

## ***Turn-Off Characteristics of SiC JBS Diodes***

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### **Abstract**

SiC junction barrier schottky (JBS) diodes, as majority carrier devices, have very different turn-off characteristics from conventional Si PiN diodes. The specification data presented in the datasheets are not enough to fully cover the turn-off characteristics of SiC JBS diodes. This application note presents comprehensive experimental results to reveal the turn-off behavior of SiC JBS diodes and serves as a supplement to the datasheets.

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## 1 Introduction

SiC JBS diodes are majority carrier devices and have no minority carriers injected into and stored in the drift layer during normal forward operation. Therefore, unlike Si PiN diodes, SiC JBS diodes have no stored charge or stored charge related reverse recovery time and can be turned off much faster.

Like any other semiconductor device, SiC JBS diodes must develop a depletion region in the drift layer in order to support a high voltage during off-state. The depletion region forms a junction capacitor in the device, which means the turn-off process of the SiC JBS diodes is essentially the charging process of the junction capacitor. The junction capacitor is fully determined by the design which makes the turn-off process of the SiC JBS diodes independent of temperature and forward current level.

During the turn-off transient, a reverse current must be developed to charge the junction capacitor. The required total charge,  $Q_c$ , is provided in the datasheets.  $Q_c$  can be measured or more accurately can be calculated by integrating the  $C_j$  vs.  $V_r$  curve of the JBS diode. The charge  $Q_c$  is completely determined by the JBS design, independent of temperature, forward current level, and  $di/dt$  rate. It will be shown that this parameter alone is sufficient to describe the recovery transient of the SiC JBS Diode.

This application note presents comprehensive experimental results to verify the above conclusions and gives a complete picture of the turn-off behavior of SiC JBS diodes.

## 2 Experiment Setup

Fig.1 shows the experiment setup used to measure the capacitive charge  $Q_c$  of a SiC JBS diode. It is a double-pulse test setup with the switch placed on the high-side so that a wide bandwidth single-ended voltage probe can be used to measure the diode voltage accurately. A SiC cascode is used as the switch. All experiments are performed at a DC bus voltage ( $V_{BUS}$ ) of 800V. The current of the JBS diode is measured with a current transformer and the  $Q_c$  is obtained by integrating the measured current waveform. For comparison, Fig. 2 presents the capacitive charge  $Q_c$  of USCi's 1200V SiC JBS diodes calculated by integrating the typical  $C_j$  vs.  $V_r$  curve.

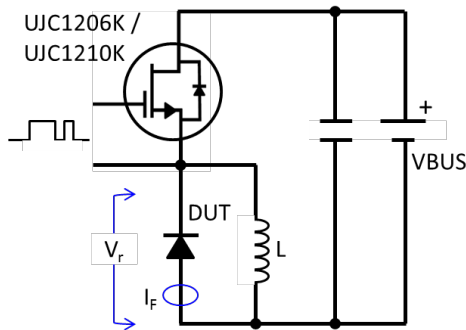


Fig. 1: Experiment setup for measuring the capacitive charge  $Q_c$  of a SiC JBS diode.

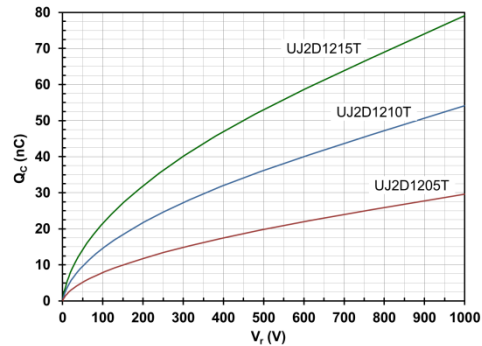


Fig. 2: Capacitive charges  $Q_c$  of USCi's 1200V SiC JBS diodes obtained by integrating the typical  $C_j$  vs.  $V_r$  curves.

### 3 Experimental Results

#### 3.1 $Q_c$ at Different Forward Currents $I_F$

Fig.3a shows the measured turn-off waveforms of the 1200V-15A SiC JBS diode UJ2D1215T at the forward current  $I_F$  equal to 6A and 16A. It is seen from Fig.3a that the reverse current oscillation is slightly larger and the turn-off speed is slightly faster at  $I_F = 6A$  because the switch (UJC1206K) turns on faster at a lower current. The switching time  $t_c$  of the JBS diode can be defined as the time interval between the time of zero-crossing of  $I_F$  to the time of  $V_r$  reaching 90% of  $V_{BUS}$ . Thus, the switching time  $t_c$  of UJC1215T is 33ns at  $I_F = 6A$  and 36ns at  $I_F = 16A$ .

