

# 200 kVA Compact IGBT Modules with Double-Sided Cooling for HEV and EV

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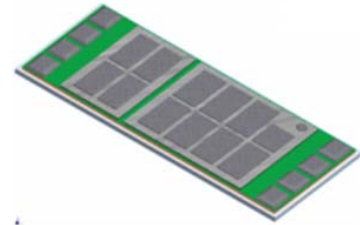
**Abstract**— High power compact IGBT half bridge modules with a current rating of 300A and a blocking voltage of 650V using ultra thin IGBTs and diodes have been successfully developed with double-sided cooling capability. The wirebond-less package building block called COOLiR<sup>2</sup>DIE<sup>TM</sup> has a small area of 28.5 mm x 16 mm with a power rating 200 kVA. This is the most compact IGBT package reported today. A low on-state voltage of 1.6V at 300A is achieved in the wirebond-less package. The combination of lower on-state voltage and larger heat exchange area due to the solderable front metal (SFM), increases the IGBT module current carrying capability by 30%.

## I. INTRODUCTION

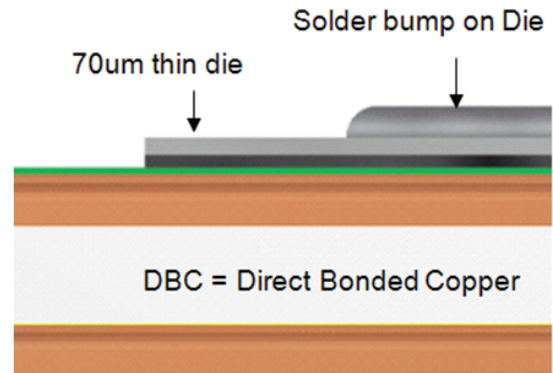
The demand for high voltage and high current in hybrid electric vehicles (HEVs) presents technical challenges for power conversion beyond those normally associated with vehicle electrical and electronic systems. An increasing demand for fuel efficiency warrants light weight and small volume power control unit (PCU) in HEV [1, 2]. Conventional IGBT power modules use wire bonds which is the common site of module failures due to coefficient of thermal expansion (CTE) difference, and is one of the main limiting factors for module life. IGBTs and free-wheeling diodes (FWD) with dual solderable metals on top and bottom of each die offer a wirebond-less assembly option with enhanced reliability and lower manufacturing cost [3, 4]. In addition, it allows double sided cooling with significantly larger heat exchange area, thus improving thermal management than wire bonds used in traditional power modules.

In this paper, we report the development of high power compact IGBT half bridge modules using ultra thin IGBTs and diodes with double-sided cooling capability. The wirebond-less package building block called COOLiR<sup>2</sup>DIE<sup>TM</sup> has a small area of 28.5 mm x 16 mm with a power rating 200 kVA. This is the most compact IGBT package reported today. A low on-state voltage of 1.6V at 300A is achieved in the wirebond-less package. The combination of lower on-state voltage and larger heat exchange area due to the solderable front metal (SFM) increases the IGBT module current carrying capability by 30%.

Fig. 1 shows (a). top view and (b) side view of COOLiR<sup>2</sup>DIE<sup>TM</sup>.



(a). Top view of a COOLiR<sup>2</sup>DIE<sup>TM</sup>



(b). Side view of a COOLiR<sup>2</sup>DIE<sup>TM</sup> attached to DBC

Fig.1 Wirebond-less package building block COOLiR<sup>2</sup>DIE<sup>TM</sup>  
(a) top view and (b) side view.

The solderable metal compositions used on the IGBTs and diodes include Ti-Ni-Ag. The ultra thin IGBT and diode dice are soldered to DBC (Direct Bonded Copper) which provides mechanical stability and good CTE match to the Si. Die attach of the ultra thin and large die (12x12mm) has been a key process development challenge. Fig. 2 shows a severe wafer warpage of 32 mm could be induced when the ultra thin wafers were coated with a thin layer of solder.



Fig.2 Wafer pre-solder of 70  $\mu\text{m}$  IGBTs showed a severe warpage of 32 mm.

