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The IGBT Module with 6th Generation IGBT

CONTENT

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Abstract
In 2007, the latest IGBT modules “NX series” was started to release. The NX series has novel flexibility of its terminal and circuit configuration by using some unified package parts and power semiconductor chips. In this 1st step of NX series, our 5th generation IGBT chip that realized high efficiency characteristics by using CSTBT™ chip technology is adopted. In this paper the 2nd step NX series with 1200V 6th generation IGBT chip technology is presented. The further improvement of efficiency and low noise characteristics on the new device will extend the application range of users.

1. Introduction

The insulated gate bipolar transistor (IGBT) is very popular semiconductor component on output stage of power electric system i.e. inverter, power supply, and motion control. Especially IGBT module integrated the power chip on its insulated package is used for wide power capacity range from less than 1kW to more than 1MW. The 1st step of NX series has higher performance of its package flexibility [1]. On the other hand, pursuing the minimizing the power dissipation on IGBT module is key point for users demands total system cost down, suppressing EMI irradiation noise, and long term lifetime. The advanced the carrier stored trench bipolar transistor (CSTBT™) chip technology on 2nd step of NX series will give the solution.

2. IGBT module “NX series”

Generally, IGBT module is designed with a various size to meet the fitted space and good cost performance. Furthermore, it consists of many different package parts element i.e. case, base plate, terminal, insulator and power chips. In NX series some unified package parts and common assembly process realized to supply wide capacity range and various circuit modules, not only single, 2in1, 7in1, CIB (converter-inverter-brake) pack but also other unique configuration as demand. Examples of package type are shown in Figure 1. It is possible that various circuits are assembled into the case and design terminal layouts freely.

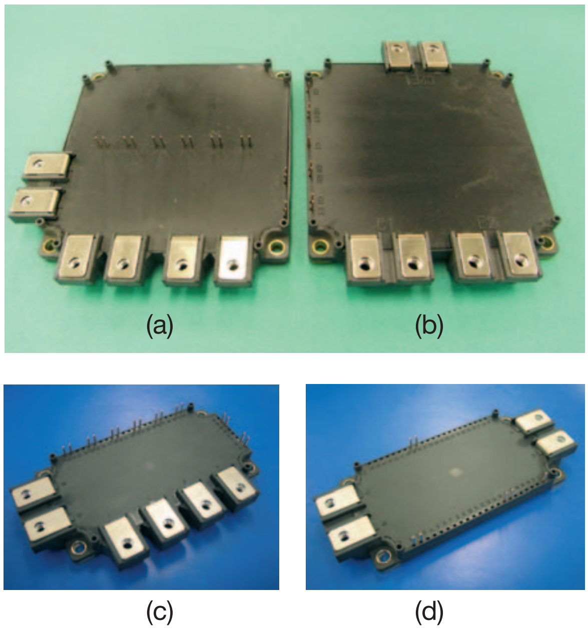


Figure 1: Example of NX series package (a)(c)7in1, (b)(d)2in1

3. Chip technologies
3.1. Progress of IGBT chip

Figure 2 shows the Figure of Merit (FOM) which indicate the transition of IGBT performance. The FOM is defined as the chip current density (J_c), divided by the product of the saturation voltage ($V_{CE(sat)}$) and the turn off energy loss (E_{off}) per pulse per unit current in inductive switching at Tj=125°C. CSTBT™ has better FOM than trench IGBT. The FOM of 6th generation IGBT is 30% larger than that of the 5th generation.

