Bodo´s Power Systems®

Using FRD MOSFETs to Achieve High Efficiency, High Power Density, and Maximize Reliability in Power Supplies

The "Super Junction" technology has dominated the power MOSFET market where the breakdown voltage exceeds 600V due to its superior figure-of-merit. This article outlines issues engineers need to consider when designing Super Junction-based power devices. It provides an optimized solution that enhances efficiency, power density, and reliability in power supply applications.

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As shown in Figure 1, one of the first considerations is that the p columns extend from the base region to create a "charge balance" in the drift area for higher doping concentration, namely lower resistance in the corresponding region. The extended junction area leads to a drawback of excessive reverse recovery charge.

Furthermore, Figure 2 shows a typical half-bridge configuration in which the current freewheels through the body diode of the high-side MOSFET during the dead time before the low-side MOSFET turns on. The body diode reverse recovery happens when the low-side MOSFET starts to turn on. The low-side MOSFET sees a negative current spike due to the reverse recovery charge of the high-side MOSFET. This causes an excessive turn-on loss in the low-side MOSFET. At the same time, the high-side MOSFET sees a high slew rate voltage rise and a spike voltage during the Tb period, which can cause an overstress on the device.

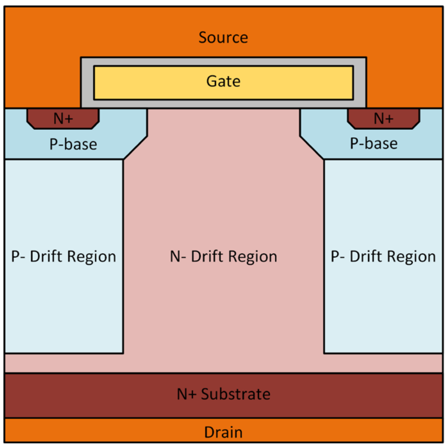


Figure 1: P-N junctions in Super Junction MOSFETs

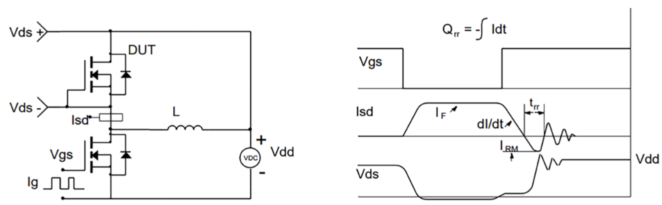
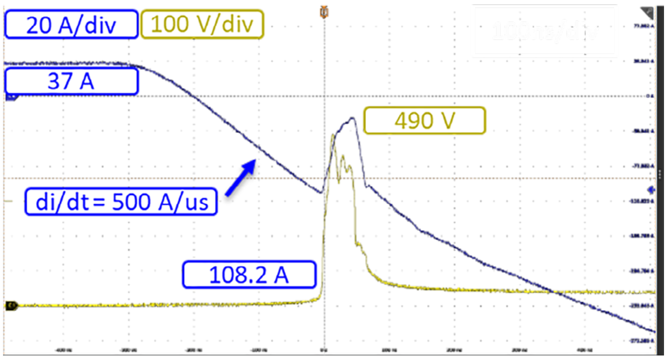


Figure 2: Body diode reverse recovery in half-bridge circuit



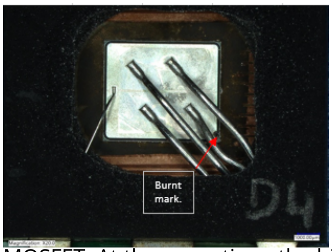


Figure 3: Illustrates a device failure caused by the body diode reverse recovery

Ultimately, as shown in an example in Figure 3, a 600V SJ device failure is caused by the body diode recovery when the forward current and the current slew rate are beyond the device's safe operation limit.

An issue to be aware of is that body diode reverse recovery in Super Junction-based power devices has deeply impacted the selection of HV power devices for power supply designs. Figure 4 shows a typical circuit in AC/DC power supply. In the PFC stage, SiC Schottky diode instead of a synchronous rectifier FET is used as the high-side device because the switching loss caused by the reverse recovery of a synchronous rectifier is too high with the target switching frequency (usually above 50kHz).

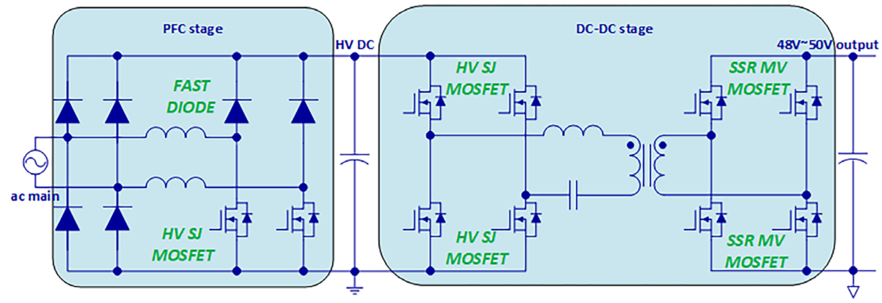


Figure 4: Typical AC/DC power supply circuit structure

In the DC-DC stage, the soft-switching LLC circuit is used where hard commutation of the HV devices does not happen in normal operation mode. The device's hard commutation causes the body diode to reverse recovery; thus, it will not be seen in this case. However, hard commutation can happen in the LLC circuit during abnormal operation conditions such as start-up and short-circuit transients. Protections against such transients are normally required in the controller design of the LLC circuit. Failure to prevent the hard commutation in the LLC circuit could lead to a failure in the HV devices due to the very snappy body diode reverse recovery transient.

