7th Generation High Reliability HPnC module for Traction Applications

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Abstract

Power conversion systems, which are using power semiconductors, are spreading in various fields. Especially in the traction field the requirements for higher current density, conversion efficiency and reliability are increasing. To fulfill those requirements, Fuji Electric has developed 1700V and 3300V "High Power next Core" (HPnC) IGBT modules based on the 7th generation "X Series" chip technology. Thus, the power dissipation has been reduced while the power density has been increased. A base plate with low linear expansion coefficient as well as ultrasonic bonding technology are used to improve the thermal power cycling capability and hence realize a higher reliability of the module.

1 Introduction

In the last years, the importance of power electronic technologies, which are used in power control and conversion systems, has been increased. The main requirements to improve the performance of power electronic systems are downsizing, weight saving and increasing efficiency. In order to meet these requirements, IGBT modules with low static losses, as well as fast switching speed to decrease switching losses, need to be realized. However, high speed switching can easily cause high surge voltages due to the internal inductance of the package. Therefore, the reduction of the internal inductance is essential when optimizing the IGBT module [1]. To increase the current capacity, especially of high current rated IGBT modules, the modules are often connected in parallel. Hence the design of new developed packages should allow easy parallel connection.

In this paper, Fuji's latest low inductance package "High Power next Core" (HPnC) [2], as shown in figure 1, has been studied. This includes electrical characteristics of the 1700V and 3300V module respectively, both with the newest 7th chip generation [2] [3].

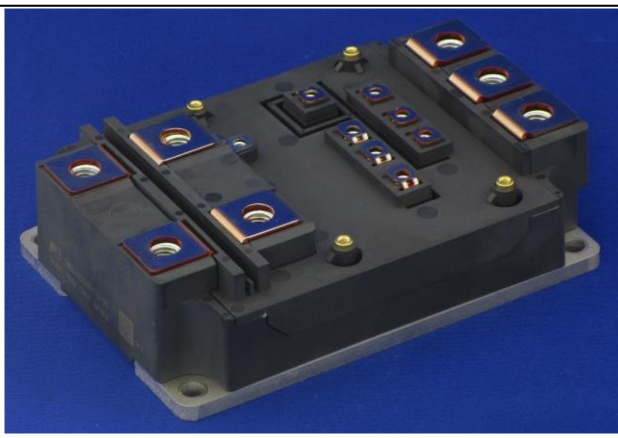

Fig1. High Power next Core (HPnC) Package

2 Newly developed package

In table 1, a comparison of the two packages, HPnC and the conventional module "High Power Module" (HPM), is shown. The surge voltage of the HPnC is smaller as the internal inductance of the module has been reduced. With the new generation of chips, which is used in the HPnC, the current density has been increased. Furthermore, the package has been optimized to improve the assembly of parallel connections. While the HPM is not RoHS compliant, the HPnC is.

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Table.1 Package characteristics

Package	HPM(Conventional)	HPnC	Improvement ratio(%)
External appearance/dimensions(mm)	L:130 D:140 H:38 	L:100 D:140 H:38 	-
Circuit	1in1	2in1	-
Rating(typical)	1700V/1200A	1700V/1200A	-
Module internal inductance(Lp)	42nH(in case of 2 in 1)	10nH	76.2
Surge voltage(V)	**1336**	**1192**	**10.8**
Foot print(cm^2)	**173.7**	**140**	**19.4**
Current density (A/cm^2)	**6.91**	**8.57**	**24.1**
Parallel connectivity	**Poor**	**Excellent**	-
Inductance during 2 in 1 parallel connection	**21nH(2400A 2pararell)**	**2.5nH(4800A 4pararell)**	89.0
Weight	**915g**	**790g**	13.6
RoHS	**Not compliant**	**Compiant**	-

2.1 Low inductance module

As shown in table 1, the internal inductance of the HPM is 42nH while the one of the HPnC is 10nH. Hence, the internal inductance could be decreased about 76%. In figure 2, the cross section of the HPnC with the anti-parallel structure between collector and emitter terminal to realize low inductance is shown. To verify the effect of the reduced internal inductance, the turn off waveforms of the HPnC and HPM with identical IGBT/FWD chip series are displayed in figure 3. The surge voltage during turn off under same di/dt condition and with same main circuit stray inductance is 144V lower for the HPnC. This result indicates that power modules with the HPnC package are suitable for faster switching conditions.

