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 (VBUS) 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.

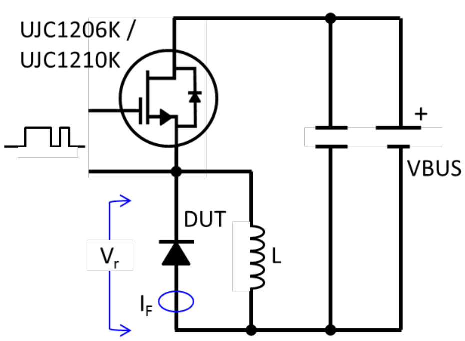


Fig. 1: Experiment setup for measuring the capacitive charge Q_C of a SiC JBS diode.

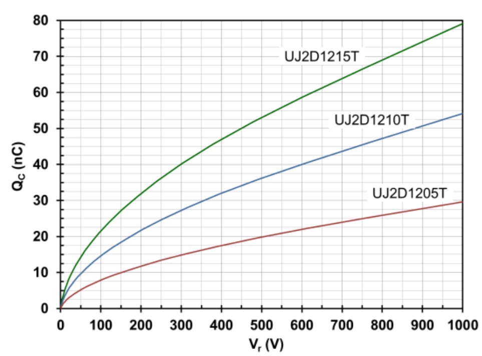


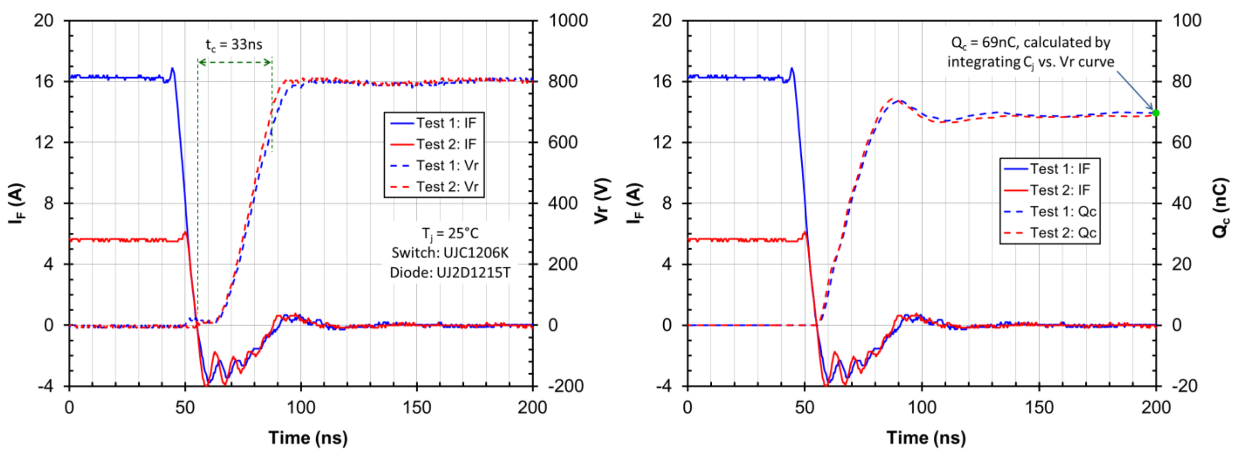
Fig. 2: Capacitive charges Q_C of USCi's 1200V SiC JBS diodes obtained by integrating the typical C_j vs. V_r curves.

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 VBUS. 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.



(a) (b)

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

3.2 Qc 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°C and 150°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°C to 150°C, confirming that the turn-off characteristics of the SiC JBS diodes is independent of the junction temperature.

3.3 Qc 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 correspondingly. But the measured capacitive charge Q_c has no change with the increase of the di_F/dt rate.

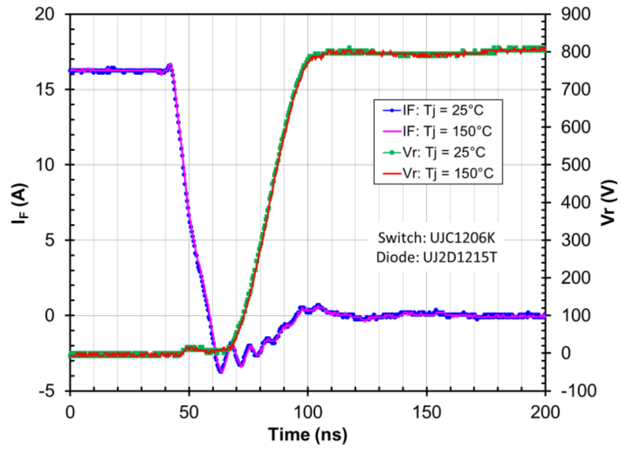


Fig.4: Measured turn-off waveforms and capacitive charge Q_c of the 1200V-15A SiC JBS diode UJ2D1215T at T_J = 25°C and 150°C.

