High Speed 650V IGBTs for DC-DC Conversion up to 200 kHz

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***Abstract*— The increasing demand for higher power density and lower cost in high voltage power supplies has driven semiconductor manufacturers to expand IGBT performance for high switching frequency beyond 100 kHz. An ultra thin punch-through IGBT with a blocking voltage of 650V has been developed and optimized targeting DC-DC conversion up to 200 kHz. Its high Tjmax of 175°C further enhances the converter compactness. This paper describes the feature of this ultra fast IGBT in a critical comparison with equivalent products available on the market today.**

Keywords: IGBT, ultra-thin wafer, DC-DC converter, switching losses

I. Introduction

IGBTs have been available as power switches for more than 30 years, largely adopted in motor control and inverter applications which require relatively low switching frequency and high current density. As the trend in power conversion constantly increases in switching frequency, IGBTs found limited use in the switching mode power supply (SMPS) applications. Power MOSFETs have been the choice of switches for high voltage SMPS applications.

Superjunction (SJ) MOSFET can achieve a better trade-off between conduction loss and breakdown voltage than the conventional power MOSFETs, for high frequency and high voltage applications at the expense of extra masks and complex fabrication process [1-4]. Due to presence of the minority carriers in IGBTs, it has been a challenge for IGBT to achieve high performance for the high frequency, hard switching applications above 100 kHz. In this paper we report for the first time, that ultra fast IGBTs fabricated with the ultra-thin wafer technology have achieved low power dissipation similar to SJ MOSFET but with a much simpler fabrication process. It has a high Tjmax of 175°C as compared with 150°C for SJ MOSFET. This new IGBT offers a cost-competitive, high performance option for the DC-DC converters up to 200 kHz.

II Device STRUCTURE and Fabrication

650V high speed IGBTs are fabricated on 70 μm thin wafers using the Punch-Through (PT) structure as shown in Fig. 1. The use of ultra thin wafers allows a lightly doped collector which reduces stored charge, thus resulting in better switching perofrmance, especially at high temperatures.

Conventional Punch-Through IGBTs use minority-carriers lifetime killing techniques, such as electron irradiation or metal doping, to increase switching speed. One of the side effects of these processes is that the leakage current increases rapidly with increasing temperature, which limits the Tjmax to 150°C.

The high speed thin IGBTs are not processed with lifetime killing techniques. The leakage current is maintained low at 175°C which enables an operation with Tjmax of 175°C. The current carrying capability of the fast switching thin IGBTs are therefore increased, further reducing the converter size.

The design of ultra fast IGBT for 200 kHz DC-DC converter involved major changes in comparison to the standard IGBT for the motion control. The SMPS applications do not require large short-circuit SOA. IGBT with higher cell density is preferred to produce lower on-state voltage drop while a smaller gate capacitance with minimal internal gate resistance R_G is required to achieve fast switching speed. The threshold voltage is designed to the standard 3-5V range. Fig. 2 shows a photograph of the high speed thin IGBT.