There are circumstances where the HV device body diode reverse recovery can't be avoided. For example, cycle-by-cycle hard commutation protection is not available in high-power LLC converters with digital controllers. In high-voltage motor drive applications, active devices (MOSFET/IGBT) are needed for both high - and low-side switches. Improved body diode performance regarding the reverse recovery charge and reliability is a key requirement for the HV power device in these applications.

An Optimized solution: αMOS5™ FRD technology

The αMOS5 FRD MOSFET platform developed by Alpha and Omega Semiconductor (AOS) is specifically optimized for low reverse recovery charge and switching robustness. Electron irradiation is applied in this technology to control the lifetime of the bipolar carriers during the reverse recovery phase. It creates defects to serve as recombination centers and accelerates the process of electron/hole pair recombination of the FRD during the forward biasing and the reverse recovery stage, significantly reducing the total number of excessive charges stored in the FRD drift region.

Comparing the Qrr waveforms of the same Super Junction structures, but with different carrier lifetime control, the ER-processed part shows a significant reduction in Qrr value. Suppressed Qrr means that a smaller power spike level will surge through the FRD, thus suppressing the risk of thermal failure.

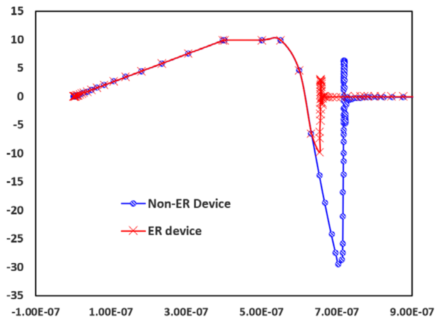


Figure 5: ER Controlled reverse recovery waveform

It is important to note that the MOSFET active/termination transition region is the most vulnerable to reverse recovery failure as it passes high current density with its limited area size. A key benefit of the αMOS5 platform is that it employs a conservative termination design to evenly spread the electric field across the transition region. This optimization prevents localized hot spot burnout due to excessive power density during the reverse recovery tb phase.

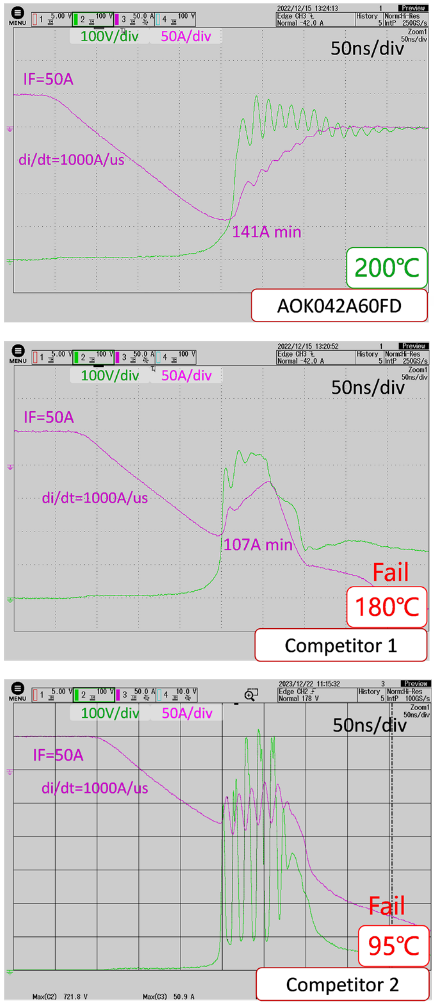


Figure 6: Body diode reverse recovery test performed on two competitive products and the AOK042A60FD αMOS5 FRD MOSFET (VDD = 400V, IF = 50A, di/dt = 1000A/us)

DUT	IF (A)	di/dt (A/us)	dv/dt (ns)		
			25°C	150°C	200°C
AOK042A60FD	50	1000	104 (pass)	46 (pass)	38 (pass)
Competitor 1			160 (pass)	92 (pass)	74 (fail)
Competitor 2			134 (pass)	122 (fail)	

Table 1: Body diode reverse recovery robustness test result for AOK042A60FD

Test Results and Conclusion

The safe operation condition regarding the body diode reverse recovery is validated with AOS αMOS5 FRD MOSFET tests. The test result is provided in the device datasheet. Figure 6 shows the test waveform of AOS' AOK042A60FD 600V 42mΩ αMOS5 SJ MOSFET, and two competitors with similar B_{Vdss} and R_{dson} specifications. The test was conducted with 50A forward current and 1000 A/us slew rate at three different temperatures. As given in Table 1, the AOK042A60FD passed the test at 200°C, while the competitors failed the test even at lower temperatures.

It is worth noticing that AOK042A60FD shows the lowest drain voltage slew rate in the T_b period waveform. This helps the device survive the harsh reverse recovery transient, as well as improve the device's EMI performance. The test result shows that the AOS αMOS5 FRD SJ device provides highly effective body diode robustness in the reverse recovery transient, which is crucial in bridge-type applications such as LLC converters to ensure the highest system reliability in abnormal and transient conditions.

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