ISO247: High-performance Ceramic-based Advanced Isolated Discrete Package for SiC MOSFET Devices

Introduction

In power electronic applications, achieving electrical isolation between a discrete semiconductor package and the heatsink often results in an increase in the thermal resistance junction-to-heatsink, $R_{th(j-h)}$. This limitation can impact the current-carrying capacity of the packaged device. Recognizing this challenge, Littelfuse has introduced the innovative isolated discrete ISO247 package.

The ISO247 package not only addresses the thermal resistance issue but also enhances power- and current-density while providing inherent isolation. Remarkably, it achieves these improvements while maintaining compatibility with the standard TO-247 package footprint. This white paper delves into a comparative analysis between the ISO247 and TO-247 devices, both housing the same 1200 V SiC MOSFET. The comparison focuses on thermal resistance, junction temperature, and power-handling capability, aiming to demonstrate the superiority of the ISO247 package for SiC power devices.

Thermal measurements indicate that the ISO247 package excels in minimizing chip junction temperature and thermal resistance junction-to-heatsink. In addition to enhancing device performance, these advantages offer the potential for increased application power output and cost savings at the system level.

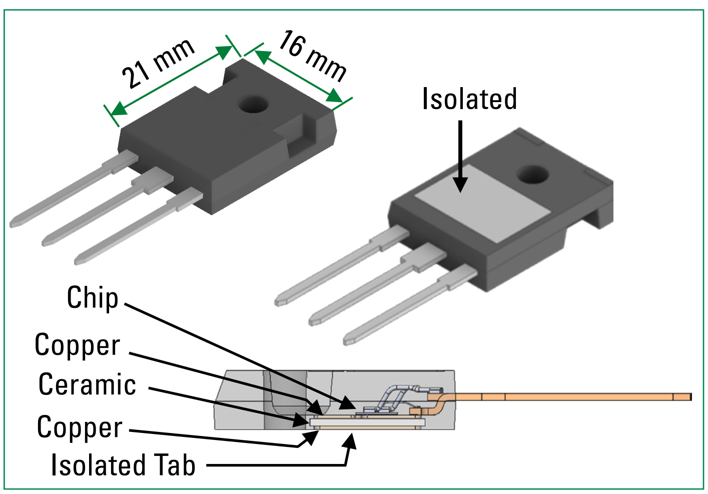

Figure 1. Internal construction of the ISO247 package

ISOPLUS™ – Revolution in Discrete Isolation Technique

ISOPLUS™ is the family of internally isolated discrete power semiconductor devices, first pioneered in 2003 by IXYS (now Littelfuse). The ISO247 belongs to the ISOPLUS™ product family and adheres to the JEDEC TO-247AD outline, ensuring pin compatibility with the standard TO-247 package. The ISO247 package is displayed in Figure 1.

The ISO247 package offers the following key advantages compared to the standard TO-247 package:

- High-performance ceramic-based Active Metal Brazing (AMB) substrate provides inherent isolation, higher thermal conductivity, and reduced thermal resistance junction-to-heatsink, $R_{th(j-s)}$ [1]
- Isolation voltage rating of 2.5 kV AC, 1 minute or 3 kV AC, 1 second
- Higher temperature and power cycling in seconds (PCsec) withstand capability ascribed to the matched coefficient of thermal expansion (CTE) for SiC chip and AMB substrate [2]
- Increased power density and simplified thermal management
- Reduced EMI, attributed to the small chip-to-heatsink stray capacitance

The primary motivation to use SiC MOSFETs in an application is to achieve greater efficiency, high power density, and the ability to operate at high frequencies, thereby enabling a compact design. It is imperative to maximize chip performance to offset the high cost associated with SiC. Conventional TO-247 packages often pose challenging limitations arising from thermal management, resulting in suboptimal utilization of the SiC chip. The ISO247 package addresses this drawback by presenting a revolutionary solution to simplify the way design engineers can address system-level performance, integration, and assembly needs. The ISO247 spans a variety of semiconductor technologies, including Si/SiC MOSFETs, IGBTs, and diodes, with voltage classes ranging from 70 V to 1600 V.

ISO247: High-Performance Ceramic-based Discrete Isolated Package

The ISO247 package is based on Direct Copper Bonded (DCB) substrates with aluminum oxide (Al_2O_3) ceramic. The widespread adoption of silicon carbide in power electronics is driven by the demand for increased power density, longer lifetimes, and elevated operating temperatures. Designers are compelled to choose advanced substrates for power semiconductor packages to fully exploit the benefits offered by SiC. In the context of isolated power semiconductor packages, the ceramic material plays a critical role in influencing thermal resistance, which in turn impacts the power density of the packaged semiconductor device.

