A new 650V Super Junction Device with rugged body diode for hard and soft switching applications

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Abstract

With the new CoolMOS™ 650V CFD2 technology a new benchmark is set for high voltage power MOSFETs with a high performance body diode of the MOSFET. The transistor combines a high blocking voltage of 650V with lowest R_{dson} and low capacitive losses together with an improved body diode ruggedness during reverse recovery especially for hard and soft switching applications. Together with the improved performance a specification of the max-value of the Q_{rr} and t_{rr} in the datasheet will be introduced. This article investigates the influence factors for improving the body diode ruggedness. The benefit of this new Superjunction device family with fast body diode is especially shown for a HID half-bridge topology.

1. Introduction

With the increasing demand for higher power density, especially soft switching topologies like half-bridge (e.g. HID half-bridge or LLC) and full-bridge concepts (e.g. ZVS bridge) seem to be the ideal solution. These topologies reduce the switching losses and increase the reliability of the system due to less dynamic di/dt and dv/dt stress on the power device. Such high stresses occur predominantly in light-load operation [1]. It is already shown that Superjunction devices like the CoolMOS™ help to overcome this problem by inherent optimized charge carrier removal during reverse recovery and eliminating the problem of latch-up of the parasitic npn-bipolar transistor [2]. A significant reduction of the reverse recovery charge can be achieved by an enhanced recombination rate of the injected carriers resulting in lower reverse recovery peak currents during turn-off and strongly reduced reverse recovery charge by almost a factor of 10. For optimized body diode (Fig.1) performance in hard switching conditions, especially the shape of the resulting reverse recovery waveform and the design conditions of the printed circuit board are important [3-4]. The new CoolMOS™ 650V CFD2 is designed in this manner with improved reverse recovery behavior together with increased safety margin in breakdown voltage.

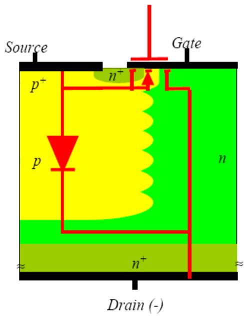

Fig. 1. Schematic cross section of the CoolMOS high voltage power MOSFET and its integral body diode

2. Reverse Recovery Behavior

The reverse recovery behavior of the new CoolMOS™ 650V CFD is shown in Fig. 2. It appears that the new CoolMOS™ 650V CFD devices have a very low reverse recovery charge Q_{rr}, reverse recovery time t_{rr} and maximum reverse recovery current I_{rrm} when compared to the standard device.

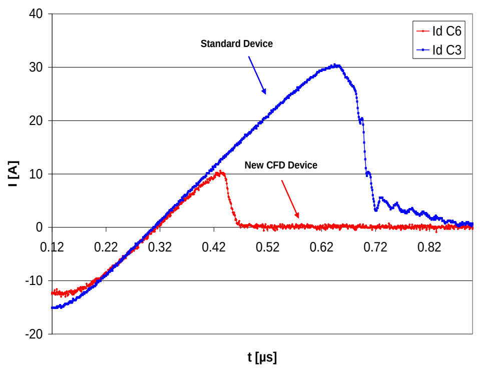

Fig. 2. Measured reverse recovery waveforms at di/dt=100A/µs, 25°C, V_r=400V. The new CFD device shows very low Q_{rr}, t_{rr} and I_{rrm} when compared to the standard device.

At the same time, the waveforms of the new device still show a soft characteristic, in spite of the strongly reduced Q_{rr}, t_{rr} and I_{rrm}. This characteristic is highly desirable during hard commutation in order to avoid voltage overshoot and to ensure reliable device operation.

3. Commutation Ruggedness

The commutation ruggedness of the CoolMOS™ 650V CFD2 device is demonstrated in reverse recovery measurements in Fig. 3, where the devices were tested up to di/dt ≈ 2000A/µs.

