 DOI:10.30420/566414022

New Developed 4.5KV/1.5KA IGBT Module based on TMOS IGBT and PIC FRD Technology

Bin Wang[1,2], Liheng Zhu[1,2], Jiacheng Xu[1,2], Xing Chen[1,2], Mengjie Wang[1,2], Pengfei Liu[1,2], Rongzhen Qin[1,2], Qiang Xiao[1,2], Haihui Luo[1,2]

[1] State key Laboratory of Advanced Power Semiconductor Devices, China

[2] Zhuzhou CRRC Times Semiconductor Co. Ltd, China

Corresponding author: Bin Wang, wangbin15@csrzic.com

Speaker: Bin Wang, wangbin15@csrzic.com

Abstract

In this paper, a new 4500V/1500A IGBT module based on TMOS IGBT and PIC FRD technology is proposed. Compared to the last generation module, the new module demonstrates a significant reduction in conduction saturation voltage, diode forward voltage and reverse recovery energy. Furthermore, the module enhanced short circuit and reverse blocking capability. The peak reverse recovery power reaches 18MW, featuring RRSOA robustness. The module has passed 150℃ 1000 hours 3600V HTRB test, exhibiting long term reliability.

1 Introduction

In recent years, the upgrading of high-voltage application systems has led to progressively higher performance demands for HV IGBT power modules, including lower losses, higher power density, elevated operating junction temperature and heightened reliability[1~3]. In response to these requirements, we have developed a new generation 4500V module with current ratings up to 1500A and temperature capability up to T_j=150℃. The module adopts standard package and incorporates TMOS IGBT and PIC FRD technologies, achieving comprehensive performance upgrades compared to the last generation module. This paper will primarily focus on IGBT and FRD chip technologies, emphasizing the improvements in loss characteristics and SOA ruggedness together with the soft recovery characteristics over the full operating temperature range up to 150℃.

2 Design Concept

TMOS IGBT structure is shown in Fig.1 which employs a refined trench gate structure and wafer thinning techniques to reduce chip losses. Optimized buffer is implemented to balance the static and dynamic anode injection efficiency, enhancing device reliability and SOA performance. Furthermore, the technology results in a significant optimization trade off between $V_{ce,sat}$ and E_{off} for the IGBT chip. The PIC FRD employs specially designed cathode and thin-film techniques[4,5], as depicted in Fig. 2. While ensuring excellent soft recovery characteristics of FRD, it improves the trade-off between V_F and E_{rec}. These performance enhancements make the new module suitable for various HV applications such as traction, medium voltage drive and so on.

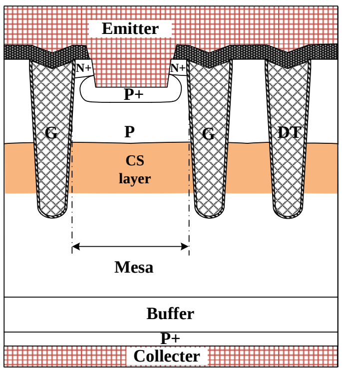


Fig. 1. TMOS IGBT structure

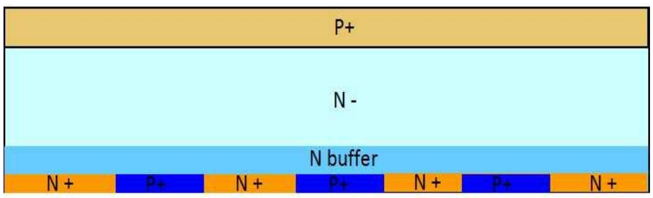


Fig. 2. PIC FRD structure

The outline of the new module is shown in Fig. 3. It is completely packaged compatible with conventional modules. Therefore, the new modules can be installed in the same applications as conventional modules to provide higher efficiency and superior performance.

ISBN 978-3-8007-6414-3

 DOI:10.30420/566414022

Fig. 3. 1500A/4500V IGBT module

3 Characteristics of 4500V Module

3.1 Static Performance

Fig. shows the static performance of the module. At 150℃ and a rated current of 1500A, the $V_{ce,sat}$ of the IGBT is 3.15V, while the V_F of the FRD is 2.95V. Compared to the output characteristics of the last generation module, the new module has much lower conduction loss.

