INNOVATIVE PACKAGING DESIGN FOR ELECTRONICS IN EXTREME ENVIRONMENTS

Extreme environments and high currents pose challenges for designers in the power electronics industry. Using multiphysics simulation, Arkansas Power Electronics International has developed new packaging to improve the performance and thermal management of power electronics devices.

By **LEXI CARVER**

EVERY TIME YOU start your car, use your phone, or turn on a modern lamp, you're relying on a product from the power electronics industry. In addition to supplying products used by billions of people on a daily basis, this industry concerns itself with energy density, power density, customer safety, and cost per watt. Consequently, there is an obvious need for ways to analyze and refine designs for these devices while increasing efficiency and lowering cost.

» PUSHING LIMITS WHILE PREVENTING FAILURE

MECHANICAL, THERMAL, and electrical properties influence the performance and thermal management of power electronics devices; a temperature increase outside the specified operating conditions may cause failure or produce increased resistance, threshold drifts, and lower switching frequencies, all of which reduce efficiency and controllability. Parasitic inductances in device packaging create voltage spikes that shorten the lifetime of a device. Arkansas Power Electronics International, Inc. (APEI), a company that designs and manufactures high-efficiency power electronics, has addressed this problem by designing new packaging systems and power modules. Brice McPherson, a lead engineer at APEI, and his colleagues are developing power modules and discrete packages with better thermal management capabilities than the industry standard (see Figure 1). One of their designs has 25 percent reduced thermal resistance and half the inductance of the widely used transistor outline (TO) package.

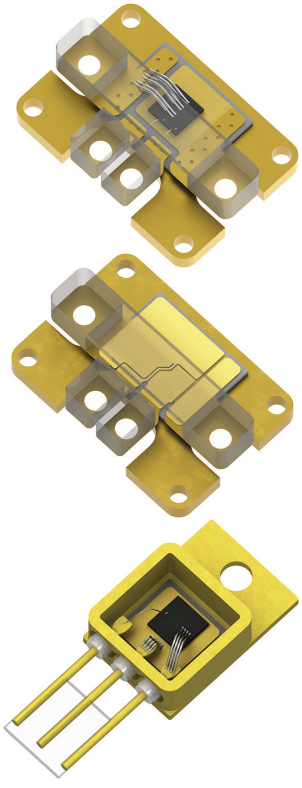

FIGURE 1: The custom SiC (top), custom GaN (middle), and TO (bottom) power modules.

Their goal is to create power modules with a packaging robust and flexible enough for use in many applications—one that is small and easy to configure, with good thermal conductivity and low inductance.

» SEMICONDUCTORS FOR EXTREME ENVIRONMENTS

A CLASS OF materials known as wide-bandgap semiconductors can operate stably at high temperatures and frequencies, and these materials therefore have an advantage over typical silicon-based power electronics. Systems based on wide-bandgap semiconductors may be more usable in extreme conditions—for example, in drilling equipment used at depths with higher pressures and temperatures than are currently reachable. It may even be possible to improve the survivability of equipment in environments as harsh as that on the surface of Venus.

Two materials have become the cornerstones for APEI's new designs: gallium nitride (GaN) and silicon carbide (SiC). For medium currents and thermal loads where extremely fast and efficient switching is required, GaN is optimal. For very high currents and thermal loading where large amounts of energy need to be processed in a small area—such as in a vehicular motor drive—SiC is the best choice. APEI worked with GaN Systems in Ottawa, Canada, a leading provider of high-performance GaN devices, to design the GaN power package. McPherson and his colleagues exploited the materials'

