

# The advantages and short circuit characteristics of SiC MOSFETs

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**Abstract.** SiC MOSFETs have exhibited considerable benefits in high-frequency, high-voltage, and high-temperature power electronics applications with outstanding material attributes as a result of the rapid advancement of power electronics technology. SiC MOSFETs' slower short-circuit tolerance and faster switching rates provide new issues for the short-circuit prevention technology. In the opening section of the study, Si and SiC MOSFETs are compared and evaluated using various models and parametric factors. It has been demonstrated that SiC MOSFETs outperform Si MOSFETs in a variety of conditions and applications. The many SiC MOSFET short-circuit failure types as well as their underlying theories are initially explained in the paper's main body. In addition, it examines the fundamentals of short-circuit test procedures and SiC MOSFET test circuits. The issues and limitations of the currently available SiC MOSFET short-circuit protection technology are then explored, along with factors impacting the short-circuit of SiC MOSFETs that are thoroughly examined. Lastly, the SiC MOSFET short-circuit protection technology development trend is forecasted, and potential future areas for improvement and innovation are considered. SiC MOSFET short-circuit protection technology will be enhanced and optimized to satisfy the needs of efficient and dependable power electronic systems as technology advances and application requirements expand.

**Keywords:** SiC MOSFET, Short-Circuit Characteristics, Short-Circuit Test, Si MOSFET.

## 1. Introduction

SiC MOSFETs have attracted a lot of interest in power electronics due to their better material properties, particularly in high-temperature pressure sensors [1]. Silicon carbide (SiC), a semiconductor material with a wider bandgap than silicon, offers remarkable electrical performance in a number of applications [2]. MOSFETs are gaining popularity because to their high operating frequency and low switching loss. In order to progress quickly, SiC MOSFETs must also be able to block more voltage and switch more quickly. SiC MOSFETs are more efficient and have higher switching frequencies than Si IGBT modules because they have lower switching losses. In hard-switched converters, SiC MOSFETs can switch at frequencies up to 100 kHz, resulting in smaller filters and higher power densities.

Additionally, silicon carbide technology provides improved material characteristics and solutions for a variety of problems. With ten times the dielectric breakdown field strength, three times the bandgap, and three times the thermal conductivity of silicon, silicon carbide is a desired material that performs

well. The main advantage of the gate oxide is its high electric field rating, which makes it a preferred choice for high-voltage and high-temperature applications [3].

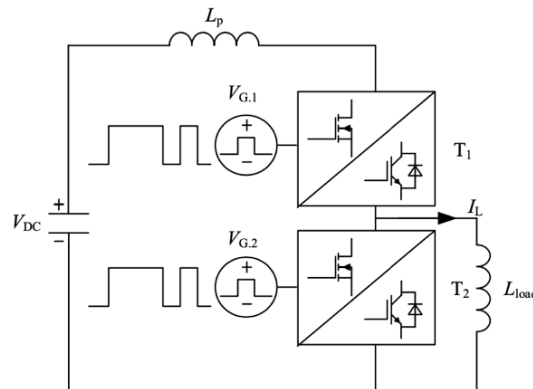
## 2. Short-circuit fault type and principle

According to the switching tube's operational state just prior to the short-circuit fault, there are two main types of short-circuits: hard switching short circuits (HSF) and short circuits under load (FUL) [4]. Table 1[5] illustrates these divisions. A switching tube in a hard-switching short circuit is one that shorts out before conduction, meaning that it is open when the short-circuit fault, such as a shoot-through, takes place. A switching tube in a load short circuit is one that is operating normally when the short-circuit is brought on by a fault [6].

**Table 1.** Types and characteristics of short circuits [5].

Type	Location	Reason	Characteristics
<b>Type I short Circuit</b>	shoot-through	Hardware failure, software failure	Circuit inductance(nH Level)
<b>Type II short circuit</b>	Short circuit between phases	Short circuit between phases, short circuit to ground	Circuit inductance ( $\mu$ H Level)

Using Figure 1 as an illustration, it is ideal that T1 and T2 are two devices with similar models, traits, and driving settings when a bridge arm series short circuit fault occurs. The driving parameters for T1 and T2 are represented in the footnote by the numbers  $x(x = 1, 2)$ . When T2 is malfunctioning while T1 is in normal conduction, they produce a series short circuit, which causes the short-circuit current  $I_{sh}$  to grow quickly. T1 short-circuits in the on-state, which belong to the second type of short-circuit, and T2 short-circuits in the opening moment, which belong to the first type of short-circuit, are classified by the short-circuit type [7].