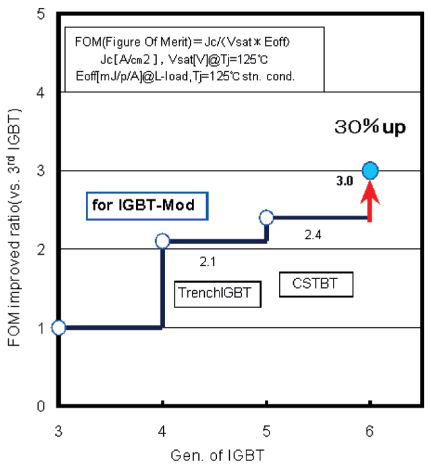
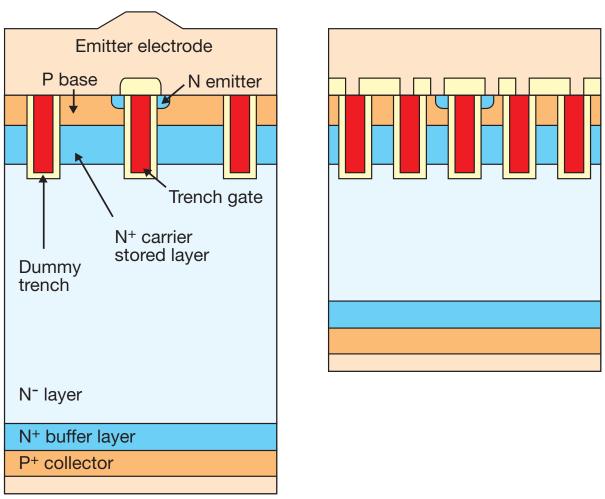


Figure 2: FOM of IGBT

3.2. 6th Generation IGBT

6th generation IGBT chip is based on the advanced CSTBT™ technology. Figure 3 shows the cross-sectional views of the 6th generation IGBT and conventional 5th generation IGBT. Both types have common concept of CSTBT™ using the carrier stored (CS) effect. At first step of the 6th generation IGBT development, the wafer structure was reexamined from NPT (Non Punch Through) type to LPT (Light Punch Through) type with the establishment of thin wafer process technology[2]. Secondarily, unit cell design was optimized for the purpose of improving the $V_{ce(sat)}$-$E_{sw(off)}$ trade off relationship.



The 5th generation IGBT　　The 6th generation IGBT

Figure 3: The cross-sectional views of IGBT

Narrowing the trench pitch of the unit cell using fine pattern technology and optimizing the doping profile of the CS-layer enhanced the CS effect on carrier stored layer [3]. As a result, as shown in Figure 4, drastic improvement was achieved on $V_{ce(sat)}$-$E_{sw(off)}$ tradeoff relationship. From another important point of view, the IGBT power loss performance has tradeoff relationship with SCSOA (Short Circuit Safe Operation Area). Figure 5 shows SCSOA waveform of 6th generation IGBT by actual measurement. Optimization of CS layer and unit cell design succeeded to obtain more than 10μsec short circuit withstands ability without sacrificing IGBT power loss performance.

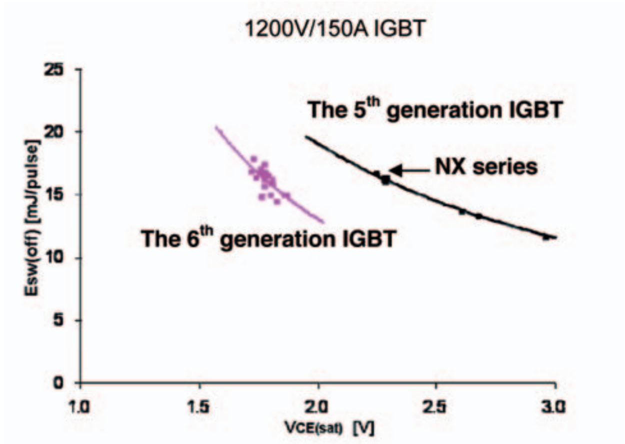


Figure 4: Relationship between $V_{CE(sat)}$ and $E_{sw(off)}$ (@Tj=125°C)