Littelfuse has developed the ISO247 package with advanced high-performance silicon nitride (Si_3N_4) ceramic, specifically tailored to meet the demanding requirements of SiC MOSFET-based applications. The impressive bending strength, high fracture toughness, and high thermal conductivity of Si_3N_4 ceramic makes it an ideal choice for substrates in electrically isolated Wide Bandgap (WBG) power semiconductor packages [3].

The bonding of Si_3N_4 ceramic substrates deviates from conventional DCB methods. While the DCB process is exclusively compatible with intermediate oxide-ceramic layers, the metallization process employed in the Si_3N_4 substrate for the ISO247 package utilizes Hybrid Active Metal Brazing (H-AMB) technology. This approach integrates the advantages of both the sputtering and AMB processes, constituting a two-step metallization procedure.

In the initial phase, the ceramic substrate undergoes a sputtering process with an active metal filler layer. In the second stage, the copper layer is brazed onto the sputtered substrate at a temperature of approximately 850 °C. The utilization of H-AMB on the ceramic substrate results in superior thermal conductivity, high reliability, a void-free bonding surface, and an improved cost per amp ratio.

Distinguished by its internal isolation using high-performance ceramic, the ISO247 package is designed to significantly reduce the thermal resistance, $R_{th(j-c)}$, while offering isolation, along with enhanced power- and current-densities. This is in stark contrast to the TO-247 package, which relies on an external isolation method.

Although the ISO247 and TO-247 packages share identical outer dimensions and pinout configurations, their internal structures and mounting approach exhibit notable distinctions, as depicted in Figure 2. The TO-247 device requires external isolation during its attachment to the heatsink. In contrast, the ISO247 device relies exclusively on thermal interface material for mounting to the heatsink [4].

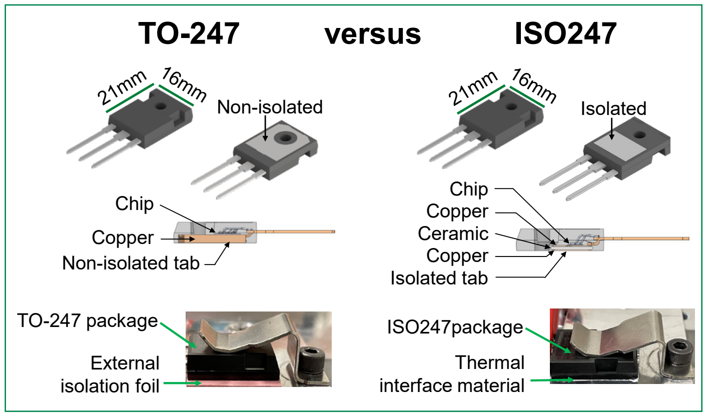

Figure 2. Internal construction and mounting differences between TO-247 and ISO247 discrete packages

Comparison of Thermal Performance between ISO247- and TO-247-based SiC MOSFETs

The standard TO-247 package has an electrically conductive mounting tab, which is typically at the drain potential. It is generally desirable to electrically isolate the device mounting tab from the heat sink due to safety concerns and the desire to mount multiple discrete devices on the same heat sink frame. A widely adopted approach in the industry is to utilize an external, thermally conductive, and electrically isolating foil between the semiconductor package and the heatsink. However, employing external isolation entails significant drawbacks such as increased thermal resistance, diminished power- and current-handling capacity, complex thermal management, and substantial efforts for assembly.

These disadvantages, particularly the reduced power-handling capabilities, are unacceptable in cases where WBG semiconductors like SiC-MOSFETs are utilized. The Si_3N_4 ceramic-based ISO247 package offers improved overall thermal resistance and power-handling capability compared to a standard TO-247 discrete with an external isolation foil, thereby helping SiC chips maintain a cooler temperature at a given DC current.

To evaluate the performance advantages of the ISO247 package, thermal measurements were conducted using a 1200 V, 25 mΩ SiC MOSFET chip packaged in ISO247 and TO-247 packages. Thermal measurements were executed using the cooling curve method in compliance with IEC 60747-8 [5], according to the measurement setup detailed in [6]. The measurements included various packaging and thermal interface configurations, as summarized in Table 1.