**Figure 1.** Principle of the double-pulse test [7].

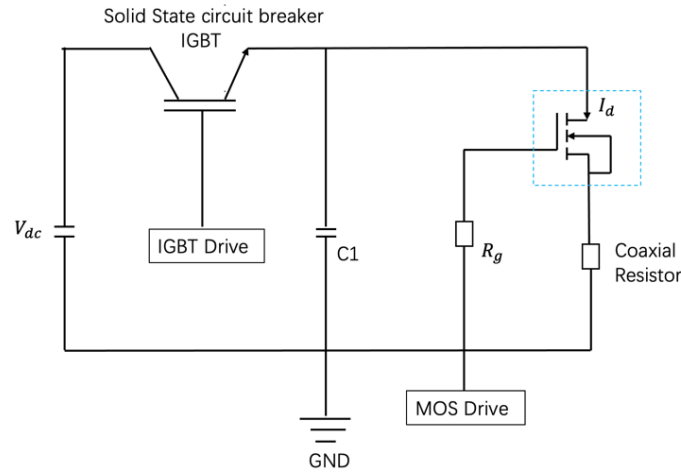
During this process, the voltages across T1 and T2 fluctuate until a constant state is reached. The selection of the series short-circuit time should pay attention to repeat the series short-circuit experiments in various situations without damaging the apparatus; at the same time, the characteristics of the series short-circuit are obvious in the selected time and are gradually stabilized with the extension of the time; in addition, the short-circuit duration of the SiC MOSFETs is shorter than that of the Si IGBTs, and the duration of the series short-circuits varies depending on the parameters of the devices.

## 3. Test circuit and Short-circuit test method

### 3.1. Test circuit

A short-circuit test circuit is created in accordance with the fundamental idea depicted in Figure 2 in order to investigate the short-circuit performance of SiC trench-gate MOSFETs. The solid-state circuit

breaker is primarily made up of an IGBT and a current-continuing diode so that if the device being tested malfunctions, the entire circuit will enter an overcurrent state, causing damage to other components. The bus voltage is one of them, and it is provided by a film capacitor bank [8], which is used to provide the energy needed for short-circuiting and to ensure that the voltage at the two ends of the drain source of the device to be tested remains stable. The coaxial resistor is in charge of measuring the current flowing between the leakage sources during the short-circuit process, while the solid-state circuit breaker is in charge of terminating the entire short-circuit process after detecting the overcurrent state to protect other components [9].



**Figure 2.** Schematic of short-circuit test principle [9].

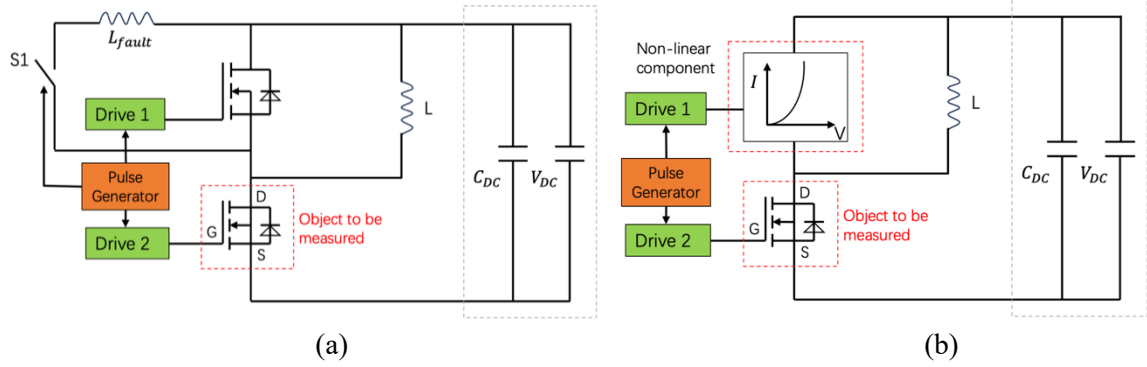
### 3.2. Short circuit test method:

The short-circuit test is a crucial technique for examining the short-circuit properties of power devices and evaluating the effectiveness of short-circuit safety circuits. Table 2 lists the two popular SiC MOSFET short-circuit test techniques now in use, along with each method's benefits and drawbacks and situations in which it is appropriate.

