1200 V Discrete SiC MOSFETs with Enhanced Interconnection Technology Enable Energy Efficient Welding Machines

In recent years, the demand for more energy efficient products for better natural resource sustainability has led to mandatory efficiency regulations for welding machines. The improved silicon carbide CoolSiC™ MOSFET 1200 V in a TO-247 package with .XT interconnection technology and the unconventional assembly and thermal design methods offer improved designs that increase efficiency and power density[1].

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In the welding machine industry trends such as improved power efficiency, reduced costs, and enhanced portability, i.e., reduced size and weight, have been the driving force behind continuous development. For instance, specific power source efficiency levels for welding machines have become, or will soon become, mandatory in standard regulations. One example of this is the latest European Union (EU) regulation for welding equipment [2] that came in force on 1 January 2023. Therefore, meeting the trends for welding machines in the medium power range of around 10 to 40 kW, where using power modules is the typical solution, has now become very demanding.

Infineon's CoolSiC MOSFET 1200 V in a TO-247 package using .XT interconnection technology for packaging significantly enhances the thermal performance and reliability of the device. Together with a specific cooling design ("in which discrete devices are directly mounted on the heat sink without any electrical isolation with the purpose of increasing the heat dissipation" [3]) it offers an improved solution for discrete devices (figure 1). It enables higher output power levels with increased efficiency and power density, and reduces the cost of medium power welding machines.

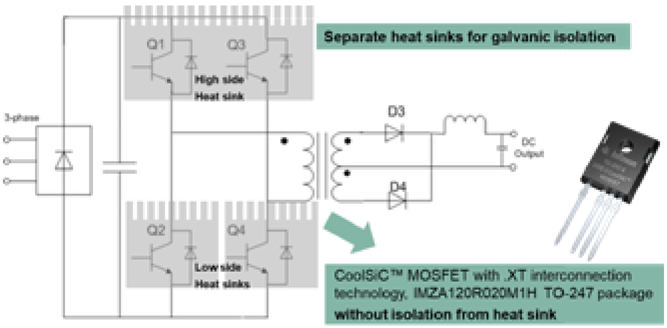


Figure 1: Welding machine power supply with 1200 V CoolSiC MOSFET discretes not isolated from the heat sink

CoolSiC MOSFET discrete with .XT interconnection technology

The enhanced CoolSiC MOSFET 1200 V takes advantage of the improved TO-247 package that uses Infineon's .XT interconnection technology. This technology features an advanced, diffusion-soldering, die attach process. The main benefit of this packaging technology, discussed at length in [4], is the significant reduction in the bond line thickness (figure 2), which, in combination with specific intermetallic alloys, results in a significantly higher thermal conductivity. This property reduces the junction-to-case thermal resistance ($R_{thj\text{-}case}$) and thermal impedance ($Z_{thj\text{-}case}$) of the device.

The reliability of the device also improves because it prevents die tilt and solder bleed-out during the die attach process, and offers practically a void free interface. Furthermore, it improves performance under thermo-mechanical stress, which means better performance during active and passive thermal cycling test conditions. Basically, the CoolSiC MOSFET 1200 V in the TO-247 package with .XT interconnection technology enables welding machine power supply designs with better thermal and reliability performance.

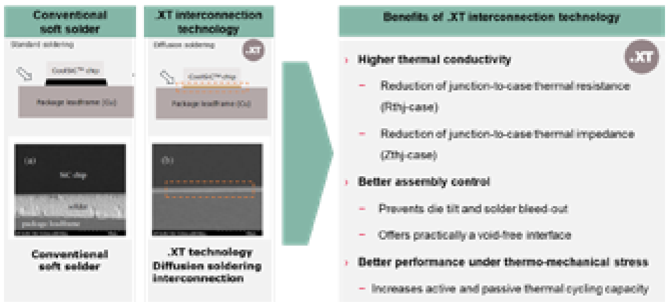


Figure 2: Infineon's .XT interconnection technology versus the conventional soft solder process

500 A welding machine power supply inverter design using CoolSiC MOSFET discrete device

The improved solution for medium power welding machines using CoolSiC MOSFET 1200 V in a TO-247 package with .XT interconnection technology was demonstrated using a unique 500 A power supply inverter design of a welding machine from a major manufacturer. It uses the cooling concept previously discussed and shown in figure 1, in which devices are mounted without electrical isolation on the heat sinks. Also, to confirm its enhanced performance, it was compared against a main competitor's SiC MOSFET under the same test conditions.

