NEW 3.3kV IGBT Module with Low Power Loss and High Current Ratings

Katsunori Azuma[1], Akitoyo Konno[2], Isamu Yoshida[3], Yasushi Toyoda[1], Katsuaki Saito[1], [1]Power System Company, Hitachi,Ltd., Ibarakiken,Japan (katsunori.azuma.em@hitachi.com), [2]Hitachi Research Laboratory, Hitachi, Ltd., Ibarakiken, Japan, [3]Yokohama Research Laboratory, Hitachi, Ltd., Yokohama, Kanagawa-ken, Japan

Abstract

A new 3.3kV IGBT module, advanced trench HiGT module, was developed. The current ratings of the advanced trench HiGT module can be increased by 20% from the present product type using new IGBT and Diode, and structural change with low thermal resistance and low internal stray inductance. To achieve low loss IGBT characteristics, advanced trench HiGT(High Conductivity IGBT) structure is adopted, and diode characteristics are optimized by lifetime control. The advanced trench HiGT modules are able to make the size of inverter and converter systems smaller.

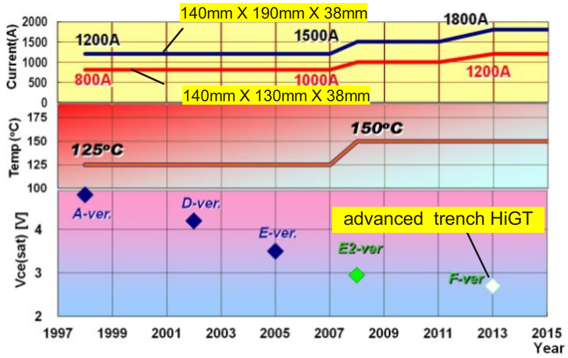
1. Introduction

The 3.3kV IGBT modules are now well used for power inverter and converters. One of the standard package size is 140mm x 130mm x 38mm, and its maximum current rating is 1000A. By an increase of the current ratings of IGBT modules, capacity of the inverter can be also increased, or the inverter size might be possible to shrink. Therefore, the higher curr ent rating IGBT module is required. In order to realize this requirement, the low loss characte ristics of IGBT and diode are important, and low thermal resistance Rth(j-c) is also needed.
Utilizing the advanced trench HiGT structure[1][2][3][4], Vce(sat) of the Advanced trench HiGT module is 0.8V lower than the existing product type at the same turn off loss and same current density at Tj=150degC. Recovery loss and turn on loss Err+Eon of the new IGBT module is 15% lower than the present product type at Tj=150degC. As a result, inverter loss can be decreased about 15%. Thermal resistance Rth(j-c) of the advanced trench HiGT module is 20% lower than the present product type by using new thermal dispersion chip layout. As a result, the current rating of the advanced trench HiGT module can be increased by 20% from the present product type. A stray inductance of the new module is 20% lower than the present product type by using new design terminals. Therefore spike voltage at turn-off of the advanced trench HiGT module with current up ratings is same as that of the present product type.

2. Target of the Development, and Design Concept

Fig.1 shows the Hitachi 3.3kV IGBT module trend with regard to current rating, junction temp erature, and typical Vce(sat). At the present product type, maximum current rating is 1500A and 1000A for 140mm x 190mm x 38mm and 140mm x 130mm x 38mm. The main target of this development is to increase current ratings by +20%. It is a challenging attempt without any sacrifice of increase of power dissipation. To cope with this issue, the advanced trench HiGT module adopts our latest IGBT and diode for the improvement of loss characteristics. Packaging technology is also improved with regard to thermal impedance and internal stray inductance. Especially for the thermal impedance, -20% from the present product type is set as the target of this development.
New IGBT and diode are assembled in the 140mm x 130mm x 38mm new package (Fig.2-Right). New Package is smaller than present product type in case of same current rating

(1200A) (Fig.2-Left). Therefore the advanced trench HiGT module can be replaced for present product type and an inverter size can be smaller without decreasing capacity of the inverter (Fig.3).