**Table 2.** Comparison of SiC MOSFET short-circuit test methods [6].

Types	Pros and Cons	Applicable occasions
Short-circuit test method based on double-pulse testing	Pros: Simulates real short-circuit conditions Cons: Can easily cause damage to the device under test	Ideal for testing the performance of short-circuit protection circuits
Non-destructive short-circuit test method based on non-linear components	Pros: Effective protection of the device under test Cons: Cannot truly reflect the short-circuit conditions	Suitable for device short circuit performance testing

(1) Double-pulse test technique based short-circuit test. In order to replicate a short circuit using this technique, a “thick and short copper bar” is used in place of the load inductance in the double-pulse test circuit, as illustrated in Figure 3(a). The upper bridge SiC MOSFET is turned on when the pulse generator sends a high-level signal to driver 1, and the HSF is realized when the pulse generator sends a high-level signal to driver 2. The FUL is realized when the pulse generator sends a high-level signal to the short-circuit control switch S1, which causes the fault inductance  $L_{Fault}$  to enter the power circuit.



**Figure 3.** Different SiC MOSFET short circuit test methods. (a) Short-circuit test method based on double-pulse test and (b) Non-destructive short-circuit test method based on non-linear elements [6].

(2) A non-destructive way of testing a short circuit based on non-linear components. Figure 6 displays several SiC MOSFET short-circuit test procedures. As seen in Fig. 3(b), the technique entails stringing a nonlinear element [10,11] within the test SiC MOSFET's short-circuit loop. In comparison to the SiC MOSFET, the nonlinear element has a reduced saturation current and a low internal resistance at rated current. When the pulse generator first activates the nonlinear element through driver 1 and then activates the test device through driver 2, the HSF may be reproduced. When the short-circuit current approaches the element's saturation current, it can no longer flow. The short-circuit current is restricted when it approaches the element's saturation current, and the element "fuses" if it continues to rise.

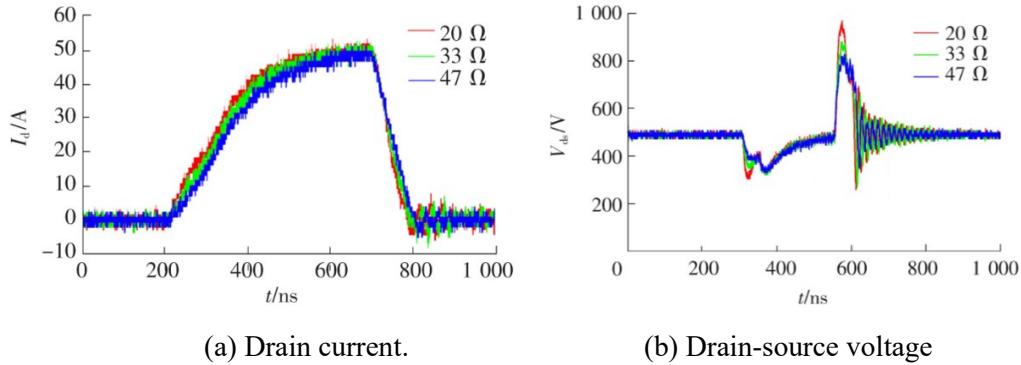
#### 4. The factors affecting the short-circuit

##### 4.1. Effects of gate resistance

In addition to the internal characteristics of the device, SiC MOSFET switching speed is strongly correlated with the gate resistance in the external driving circuit [12]. that is,

$$I_g = \frac{V_{gs} - V_{miller}}{R_g} \quad (1)$$

$I_g$  stands for the gate drive current in Equation 1, and  $V_{miller}$  for the Miller plateau voltage.  $R_g$  calculates the size of  $I_g$  from equation (1) when  $V_{gs}$  is constant.  $R_g$  will impact the SiC MOSFET's turn-on speed because  $I_g$  impacts the input capacitance's ( $C_{iss}$ ) charging and discharging rate. The experimental platform is used to conduct short-circuit comparison experiments by changing  $R_g$  (the internal gate resistance of the device under test is 6.5) while keeping the other conditions constant ( $V_{DC} = 500$  V, single pulse time is 2 s,  $C_{gs} = 0$  nF). This allows us to assess the impact of  $R_g$  on the short-circuit characteristics. Figure 4 illustrates how  $R_g$  affects the drain current and the voltage between the drain and source. [13]