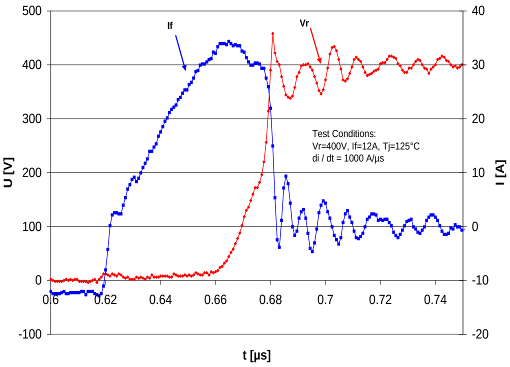

Fig. 3. Measured reverse recovery waveforms for the new CoolMOS 650V CFD2 device. The devices could not be destroyed even at the maximum capability of the tester

No device could be destroyed under these conditions and the waveforms show still a soft characteristic, compared to snappy waveforms for other superjunction devices. This is a clear advantage for the designer, once one can optimize its application for maximum performance without being concerned with device destruction during hard commutation of the body diode.

4. Dependence of Q_{rr} and t_{rr} with temperature

Of utmost importance for the designer is the dependence of Q_{rr} and t_{rr} on temperature. The Q_{rr} and t_{rr} values tend to increase with temperature, due to increased carrier generation in the device. This dependence is shown in Fig. 4 for the 310mΩ 650V CFD2 device. A linear increase of Q_{rr} and t_{rr} with temperature is observed.

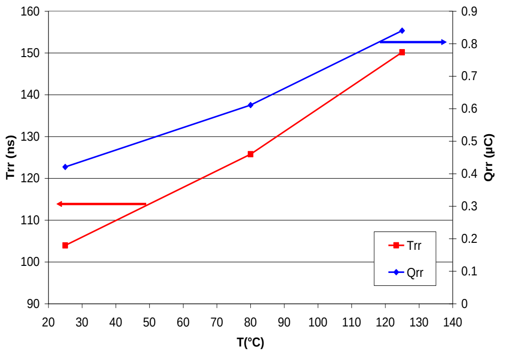

Fig. 4. Dependence of Qrr and Trr with temperature for the 310mΩ 650V CFD device

5. Dependence of Qrr and Trr with Rdson

Another important aspect to be considered is the dependence of Q_{rr} and t_{rr} on the device R_{dson}. This can be seen in Fig. 5 and Fig. 6, respectively, where the new 650V CFD2 device is compared with the former Infineon's CoolMOS™ fast diode technology.

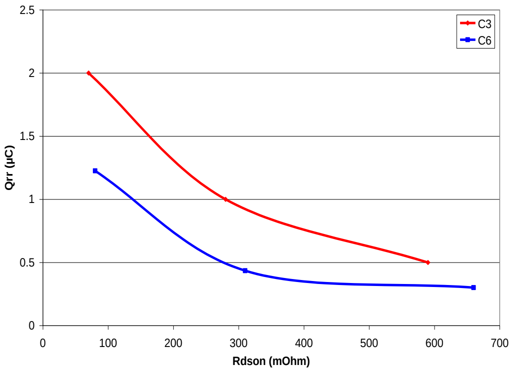

Fig. 5. Dependence of Q_{rr} on R_{dson}, measured at 25°C and for the 80, 310 and 660mΩ 650V CFD2 devices in comparison with the former 600V CFD technology

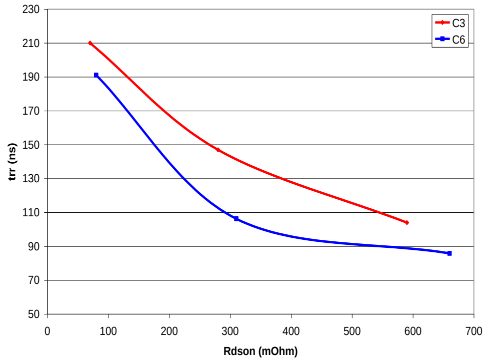

Fig. 6. Dependence of t_{rr} on R_{dson}, measured at 25°C and for the 80, 310 and 660mΩ 650V CFD2 devices in comparison with the former 600V CFD technology

The new 650V CFD2 device clearly offers an even better trade-off then the former technology between dynamical characteristics (Q_{rr},t_{rr}) and lowest R_{dson}.