Item	E2 version	F version	Ratio
Current Ratings	1500A（140x190mm²） 1000A（130x140mm²）	1800A（140x190mm²） 1200A（130x140mm²）	＋20%
Rth(i-c) IGBT（K/kW）	12.0（1200A）	10.0（1200A）	−20%
Rth(i-c) Diode（K/kW）	24.0（1200A）	20.0（1200A）	−20%
Stray inductance	18（1200Aﾓｼﾞｭｰﾙ）	14.4（1200A）	−20%
RoHS Compliance	Not applicable	Applicable	−

Fig. 1. Hitachi's 3.3kV IGBT trend(Left) and the target of the development(Right)

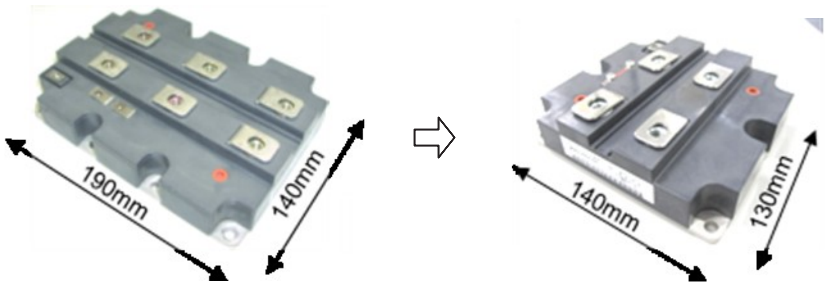


Fig. 2. 3.3kV 1200A present product type(Left) and advanced trench HiGT module(Right)

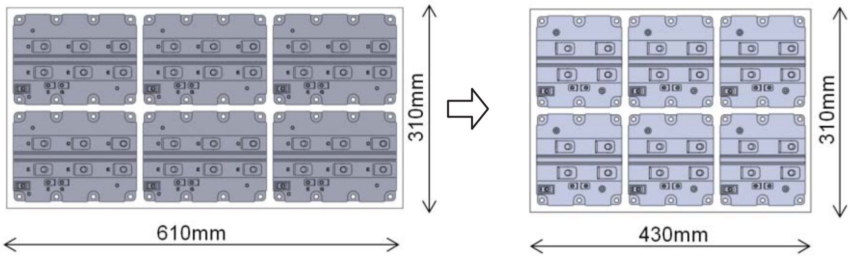
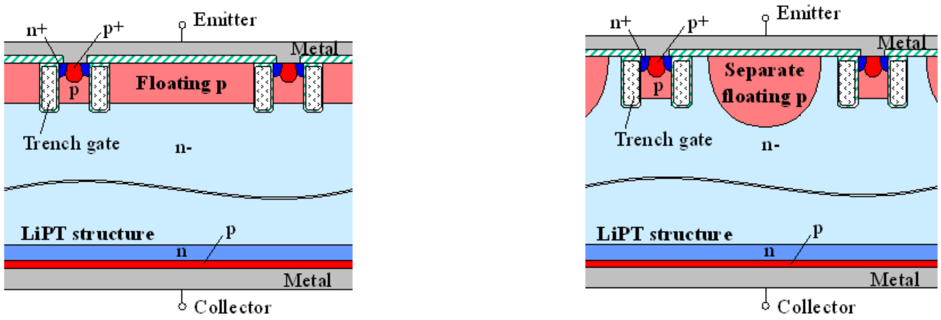


Fig. 3. Expamples for 2-level inverter size, present product type(Left) and advanced trench HiGT module(Right)

3. 3.3kV advanced trench HiGT

The new IGBT adopted the advanced trench gate structure(Trench HiGT structure[3]) 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.4 by comparison with conventional trench IGBT. The difference of these structu res is the floating p-layer separated from the trench gates. This gate structure can suppress excess V_{GE} overshoot at IGBT turn-on and at the same time, Irp of diode recovery decrease [2]. As a result, diode recovery dV_{AK}/dt decreases. The advanced trench HiGT recovery dV_{AK}/dt is shown in Fig.5 by comparison with conventional trench IGBT. The recovery dV_{AK}/dt for the advanced trench HiGT can be reduced by 73% from the conventional trench IGBT. This easy dV_{AK}/dt controllability enable a reduction of voltage surge, which may cause

EMI problem and insulation degradation of the motor coils. Fig.6 shows the turn-off durability of advanced trench HiGT, confirmed up to the turn-off current of rated Ic x 5 in the chip level test.