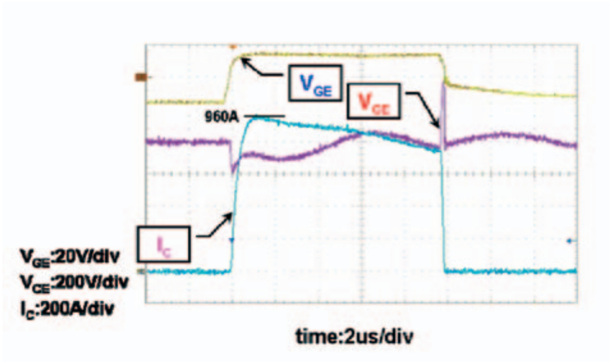


Figure 5: SCSOA waveform(1200V/150A rating device V_{CC}=800V, V_{GE}=+15V/-15V, R_G=30Ω, tp=10μs, Tj=125°C)

3.3. New designed FWDi

Figure 6 shows the structure of new designed Free Wheel Diode (FWDi) and conventional FWDi. As shown in Figure 7, the thin wafer process technology contribute to an improvement of radeoff relationship between forward voltage VF and recovery switching loss Esw(rec).

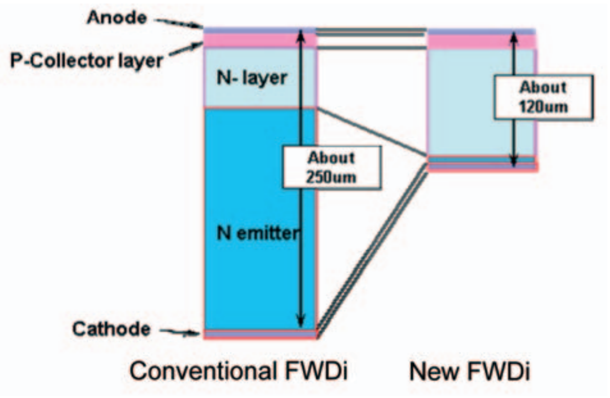


Figure 6: The cross-sectional views of FWDi

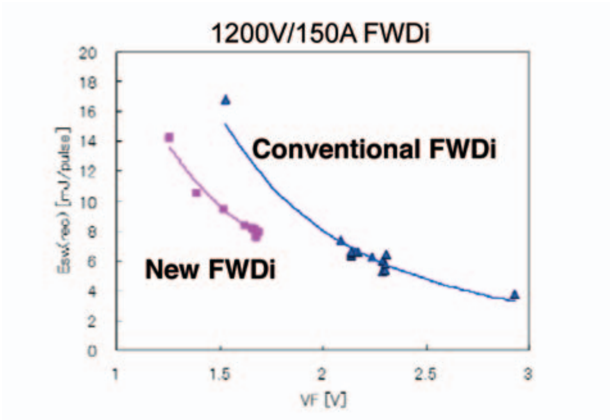


Figure 7: The relationship between VF and E_{sw} (@Tj=125°C)

4. Turn-on behaviour

Reducing the dv/dt at the turn on switching waveform often works well for suppressing the EMI irradiation noise from equipment. Generally, by controlling the gate drive speed in external circuit, the turn-on dv/dt can be reduced. Otherwise, reducing the dv/dt will increase the turn-on switching loss ($E_{sw(on)}$) in IGBT chip. Figure 8 shows the trade-off relationship between $E_{sw(on)}$ and dv/dt. Switching speed can be controlled by changing the gate resistance. The $E_{sw(on)}$ of 6th generation IGBT is 20% lower than the conventional IGBT at the point of dv/dt = 7.5kV/µs which is assumed the condition of user.

Softness of reverse recovery current on FWDi and reverse transfer capacitance (C_{res}) on IGBT contribute to improve the $Es_{sw(on)}$-dv/dt trade off. The result means that 6th generation IGBT has wider selection range and good controllability of power loss vs. noise performance.