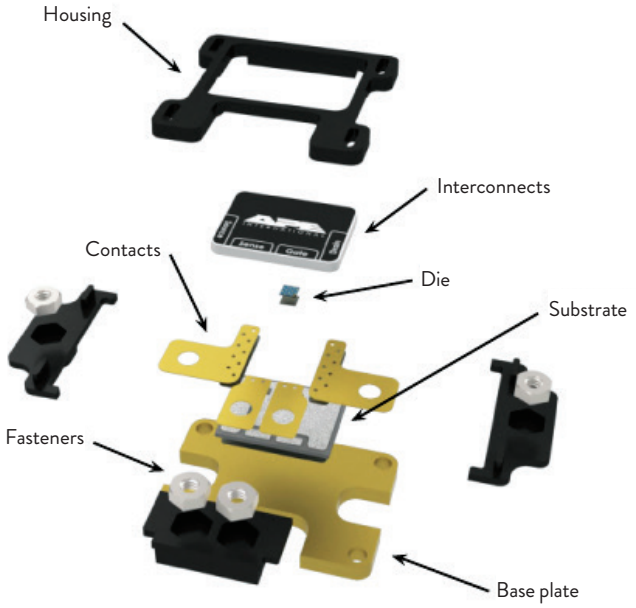

FIGURE 2: Power module components (above) and the assembled power module (bottom). Fully assembled, the entire device is a little larger than a quarter.

SiC Power Package	
Inductance	7.83 nH
Thermal Resistance	0.38°C/Watt
Operating Temp	225°C

properties to develop breakthrough power-packaging technology.

» IMPROVING PERFORMANCE THROUGH REDUCED THERMAL RESISTANCE AND INDUCTANCE

TO ACCOMPLISH THIS, they embarked on a search for the right combination of geometry and thermal and electrical properties to effectively optimize power density, weight, and switching frequency. They wanted a design that offered the ease of use and capabilities of a larger, higher-power module but was no larger than the TO option. Their new power module includes the die (the device), a copper base plate, contacts, interconnects, fasteners, a housing, and a metal substrate between the contacts and the base plate (see Figure 2).

McPherson combined his packaging and systems expertise with the simulation tools of COMSOL Multiphysics®. The LiveLink™ *for* SolidWorks® add-on let him directly import his geometry from SolidWorks® and run a parametric sweep analysis in COMSOL. He compared his designs, applied temperatures and voltage boundary conditions, and analyzed their electrical and thermal performances. He tested the effects of changing device dimensions, base plate thickness, substrate thickness, and material properties.

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> **—BRICE McPHERSON, LEAD ENGINEER, APEI**

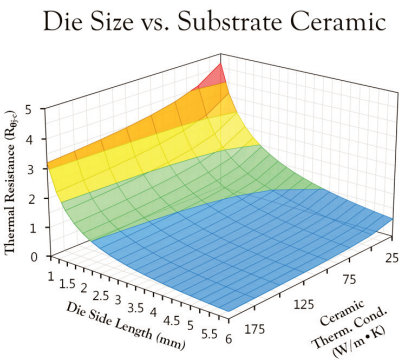

FIGURE 3: Parametric sweep showing how thermal resistance varies with changes in device size and thermal conductivity of the substrate.

One major benefit of the multiphysics modeling process was being able to model Joule heating and analyze the amount of heat generated in the conductors. "APEI specializes in high power density products, which need a lot of precise testing before they're perfected. It's very valuable to be able to simulate something before you invest money and time into prototyping and building it," McPherson says. The majority of the parametric sweeps he performed (one is shown in Figure 3) aimed to optimize thermal resistance, current-carrying capacity, and footprint.

"Designing for low thermal resistance involves selecting materials with high thermal conductivity, reducing the distance heat travels to leave the layers, and optimizing layer thickness to take advantage of thermal spreading," McPherson explains. "That's where parametric modeling is your best friend: You can set up parametric sweeps to find out exactly what's influencing