a) conventional trench HiGT b) advanced trench HiGT

Fig. 4. IGBT unit cell structure

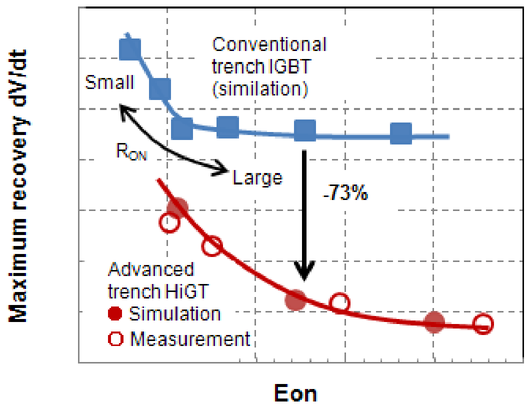


Fig. 5. Trade-off characteristics between maximum recovery dV_{AK}/dt and Eon

Conditions: Vcc=2200V, Ic=375A, Vge=+20V/15V, Ls=1.7uH, Tj=150degC

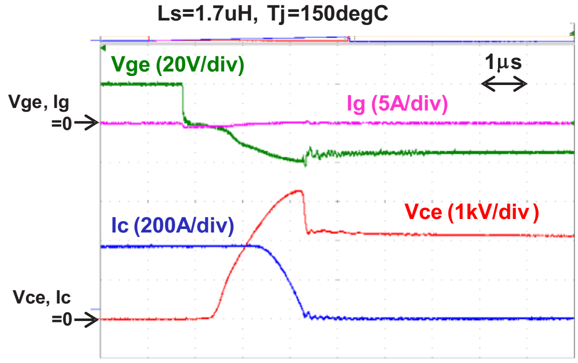
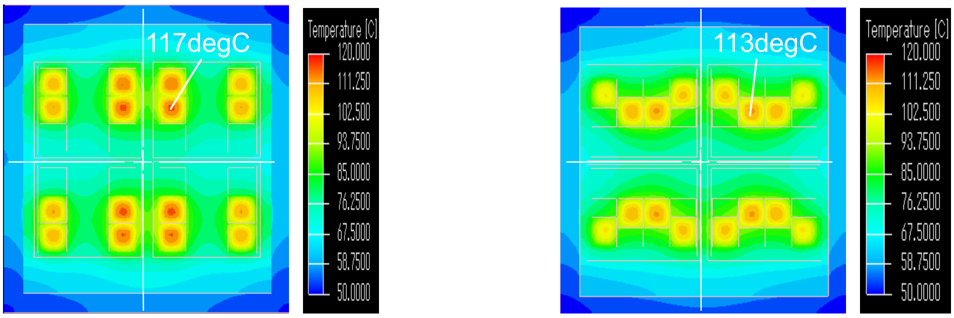


Fig. 6. IGBT(advanced trench HiGT) turn-off durability (chip level test)