Fig.3b shows the measured capacitive charge  $Q_c$  by integrating the reverse current waveforms starting at  $t = 55ns$  where the forward currents  $I_F$  cross zero. It is seen that the measured  $Q_c$  is basically the same at  $I_F = 6A$  and  $I_F = 16A$ , confirming that the capacitive charge  $Q_c$  is independent of the forward current level. It also can be seen from Fig.3b that the measured  $Q_c$  is very close to the  $Q_c$  obtained by integrating the typical  $C_j$  vs.  $V_r$  curve, indicating the “reverse recovery charge” of SiC JBS diodes is capacitive charge in nature.

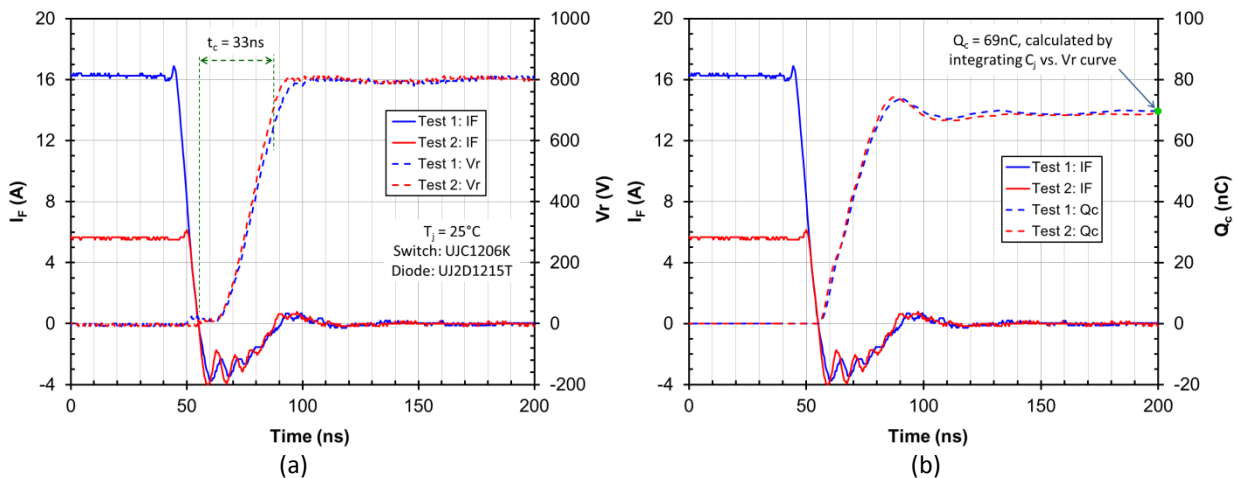


Fig.3: Measured turn-off waveforms of the 1200V-15A SiC JBS diode UJ2D1215T at different forward currents (a) and measured capacitive charge  $Q_c$  by integrating the reverse current waveform (b).

#### 3.2 $Q_c$ at Different Junction Temperatures $T_j$

Fig.4 presents the measured turn-off waveforms of the 1200V-15A SiC JBS diode UJ2D1215T at  $T_j = 25^\circ C$  and  $150^\circ C$ . It is seen that there is almost no change in the turn-off current and voltage waveforms when the junction temperature is increased from  $25^\circ C$  to  $150^\circ C$ , confirming that the turn-off characteristics of the SiC JBS diodes is independent of the junction temperature.

#### 3.3 $Q_c$ at Different $di_F/dt$ Rates

Fig.5 shows the measured turn-off waveforms and the capacitive charge  $Q_c$  of the 1200V-15A SiC JBS diode UJ2D1215T at different  $di_F/dt$  rates. The  $di_F/dt$  rate is measured at the zero-crossing point of the forward current  $I_F$ . When the  $di_F/dt$  rate is increased, the peak reverse current is also increased correspondently. But the measured capacitive charge  $Q_c$  has no change with the increase of the  $di_F/dt$  rate.