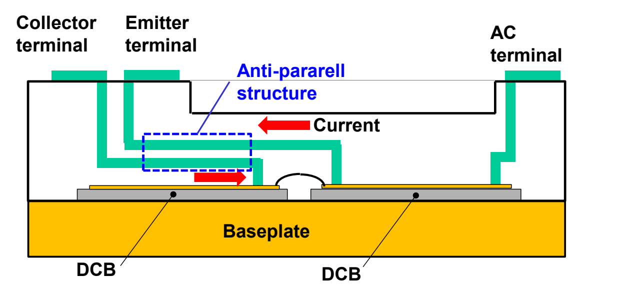

Fig2. Cross sectional picture of HPnC

2.2 High current density

Table 1 shows the comparison of the current density between HPnC and HPM for 1700V modules. The HPnC achieves a footprint based current density of 8.57A/cm2, which is about 24.1% higher than that of HPM with 6.91A/cm2. This is because chip current density and thermal resistance have been improved.

One reason is the improved chip current density of the 7th generation IGBT chip compared to the chips used in the HPM. The other reason is the improved thermal resistance of baseplate. The baseplate of the HPnC consists of MgSiC, which has a 1.5 times higher thermal conductivity than the AlSiC baseplate, which is used for the HPM. With these improvements, the HPnC package can realize high current density.

2.3 Easy parallel connection

Table 2 shows a schematic assembly of the parallel connection of conventional HPM and HPnC packages for comparison. The HPM configuration consists of two parallel 1in1 modules with 1200A current rating each. Thus, the total current rating of the resulting 2in1 configuration is 2400A. The HPnC configuration consists of four 2in1 modules with 1200A current rating each, resulting in a total current rating of 4800A. Hence, these two investigated configurations have almost the same current rating.

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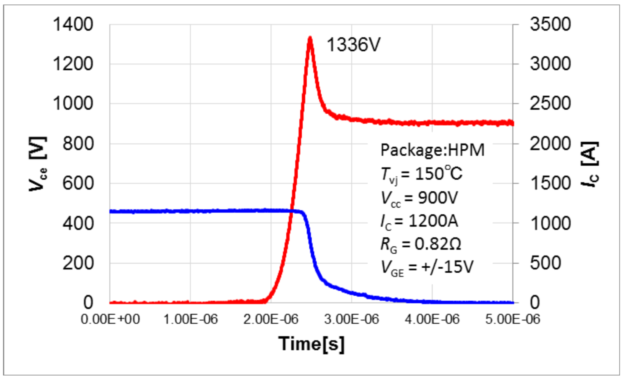

Fig3.1 Turn off surge voltage of HPM

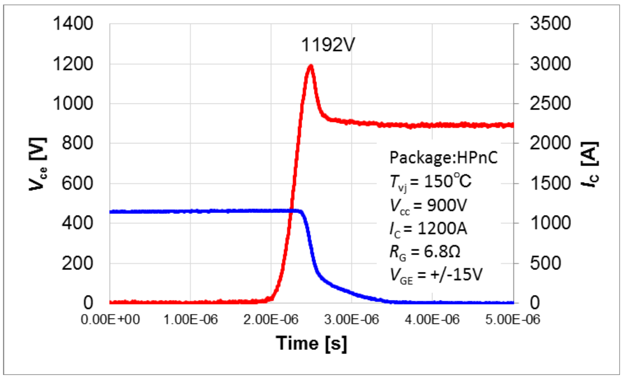

Fig3.2 Turn off surge voltage of HPnC

As can be seen in the drawing, the connection of the AC terminals of the HPM packages is obviously more complex than the one of the HPnC packages. While the HPM connection leads to an overlap of the three main circuit layer, the situation is much better for the HPnC, as the AC terminals are on the opposite site to the collector and emitter terminals. The whole configuration is easier to be connected to the main circuit. Another drawback of the HPM package related to parallel connection is the position of the emitter terminal. It is not close to the capacitor and thus the emitter bus bar needs to be lengthened, which causes an increase in the main circuit inductance. In the HPnC, the positions of the collector terminal and emitter terminal are close to the capacitor, which shortens the length of the bus bar and reduces the inductance of the main circuit.