Table 1. Devices featuring SiC MOSFETs for comparison of thermal meaurement

Device Number	Device Type	MOSFET Chip	Device-to-heatsink Isolation
Device 1	TO-247	1200 V, 25 mΩ SiC	External isolation foil with thermal conductivity 1.8 W/mK
Device 2	TO-247		External isolation foil with thermal conductivity 6.5 W/mK
Device 3	ISO247		Internal isolation with high performance Si_3N_4 ceramic*

*DOWSIL 340 thermal grease was used

For thermal measurements of the TO-247 devices, external isolation foils with thermal conductivity values of 1.8 W/mK and 6.5 W/mK were utilized between the package and the heatsink to replicate real-world applications. The ISO247 device employed a thermal paste between the package and the heat sink. The devices were mounted on temperature-controlled, water-cooled heatsinks maintained at a constant temperature of 30 °C. The thermal data obtained for all three devices was subsequently compared, with a focus on parameters such as thermal resistance, $R_{th(j-h)}$, and junction temperature, T_{vj}, under identical heating current, I_H, conditions. These comparisons are visualized in Figure 3 and Figure 4.

As evident from Figure 3, the ISO247 package with high-performance ceramic improves the steady state thermal resistance, $R_{th(j-h)}$, by up to 64 % compared to the TO-247 devices with external isolation, while carrying the same SiC chip. This directly translates into an increased power-handling potential and lower chip temperature at a given current.

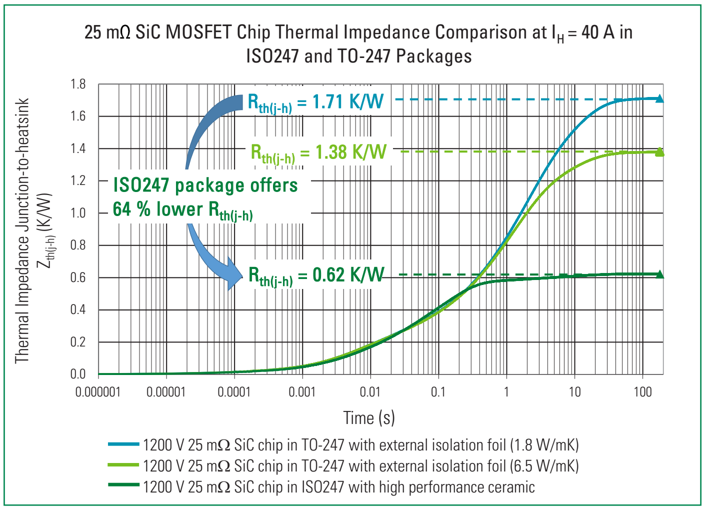

Figure 3. Comparison of thermal impedance measurement between ISO247 and TO-247 discrete devices

Likewise, as depicted in Figure 4, the SiC chip in the ISO247 package with advanced ceramic stays up to 60 °C cooler when compared to the SiC chip in the TO-247 device with external isolation at I_H = 40 A. This results in a lower temperature swing between the junction and heatsink, ΔT_{j-h}, at the given heating current. The ISO247 with high-performance ceramic exhibits a nearly 53 % reduction in temperature swing, ΔT_{j-h}, compared to the standard TO-247 discrete, significantly enhancing the lifetime of the ISO247 device, and consequently, the application's reliability.

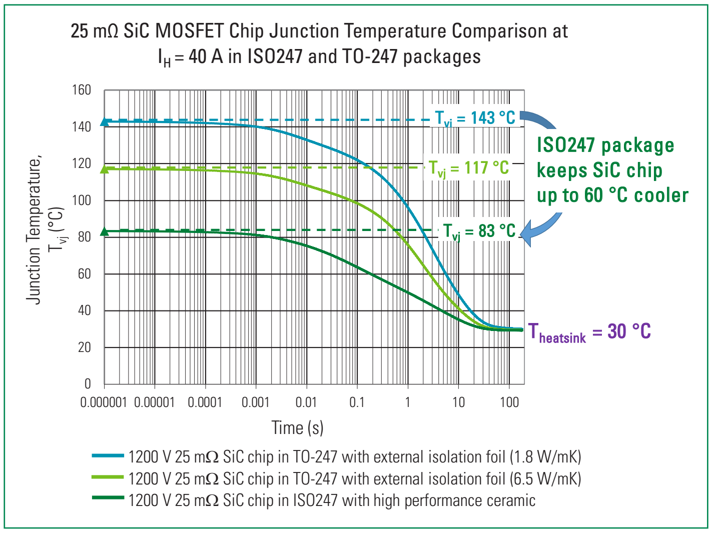

Figure 4. Comparison of junction temperature between ISO247 and TO-247 discrete devices

It is important to note that the practical limit for T_{vj} within applications is typically up to 130 °C to ensure safe operation. Therefore, a performance comparison of the ISO247 device to the TO-247 (Device 2), utilizing a higher quality and more expensive 6.5 W/mK isolation foil, offers a more realistic comparison. As depicted in Figure 3 and Figure 4, the ISO247 package with high-performance ceramic improves thermal resistance, $R_{th(j\text{-}h)}$, by 55 % and offers a 39 % lower temperature swing, $\Delta T_{j\text{-}h}$.

