# Compact Models for Silicon Carbide Power Devices

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## I. Introduction

Recently, silicon carbide (SiC) power devices have begun to emerge with performance that is superior to that of silicon (Si) power devices. Prototype devices have already demonstrated improvements over Si technology for devices of various current and voltage ratings [1,2], and SiC Schottky diodes have already become made commercially available.

In order for circuit designers to fully utilize the advantages of the new SiC power device technologies, compact models are needed in circuit and system simulation tools. Physics-based models, as represented in Fig. 1, are preferred over empirical or semi-empirical models in order to obtain a better fit to measured data over a wide range of application conditions, and to provide known and extractable parameters, such as dopant density, base width, device area, and mobility, to name a few. SiC material physics and the resulting structural designs are an important aspect of developing SiC power devices models that are applicable over a wide range of application conditions.

## II. Modeling Silicon Carbide Power Device Characteristics

Silicon Carbide, specifically, 4H-SiC, has an order of magnitude higher breakdown electric field ($2\times10^6$ V/cm to $4\times10^6$ V/cm) than silicon, thus leading to the design of SiC power devices with thinner (0.1 X Si devices) and more highly doped (10 X higher) voltage-blocking layers. For majority carrier power devices such as power MOSFETs, this combination can yield a SiC device with a 100 X advantage in resistance compared to that of Si majority carrier devices. This resulting output characteristics of such a device are shown in Fig. 2. For a typical Si MOSFET the output curves are linear in the on-state region and have a pronounced change in curvature as the pinch-off region is approached. This occurs because the Si power MOSFET has a large epitaxial layer resistance in series with the MOSFET channel, and the channel has a very high transconductance. The SiC curves in Fig. 2 on the other hand, gradually transition from the linear region to the saturation region. In SiC MOSFETs, the epitaxial layer resistance is much smaller and the channel resistance is higher, thus making the MOSFET channel a more significant contributor to the on-state voltage. This is due to the low channel surface mobility of SiC compared to Si. Because the SiC curves have less resistance in series with the MOSFET channel, an enhanced linear region transconductance model is essential for these devices [3].

The SiC PiN diode also exhibits different characteristics due to the thinner, more highly doped base, as compared to Si PiN diodes. The higher doping in the base region, along with lower doping in the emitter and end regions due to deeper impurity levels in SiC, result in minority injection from the base into the emitter and end regions dominating forward conduction at much lower current densities. This can be seen in Fig. 3, where the total charge in the base or area under the current-time curve stops increasing after 2 A of forward current, yielding emitter and end region recombination currents dominating above 2 A. The SiC diode model utilizes separately extractable diode model parameters, saturation current and ideality factor [4,5], to predict the end region effects.

Fig. 4 shows the SiC MOSFET simulated and measured turn-on waveforms versus gate resistance under resistive load conditions. The ion implantation method used to construct the DiMOSFET results in shallower p-well depths with less resistance between the p-wells. As a result, the gate-drain overlap area in the SiC DiMOSFET can be made much smaller than for the Si VDMOSFET. Furthermore, neck region implants can be avoided, resulting in a lower effective gate-drain capacitance, which increases the speed during the plateau region.

The temperature dependent material properties are also important when using physics-based models to predict the terminal characteristics of the SiC devices [6]. There are two types of temperature dependencies used to model devices. First, there are functional expressions, such as the temperature dependence of the threshold voltage or transconductance, which utilize equations that are independent of structural parameters, e.g. gate thickness or dopant density. On the other hand, there are well-characterized physical expressions that model the change in physical properties over a wide range of temperatures, such as the carrier mobility expression that is used to describe the temperature dependence of the base resistance $R_b$ from Fig. 1, and the bandgap expression that is used to describe the temperature dependence of the diode saturation currents as shown in Fig. 5.

## III. Conclusion

In order to accurately predict device characteristics over a wide range of application conditions, a physics-based approach is used to model SiC power devices. Different structural properties, such as a thinner more highly doped base region, or material properties, such as carrier mobility and bandgap, result in different compact modeling methods as compared to silicon technology.

## References

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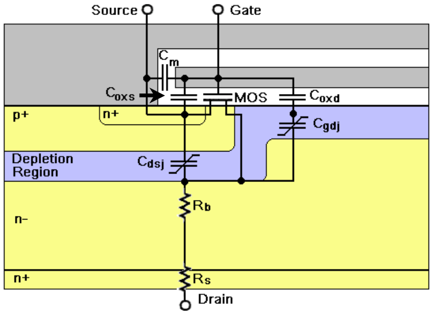

Fig. 1. Representation of physics-based model of VDMSOFET.

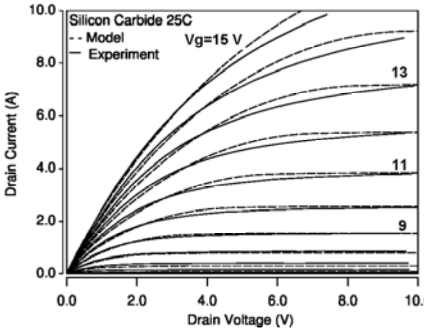

Fig. 2. SiC DiMOSFET output characteristics.

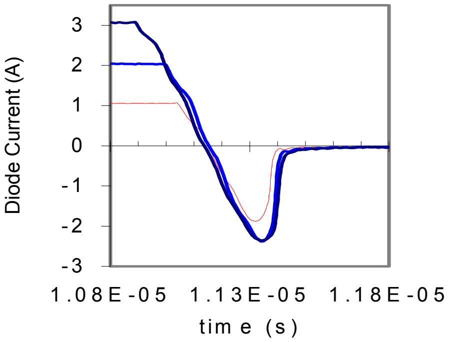

Fig. 3. End and emitter recombination efects on reverse recovery.

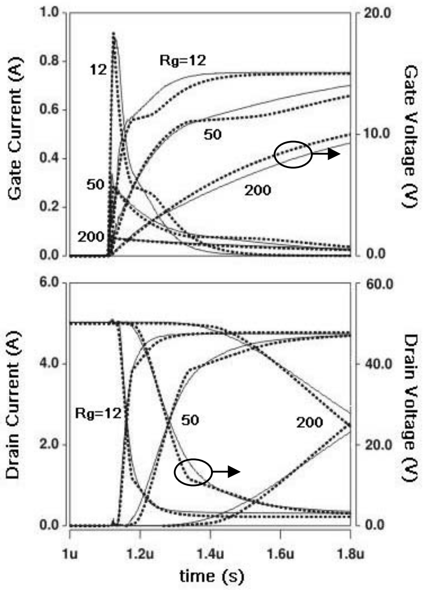

Fig. 4. SiC DiMOSFET switching characteristics vs gate resistance.

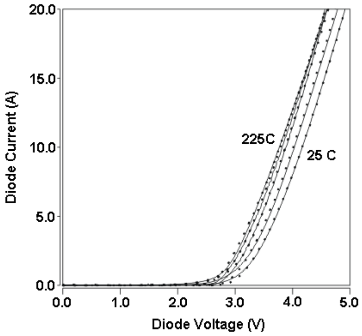

Fig. 5. SiC 5 kV, 20 A PiN diode on-state characteristics.