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# High Performance Silicon Carbide Power Modules for Extreme Environment Applications

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## 1. Introduction

The requirements of modern high-performance power electronics systems are quickly surpassing the power density, efficiency, and reliability limitations set by the inherent properties of silicon-based power devices. The advantages of SiC are well known, including high temperature operation, high voltage blocking capability, high speed switching, and high efficiency. In this presentation, APEI, Inc. will discuss the status of development of our high performance SiC power modules for extreme environment applications, including: hybrid electric vehicle systems, aerospace systems, and down-hole systems. The power modules under discussion range from a few hundred watts to > 50kW, implement both SiC MOSFET and JFET solutions, operate at temperatures in excess of 250 °C, and are being optimized for high speed switching.

## 2. Summary

During the late 1960's, the electronics industry was revolutionized by the development of the silicon integrated circuit (IC) technology, resulting in microelectronics applications shrinking by orders of magnitude in comparison with their discrete component counterparts— and ultimately leading to vast cost reductions in the electronics markets. A similar type of revolution is presently under way in the power electronics industry. In this case, however, the change will not be driven by microelectronic IC technology; rather it will be driven by the SiC power switch. SiC has 1/10th the switching losses of silicon, 10× the blocking voltage, 4× the thermal conductivity, 10× the switching speeds, and a junction temperature threshold in excess of 600 °C. All of these physical advantages that SiC has over the present silicon technology will greatly increase power density capability (the chief limiting factor of today's power electronic systems), significantly enhance energy efficiency, and drive power electronics systems to shrink in size by an order of magnitude; all of which will result in cost savings. Whereas the microelectronics IC drove computer mainframes the size of wall cabinets to shrink in size to fit on a desktop, so too will SiC technology be the primary mover behind shrinking wall sized power electronics systems to the size of suitcases.

A powerful argument for using SiC power electronics is the size and weight reductions that can be achieved by high temperature operation. For example, a silicon-based power module with a 3 kg forced air cooled heatsink can achieve a maximum power of 5 kW assuming a junction temperature of 150 °C; while APEI, Inc. has demonstrated a SiC-based power module with a 0.3 kg heatsink can achieve a maximum power of 7.5 kW assuming a junction temperature of 600 °C. This illustrates that the use of SiC technology allows for a 50 % increase in power and a 90 % reduction in both weight and volume. To take full advantage of the high power density capabilities offered by SiC electronics, the development of high-temperature electronics as well as high-temperature packaging technologies and design methodologies are required. Additionally, the integration of high temperature power devices and high temperature drive electronics into a single module greatly minimizes parasitics, enabling high frequencies of operation.

Arkansas Power Electronics International, Inc. (APEI, Inc.) and its partners have developed a number of SiC power modules capable of extreme environment operation, as well as SiC-based power converters to demonstrate the true potential of the SiC technology. Figure 1 illustrates a complete SiC-based multichip power module (MCPM) that operates at temperatures in excess of 250 °C ambient. This highly compact 4 kW three-phase MCPM inverter integrates SiC JFET power transistors with high-temperature silicon on insulator (HTSOI) control electronics. The high-temperature operation of the MCPM allows for increased power density by an order of magnitude when compared to equivalent silicon-based systems. This opens new possibilities in the design of many power systems.

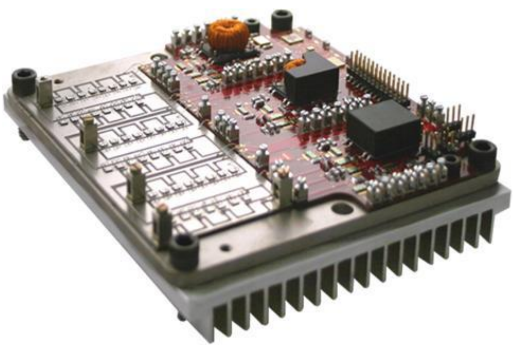

Figure 1. High-temperature (> 250 °C) SiC MCPM, 4kW 3-phase motor drive.

APEI, Inc. engineers, in conjunction with Rohm Semiconductor and the University of Arkansas, developed a high temperature 250 °C SiC power module capable of operating up to 50 kW, illustrated in Figure 2. This power module integrates a SiC half-bridge implementing Rohm SiC MOSFET devices (bottom layer), with a high-temperature silicon-on-insulator (HTSOI) based gate driver built on low temperature cofirable ceramic (LTCC— top layer).

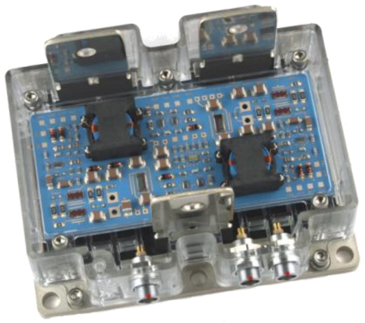

Figure 2. High-temperature (> 250 °C) SiC power module.

Figure 3 shows the half-bridge power modules in a DC motor drive demonstration. This demonstration operated at 5kW completely without a heatsink. Figure 4 illustrates thermal image of the SiC MOSFET power stage in this test, with junction temperatures exceeding 250 °C.

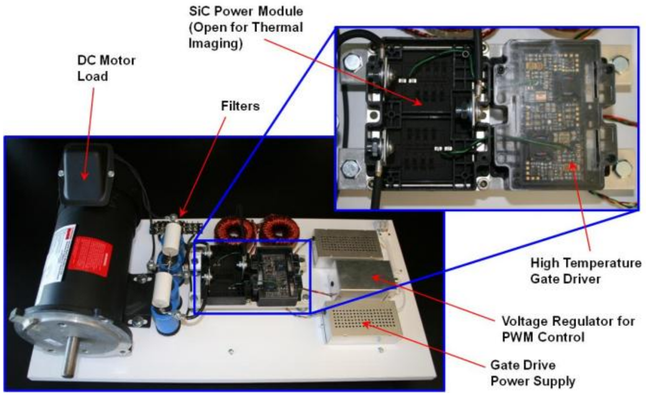


Figure 3. SiC power module in DC motor drive demo.

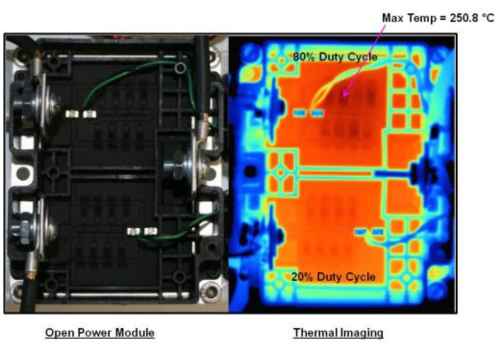


Figure 4. Thermal image of SiC power module power stage operating at ~ 250 °C junction.

### 3. Conclusions

APEI, Inc. will present these results and others at SSDM 2010 for our state-of-the-art extreme environment SiC power module development.

### Acknowledgements

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