Application Note AN-301
Qspeed™ Family

Reverse Recovery Charge, Current and Time

Abstract

When a power diode is quickly reverse biased while it is conducting a high forward current (hard switching), a finite amount of time is required to clear it of charge carriers so that it can block the reverse voltage. The amount of time it takes a hard-switched diode to recover (t_{RR}) has been the typical performance metric used to evaluate diode reverse recovery. However, the amplitude of the reverse current that flows through the diode during the recovery time is a better measure of the performance in a power conversion circuit than t_{RR} alone. This application note will show why the Q_{RR} (the integral of the recovery current over the recovery time) of devices being compared should be used to predict in-circuit performance. Additionally, softness factor will be explained, along with why a high softness ratio is important.

Introduction

A diode's reverse recovery characteristics are quantified by three parameters: the reverse recovery time (t_{RR}), the reverse recovery current (I_{RR}), and the reverse recovery charge (Q_{RR}). I_{RR}, t_{RR} and Q_{RR} are the three main parameters that are used to characterize the diode's reverse recovery behavior, and are typically specified on the datasheet. Another parameter that is not always specified on the datasheet is the softness of the diode's I_{RR} waveform. Those four parameters are determined by the manufacturing processes used to produce a particular device family.

Diode Reverse Recovery Parameters

The Q_{RR} of a power diode is a direct measure of its stored charge; either from the barrier junction capacitance of Schottky devices or the minority carriers that flow within the cathode and drift region of PN-junction-based devices. All stored charge must be removed so that the depletion region can become big enough to block the reverse voltage. In order to block a high reverse voltage (600 V), those diodes require a wide drift region. The wider the drift region, the more minority charge carriers it can contain during forward conduction. Semi-conductor design engineers can use various techniques to control the duration or the lifetime of minority carriers, such as introducing recombination centers in the drift region of the device structure.

Recombination centers effectively shorten the lifetime of the minority carriers injected by the anode. Shortening minority carrier lifetime reduces the Q_{RR}, I_{RR} and t_{RR} of the device.

Softness Factor

The I_R Softness is the ratio of the two parts of the reverse recovery current: stored charge removal and the return to zero current. Softness is calculated by dividing the time required to remove the stored charge carriers from the diode (t_a) into the time it takes for the resultant reverse current to fall from its peak negative value (I_{RR_PEAK}) back to zero (t_b). Softness = t_b/t_a, and the parts of the waveform are shown in Figure 2. The softness of a device's I_{RR} will depend on the lifetime control technique used to reduce Q_{RR}. The softness factor can easily be calculated for diodes that do not have this parameter specified in their data sheets. Platinum (Pt) doping can limit t_{RR} significantly, but it produces an abrupt, snappy cessation of I_{RR}, like that shown Figure 1. It is clear from the curves in Figure 1 that reducing Q_{RR} lowers I_{RR} and t_{RR}. However, the reduction of t_{RR}