In addition, as can be seen in table 2, the internal inductance for two pairs of HPMs connected in parallel is 21nH, while the one for four HPnC modules connected in parallel is only 2.5nH. It is a reduction of the internal inductance about 90%. The total inductance is determined by the internal inductance of the module and the one of the main circuit. Since the switching speed is, as indicated earlier, limited by the inductance, reducing the inductance of the modules and the main circuit, allows faster switching.

The current imbalance of the parallel connection of the HPnC packages is shown in figure 4. At turn off, the current ranges from 985A to 1030A, which lies within the 6% difference tolerance and hence allows the conclusion that the waveforms of the paralleled modules can be considered as identical.

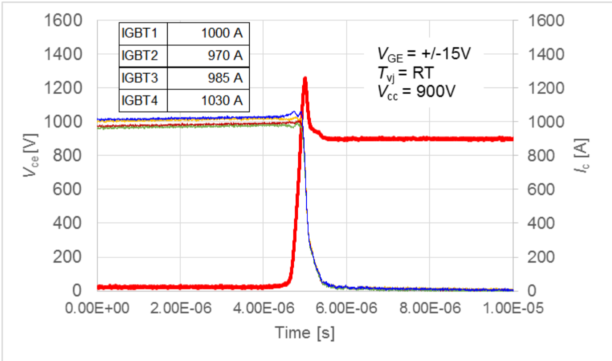

Fig4.Turn off waveform and in 4 parallel connection

2.4 RoHS compliance

In order to comply with the RoHS Directive, ultrasonic bonding is used to join the terminals and insulating substrate of the HPnC instead of solder bonding as is used in the HPM.

With this change of technique, the delta Tc P/C capability is increasing as the coefficients of the linear thermal expansion of the joined materials is more similar.

3 7th generation IGBT technologies

The 7th generation of IGBT chips uses an optimized trench-gate structure. The drift layer thickness of that new generation has been reduced by applying a thinner wafer compared to the previous generation. Due to the thinner drift layer, lower on-state voltage drop and lower conduction loss can be realized. Additionally, the trade-off relationship between on-state voltage drop and turn-off losses has been further improved by the

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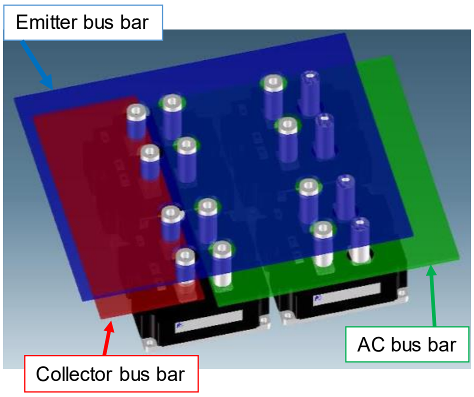
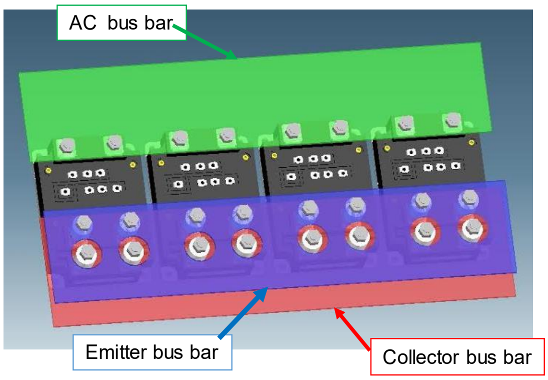
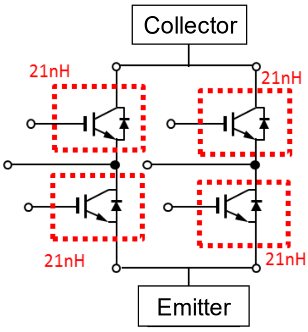
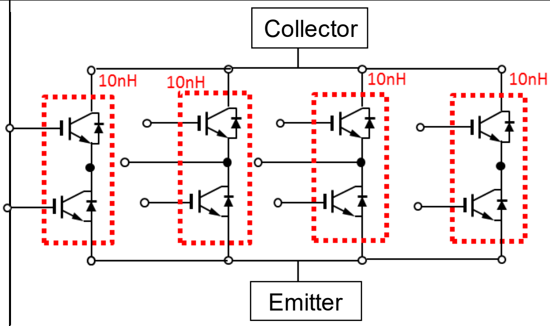
Table.2 Comparison of parallel connections