Two units of COOLiR<sup>2</sup>DIE<sup>TM</sup> were assembled to make a half bridge module called COOLiR<sup>2</sup>BRIDGE<sup>TM</sup>. Fig. 3 is a photograph of a COOLiR<sup>2</sup>BRIDGE<sup>TM</sup>. The module is capable of blocking 650V.

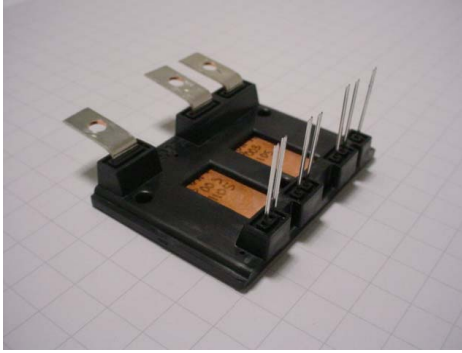


Fig.3 A photograph of COOLiR<sup>2</sup>BRIDGE<sup>TM</sup> module.

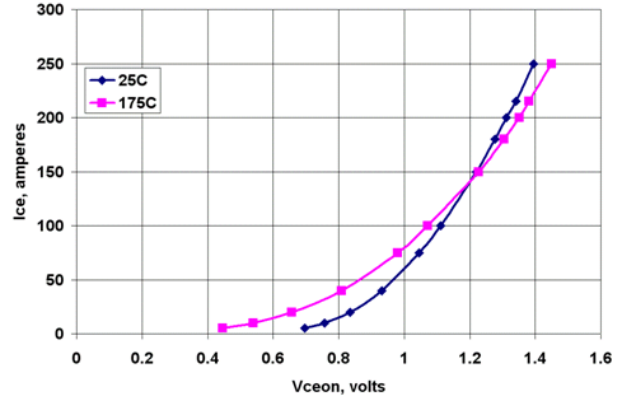
## II. ELECTRICAL CHARACTERIZATION OF COOLiR<sup>2</sup>DIE<sup>TM</sup>

IGBT with field stop (FS) structure offers a superior trade-off between static and dynamic losses as compared with Punch-Through (PT) - IGBTs [5]. The typical thickness of 650V FS IGBT is in the range of 65 – 75  $\mu\text{m}$ . Thin wafers could be severely warped due to compressive or tensile metal stress, thus resulting in high mechanical breakage and poor yield [6, 7].

In this paper, we report for the first time, that large trench IGBT dice of 12 mm x 12 mm with solderable metals on both front and back sides of the 70  $\mu\text{m}$  thin wafers successfully developed with a current carrying capability of 300A and a blocking voltage above 700V. Fig. 4a shows a photograph of the high power IGBT die. The forward conduction characteristics are shown in Fig. 4b.



(a). Top view of the IGBT die



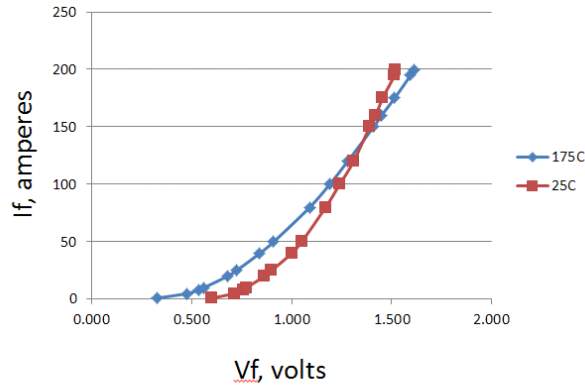
(b). IGBT forward conduction characteristics

Fig. 4 (a). Top view of the IGBT die with SFM and (b). Forward conduction characteristics of IGBT.

Optimal performance of IGBT modules in HEV/EV power train requires compatible diodes with fast speed and soft recovery to minimize the turn-on loss of IGBT and to reduce the voltage overshoot and oscillation which are commonly observed in many power conversion applications. In this paper, we report 300A, 700V diodes with solderable metals on both front and back sides of the 70  $\mu\text{m}$  thin wafers. A top view of the diode chip and its static characteristics are shown in Fig. 5a and 5b, respectively.