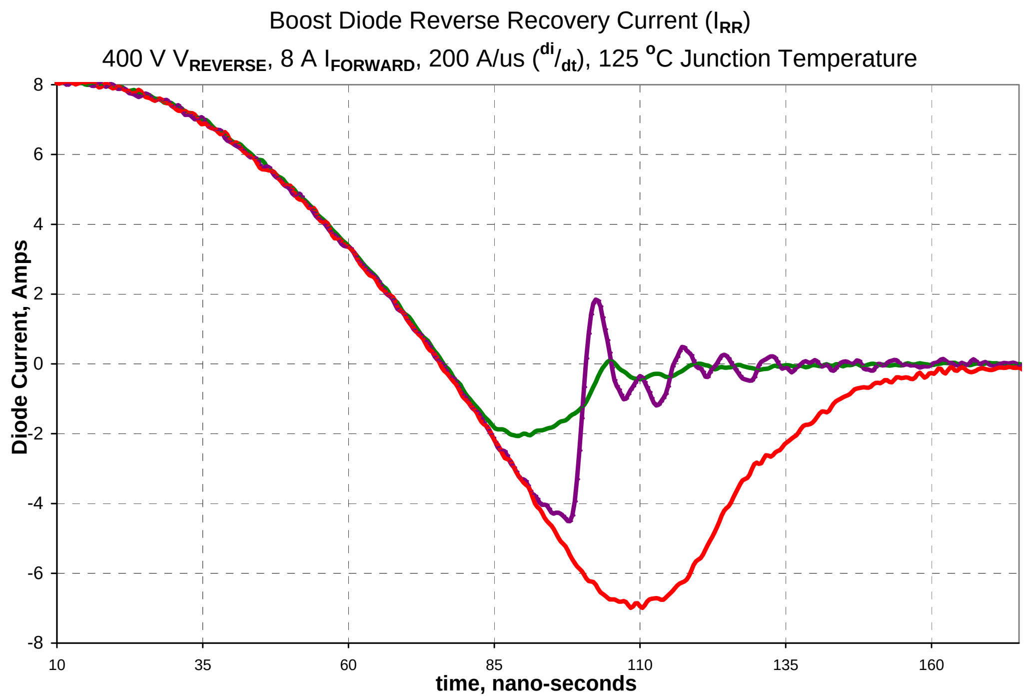

Figure 1. The I_{RR} waveforms of some commonly used PN-junction boost diodes and the Q_{RR} values that were measured for each device. [1].

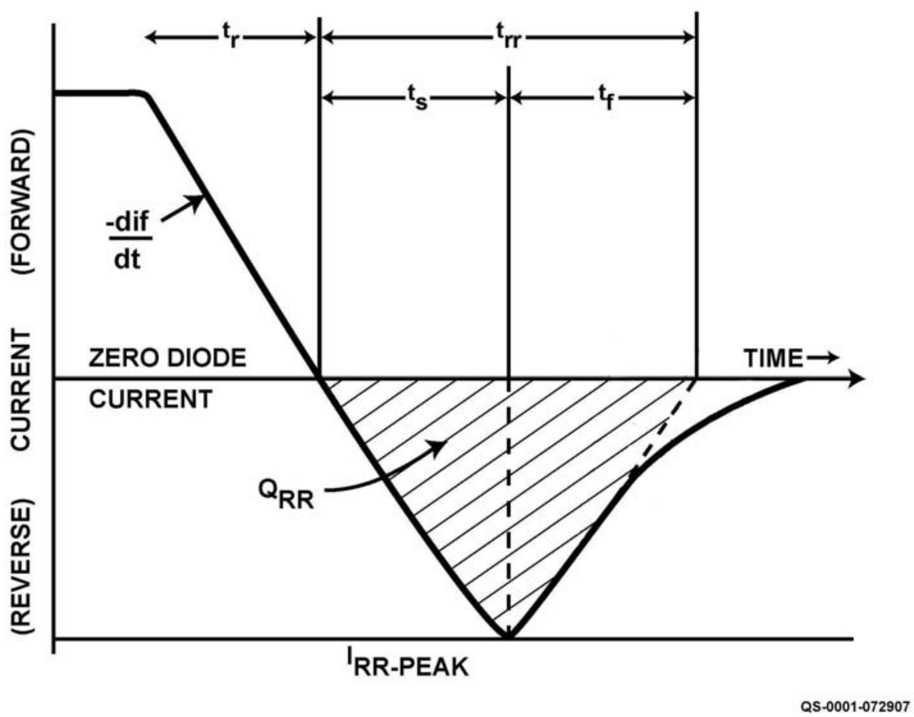

Figure 2. An I_{RR} waveform that shows the two recovery segments that make up the softness ratio.

obtained by platinum doping does not significantly lower the Q_{RR} and I_{RR} of the device.

Although the t_{RR} of the Q-Series and a Platinum doped device are about equal, the peak I_{RR} of the Platinum doped diode is more than two times the value of the Q-Series diode.

Abrupt recovery also produces excessive EMI and voltage stress across the diode, which requires snubber circuitry or larger EMI filter components. Soft recovery reduces voltage stress and EMI, without the use of snubbers.

Junction Temperature and Q_{RR}, I_{RR} and t_{RR}

In PN-junction based power diodes, Q_{RR}, I_{RR} and t_{RR} vary with junction temperature. Thermal interference slows down minority carrier recombination as junction temperature increases [2]. Therefore, Q_{RR}, I_{RR} and t_{RR} will all increase as the junction temperature rises. Figure 3 shows the dependence of Q_{RR} on junction temperature, for the same three diodes shown in Figure 1. The Q-Series family of parts was designed so that the Q_{RR} of all devices have a low, positive temperature coefficient. That means that the Q_{RR}, I_{RR} and t_{RR} of those diodes will not increase significantly over the normal operating junction temperature range.