6. Performance Evaluation in HID-Bridge

We have also compared the performance of the new devices with the commercial available SPD07N60C3 in a HID half-bridge application. Using the new CoolMOS™ CFD2 devices, the diodes D2, D3, D4 and D5 can be eliminated and allow reduced system costs (Fig. 7).

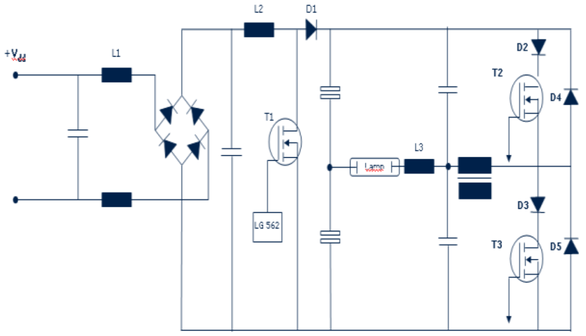

Fig. 7. Typical HID Half-Bridge circuit. By replacing the transistors T2 and T3 with the new CoolMOS™ 650V CFD2 device, the diodes D2 to D5 can be eliminated.

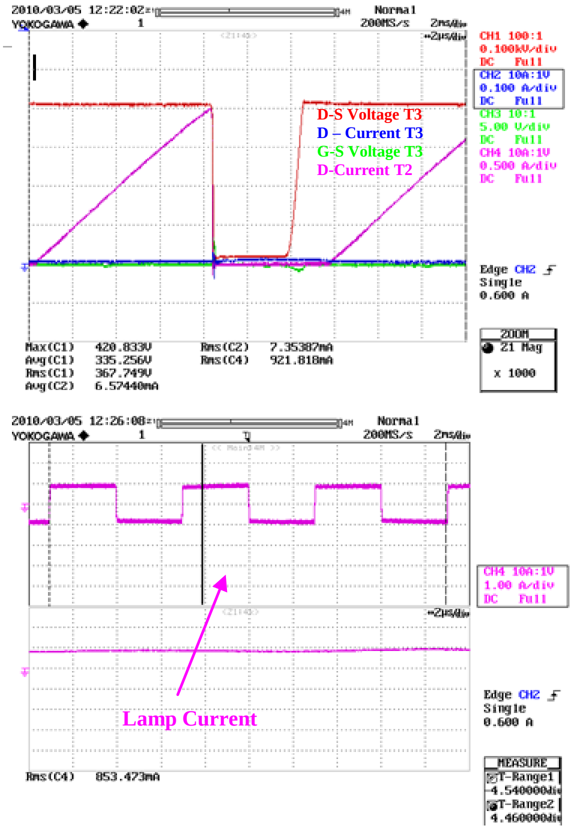

Fig. 8. Circuit wave forms during the turn-off phase of transistor T3 with SPD07N60C3 as switch and the diodes D2 – D5. An efficiency of 91,81% is achieved.

For reference Fig. 8 shows, the wave forms obtained by using the SPD07N60C3 device as transistors T2 and T3 and additionally the diodes D2, D3, D4 and D5. With this setup, we achieved an efficiency of 91,81%.

By removing the diodes in series to the transistors, the additional voltage drop in forward operation is eliminated. This solution requires, however, an even superior performance of the internal body diode of the MOSFET once the switching losses increase due to the reverse recovery charge stored in the MOSFET. This situation is depicted in Fig. 9.

