New 4.5kV IGBT Module with Low Power Loss and High Current Ratings

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Abstract

A new 4.5kV IGBT module with high current rating and maximum junction temperature (Tjmax) was developed. The module has an advanced trench HiGT structure applied to achieve low loss characteristics [1][2]. The electrical and thermal characteristic of the module were optimized in order to reduce thermal resistance and improve reliability. Comparing with the conventional product type, Tjmax of new IGBT is improved by 25K. Therefore, the current ratings of new IGBT module can be increased by 25%.

1. Introduction

4.5kV IGBT modules are widely used for inverters and DC-DC converters in power application like wind power and traction applications. Recently, it is required for these applications to increase output power density of inverters and converters. For high power density inverter, it is important to realize the robustness at high temperature.
To meet these requirements, we developed the new 4.5kV IGBT module with 25% higher current ratings.

2. Target of the Development, and Design Concept

Fig.1 shows the Hitachi 4.5kV IGBT module trend with regard to current rating, junction temperature, and typical Vce(sat). Concerning the conventional product type, maximum current rating is 1200A and 800A for 140mm x 190mm and 140mm x 130mm respectively. In this development, our target is to increase current ratings by 25% in comparison with conventional product type. Fig.2 shows comparison of specifications between new IGBT and conventional type. In order to increase current rating, it is necessary to decrease the power loss of Si chips, to reduce thermal resistance Rth(j-c) and to increase Tjmax. And to increase Tjmax, it is necessary to improve Si chip durability at higher Tj and the reliability of package.

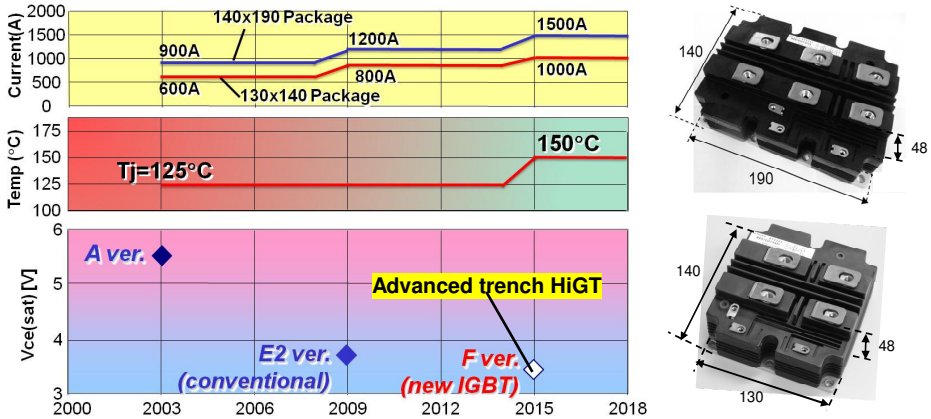


Fig. 1. Hitachi's 4.5kV IGBT trend(Left) and external appearance of advanced trench HiGT module(Right)

Model Name	Conventional	New IGBT	Ratio
Current Rating	1200A(140x190mm^2) 800A(130x140mm^2)	1500A(140x190mm^2) 1000A(130x140mm^2)	+25%
VCE(sat)	4.3V	3.6V	-16%
Eoff(full)	4.5J/P	4.1J/P	-9%
VF	3.2V	2.8V	-13%
Eon+Err(full)	7.9J/P	7.0J/P	-11%
Rth(j-c) Diode	0.026	0.021	-20%
Tj	125°C	150°C	+25K

Fig. 2. Comparison of specification between new IGBT and conventional type (Eoff(full), Eon+Err(full) and Rth(j-c)Diode are specifications of 140 x 190 size)

3. 4.5kV advanced trench HiGT

This new IGBT has the advanced trench gate structure(Advanced Trench HiGT structure) with deep floating-p layer to realize the improvement of Vce(sat) vs. Eoff trade-off relationship. The thickness of n-type bulk layer and structure of backside are tuned and optimized for soft switching and reduction of Vce spike at turn off. The advanced trench HiGT structure is shown in Fig.3 in comparison with conventional IGBT. The characteristic structures are the floating p-layer separated from the trench gates. This gate structure can suppress excessive VGE overshoot at IGBT turn-on, and then Irp of diode recovery decrease.