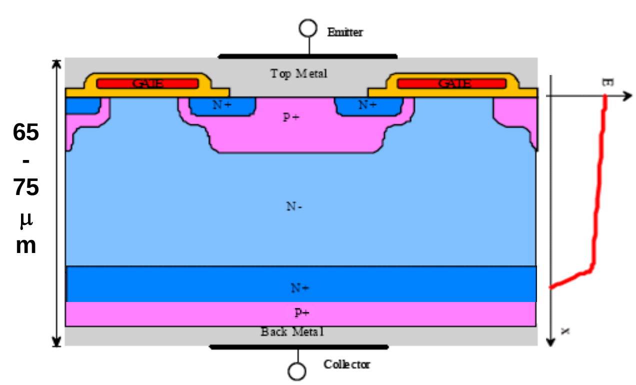


Fig. 1 Punch-Through thin IGBT structure

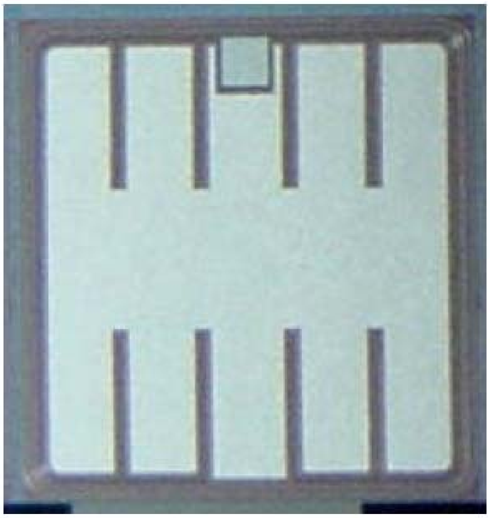
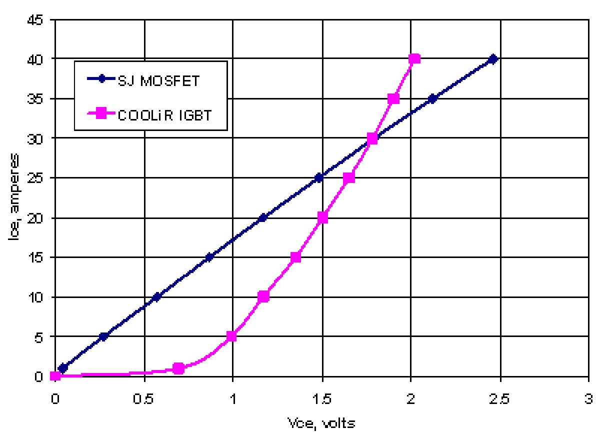


Fig. 2 Photograph of a high speed thin IGBT

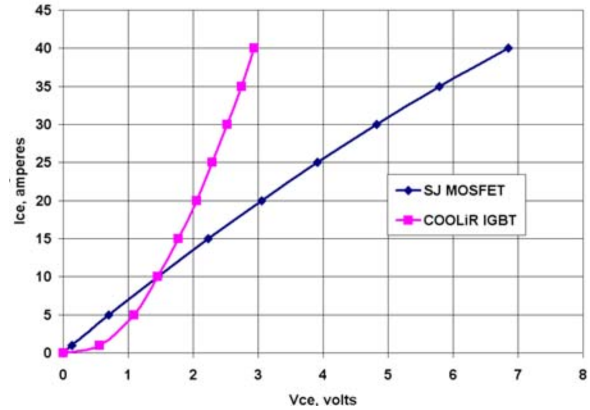
II. RESULTS AND DISCUSSION

Comparison between MOSFET and IGBT can be difficult sometimes because devices are rated in different ways. MOSFET shows a resistive behavior and therefore on-state voltage drop increases linearly with current. IGBT has threshold-like I-V characteristic where the V_{CEsat} does not vary linearly with current.

Fig. 3 compares the I-V curves of the fast switching IGBT and a commercially available SJ MOSFET. The die area is almost identical for these two devices. The Rdson of the SJ MOSFET is low at room temperature; it increases rapidly with increasing temperature, by 260% from 25°C to 150°C, while the high speed thin IGBT only increased by 37%. The reverse blocking characteristics of the fast switching IGBT and SJ MOSFET is shown in Fig. 4. Both devices have similar blocking voltage of 690V.



(a)



(b)

Fig. 3 Comparison of the forward conduction characteristics of COOLiRIGBT™ and SJ MOSFET: (a) 25°C and (b) 150°C.

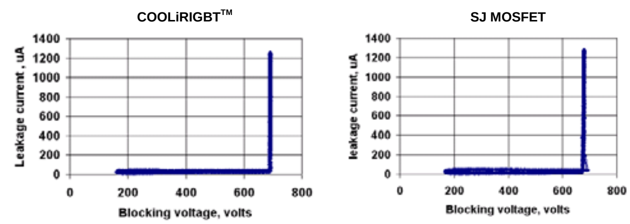


Fig. 4 Comparison of the reverse blocking characteristics of COOLiRIGBT™ and SJ MOSFET.

The turn-on and turn-off power losses were measured in the test circuit shown in Fig. 5. The turn-on energy of the DUT is strongly dependent on the reverse recovery characteristics of the fast diode [5]. An external diode is chosen for the test circuit to ensure a valid comparison for the turn-on of IGBT and MOSFET.