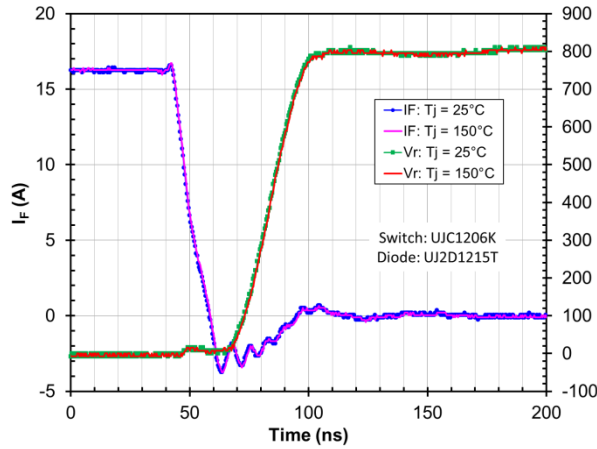


Fig.4: Measured turn-off waveforms and capacitive charge  $Q_c$  of the 1200V-15A SiC JBS diode UJ2D1215T at  $T_j = 25^\circ\text{C}$  and  $150^\circ\text{C}$ .

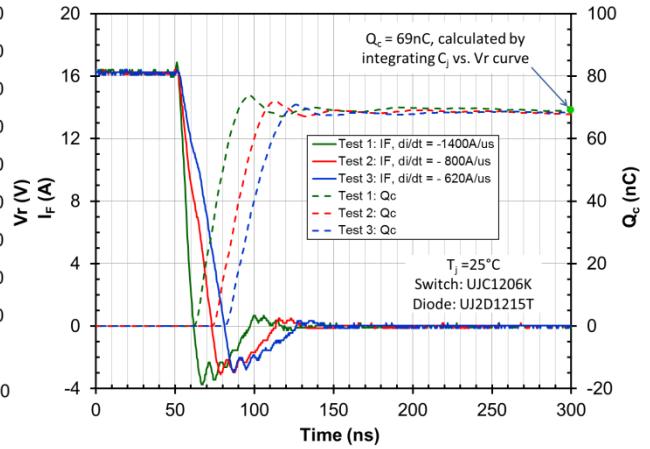


Fig.5: Measured turn-off waveforms and capacitive charge  $Q_c$  of the 1200V-15A SiC JBS diode UJ2D1215T at different  $dI_F/dt$  rates.

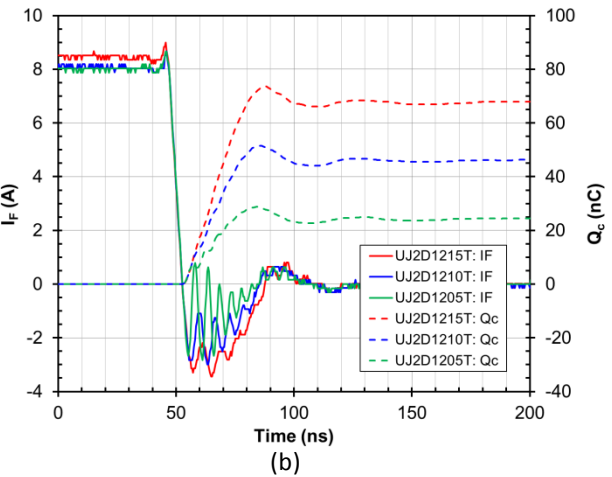
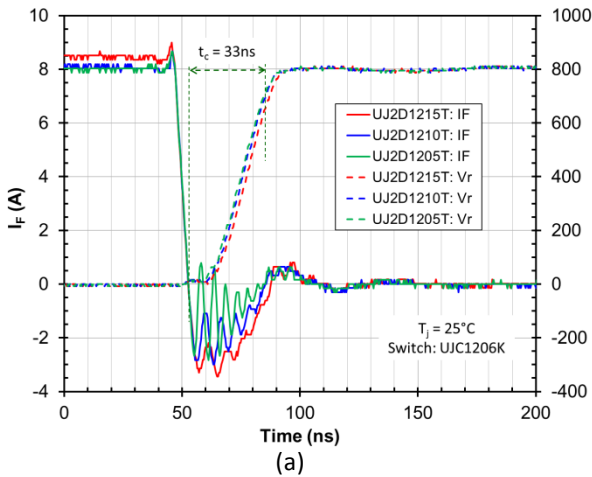


Fig.6: Measured turn-off waveforms (a) and capacitive charge  $Q_c$  (b) of the 1200V SiC JBS diodes UJ2D1215T, UJ2D1210T, and UJ2D1205T at  $T_j = 25^\circ\text{C}$ . Switch: UJC1206K.

### 3.4 Switching Time $t_c$

The switching time  $t_c$  of SiC JBS diodes is essentially the time it takes to charge the junction capacitor  $C_j$  from 0V to the DC bus voltage  $V_{BUS}$ . This capacitor charging process is strongly dependent on the testing system setup, such as the system RC time constant and the switching speed of the switch, etc. Therefore, the switching time  $t_c$  is not a good parameter for describing the switching performance of SiC JBS diodes and is not provided in the datasheets of USCI's SiC JBS diodes.