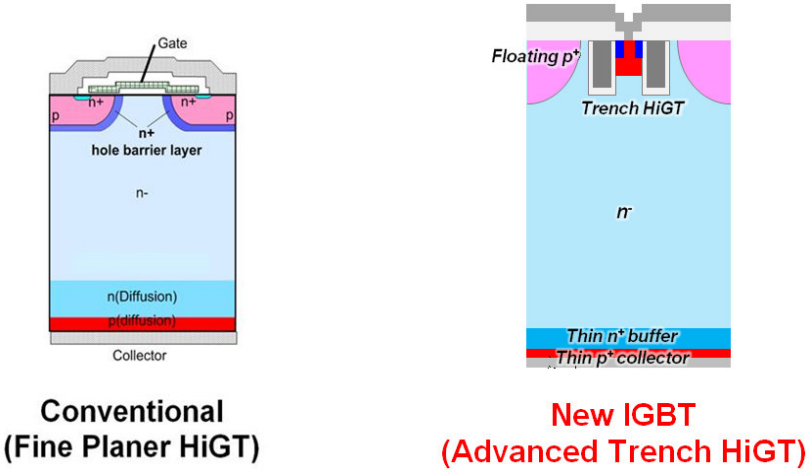
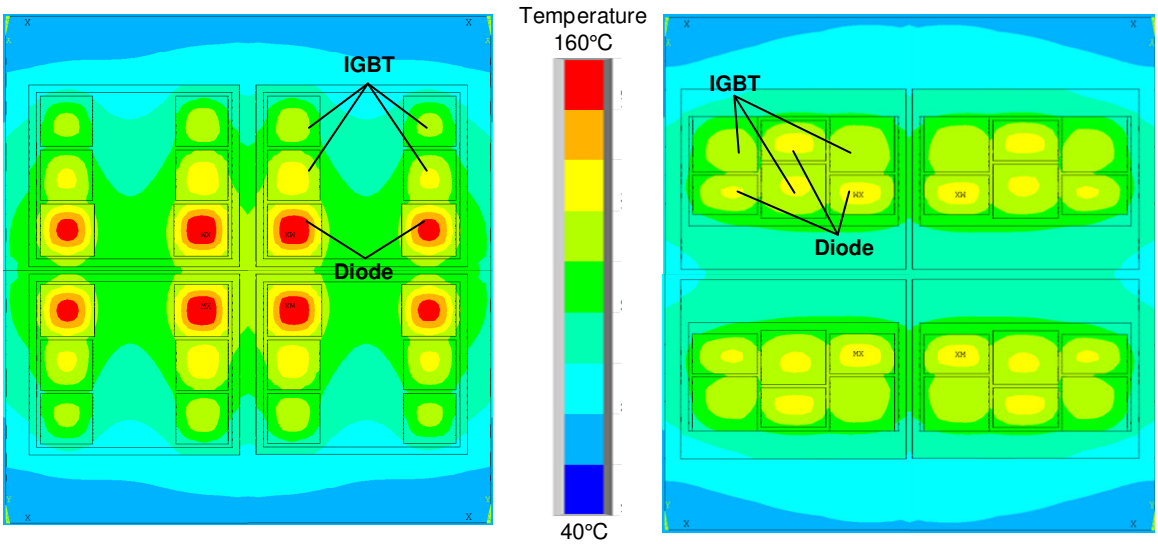


Fig. 3. IGBT unit cell structure

4. Package

In order to reduce thermal resistance of diode, chip layout is optimized. Active areas of diodes are enlarged by 20% and dispersed in order to realize the effective heat spread [3][4]. Fig. 4 shows temperature simulation of the advanced trench HiGT module in comparison with conventional product type. In addition, a staggered arrangement of diode chips suppresses thermal interference between two chips. As a result, thermal resistance of diode 20% reduction is achieved without compromising electrical characteristics.

To achieve higher Tjmax than conventional products, our newest package technologies same concept as 3.3kV latest IGBT are used [3][4]. Using these new technologies, long-term reliability of IGBT modules at high operation temperature can be achieved.



Ta=40°C, Icpeak=1000A(707Arms), Vcc=2800V,
Rth(hs-a)=0.015(K/W), Modulation ratio = 98%, Power factor = 90%