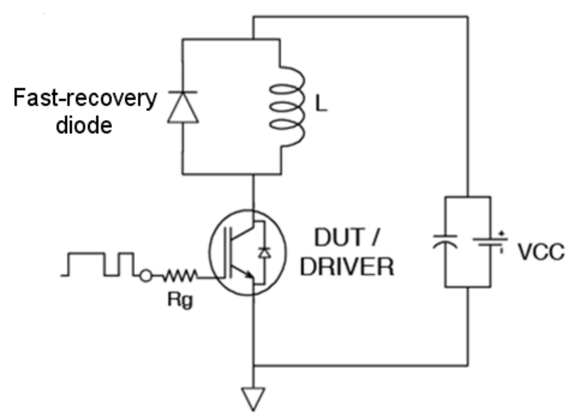


Fig. 5 Test circuit used for the measurements of the switching characteristics of IGBT and MOSFET.

The switching waveforms of the high speed IGBT and SJ MOSFET at 150°C are shown in Fig. 6 and 7, respectively. The turn-on energy of the high speed IGBT at 10A is 156 uJ as compared with 135 uJ observed for the SJ MOSFET, which is mainly influenced by the recovery behavior of the fast-recovery diode. The turn-off energy is controlled by the DUT itself. The high speed IGBT exhibits a relatively low turn-off energy of 87 uJ while 70 uJ was recorded for the SJ MOSFET.

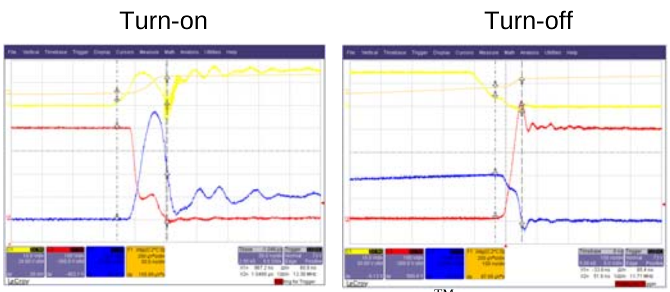


Fig. 6 Switching waveforms of COOLiRIGBT^{TM} at Ic=10A, Vcc=400V and 150°C

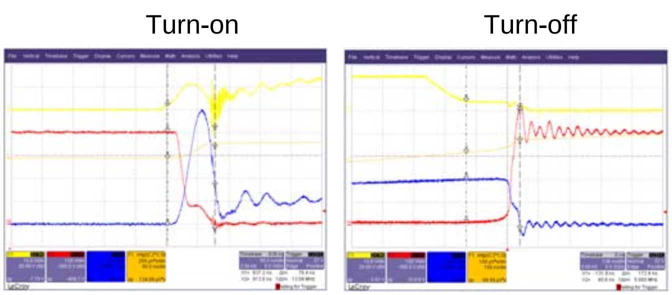


Fig. 7 Switching waveforms of a SJ MOSFET at Ic=10A, Vcc=400V and 150°C

For hard switching pulse-width-modulated (PWM) applications, the total power loss incurred in each power transistor consists of conduction loss, turn-on loss and turn-off loss. For a DC-DC converter with a switching frequency of 200 kHz, the total power losses were calculated for the high speed IGBT and SJ MOSFET, base on 50% duty cycle. The results are summarized in Table 1. The high speed IGBT and SJ MOSFET show similar on-state forward voltage drop at a low current of 10A. The switching loss of the IGBT is 14% higher than that in SJ MOSFET. Thus the total power loss for the high speed IGBT is 11% higher than SJ MOSFET.

Table 1 power losses at Ic=10A and 150°C

	COOLiRIGBT^{TM}	SJ MOSFET
Eon, uJ	156	143
Eoff, uJ	87	70
switching loss, W	24.3	21.3
conduction loss, W	7.25	7.25
total power loss, W	31.55	28.55

As the current level is increased to 15A, the on-state voltage of the high speed IGBT becomes much lower than that of SJ MOSFET (1.77 vs 2.23V as shown in Fig. 3b). The IGBT conduction loss becomes significantly lower than that of SJ MOSFETs by 26% while its switching loss is slightly higher by 8%. At this current level of 15A, the high speed IGBT and SJ MOSFET show similar power losses.