(a). Top view of the diode



(b). Diode forward conduction characteristics

Fig. 5 (a). Top view of the diode and (b). Forward conduction characteristics of the diode.

The turn-on power dissipation of IGBTs and Electro-Magnetic Interference (EMI) noise are strongly dependent upon the reverse recovery characteristics of the FWD's. We have successfully developed soft recovery diodes which exhibit oscillation-free feature while maintaining the low turn-on power dissipation for IGBTs. Fig. 6 compares the turn-on waveforms of IGBTs using previous generation fast recovery diodes and the newly developed diodes without oscillation.

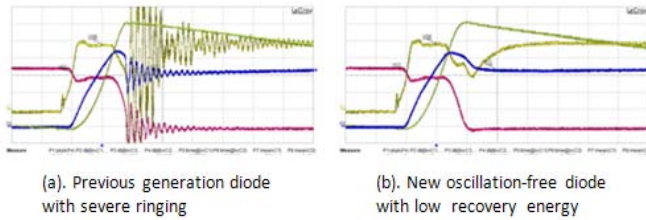


Fig. 6 Comparison of FWDs with (a). severe ringing and (b). oscillation-free feature.

### III. ELECTRICAL CHARACTERIZATION OF COOLiR<sup>2</sup>BRIDGE<sup>TM</sup> MODULE

Two units of COOLiR<sup>2</sup>DIE<sup>TM</sup> were assembled to make a half bridge module called COOLiR<sup>2</sup>BRIDGE<sup>TM</sup> as shown in Fig. 3. The output characteristics of the IGBTs are shown in Fig. 7. It exhibits a low  $V_{ceon}$  of 1.6V at 25C. The COOLiRIGBT<sup>TM</sup> exhibits positive temperature coefficients; the  $V_{ceon}$  is increased with increasing temperature which is ideal for paralleling multiple units of COOLiR<sup>2</sup>DIE<sup>TM</sup> to meet various output power required in HEV and EV systems.

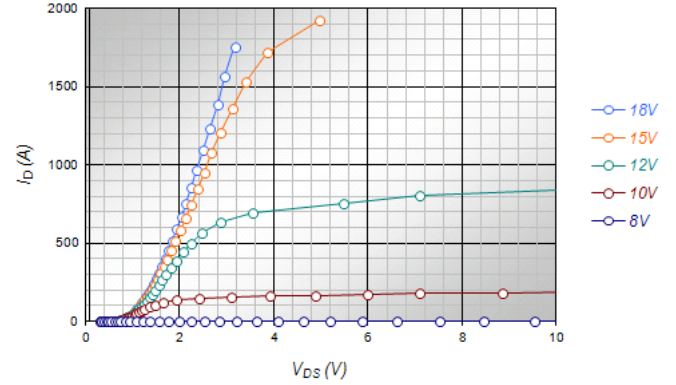


Fig. 7 Typical output characteristics of IGBTs from the COOLiR<sup>2</sup>BRIDGE<sup>TM</sup> module. .

The turn-on and turn-off power dissipation of IGBTs were measured at 25°C and 150°C, respectively. The turn-on waveforms of IGBTs exhibit oscillation-free feature. In addition, the turn-on power loss of IGBTs shows a very small increase of 3.8% when temperature is changed from 25°C to 150°C, This suggests the reverse recovery of the new diodes called COOLiRDiode<sup>TM</sup> are not sensitive to the operation temperature of the inverters.

The turn-off of the IGBT are very fast with a  $t_{fall}$  time of 70 ns at 25°C and 90 ns at 150°C. The turn-off power dissipation of IGBTs is increased by 22% at 150°C. Table 1 summarizes the average switching characteristics of IGBTs and diodes from the COOLiR<sup>2</sup>BRIDGE<sup>TM</sup> module .