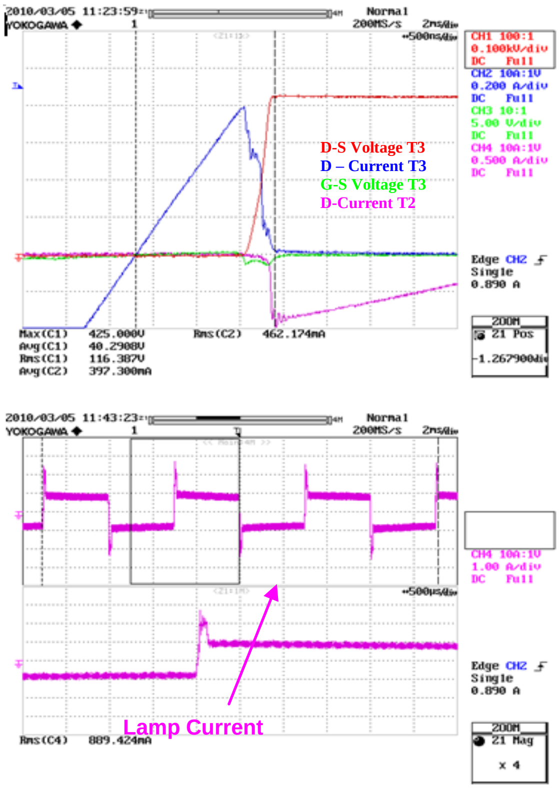

Fig. 9. Circuit wave forms during the turn-off phase of transistor T3 with SPD07N60C3 without the diodes D2–D5. An efficiency of 89,72% is achieved.

In addition to increased switching losses, this setup also has the disadvantage that the MOSFET's can eventually be destroyed due to the high reverse recovery current.

A superior solution is achieved by using the new IPD65R660CFD device. Due to the superior performance of the internal body diode of the MOSFET, it is possible to implement a solution without the diodes D2-D5 and obtain at the same time a considerably better efficiency. This is shown in Fig.10.

The optimized construction of the internal body diode of the new IPD65R660CFD device combined with a very low reverse recovery charge also enable reliable device operation.

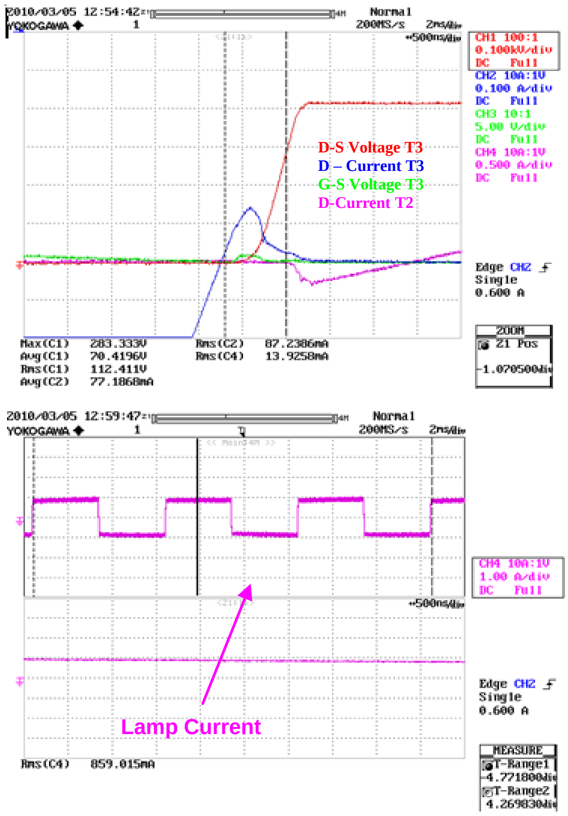

Fig. 10. Circuit wave forms during the turn-off phase of transistor T3 with IPD65R660CFD without the diodes D2–D5. An efficiency of 92,81% is achieved.

7. Conclusion

Infineon's new CoolMOS™ CFD2 device, offers the lowest R_{dson} combined with a high blocking voltage of 650V. This new device features also a very low reverse recovery charge combined with a robust integral body diode. A specification of the max-values of the Q_{rr} and t_{rr} will be available in the datasheet. We have also evaluated the performance of this new device in a typical HID Half-Bridge circuit, leaving out four diodes and getting superior efficiency. Due to the breakdown voltage of 650V and the robust construction of the integral body diode, this new device offers additional safety against destruction during hard commutation of the MOSFET.

8. Literature

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