Table 2 power losses at Ic=15A and 150C

	COOLiRIGBT^{TM}	SJ MOSFET
Eon, uJ	214	195
Eoff, uJ	143	139
switching loss, W	35.7	33
conduction loss, W	13.28	16.73
total power loss, W	48.98	49.73

For soft-switching such as zero-voltage–switching (ZVS) applications, the turn-on energy is negligible because the transistors get switched to on-state when the voltage across the device reaches zero. In this case, the conduction loss and turn-off loss are the main contributors to the total power loss for each transistor. Table 3 compares the power losses for the high speed IGBT and SJ MOSFET for ZVS applications. The total power loss of the high speed IGBT is 6% lower than that in SJ MOSFET. For converters with higher output power, COOLiRIGBT^{TM} can offer much lower conduction loss than SJ MSOFET while keeping similar turn-off power loss as SJ MOSFET. This will make COOLiRIGBT^{TM} a better choice of transistors for DC-DC converters to achieve a higher efficiency.

Table 3 power loss at Ic-15A and 150C

	COOLiRIGBT^{TM}	SJ MOSFET
Eoff, uJ	143	139
switching loss, W	28.6	27.8
conduction loss, W	13.28	16.73
total power loss	41.86	44.53

For ZVS converts with a bus voltage of 400V and 50% duty cycle, the turn-on loss is negligible. The maximum current allowed for various switching frequencies were calculated for COOLiRIGBT^{TM} and SJ MOSFET using Tjmax=150C. The results are shown in Fig. 8. COOLiRIGBT^{TM} and SJ MOSFET show similar maximal input current, ~14A at 200 kHz.

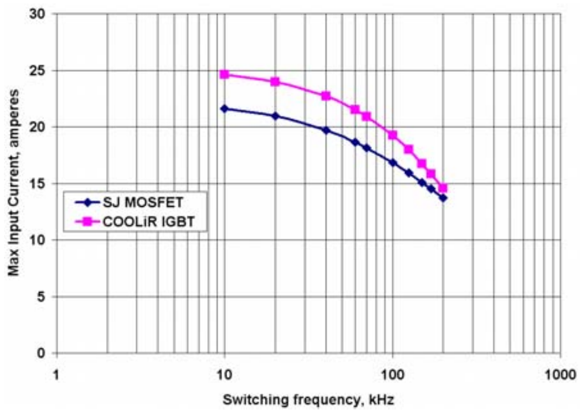


Fig. 8 Comparison of maximum input current at various switching frequencies for COOLiRIGBT™ and SJ MOSFET at 150°C for ZVS applications.

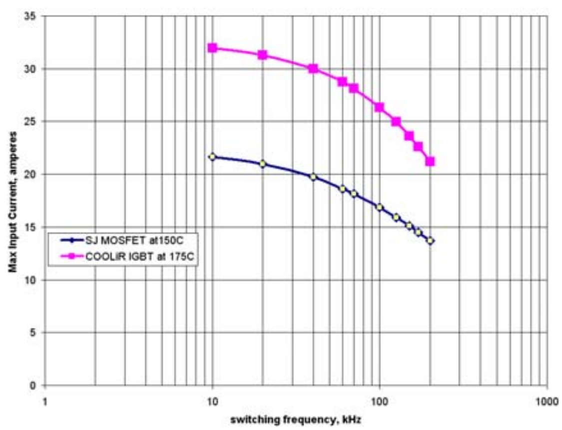


Fig. 9 Maximum input current at 200 kHz is increased by 50% for COOLiRIGBT™ with Tjmax=175°C comparing with 14A for SJ MOSFET with Tjmax=150°C.

The Tjmax of the COOLiRIGBT™ is rated at 175°C while the SJ MOSFET is limited to a Tjmax of 150°C. At 175°C, the on-state voltage drop of the COOLiRIGBT™ is increased by 8% and the turn-off energy is increased by 1.4%. Fig. 9 compares the maximum input current vs switching frequency for COOLiRIGBT™ at Tjmax=175°C and SJ MOSFET at Tjmax=150°C. The COOLiRIGBT™ has its maximum input current increased to 21A, which is 50% higher than SJ MOSFET.

In addition, COOLiRIGBT™ exhibits superior robustness with large safe-operating-area (SOA) - full square RBSOA at Vcc=480V and Ic=120A and short-circuit SOA of 10 µs at Vcc=400V and 150°C.

A simple fabrication process along with high current carrying capability and large SOA enables the COOLiRIGBT™ a low cost and high performance switch option for high frequency DC-DC converters.

III. CONCLUSION

High speed punch-through IGBT on ultra thin wafer was successfully developed for DC-DC conversion up to 200 kHz. A simple fabrication process in conjunction with high current carrying capability and large SOA make the high speed IGBT a cost-competitive and high performance switch option for the DC-DC converters.

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