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How Silicon Carbide can Enable Next-generation Solid State Circuit Breakers

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The performance benefits which Silicon Carbide (SiC) devices are bringing to electric vehicles (EV) and solar photovoltaic (PV) applications are well versed. However, the material advantages of SiC can potentially be exploited in other applications, and circuit protection has been proposed as one such area. This article reviews developments in this field, including the merits of mechanical protection versus solid-state circuit breakers (SSCB) implemented with different semiconductor devices. Finally, it discusses why SiC will become an increasingly attractive option for SSCBs.

Protecting Electrical Infrastructure and Equipment
Electrical transmission and distribution systems and sensitive equipment require protection against extended overload and transient short-circuit conditions. With electrical systems and EVs using increasingly higher voltages, the maximum potential fault currents are higher than ever. Protecting against these high current faults requires ultra-fast AC and DC circuit breakers. While mechanical circuit breakers have traditionally been the most popular choice for this application, the increasingly demanding operating requirements have made solid-state based circuit breakers more popular. Commonly referred to as solid-state circuit breakers, they have several advantages over mechanical approaches:

Robustness and Reliability: Mechanical circuit breakers contain moving parts which make them fragile. This means they can be easily broken or accidentally trip due to movement and are subject to wear and tear each time they are reset over the course of their lifetime. In contrast, since SSCBs contain no moving parts, they are more robust and much less likely to suffer accidental damage, enabling them to be used repeatedly over thousands of cycles.

Temperature Flexibility: The operating temperature of mechanical breakers depends on the material used in their construction and limits the operating temperature, the operating temperature of SSCBs are higher then mechanical breakers and are settable.

Remote Configuration: Once tripped, a person must reset a mechanical breaker manually which can be both time-consuming and costly, especially when scaled across multiple installations, and it may also have safety implications. SSCBs can be reset remotely using either a wired or wireless connection.

Faster Switching and No Arcs: When a mechanical breaker is switched, arcing and voltage fluctuations large enough to damage load equipment can occur. The effects of these inductive voltage spikes and capacitive inrush currents can be protected against using soft-start methods in SSCBs, with much faster switching, in the order of a few microseconds, if a fault occurs.

Flexible Current Rating: Mechanical circuit breakers have a fixed current rating, whereas current ratings are programmable for SSCBs.

Reduced Size and Cost: Compared to mechanical breakers, SSCBs reduce weight, are significantly lighter and take up less space.

Limitations of Existing SSCBs

While SSCBs have advantages over mechanical breakers, they have some disadvantages, including limited voltage/current ratings, higher conduction losses, and they are more expensive. SSCBs are commonly based on TRIACs (silicon-controlled rectifiers) for AC applications or standard planar MOSFETs for DC systems. The TRIACs or MOSFETs implement the switching function, while optically isolated drivers act as the controlling element. However, high-current MOSFET-based SSCBs require heat sinks at high output currents meaning they cannot realize the same power density levels as mechanical circuit breakers.

Similarly, heat sinks are also required for SSCBs implemented using insulated gate bipolar transistors (IGBT) where saturation voltage causes excessive power loss for currents exceeding a few tens of amps. For example, at 500 amps, a voltage drop of 2V across an IGBT would dissipate 1000W. For this amount of power, a MOSFET would require an on-resistance of approximately 4 mΩ. This resistance level is not currently achievable with single devices with voltage ratings now heading for 800V (and beyond) in EVs. While this figure could theoretically be realized by connecting devices in parallel, such an approach would substantially increase solution size and cost, even more so where bi-directional current flow must be accommodated.

Using SiC Power Modules to Realize Next-generation SSCBs

A SiC die can be up to ten times smaller than its silicon equivalent for the same rated voltage and on-resistance. Furthermore, SiC devices can switch at least one hundred times faster and operate at peak temperatures more than twice that of silicon. At the same time, its superior thermal conductivity makes it more robust at high lower levels. onsemi has exploited these properties in its range of EliteSiC power modules with on-resistance values as low as 1.7mΩ for 1200V devices. These modules integrate between two and six SiC MOSFETs in a single package.

Sintered die technology (which joins two individual die inside a package) offers reliable product performance even at high power levels. This device's fast switching behaviour and high thermal conductivity allow it to quickly and safely 'trip' (open-circuit) an end application if a fault occurs, stopping current from flowing flow until normal operating conditions are restored. Modules like this show how it is increasingly possible to integrate multiple SiC MOSFET devices into a single package to deliver the low on-resistance values and small form factors required for practical circuit breaker applications. Furthermore, onsemi offers EliteSiC MOSFETs and power modules which withstand voltage ranging from 650V up to 1700V, meaning they can also be adapted for SSCBs in single and three-phase domestic, commercial and industrial applications. onsemi's vertically integrated SiC supply chain offers near-zero defects products which undergo exhaustive reliability testing to SSCB manufacturers.