The welding machine power supply consisted of a three-phase, full-bridge topology inverter using four Infineon 20 mΩ 1200 V CoolSiC MOSFETs with .XT interconnection technology (IMZA120R020M1H) in a TO-247 4-pin package device. The basic specifications of the power supply inverter are listed in Table 1:

Parameter	Value
Input supply voltage	3-phase, 400 V, 50 Hz
Output current	500 A_{DC}
Output voltage	40 V_{DC} at 500 A_{DC}
Duty cycle	60%
Switching frequency	50 kHz
Operating $t_{ambient}$	40°C
Operating $T_{heat\ sink}$	80°C

Table 1: Basic specifications of the welding machine power supply inverter

Note that compared to the typical IGBT module solution of medium power welding machines operating at 10 to 20 kHz switching frequency, the ultra-high switching speed of the SiC MOSFET enables a significant increase in the typical operating switching frequency. This helps in reducing the size of the magnetic and passive components and thus of the inverter.

Furthermore, to meet the requirements listed in Table 1, the heat sink and air flow were selected to have the proper thermal time constant. All the heat sinks reached the thermal steady state condition in about five minutes, and thus the cooling system design (figure 3). As a result, during the 60% welding duty cycle of maximum operating requirement the SiC MOSFET devices reached the thermal steady state condition.

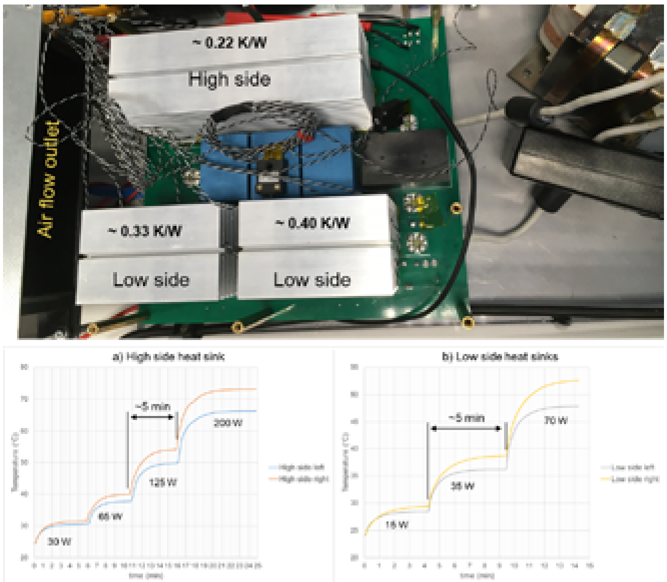


Figure 3: Thermal steady state condition and power dissipation capability of heat sinks

The power supply inverter tests were performed at the following test conditions:

- Output power: 408 A at 47.7 V, ~19.5 kW. Target 20 kW, 500 A at 40 V
- Welding duty cycle: 60%, 6 min ON, 4 min OFF
- DC bus voltage of the inverter: 530 V_{DC}
- Switching frequency: 50 kHz
- VGS, 20 mΩ CoolSiC MOSFET: 18/-3 V
- VGS, competitor 20 mΩ SiC MOSFET: 20/-4 V
- Low side heat sink R_{th}: ~0.36 K/W
- High side heat sink R_{th}: ~0.22 K/W
- Paste thermal conductivity: 6.0 W/mK
- Mounting clip force: 60 N (13.5 lbs.)
- Ambient temperature: Room temperature
- Forced air cooling
- RCL load.

As expected, because of the proper gate driver, RC snubber, and PCB layout design, there was not a significant difference between Infineon's CoolSiC MOSFET and the competitor's SiC MOSFET, both of which showed similar waveform performance (figure 4).