Increasing Application Power Output using the ISO247

To demonstrate the improvement in application power output using the ISO247, thermal measurements with a heating current, I_H, resulting in a chip temperature, T_{vj}, of 130 °C, were applied to different packages, all containing the same 25 mΩ SiC chip. A junction temperature, T_{vj}, of 130 °C was selected as most real-world applications are designed to operate with chip temperatures, T_{vj}, ≤ 130 °C. The results from the thermal measurements are summarized in Table 2.

Table 2. Thermal measurement results at T_{vj} = 130 °C

Device and Isolation Type	T_{vj} (C)	I_H (A)	$R_{th(j\text{-}h)}$ (K/W)	$P_{D(j\text{-}h)}$ (W)
TO-247 with 1.8 W/mK isolation foil	130	38.8	1.71	59
TO-247 with 6.5 W/mK isolation foil	130	42.2	1.38	73
ISO247 with high performance ceramic	130	50.8	0.62	160

When the results are interpreted, the advantages offered by the ISO247 device at the application level are obvious. The SiC chip in the TO-247 package with external isolation foil reached a junction temperature, T_{vj}, of 130 °C with I_H = 38.8 A. The same SiC chip in the ISO247 with high-performance ceramic reached a junction temperature, T_{vj}, of 130 °C with I_H = 50.8 A. This translates to an almost 30 % increase in the current-carrying capacity of the SiC chip in the ISO247 device to reach the same junction temperature, T_{vj}, of 130 °C.

As demonstrated by the data presented in Table 2, when considering the SiC chip operating at a junction temperature of 130 °C, it becomes apparent that the ISO247 package shows a remarkable 170 % improvement in power-handling capacity compared to the TO-247 solution.

These measurements show that the ISO247 with advanced ceramic takes a 30 % higher current to reach a chip temperature of 130 °C. The exceptional thermal performance exhibited by the advanced ISO247 package unleashes the potential for enhancing power density and output power in the end-use application.

Upgrading a given application with a DC-link voltage of 800 V, originally designed for 20 kW from 1200 V, 25 mΩ SiC MOSFETs in a TO-247 package with external isolation foil, to the same SiC MOSFETs in a high-performance ceramic-based ISO247 packaging solution could potentially increase the DC power output of this system to 30 kW. This represents a substantial 50 % increase in DC power output, as depicted in Figure 5.

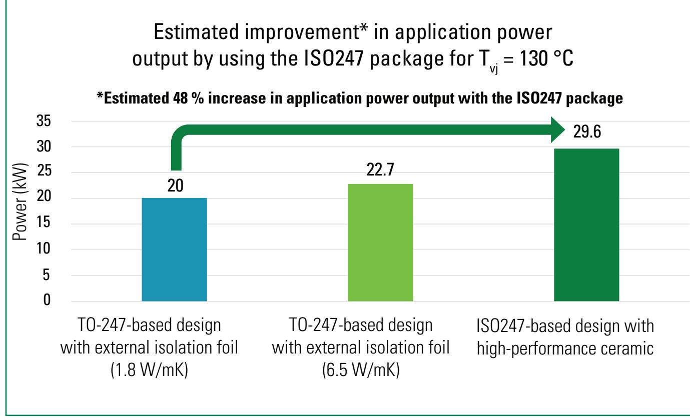

Figure 5. Estimated increase in application power output by using ISO247

Conclusion

The increasing prevalence of Wide Bandgap (WBG) devices necessitates innovative advancements in packaging technology. ISO247, an isolated package from Littelfuse that is specifically designed for SiC-based applications, offers a unique solution while remaining compatible with the standard TO-247 footprint. Notably, the ISO247 package, featuring high-performance Si_3N_4 ceramic, achieves a remarkable 64 % reduction in thermal resistance, $R_{th(j-h)}$, and a 53 % reduction in temperature swing, ΔT_{j-h}, compared to the TO-247 package. As a result, SiC MOSFET chips housed in the ISO247 package remain up to 60 °C cooler at the same DC power, which significantly enhances the lifetime of the device and improves application reliability. Additionally, this package enables a 50% increase in application power output, as demonstrated in a 20 kW application scenario.

Engineers can capitalize on the improved thermal performance and power dissipation of the ISO247 package by selecting higher $R_{DS(on)}$ chips for a given application power rating. This cost-saving opportunity extends to system-level benefits, including simplified thermal design, reduced mounting efforts, space-saving, and increased power density. The advanced ISO247 package developed by Littelfuse is poised to revolutionize discrete semiconductor isolation in WBG semiconductor applications.

References

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