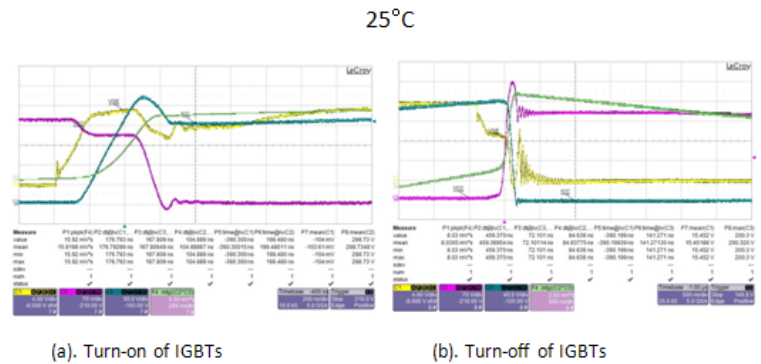


Fig. 8 The turn-on and turn-off waveforms of IGBTs at 25°C.  $V_{cc}=240V$ ;  $I_c=270A$ ;  $R_g=6.8\Omega m$ .

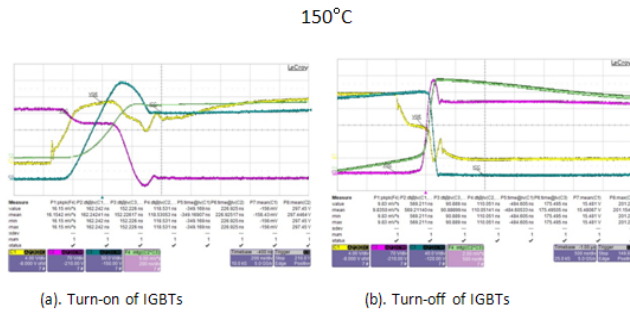


Fig. 9 The turn-on and turn-off waveforms of IGBTs at 150°C.  $V_{cc}=240V$ ;  $I_c=270A$ ;  $R_g=6.8\Omega m$ .

Table 1: summary of switching characteristics of IGBTs

	$E_{on}, \mu$	$E_{off}, \mu$	$t_{fall}, ns$
25C	15730	7860	70
150C	16328	9620	90

Test conditions:

$V_{cc}=240V$ ;  $I_c=270A$ ;  $R_g=6.8\Omega m$ .

The reverse recovery waveforms of the COOLiRDiode™ diodes are shown in Fig. 10 which exhibit small reverse recovery current without oscillation. The clean waveforms obtained from COOLiR<sup>2</sup>BRIDGE™ module is a good indication that COOLiR<sup>2</sup>BRIDGE™ modules have very low paracitics compared with standard IGBT modules assembled by wire bond approach.

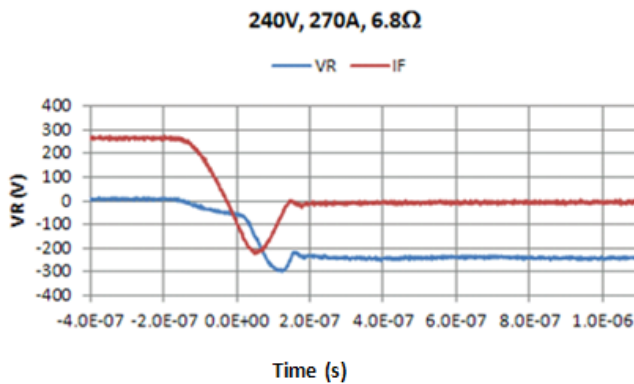


Fig. 10. Typical reverse recovery waveforms of the FWD diodes from the COOLiR<sup>2</sup>BRIDGE™ module. .

#### IV. CONCLUSION

High power compact IGBT half bridge modules with a current rating of 300A and a blocking voltage of 650V using ultra thin IGBTs and diodes have been successfully developed with double-sided cooling capability. The wirebond-less package building block called , COOLiR<sup>2</sup> DIE has a small footprint of 28.5 mm x 16 mm with a power rating of 200 kVA, This is the most compact IGBT package reported today. The combination of low loss IGBTs and oscillation free FWDs in a low - paracitic module package significantly enhance the performance of COOLiR<sup>2</sup>BRIDGE™ modules.

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