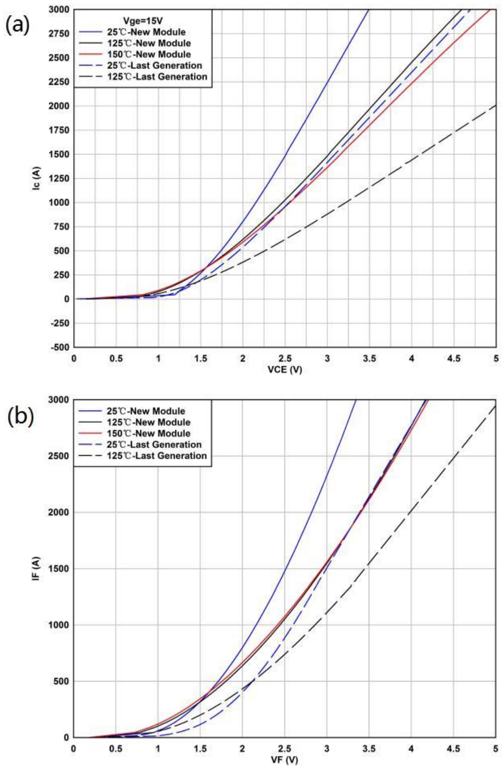


Fig. 4 (a) IGBT output characteristics, (b) FRD output characteristics

3.2 Dynamic Performance

The turn on the turn off waveforms of the IGBT are shown in Fig.4, featuring the soft switching behavior due to the optimized thickness and buffer design.

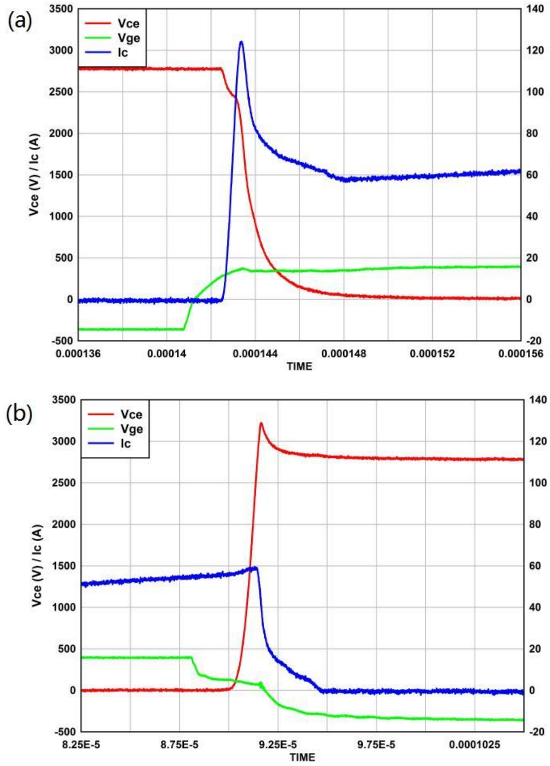
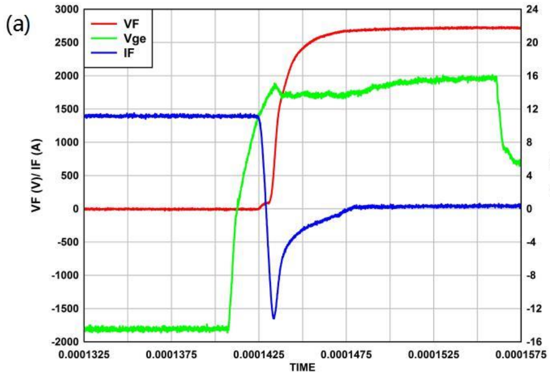


Fig. 4. (a) IGBT turn-on switching waveform at nominal condition at T_j=150℃ and with $R_{g,on}$=1.0Ω (E_{on}=7.15J), (b) IGBT turn-off switching waveform at nominal condition at T_j=150℃ and with $R_{g,off}$=3.3Ω (E_{off}=5.1J)

Fig. 5(a) and (b) depicts the reverse recovery performance at nominal current at 150℃ and low current at 25℃, respectively. Thanks to the PIC technology, the FRD shows a very soft recover characteristic even at very low current at room temperature. The P^+ doping region in the backside N^+ region provides additional holes during the FRD reverse recovery which helps to increase excess carriers in drift area before the space charge area building.



ISBN 978-3-8007-6414-3

 DOI:10.30420/566414022

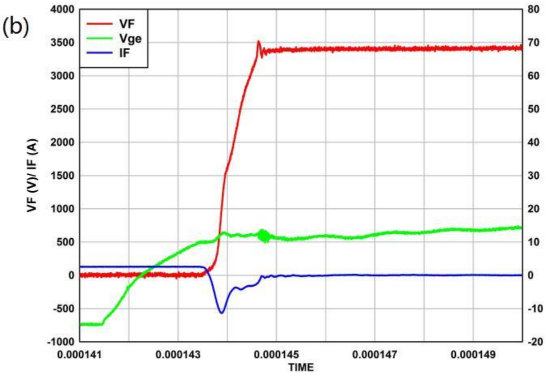


Fig. 5. (a) FRD reverse recovery waveform at nominal condition, I_F=1500A at T_j=150℃ and with $R_{g,on}$=1.0Ω (E_{rec}=3.04J), (b) FRD reverse recovery waveform at harsh condition, I_F=100A at T_j=25℃

Compared to the last generation of the device, the overall performance of the new one has been comprehensively improved, the trade off between the switching losses and the conduction loss is show in Fig. 6.