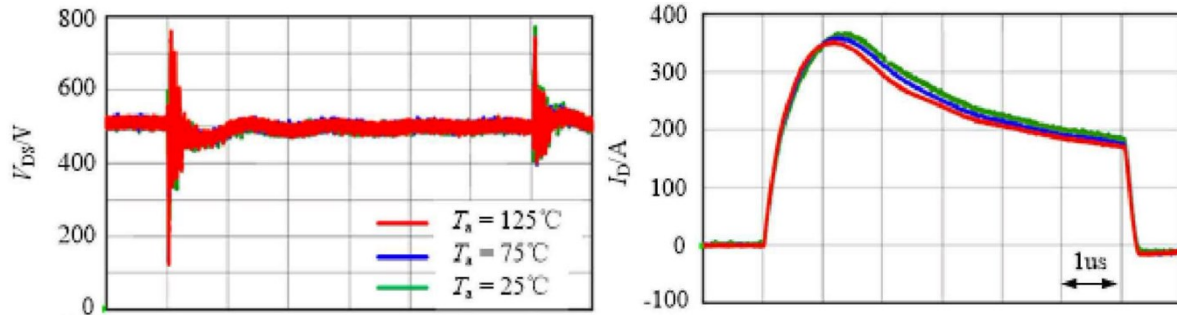
**Figure 4.** Effect of  $R_g$  on the short-circuit characteristics of SiC MOSFET [13].

Figure 4(a) shows that, although  $R_g$  has little impact on the short-circuit current, the greater  $R_g$  is, the slower the slope of the increase of  $I_d$  is during short-circuit, the lower the peak value, and the lower the slope of the fall of the current is during the shutdown. As observed in Figure 4(b), raising  $R_g$  has a better suppressant effect on the overshoot and oscillation of the turn-off voltage. Therefore, a greater gate shutdown resistance (soft shutdown) can be employed in the design of the short-circuit fault shutdown strategy to meet the goal of suppressing the shutdown voltage spikes and oscillations in order to lessen the voltage stress on the device during fault shutdown [13].

#### 4.2. Effect of operating temperature

According to the datasheet, when the operational temperature rises, the SiC MOSFET's on-resistance rises as well. This causes the short-circuit circuit's impedance to climb along with the temperature, which in turn causes the peak to short-circuit current to drop. The SiC MOSHET short-circuit waveforms at various operating temperatures are shown in Figure 5. When conducting a short-circuit test, the shed driving voltage is held constant at 20 V, the bus voltage is held constant at 500 V, and the operating temperatures of the SiC MOSFETs are set to 25°C, 75°C, and 125°C using a heating table. It can be seen that as the temperature increases, the peak short-circuits current of the SiC MOSFETs decreases.

Nonetheless, SiC MOSFETs are known for their outstanding temperature performance, and the increase in temperature has a limited effect on their on-resistance, so the effect of temperature change on the peak short-circuits current of SiC MOSFETs is also limited [14]. As a result, the effect of temperature change on the peak short-circuits current of SiC MOSFETs is not significant.



**Figure 5.** Short-circuit waveforms of SiC MOSFETs at different operating temperatures [30].

## 5. Conclusion

In summary, SiC MOSFETs have a lot going for in the field of high-frequency, high-voltage, and high-temperature power electronics applications, but instead it also come with some new difficulties due to the fast-switching speeds and weak short-circuit tolerance. This paper proves that SiC MOSFETs offer performance advantages over Si MOSFETs in various environments and scenarios. It does this through

a comparison study of Si MOSFETs and SiC MOSFETs, experiments using different models, and parametric variables. The principles of SiC MOSFET test circuits and short circuit test methods are analyzed, and various SiC MOSFET short circuit types and test methods are discussed in detail in the main paragraphs. The issues and difficulties of the current SiC MOSFET short circuit protection techniques in applications are also discussed, along with a thorough analysis of the factors influencing the short circuit of SiC MOSFETs.

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