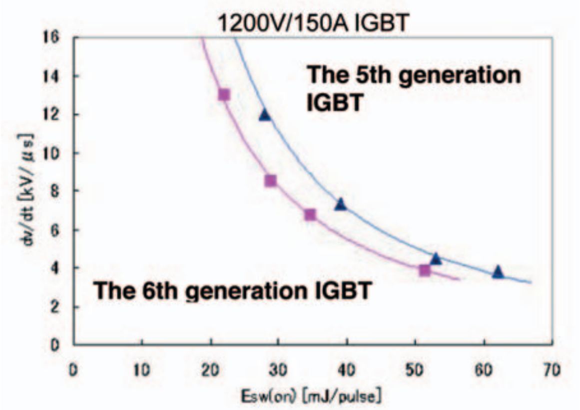


Figure 8: Relationship between $E_{sw(on)}$ and dv/dt (@Tj=125°C)

5. Turn-off behaviour

At the moment turn off, there are a lot of electron hole and free electron in N- layer yet. So collector current cannot be blocked off soon. The collector current gradually decreases at the time which depends on the lifetime of electron. Incidentally, the 6th generation IGBT improves the tail current because of optimizing LPT structure. Figure 9 shows turn off waveforms. The tail current of 6th generation IGBT is lower than that of 5th generation. Lower tail current leads to lower $E_{sw(off)}$ loss.

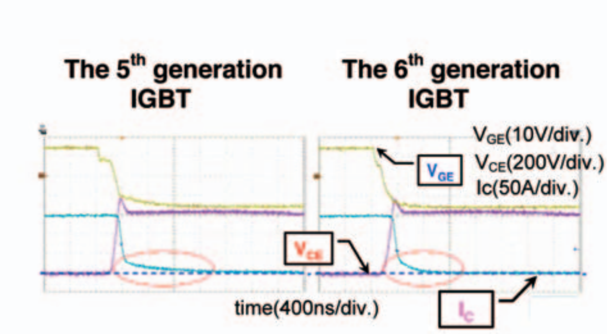


Figure 9: Turn off waveform @Ic=150A, V_{CC}=600V, Tj=125°C

6. Power loss performance

Power loss in general PWM inverter drive application was estimated for 5th and 6th generation IGBT modules (Figure 10) for a 1200V/150A rated module used in a 30kW capacity full load at 400VAC. The gate resistor was selected in each device so that dv/dt at the turn-on switching waveform was set to same value (7.5kV/µs). Total power loss on

IGBT/FWDi chip consists of switching loss and static loss. From this calculation result, it was clarified the loss of 6th generation IGBT module is about 20% lower than the conventional module.

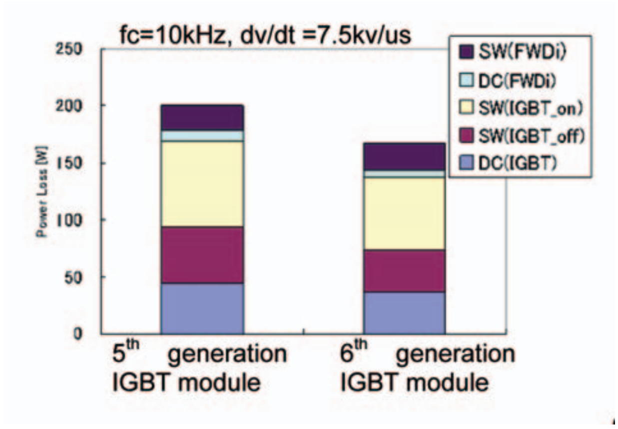


Figure 10: The simulated loss

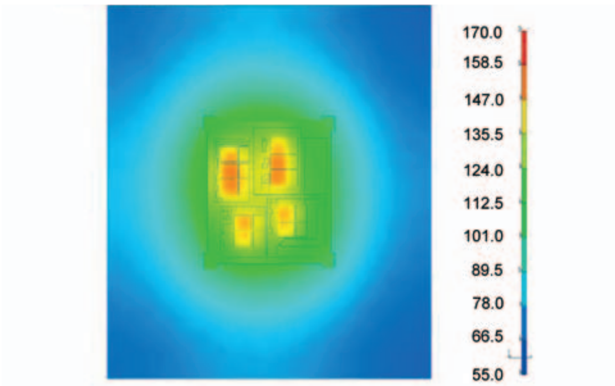
7. Thermal simulation

The thermal simulation of NX series is shown in Figure 11. The simulation was executed supposing 1200V 1000A rating device with NX series large 2in1 package and 400V input 185kW capacity inverter full load operation. The Junction temperature (Tj) of 6th generation IGBT is an average of 25°C lower than that of conventional one. And new FWDi Tj is an average of 21°C lower than conventional one. So it is possible to reduce space, weight and cost for cooling system.