a) Conventional module b) New IGBT module

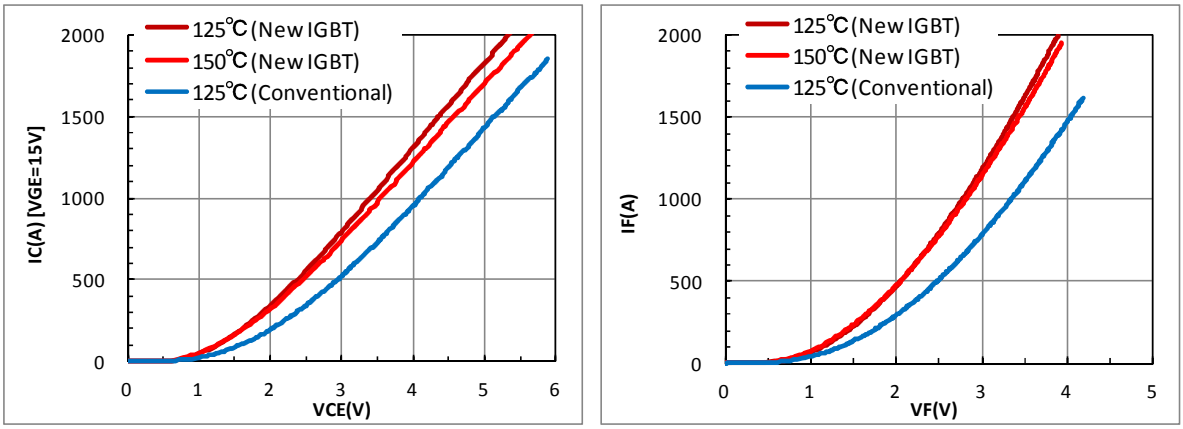
Fig. 4. Comparison of temperature distribution(simulation)

5. Electrical characteristics

5.1. Loss characteristics

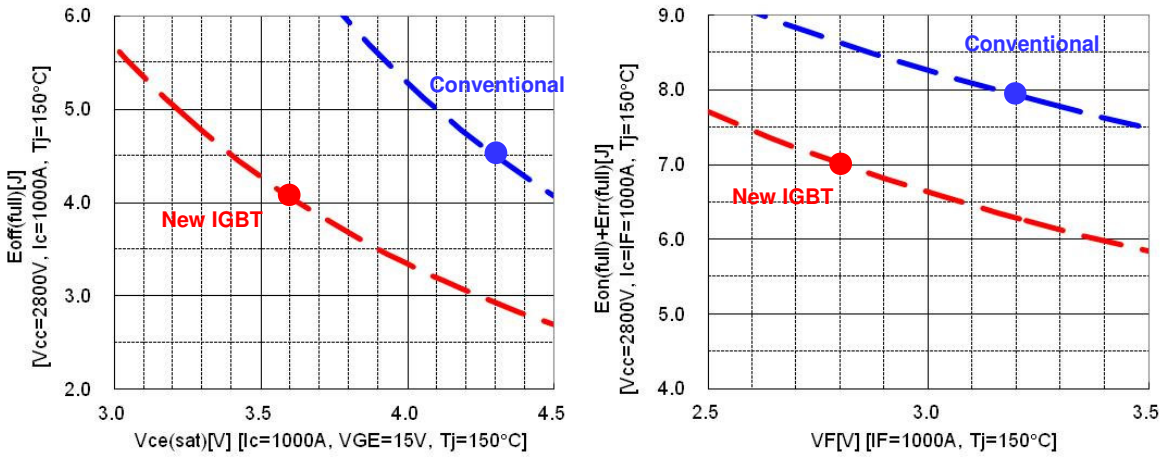
Output characteristics of new 4.5kV IGBT and conventional product type are shown in Fig.5. Comparing with conventional product type, VCE(sat) of new IGBT at Tj = 125°C is reduced by about 17% and VF at Tj = 125°C is also reduced by about 14%.

The improvement of VCE(sat) vs. Eoff trade-off relationship and VF vs. Eon+Err trade-off relationship of new IGBT module are shown in Fig. 6. The advanced trench HiGT module's Vce(sat) vs. Eoff trade off is improved from the conventional product type. VF vs. Eon+Err trade off is also improved. Eoff of the advanced trench HiGT module is 9% lower than that of the conventional product type and Vce(sat) is decreased by 0.7V at Tj=150°C. Eon+Err of the advanced trench HiGT module is 11% lower than that of the conventional product type and VF is decreased by 0.4V at Tj=150°C.



a) VCE(sat) vs. IC b) VF vs. IF

Fig. 5. Output characteristics comparison between conventional product type and new IGBT (package size = 130 x 140 mm)



a) Vce(sat) vs. Eoff trade-off b) VF vs. Eon + Err trade-off

Fig. 6. Trade off comparison between conventional product type and new IGBT (package size = 130 x 140 mm)

5.2. Electrical durability

Fig.7 shows waveforms of RBSOA and RRSOA of the new IGBT module. And Fig.8 shows the waveform of SCSOA. From these results, electrical durability at high temperature is achieved.

