# WIDE-BANDGAP SEMICONDUCTORS

Gallium Nitride, GaN - Silicon Carbide, SiC

## Introduction-motivation[i]

A new type of power transistor is becoming available that will impact the power electronics industry well into the 21st century. This transistor is fabricated using what is referred to as a *wide bandgap* (WBG) semiconductor. The principle WBG semiconductors for use in power electronics are gallium nitride (GaN) and silicon carbide (SiC). Traditional silicon (Si) is a narrow bandgap semiconductor. Compared to Si devices, WBG devices have several desirable characteristics. To name a few, they are more compact, have greater power density[1] and efficiency, are more reliable, and can operate at higher switching frequencies.

A few distinct advantages of utilizing SiC devices in inverters[2] are demonstrated below. In the first example, the inverter provides the AC power to drive an electric vehicle motor, and in the second the inverter is used to convert the DC voltage of a solar panel to AC.

### 1. Formula E all-electric vehicle performance enhancement through Inverter size and weight reduction

The performance of the Venturi Formula E Electric Vehicle (Figure 1) is enhanced through the significant reduction of the size and weight of the inverter, designed utilizing the ROHM SiC power module[ii]. As shown in Figure 2, the season 4 inverter is 43% smaller and 6kg lighter than the inverter used in season 2.

*Figure 1 Venturi Formula E Electric Vehicle. (Source: ROHM Semiconductor)*

[1] Power density is a measure of power output per unit volume. If a device has high power density, then it can output large amounts of energy based on its volume. For example, a tiny capacitor may have the same power output as a large battery, but because the capacitor is so much smaller, it has a higher power density.

[2] Inverters are primarily used in high power applications for converting DC to AC.


*Figure 2 Inverter size and weight reduction. (Source: ROHM Semiconductor)*

## 2. Substantial decrease in size, weight, power losses, and material costs of PV string inverters

Figure 3 presents a comparison of a typical 50kW Si IGBT (Insulated Gate Bipolar Transistor) string inverter and a Cree-designed 50kW SiC-based string inverter for solar energy conversion[iii]. The SiC-based inverter is one-fifth the weight and volume of the Si IGBT-based inverter; overall inverter losses are also reduced by 40 percent. These performance improvements are possible due to the fundamental properties of SiC technology, to be discussed in a later section. As shown in Figure 4, the use of SiC technology in the string inverter also results in a 15% reduction in the overall bill of materials cost.


*Figure 3 Relative size comparison of a typical 50 kW Si IGBT string inverter and a Cree-designed 50 kW SiC-based string inverter demonstration unit. (Source: Cree)*

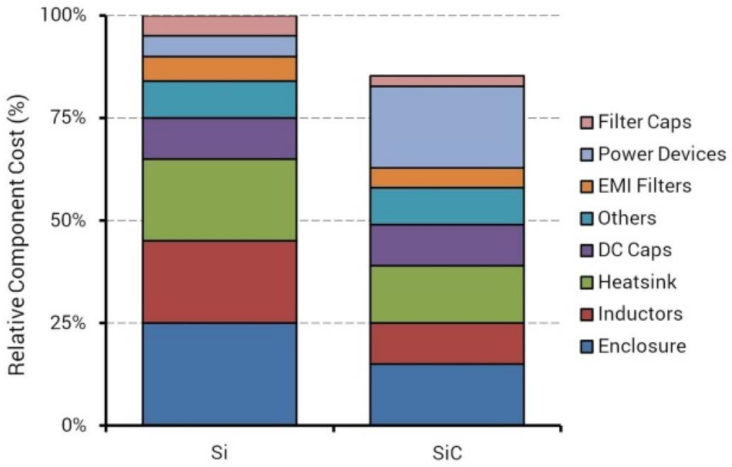


*Figure 4 Relative component costs within Si IGBT-based and SiC MOSFET-based 50 kW string inverter.*

Silicon (Si) has been the leading semiconductor material since the mid-20$^{th}$ century, and it has been one of the primary building blocks of the power electronics industry. However, the need for using energy more efficiently is bringing about a shift to WBG semiconductors, which are smaller, faster, more reliable, more durable and more efficient than silicon. The automotive sector is a prime example. Both GaN and SiC are becoming attractive in internal combustion engine (ICE), hybrid (H), and hybrid electric (HE) automotive applications (Figure 5). As 48 DC volts becomes the standard automotive DC bus voltage, conversion from 48v to 12v, as well as other DC-DC, DC-AC, and AC-DC conversions will be needed in emerging automotive applications such as LIDAR for driver-assisted technology, high intensity headlights, infotainment, etc. WBG semiconductors have the potential for significantly increasing the power efficiency in these subsystems.


*Figure 5 Application of WBG devices in the automotive sector.*

WBG semiconductors are expected to bring about energy-saving innovations in a variety of areas, including:

Energy Delivery

- Solar inverters and grid integration
- Telecom/5G
- Uninterruptible power supplies (UPS)
- Data center server power supplies

Consumer

- Wireless chargers
- HDTV power supplies
- Audio amplifiers

Industrial

- DC/DC converters[3]
- Factory automation and robotics
- Medical imaging
- Motor drives
- Drones

Automotive

- AC traction drives
- Onboard/offboard chargers

[3] A voltage converter changes the voltage (either AC or DC) of an electrical power source. There are two types of voltage converters: *step up converters* (which increase voltage) and *step down* converters (which decrease voltage).

- Light Distancing and Ranging (LIDAR)
- DC/DC converters

**Module Overview**

In section 1 the history of the development of WBG power devices is presented. This is followed in section 2 by a discussion of their numerous advantages and their use as switching devices. In section 3 the structure and operation of WBG devices are reviewed. Device driving issues and typical circuitry are considered in section 4. In section 5, applications and sample circuit block diagrams are presented. A case study of high power inverters with application to photovoltaics or electric vehicles is described in the final section.

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[i] Webinar presented by Consultant Paul Pickering, March 14, 2019. To view, register at: ON Semiconductor: Webinar: The Fundamentals of Wide Bandgap Semiconductors for Power-Efficient Design, www.onsemi.com

Texas Instruments Training Video:
Suxuan Guo, "How to driver SiC MOSFETs the right way," October 9, 2017,
How to drive SiC MOSFET…. The right way !! | TI.com Videos

[ii] "ROHM supplies full SiC power modules to Formula E Racing Team Venturi," ROHM Semiconductor, https://www.rohm.com/news-detail?news-title=rohm-supplies-full-sic-power-modules-to-formula-e-racing-team-venturi&defaultGroupId=false

[iii] Marcelo Schupbach, "*The Impact of SiC on PV power economics,"* 2015, The impact of SiC on PV power economics - Electronic Products, www.electronicproducts.com