<table>
<tr><th></th><th>2 pair of 1 in 1 HPMs connected in parallel
(Total : 2400A/1700V)</th><th>Four 2 in 1 HPnC modules connected in parallel
(Total : 4800A/1700V)</th></tr>
<tr><td>Comparison of assembly during module parallel connections</td><td>
</td><td>
</td></tr>
<tr><td>Comparison of module inductance during parallel connections</td><td>

Total inductance : (21+21)/2=21nH</td><td>

Total inductance : 10/4=2.5nH</td></tr>
</table>

optimization of the surface structure resulting in smaller switching losses.

3.1 Improvement of 1700V IGBTs

Figure 5 shows the improvement of the characteristics compared to the conventional IGBT chips at Tvj = 150°C.The on-state voltage of the 7th generation IGBT has been reduced and with 1200A collector current it is about 0.35V below the one of the conventional IGBT.

Figure 6 shows the turn off energy (E_{off}) - Saturation voltage ($V_{ce(sat)}$) trade-off. Considering the same E_{off} condition, $V_{ce(sat)}$ has been improved by 0.35V. This proves that the E_{off} -$V_{ce(sat)}$ trade-off has been dramatically improved by adopting the 7th generation IGBT. This improvement could be achieved by expanding the active area of the chip through edge structure optimization as well as thinning the drift layer.

3.2 Improvement of 3300V IGBTs

The trade-off relationship between on-state voltage drops $V_{CE(sat)}$ and E_{off} for 450A/3300V HPnC module is shown in figure 7. A reduction of 0.6V of $V_{CE(sat)}$ and approximately 12% reduction of Eoff have been realized compared to the conventional IGBT. By adopting the 7th Generation IGBT, the efficiency of the power conversion system will be improved about 10%.

3.3 Power dissipation comparison of 1700V modules

The result of calculation power dissipation is shown in Fig.8. Considering an output current Io of 600Arms and a carrier frequency of 1.5 kHz ~ 5 kHz, the power dissipation of the HPnC is 4.7% ~ 8.6% lower than the one of the conventional module.

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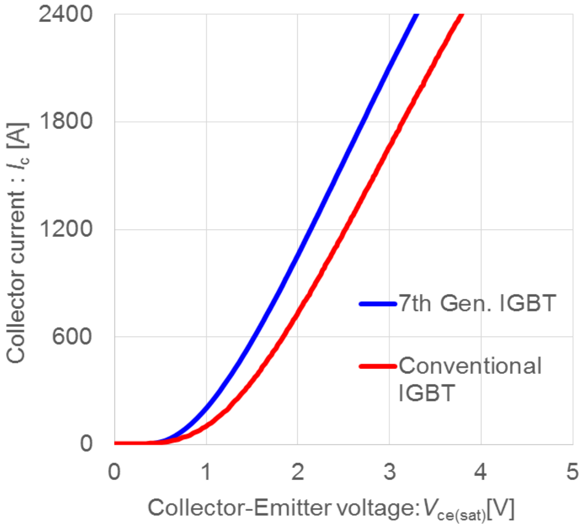