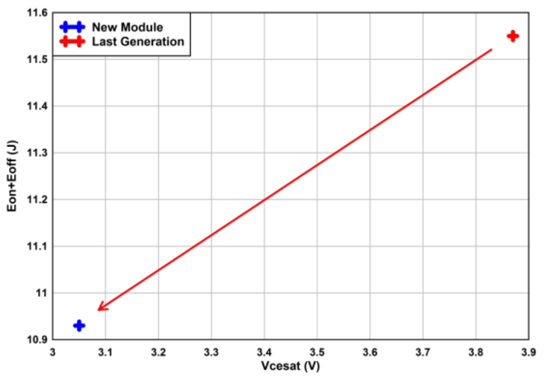
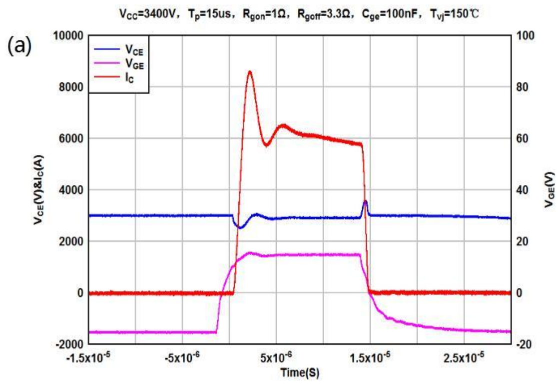


Fig. 6. (a) Comparison of the trade-off between E_{on}+E_{off} and $V_{ce,sat}$ for the new module and the last generation module at nominal condition, T_j=125℃

3.3 SOA Performance

Fig. 7 demonstrates the short circuit behaviors at high and room temperatures. At high and room temperature, the current level reaches about 8.6kA(~5.7×I_{nom}) and 12kA(~8×I_{nom}).



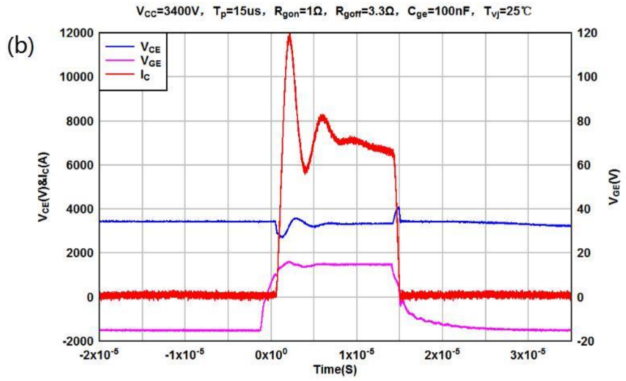


Fig. 7. IGBT short circuit waveforms. (a) V_{ce}=3400V, T_j=150℃, (b) V_{ce}=3400V, T_j=25℃

The RBOSA performance is shown in Fig. 8, where a current of 5000A is switched off at 150℃. The V_{ce} peak remains below the rated voltage of 4500V which shows the robustness of the IGBT turn off capability. The RRSOA behavior is shown in Fig. 9, the peak P_{rec} is 18MW, proving the robust recovery characteristic of the PIC FRD.

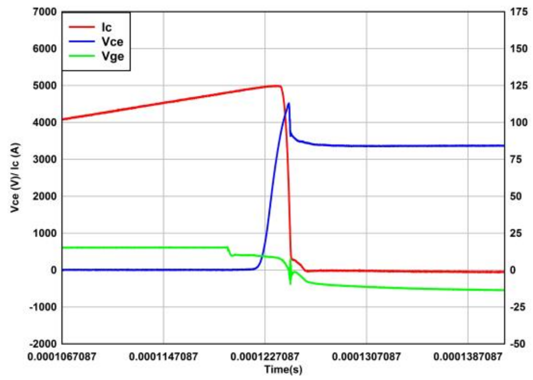


Fig. 8. IGBT RBSOA waveform, V_{ce}=3400V, I_c=5000A, T_j=150℃

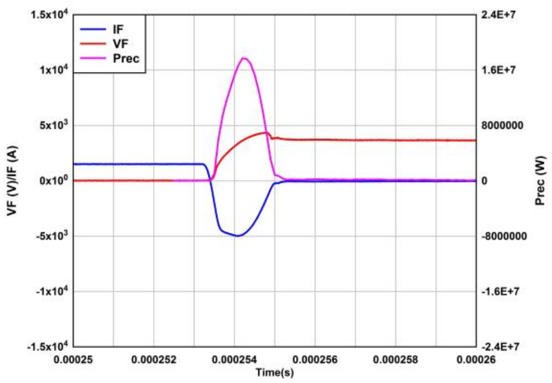


Fig. 9. FRD RRSOA waveform, V_{ce}=3400V, I_c=5000A, T_j=150℃

3.4 Reliability Performance

In order to improve the long term reliability, the junction termination structure of the IGBT and FRD chips is optimized. Compared to the last generation module,

ISBN 978-3-8007-6414-3

DOI:10.30420/566414022

the leakage current of the new module has been much reduced. The new module has pass 150℃ 3600V 1000h HTRB test, as shown in Fig. 9. The result proves the long term reliability of the new module.