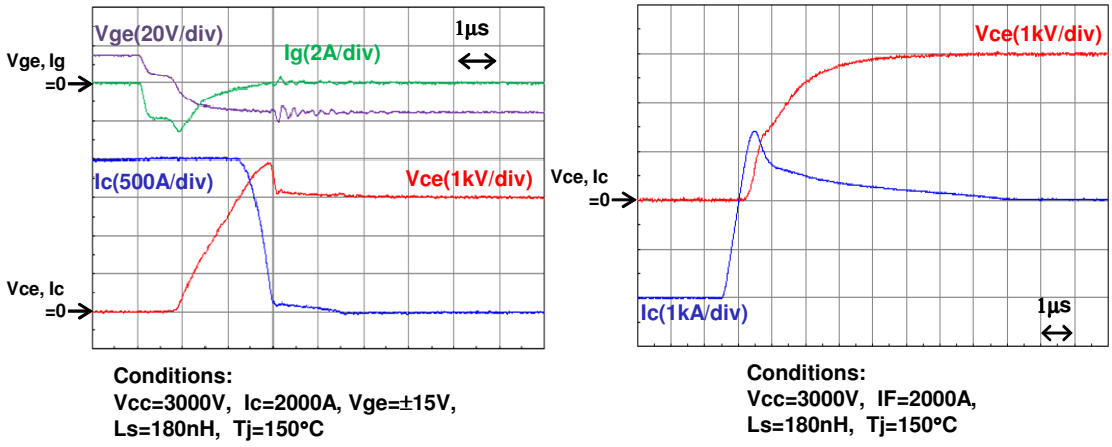


Fig. 7. RBSOA(Left) and RRSOA(Right) of new IGBT module (package size = 130 x 140 mm)

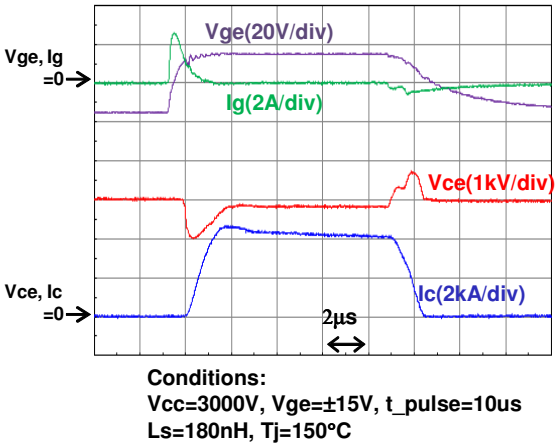


Fig. 8. SCSOA of new IGBT module (package size = 130 x 140 mm)

6. Maximum phase current

Maximum phase current is calculated and is shown in Fig.9. Output current improved more than 25% at Tj=Tjmax-15K.

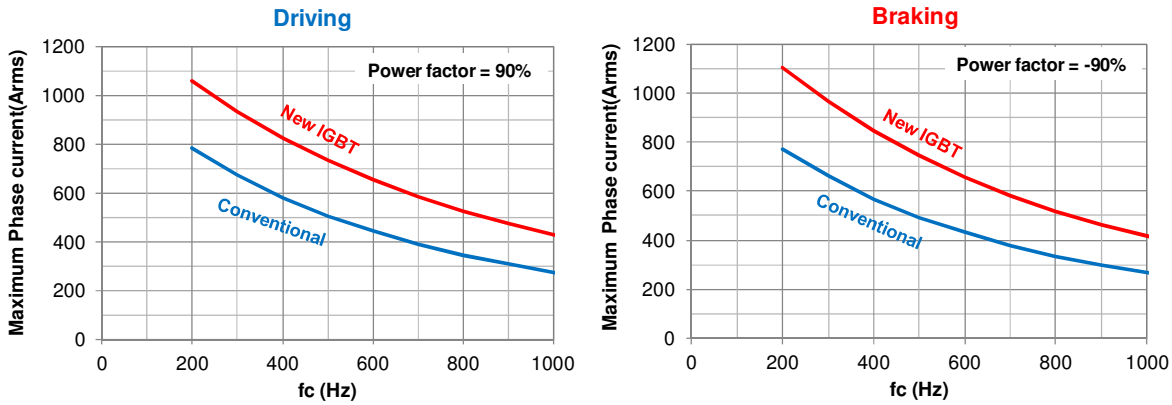


Fig. 9. Calculation of maximum phase current

7. Conclusion

A new 4.5kV IGBT module with high current rating was developed by employing the advanced trench HiGT and optimizing package designs. Output current of inverters can be increased by more than 25% in comparison with conventional product type.

8. Reference

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