Fig5. 7[th] Gen IGBT/Conventional IGBT output characteristic

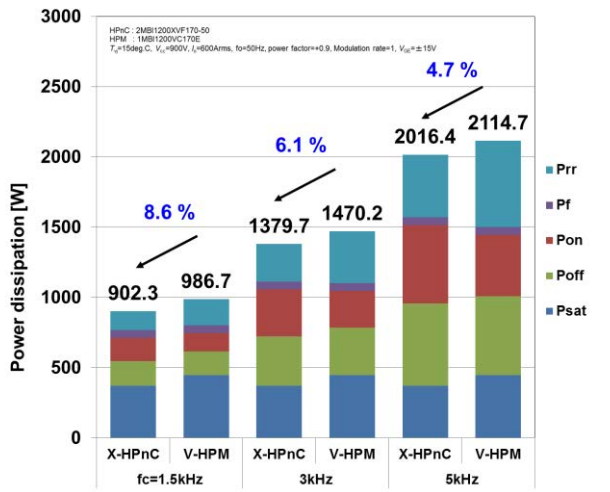


Fig8. Comparison of Power dissipation

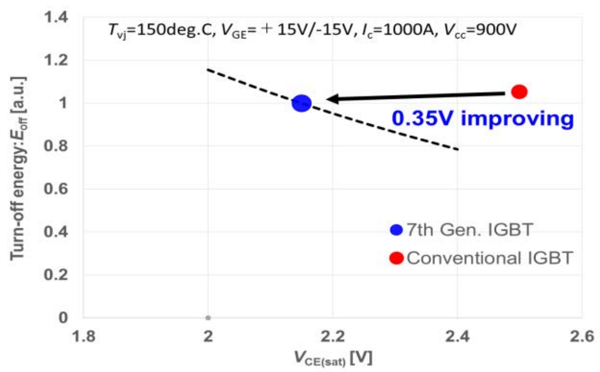


Fig6.7[th] Gen IGBT trade-off relationship

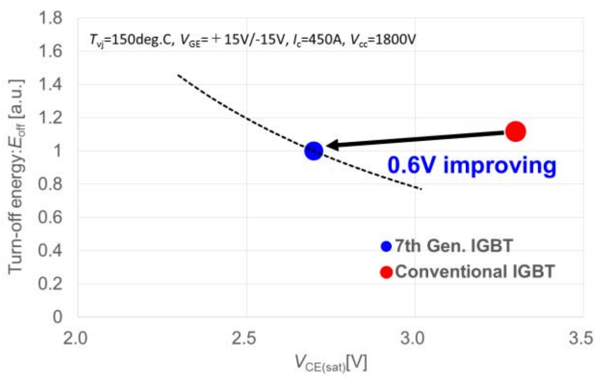
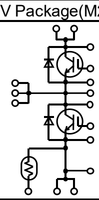


Fig7. 7[th] Gen IGBT trade-off relationship between on-state voltage and turn off energy

4 Line-up with HPnC

Table 4 shows the line-up of the 1700V and 3300V IGBT modules with HPnC package. The HPnC modules consist of a half-bridge circuit including a thermal sensor for over-heating protection. The 1700V module is available in two different current ratings, 1000A and 1200A. The 3300V module is available with a 450A current rating.

Table4. The line-up of rated voltage and current and chip combination

Rated volatage	Rated current	Viso	Generation	LV Package(M292) 
1700V	1000A	6.0kV/60s	X-series	2MBI1000XVF170-50
	1200A	6.0kV/60s		2MBI1200XVF170-50
3300V	450A	6.0kV/60s		2MBI450XVF330-50

5 Conclusion

The newly developed 7th Generation 1700V and 3300V IGBT module with HPnC package has significant benefits for traction application. These technology innovations have achieved higher reliability and the module greatly improves lower power dissipation. We believe this new low

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inductance package HPnC will contribute greatly to realize traction application systems with light weight, higher efficiency and higher reliability.

6 References

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