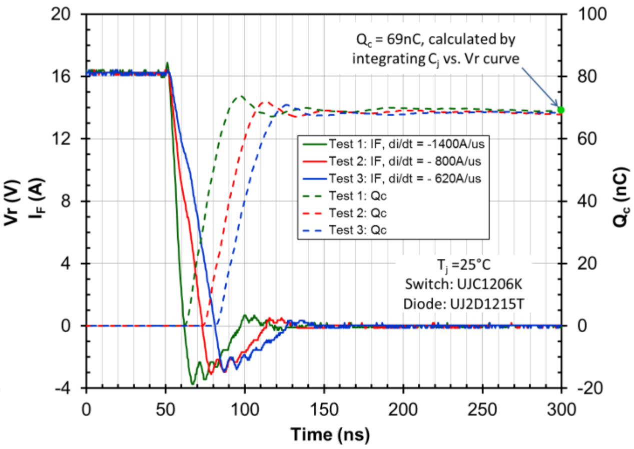


Fig.5: Measured turn-off waveforms and capacitive charge Q_c of the 1200V-15A SiC JBS diode UJ2D1215T at different di_F/dt rates.

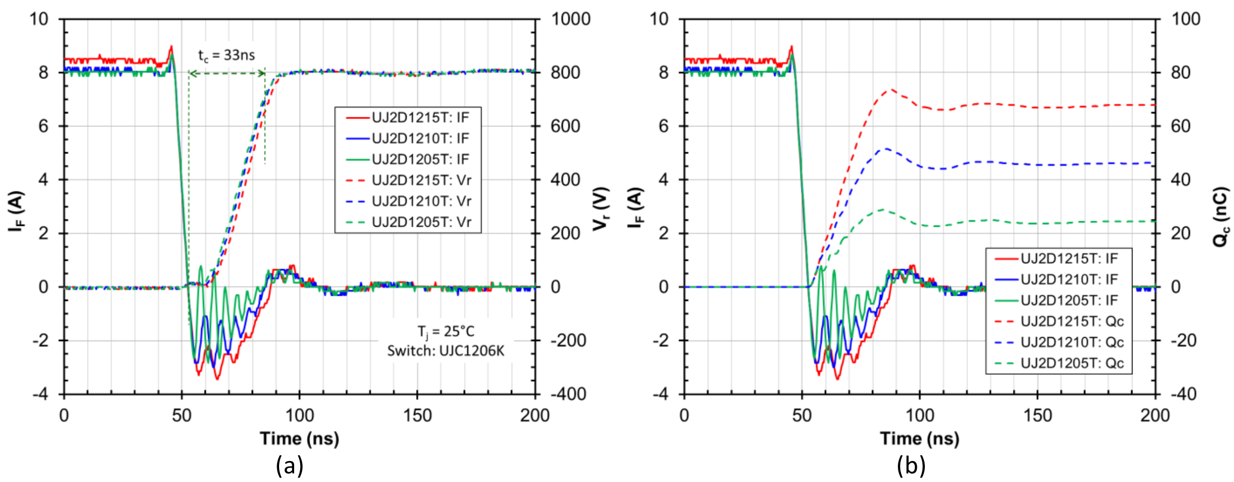


Fig.6: Measured turn-off waveforms (a) and capacitive charge Qc (b) of the 1200V SiC JBS diodes UJ2D1215T, UJ2D1210T, and UJ2D1205T at T_J = 25°C. Switch: UJC1206K.

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 VBUS. 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

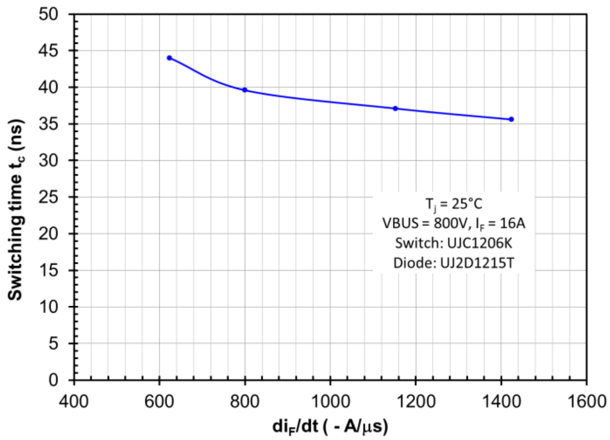


Fig.7: Measured switching time t_c of the SiC JBS diode UJ2D1215. T_J = 25°C, VBUS = 800V, I_F = 16A, Switch: UJC1206K.

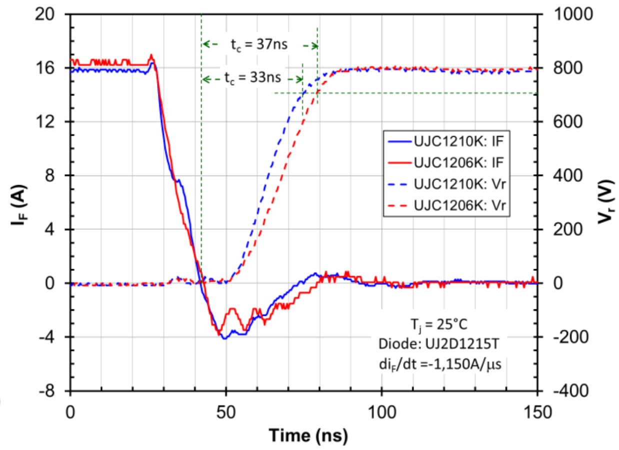


Fig.8: Comparison of the turn-off waveforms of the SiC JBS diode UJ2D1215T with different switches.

UJ2D1215T at different di_F/dt rates. When the di_F/dt rate is increased from 600A/□s to 1,400A/□s, the switching time t_c is decreased from 44ns to 36ns. 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 37ns to 33ns 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 tine t_c is mainly determined by the test system.