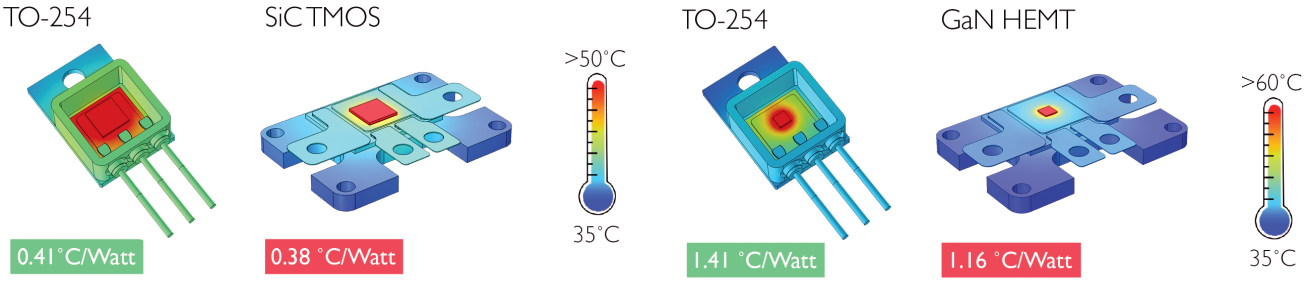

FIGURE 4: Thermal resistance results when comparing TO-254 to SiC (left) and TO-254 to GaN (right).

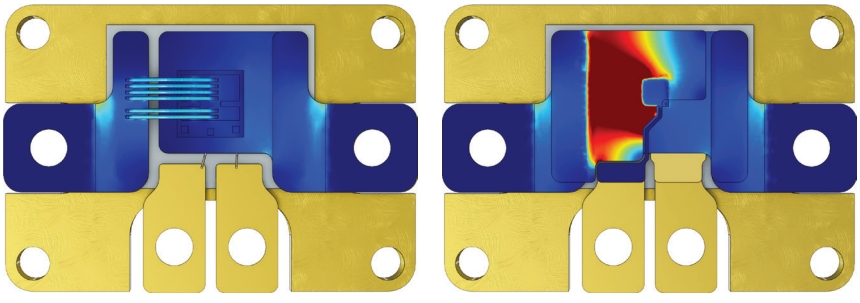

FIGURE 5: Current density gradients in the SiC (left) and GaN (right) geometries. In the SiC package, the current shows a relatively low density (preferred for higher currents), with the major concentrations found in the wire bonds. The GaN package has a higher average density, but more area available for conduction (ideal for low inductance).

the system the most and get the best compromise among performance, complexity, and cost." McPherson modeled a TO-254, a common TO transistor, to see how his designs (see Figure 4) compared.

Figure 5 gives a detailed view of current density in both packages. According to the simulations, APEI's power modules had lower thermal resistance than the TO-254 (see Figure 4). Even better, they both showed significantly lower inductance. The parameter with the greatest influence on the inductance turned out to be the device size, followed by the thickness of the base plate. To reduce inductance, it was critical to maximize the cross-sectional area of the device and minimize the current path length, while maintaining an acceptable thermal performance. The GaN module shows the least inductance, and the TO-254 exhibits the highest (12.98 nanohenries for the TO-254 vs. 7.5 nH and 7.83 nH for GaN and SiC, respectively). The current path length and conductor geometry drive the inductance trends, while the die size and material are less influential than in the thermal simulations.

> *"You can set up parametric sweeps to find out exactly what's influencing the system the most and get the best compromise among performance, complexity, and cost."*
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> —BRICE McPHERSON

APEI's new packaging is flexible enough to be used with either material, according to the needs of the customer. It operates well with GaN and SiC, which both allow for rapid, clean switching.

» APEI DELIVERS THE NEW PACKAGING STANDARD USING MULTIPHYSICS SIMULATION

MCPHERSON SUCCESSFULLY created a power module that improves on industry standards, with a packaging that ensures low inductance, good thermal management, and can be operated at temperatures over 225°C. His work demonstrates the potential of improving packaging to enhance current electronics technology and the use of a powerful simulation tool such as COMSOL to aid the design process. McPherson hopes that this design, with its strong thermal performance, will improve existing options but also open doors to new applications. His remarkable results are an encouraging move toward more efficient power modules, paving the way for power electronics to deliver higher currents and be used in more extreme conditions. Perhaps Venus is not so far away after all.