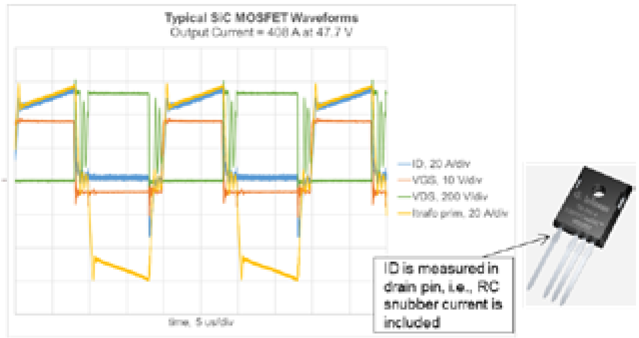


Figure 4: Typical SiC MOSFET waveforms during a welding machine power supply inverter operation

However, the thermal and power loss results demonstrated an enhanced performance of the CoolSiC MOSFET. The temperature profiles (figure 5) showed significantly better performance of the 20 mΩ IMZA120R020M1H CoolSiC MOSFET as opposed to the competitor's device. On average, the CoolSiC MOSFET showed about 6 percent lower heat sink temperature, 17 percent lower estimated power losses, and 14 percent lower case temperature than the competitor's device.

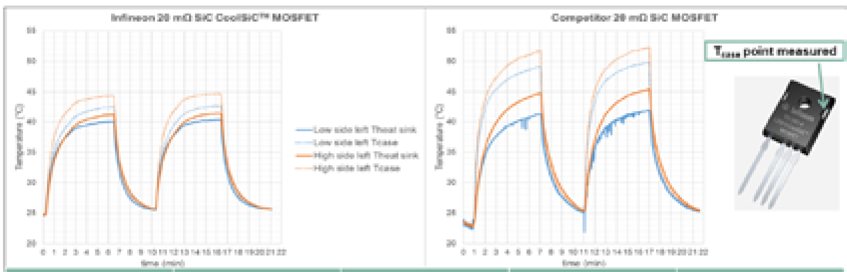
Moreover, as expected from the cooling design's data information, the CoolSiC MOSFET reached the thermal steady state condition after five minutes of operation. The competitor's SiC MOSFET, on the other hand, never reached the thermal steady state condition, implying that its power losses continue increasing after six minutes of system operation.

Lastly, the requirement of 80°C maximum heat sink temperature is easily meet by this SiC MOSFET discrete solution, even if the maximum ambient temperature of 40°C is considered.

In summary, the test results confirmed and demonstrated that the CoolSiC MOSFET discrete solution, using a cooling concept in which devices are mounted without electrical isolation on heat sinks, enables the design of inverters for medium power welding machines ranging from 20 kW and above, where power module solutions are the typical choice.

Conclusion

An improved power supply for welding machines using CoolSiC MOSFET 1200 V in a TO-247 package with .XT interconnection technology, and a well-known but unconventional cooling design, has been substantiated. The design significantly enhances heat dissipation, enabling higher output power levels typically achieved by



Inverter Position	SiC MOSFET	Maximum $T_{heat\ sink}$	Maximum T_{case}	Estimated P_{loss}
Low side	Infineon	40.4°C	42.7°C	47.6 W
	Competitor	42.0°C	49.8°C	54.3 W
High side	Infineon	41.4°C	44.7°C	42.0 W
	Competitor	45.4°C	52.3°C	53.2 W

Figure 5: 20 mΩ 1200 V SiC MOSFET's thermal and power losses performance at 60 percent welding DC operation, Infineon CoolSiC MOSFET IMZA120R020M1H versus the main competitor's device

power module solutions. The benefits of Infineon's .XT interconnection technology enables better thermal, and therefore, reliability and lifetime performance for the inverter. The proposed discrete solution enables higher efficiency and power density, helping fulfill the demand for more energy efficient welding machines and meeting welding machine industry trends such as cost, weight, and size reduction.

References

[1] This article is an updated version of the paper "Improving the power efficiency of welding machines using 1200 V CoolSiC MOSFET discretes with .XT interconnection technology" presented by the author (Jorge Cerezo) in PCIM Europe 2022, Nuremberg. https://pcim.mesago.com/nuernberg/en.html
[2] Commission Regulation (EU) 2019/1784 of 1 October 2019 laying down eco-design requirements for welding equipment pursuant to Directive 2009/125/EC of the European Parliament and of the Council.
[3] "TO-247PLUS IGBT discrete device enhances power density in welding machines," AN2019-10. Infineon Technologies AG.
[4] M. Holz, J. Hilsenbeck, R. Otremba, A. Heinrich, P. Türkes, R. Rupp, "SiC Power Devices: Product Improvement using Diffusion Soldering," Materials Science Forum Vols. 615-617 (2009) pp 613-616.

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