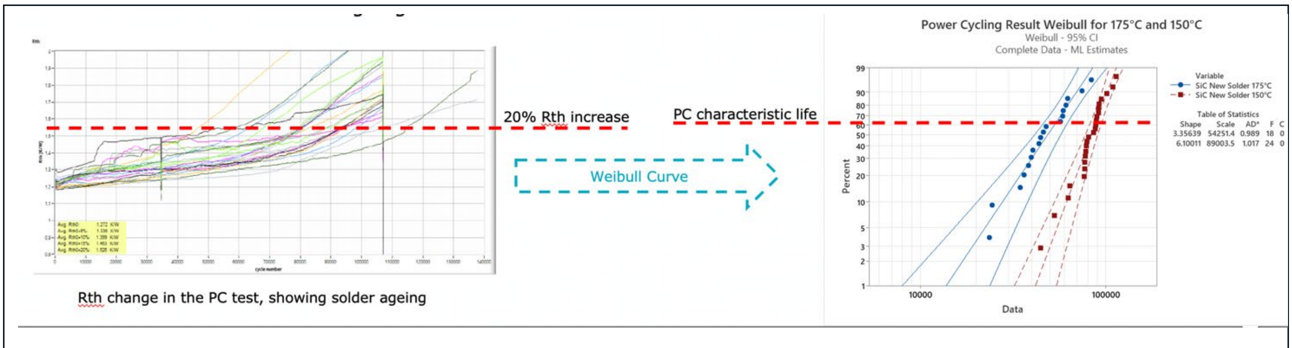

Figure 3: Impact of power cycling on the temperature resistance, including failure criterion (left) and Weibull analysis yielding the characteristic life (right)

The first graph presents the evolution of the thermal resistance at the die-substrate interface of each tested chip. The number of power cycles required to induce failure is determined by the intersection of the plotted lines and the dashed line indicating the failure criterion. Analyzing the failure data using a Weibull analysis revealed the average number of cycles required to trigger the failure of two-thirds of all dies tested, considered to be the characteristic life of the component.

5 Assessing the module's expected lifetime

Next, we compared the power cycling capability of SiC power modules with that of standard Si devices, using both Vincotech and competitor modules with a standard solder. The tests, carried out at a maximum junction temperature, T_{jmax}, of 150 °C and 175 °C, confirm that the higher stress on the solder joints experienced by SiC devices reduces power cycling capability by a factor of seven when compared to Si devices, regardless of whether a Vincotech or a competitor module was used. As expected, the higher temperature and stress experienced by the module at T_{jmax} = 175 °C considerably reduced the module's power cycling capabilities.

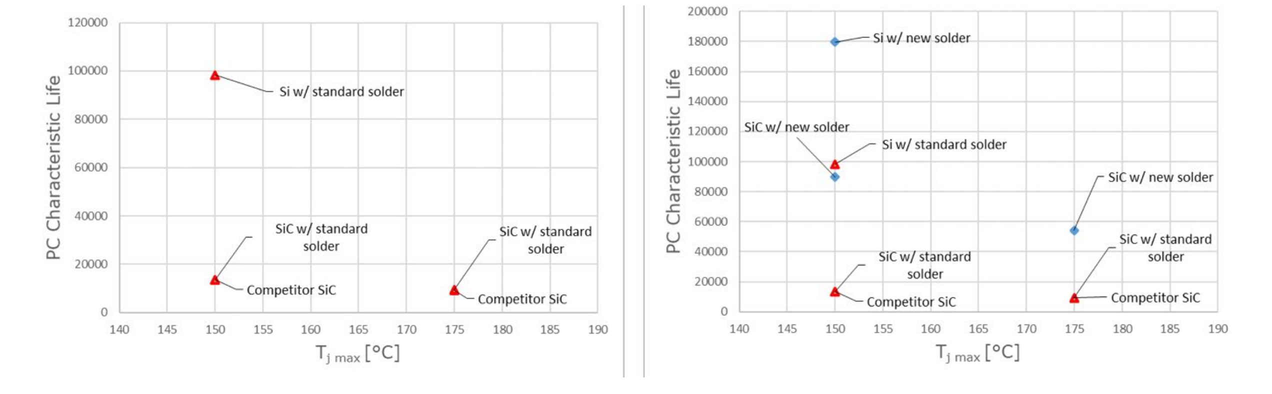

Figure 4: Power cycling benchmark with the standard solder (left) and the new solder (right)

Based on these results, we used a lifetime model to predict the expected lifetime of modules in EV chargers deployed in the field. Assuming a mission profile of 24 cycles per day at a constant maximum junction temperature, T_{jmax}, of 125 °C and a temperature swing of 100 K, the expected lifetime of SiC power modules would be only 2.2 years, compared to 16 years expected of Si power modules.

Running the same comparison using the new solder alloy implemented at Vincotech, we raised the cycling capability to close to the level achieved by silicon devices using a standard solder. Power cycling performance also improved considerably at the higher maximum junction temperature, T_{jmax}, of 175 °C, with the new solder alloy vastly improving device performance against competitor SiC modules. Assuming the same charger mission profile as before, the new solder alloy would increase the lifetime of a SiC power module to around 15 years, close to that of silicon devices, and past the current threshold required for market adoption.

6 Prepared to serve the fast-growing EV charging market

Vincotech's advanced die-attach technology is an efficient and cost-effective solution to the reliability challenges facing SiC power modules in terms of power cycling capability. Our engineering teams continue to pursue their investigations into new solder alloys that make it possible to harness the full potential of this interconnection technology. At the same time, they are exploring new technologies such as sintering, which could further improve power cycling capability if the reliability of wire bonds – the second weakest link in today's solutions – is also improved.

Vincotech has a vast portfolio of housings using SiC technology, with more than 40 different part numbers, that is based on a multi-source chipset supply chain. In addition, we offer dedicated product lines for DC fast charger applications with a comprehensive portfolio for each conversion stage.To accompany the fast growth of the EV charging station market, we have a strong roadmap of dedicated SiC power module technologies that meet the specification with high reliability.

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