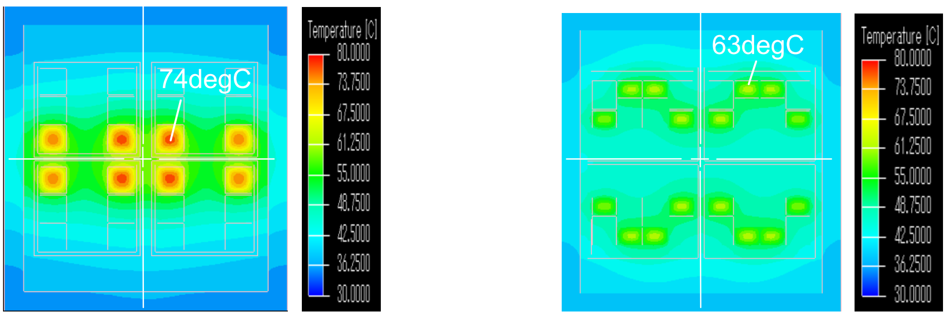
4. Package

The advanced trench HiGT module has good heat dispersion layout and some other parame ters are also tuned in order to achieve effective heat spread for low thermal resistance. Fig.7, 8 and 9 show temperature simulation of the advanced trench HiGT module by comparison with present product type. IGBT and diode chips of the advanced trench HiGT module are arranged as far as possible from the center of the module for effective distribution of heat generations. IGBT maximum temperature of the advanced trench HiGT module is 4degC lower than that of present product type (Fig.7). The number of diode chips increase double from the present product type. Diode maximum temperature of the advanced trench HiGT module is 11degC lower than that of present product type (Fig.8). At a combination heat of IGBT and diode, maximum temperature of the advanced trench HiGT module is 4degC lower than that of present product type (Fig.9). As a result of these optimization from the present product type, the thermal resistance $Rth(j\text{-}c)_{IGBT}$ and $Rth(j\text{-}c)_{diode}$ are decreased by more than 20%. The main terminal structure is designed to reduce internal stray inductance for larger current ratings. Fig.10 shows a new terminal stray inductance simulation compared with the present product type. By arranging most of area of new terminals face to face with short distance, stray inductance decreases by more than 20%. The main terminals are attached to substrate circuit pattern with ultrasonic bonding technology which lead to high joint reliability and compliance with RoHS. As a result of the improvements above, the current rating of 140mm x 130mm x 38mm package size is increased from 1000A for the present product type to 1200A for the advanced trench HiGT module.



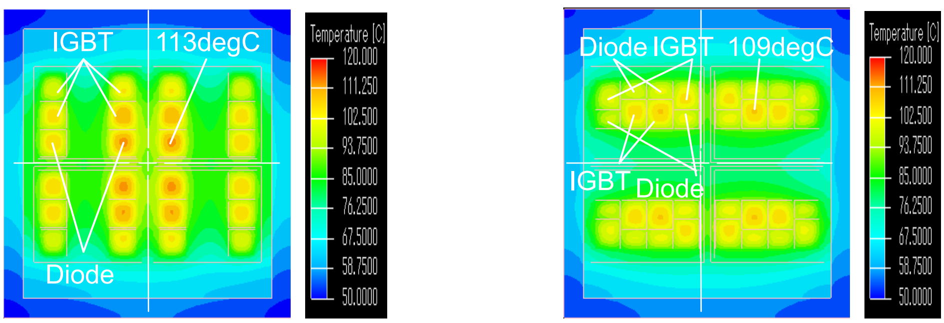
a) Present product type b) advanced trench HiGT module

Fig. 7. Comparison of the heat spread of the IGBT (simulation)



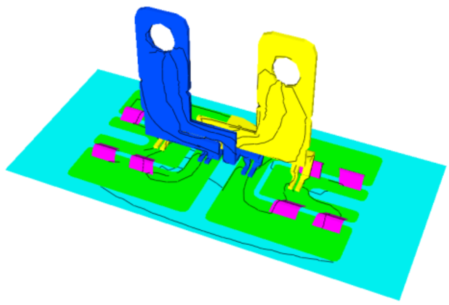
a) Present product type b) advanced trench HiGT module

Fig. 8. Comparison of the heat spread of the diodes (simulation)

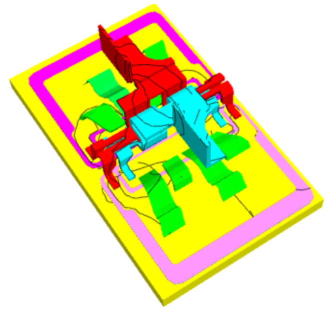


a) Present product type b) advanced trench HiGT module

Fig. 9. Comparison of the heat spread of the IGBT and Diode (simulation)



a) Present product type

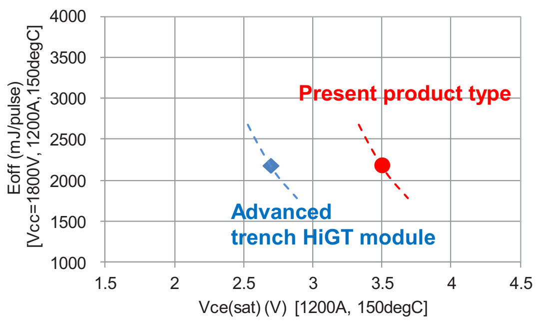


b) advanced trench HiGT module

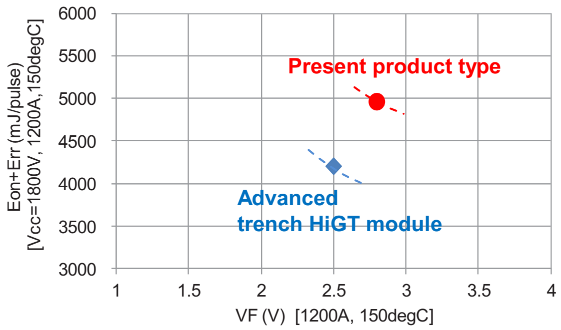
Fig. 10. Comparison of the main terminal structure (Stray inductance simulation)