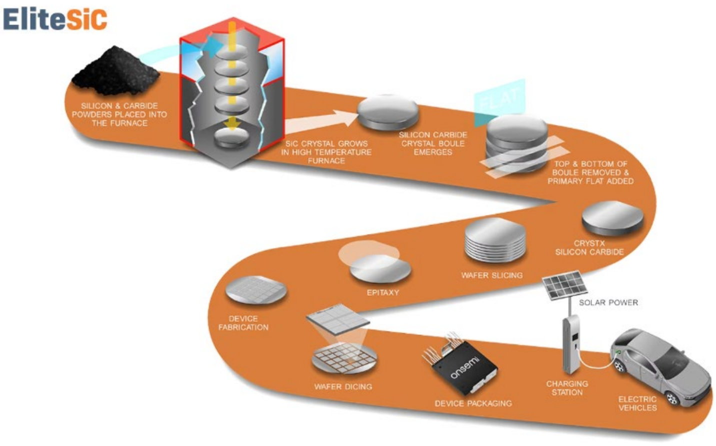


Figure 1: onsemi's Complete End-to-End Silicon Carbide (SiC) Supply Chain

Below figure shows implementation of SSCB in a module with multiple 1200V SiC die with multiple switches in parallel in a back to back configuration to achieve lowest rdson and optimized thermal dissipations. Fully integrated Modules as below with optimized pin-position and layout will help reduce parasites and improve switching performance and fault response times. onsemi offers a wide portfolio of SIC modules with 650V, 1200V and 1700V rated with modules with base plate and without base-plate based on the end application requirements and efficiency needs.

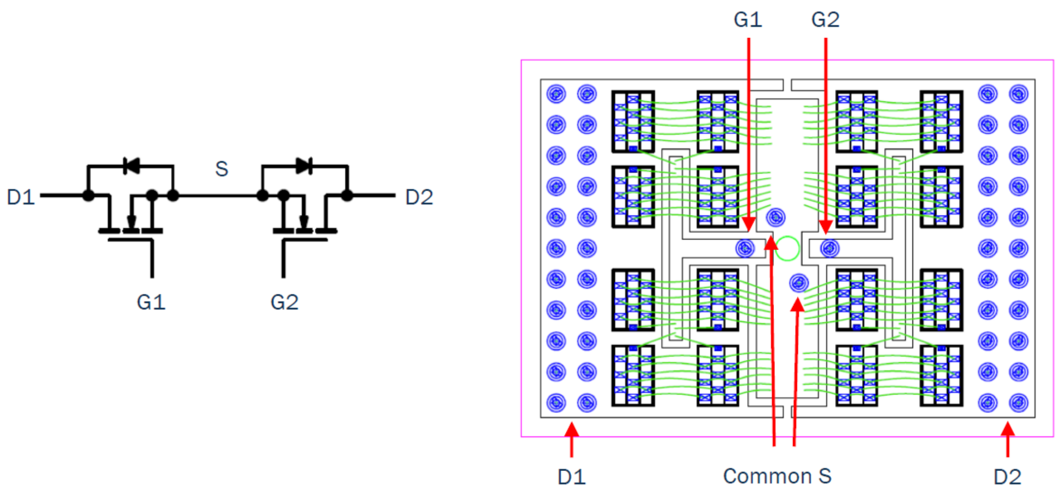
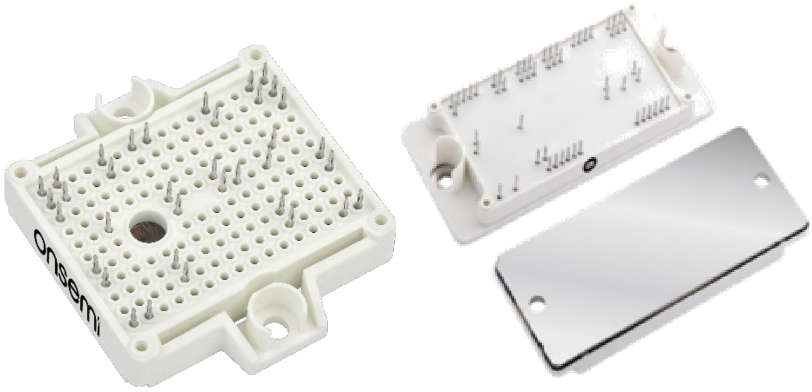


Figure 2: SiC B2B Module for Solid State Circuit Breaker- 480VAC -200A



F2 PIM (no-baseplate) Q2 PIM (with baseplate)

Figure 3 : onsemi modules addressing SSCB applications

SiC and SSCBs will Coevolve

Mechanical circuit breakers have low power losses and higher power density and are currently less expensive than SSCBs. Still, they are prone to wear and tear from repeated use and require costly manual maintenance associated with resetting or replacement. The demand for circuit breakers and SiC devices will continue to grow in line with increasing EV adoption, making this wide bandgap technology increasingly cost-competitive and increasing its attractiveness for use in SSCB solutions. As SiC process technology advances and the resistance of standalone SiC MOSFETs falls further, eventually reaching comparable levels to mechanical circuit breakers, power losses will become even less of an issue. Providing the benefits of fast switching, no arcing, and significant cost savings through zero maintenance, SSCBs constructed from SiC-based devices will inevitably become the norm.