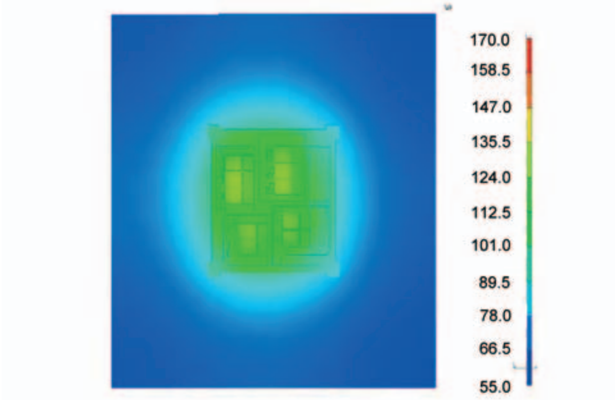
8. Reliability limits

In many cases the lifetime of IGBT module is dominated by the junction temperature cycling in the intermittent operation mode.

Figure 12 shows the power cycling lifetime of latest NX series and other old type module (H series). NX series with 6th generation IGBT is the same power cycling lifetime of latest NX and better than that of H series. Incidentally, the expansion of Tj maximum limit is required. NX series with 6th generation IGBT is prepared to allow the Tj maximum limit up to 175°C. NX series were tested at two condition (Tj(max)=125°C and 175°C). It was realized that Tj(max)=175°C is intermediate between Tj(max)=125°C of NX series and Tj(max) =125°C of H series.



(a) NX series 2in1 large package with 5th generation IGBT and conventional FWDi



(b) NX series 2in1 large package with 6th generation IGBT and new FWDi

Figure 11: The thermal profiles simulation of NX series output current 420A rms, carrier frequency 2.5kHz, power factor 0.85 and 3-phase modulation

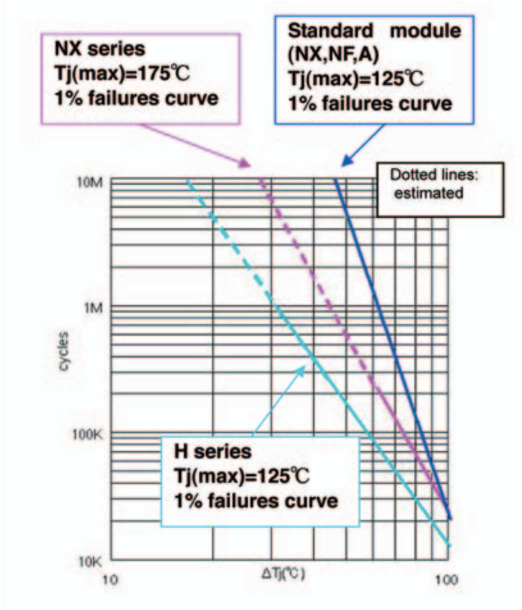


Figure 12: Power cycling lifetime

9. Conclusion

For the development of the 6th generation IGBT and new FWDi, NX series minimizes the power dissipation and controls lower heat than ever before. It is possible to become better efficiency user's total system. And it has higher performance of its package flexibility and improves characteristic, which will extend the application range of users. NX series will have great potential for development of power electric systems.

10. Literature

[1] Manabu Matsumoto,et al.
"The Development of new IGBT Module with the Unified Package parts" PCIM CHINA 2007

[2] Tetsuo Takahashi, et al. "CSTBT™(III) as the next generation IGBT" ISPSD 2008

[3] Katsumi Satoh, et al. "New chip design technology for next generation power module" PCIM Europe 2008

Notes

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