5. Loss characteristics and inverter simulation

Trade-off characteristics of the conduction loss and the switching loss between the advance d trench HiGT module and present product type were compared (Fig.11). The advanced trench HiGT module's Vce(sat) vs. Eoff trade off is improved from the present product type. VF and Eon+Err trade off were also improved. Vce(sat) of the advanced trench HiGT module is 0.8V lower than the present product type at the same turn off loss at Tj=150degC. Eon+Err of the advanced trench HiGT module is 15% lower than that of the present product type and VF decrease by 0.3V at Tj=150degC. Fig.12 shows 2-level inverter loss simulations of the present product type and advanced trench HiGT module. In the whole carrier frequenc y range shown on here, the advanced trench HiGT module shows lower loss than present product type. Inverter loss can be decreased about 15% from the present product type at 1000Hz



a) Vce(sat) vs. Eoff trade-off



b) VF vs. Eon+Err trade-off

Fig. 11. Trade off characteristics

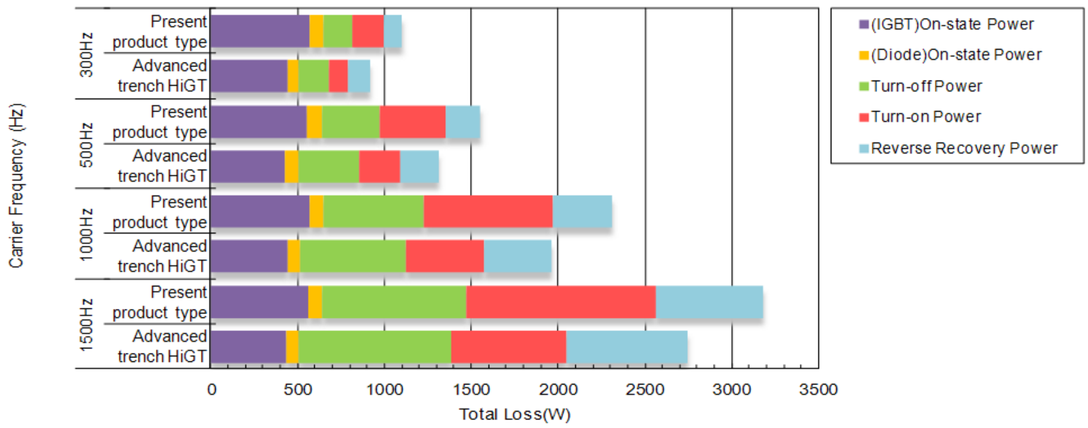


Fig. 12. 2-level inverter simulation

6. Conclusion

The loss characteristics of the advanced trench HiGT module are improved by adopting the advanced trench HiGT and optimized diode. Thermal resistance Rth(j-c) and internal stray inductance are also decreased by the structural change of the packaging. As a result of these improvements, the current ratings can be increased by 20% from the present product type. Using the advanced trench HiGT module, inverter size can be smaller without decreasi ng capacity of the inverter.

7. Literature

[1] T. Arai, et al.,The Advanced Trench HiGT with Separeate Floting p-Layer for Easy Controllability and Robustness", PCIM Europe 2011,pp.313-319.

[2] S. Watanabe et al.,"1.7kV Trench IGBT with Deep and Seperate Floating p-Layer Designed for Low Loss, Low EMI Noise, and High Reliability", ISPSD 2011, pp.48-51.

[3] M. Mori, et al. "A Trench-Gate High-Conductivity IGBT (HiGT) With Short-Circuit Capability", IEEE Transact. on Elec. Dev, vol. 54, No.8, Aug. 2007, pp. 2011-2016.

[4] K. Oyama, et al."Advanced HiGT with Low-injection Punch-through (LiPT) structure", in Proc. ISPSD, 2004, pp. 111-114.