Fig.6 shows the measured turn-off waveforms and capacitive charge of USCI's 1200V SiC JBS diodes UJ2D1215T, UJ2D1210T, and UJ2D1205T. The USCI's 1200V SiC cascode UJC1206K is used as the switch. It is seen that these three SiC JBS diodes display basically the same switching time  $t_c$  of about 33ns even though they have very different capacitive charges  $Q_c$  and current ratings. This indicates the switching time  $t_c$  is pinned by the testing system or the switch UJC1206K. When the status of the testing system is changed, for example the switching speed or  $dI_F/dt$  rate is increased, the switching time  $t_c$  will change accordingly. Fig.7 the switching time  $t_c$  of

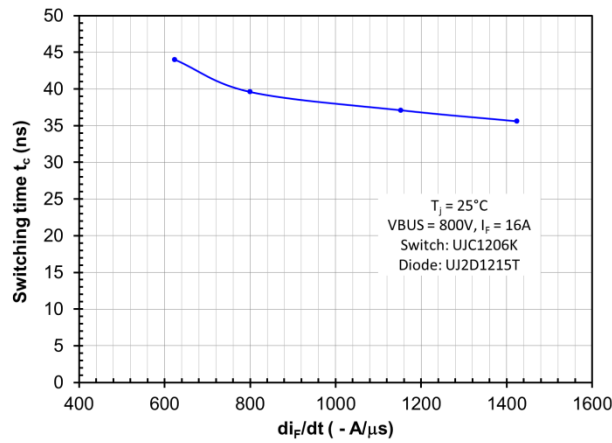


Fig.7: Measured switching time  $t_c$  of the SiC JBS diode UJ2D1215.  $T_j = 25^\circ\text{C}$ ,  $V_{BUS} = 800\text{V}$ ,  $I_F = 16\text{A}$ , Switch: UJC1206K.

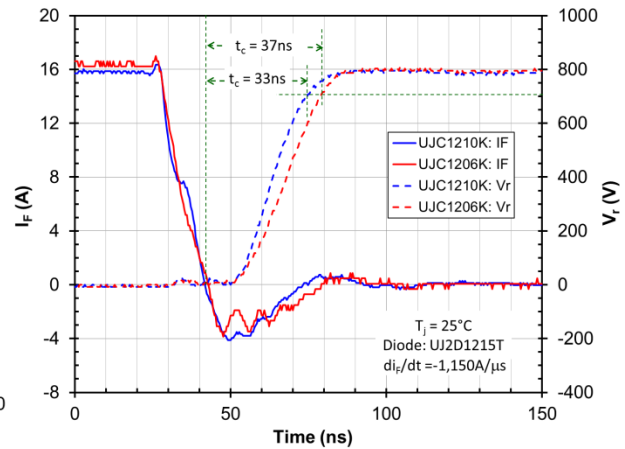


Fig.8: Comparison of the turn-off waveforms of the SiC JBS diode UJ2D1215T with different switches.

UJ2D1215T at different  $di_F/dt$  rates. When the  $di_F/dt$  rate is increased from  $600\text{A}/\mu\text{s}$  to  $1,400\text{A}/\mu\text{s}$ , the switching time  $t_c$  is decreased from  $44\text{ns}$  to  $36\text{ns}$ . Fig.8 compares the turn-off waveforms of the SiC JBS diode UJ2D1215T with different switches in the test setup. It is seen that, under about the same  $di_F/dt$  rate, the switching time  $t_c$  is decreased from  $37\text{ns}$  to  $33\text{ns}$  when the switch in the testing system is changed from UJC1206K to UJC1210K. This is because UJC1210K has smaller capacitances than UJC1206K and turns on faster.

## 4 Summary

SiC JBS diodes are majority carrier devices having no stored charge, and can be turned off much faster than Si PiN diodes. The key features of SiC JBS diodes are listed below:

- Turn-off process is the charging process of the junction capacitor;
- Capacitive charge  $Q_c$  is independent of the junction temperature  $T_j$ ;
- Capacitive charge  $Q_c$  is independent of the forward current level  $I_F$ ;
- Capacitive charge  $Q_c$  is independent of the  $di_F/dt$  rate;
- Capacitive charge  $Q_c$  is solely determined by the device design;
- Switching time  $t_c$  is mainly determined by the test system.