The fact that the Q_{RR} and I_{RR} of the Q-Series devices remain consistently low, over a normal operating temperature range, can help to ensure that power supply efficiency and EMI remain within specification, even at the worst-case operating conditions.

Summary

The Q_{RR} of PN-junction, power diodes has been shown to be a more accurate performance metric than its t_{RR}, since devices with low t_{RR} do not necessarily have low Q_{RR} and I_{RR}.

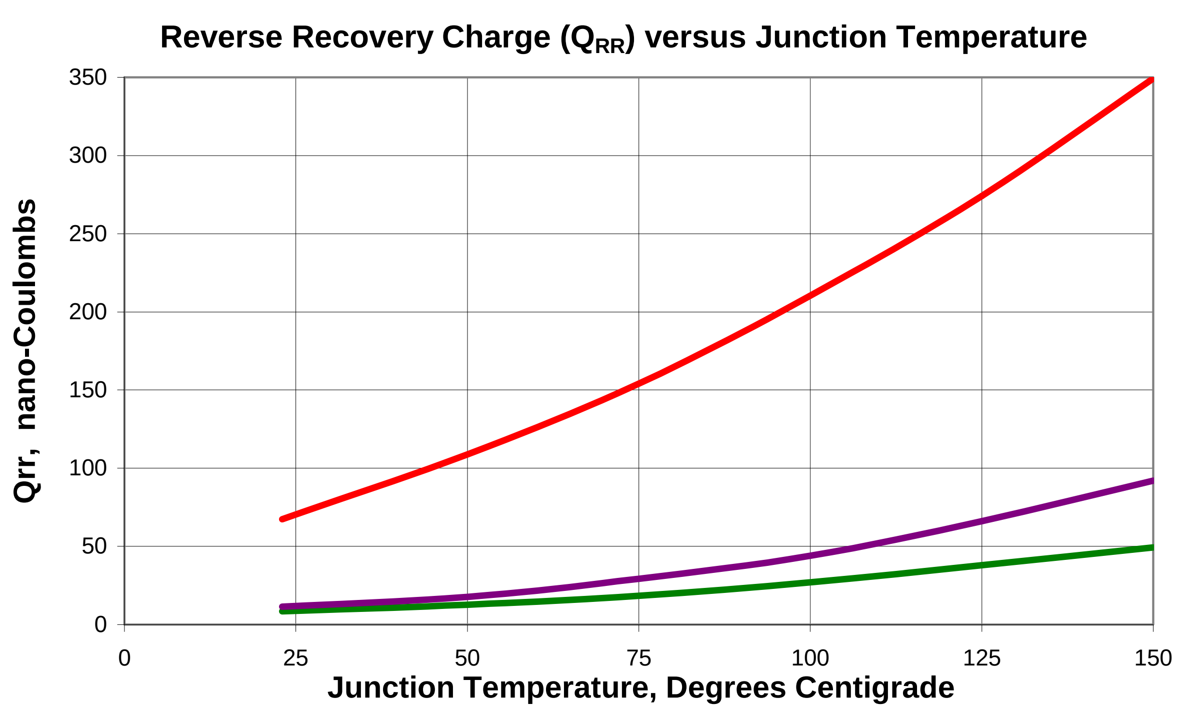

Figure 3: Plots of Q_{RR} versus junction temperature for some commonly used boost diodes [3].

Additionally, the softness of a diode's I_{RR} waveform will determine if snubber circuits will be required to use it safely and to meet conducted and radiated EMI test limits.

References

1. Data taken on device characterization test fixture, Apr., 2007.
2. W. Shockley, W.T. Read, "Statistics of the recombination of holes and electrons", Physical Review, Vol. 87, No. 5, pages 835-842, September, 1952.
3. Data taken on device characterization test fixture, Oct., 2007.

Revision	Notes	Date
1.2	Released by Qspeed	04/08
1.3	Converted to Power Integrations Document	01/11

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