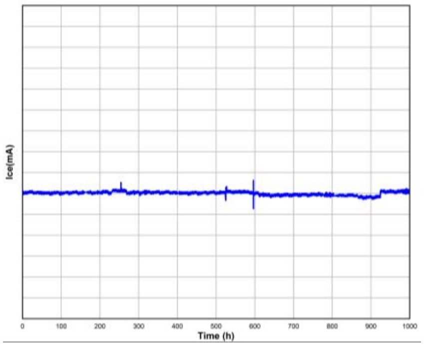


Fig. 9. 150℃ 3600V 1000h HTRB test

4 Application of 4500V Module

The new 4500V module can be used in medium voltage drives for heavy industry applications such as mining, oil and gas, et al. In order to evaluate the performance of the new 4500V module in such applications, we did simulation based on 3-level topology at given working condition. The topology is show in Fig.10. The simulation setup is shown in table 1.

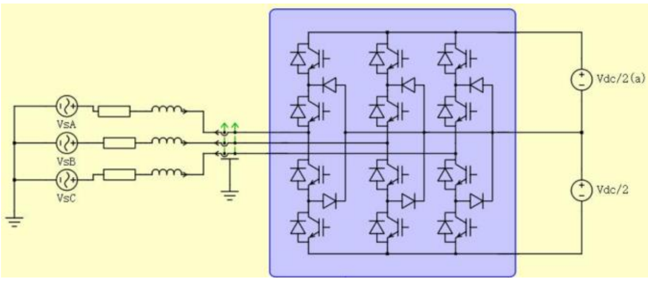


Fig. 10. Simulation topology

Table. 1. Simulation setup

System Voltage	3300V
IGBT Switch Frequency	700Hz
Current	650A~780A
Power Factor	0.9
Modulation Index	0.95
Heat Sink	Fixed at 70℃
Control strategy	SVPWM

The simulated power dissipation at given working conditions is shown in Fig. 11. According to the simulation, the maximum junction temperatures for IGBT and FRD are 116℃ and 71℃.

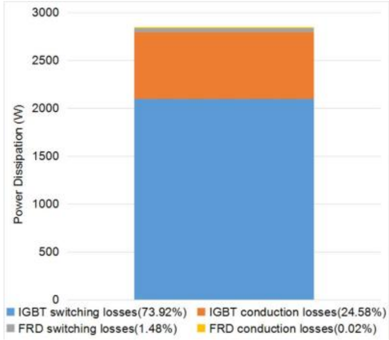


Fig. 11. Power dissipation at given working condition

5 Conclusions

In summary, we introduce a new generation of 4500V module based on TMOS IGBT and PIC FRD in this paper. The new module with design improvements were implemented successfully to enhance the performance of the module, such as low losses, high SOA. The new module has passed 3600V 150℃ 1000 hours HTRB test, featuring long term reliability.

6 References

[1] Tatsuya Matsumoto, Ryoichi Suzuki, Takahiro Saiki, Yoshihiko Koike: New 4.5kV IGBT Module with Low Power Loss and High Current Ratings, PCIM Europe 2015, 88-93.

[2] Katsumi Nakamura, Ze Chen, Shin-ichi Nishizawa, Akihiko Furukawa: CSTBTTM for high Voltage applications with high dynamic robustness and low overall loss, Microelectronics Reliability 110, 113635, 2020.

[3] Maxi Andenna, Boni Boksteen, Daniel Prindle, Luca De-Michielis, Virgiliu Botan, Evgeny Tsyplakov, Gontran Pâques: Rugged 4500V Hipak Module with 1500A Current Rating and 150℃ Capability for Traction Application, PCIM Europe, 2020, 229-236.

[4] Xubin Ning, Rongzhen Qin, Haihui Luo, Qiang Xiao, Feiyu Zhou, Yuan Teng, et. al.: High Power Density Oscillation Free 1800A/3300V E2 IGBT Module with TMOS+ IGBT and PIC FRD Technology, PCIM Europe 2019,1-4.

[5] Feiyu Zhou, Hui Wang, Liheng Zhu, Pengfei Liu, Haibo Xiao, Rongzhen Qin, et al.: New Developed 1000A/6500V IGBT Module Based on TMOS+ IGBT and PIC FRD Technology, PCIM Aisa 2021, 1-5.

