A Method for Thermal Resistance Test of Reverse-Conducting IGBT (RC-IGBT)

Y Chen¹, ², P Zhang³, X F Hu³, H Z Huang², P Lai¹, Z Y He¹ and Y Q Chen¹

¹Science and Technology on Reliability Physics and Application of Electronic Component Laboratory, The 5th Electronics Research Institute of MIIT, Guangzhou, China
²School of Mechanical and Electrical Engineering, University of Electronic Science and Technology of China, Chengdu, China
³South China University of Technology, Guangzhou, Guangdong

E-mail: chenyuan@ceprei.com

Abstract. The RC-IGBT is integrated IGBT and fast recovery diode (FRD) on the same chip. RC-IGBT has smaller size, higher power density, lower cost, and higher reliability. However, due to the snap-back effect, the traditional test circuit and method cannot accurately measure the thermal resistance of RC-IGBT. In this paper, a thermal resistance test circuit based on series compensation of two devices is proposed, and the voltage drop Vec of the body diode is taken as the temperature sensitive parameter of RC-IGBT. The thermal response curve is obtained basing on the change of Vec with temperature. By comparing the traditional method with the new method, it can be seen that the new method can greatly improve the test accuracy.

1. Introduction
RC-IGBT is a new IGBT device [1], which was first proposed in 1988[2]. It integrates the traditional IGBT cell and FRD cell on the same chip. Comparing with the IGBT devices, RC-IGBT has more advantages in cost and performance [3-4]. The huge market demand makes RC-IGBT become the focus of foreign manufacturers [5]. The principle of RC-IGBT are shown in Figure 1. Figure 1A is the structure of IGBT, and Figure 1B is the RC-IGBT.
By comparison, it can be found that most of the physical construction of RC-IGBT is similar to the traditional IGBT. The biggest difference is that the collector of RC-IGBT is not a continuous P + region, but some N + short-circuit regions are introduced intermittently. A RC-IGBT is equivalent to an IGBT in anti-parallel with a fast recovery diode, but it is realized on the same chip. When the $V_{CE}$ is subjected to negative voltage, the fast recovery diode conducts. So it is called a reverse-conduction IGBT. During the turn-off period, the RC-IGBT provides an effective channel for excess carriers in the drift area, which greatly shortens the shut-off time.

While RC-IGBT has many advantages, it also brings some problems. Snap-back effect is one of the main problems [8]. The conduction characteristic curve of a RC-IGBT is shown in Figure 2. At the beginning of IGBT conduction, the current density is small and the $V_{CE}$ is large. However, when the $V_{CE}$ is greater than a specific value of $V_p$, the $V_{CE}$ drops sharply and the current density increases sharply. The change in current and voltage is similar to secondary breakdown of the bipolar transistor. Of course, the principle is completely different. A large negative resistance area appears on the conduction characteristic curve, which is called snap-back effect (also known as switch-back effect). If the current density continues to increase, a series of secondary snap-backs will appear on the conduction characteristic curve, as shown in Figure 2.

Because of the snap-back effect of RC-IGBT, the traditional circuit and method for thermal resistance test can not accurately extract the thermal resistance of RC-IGBT. In this paper, a new test circuit and method for extracting the thermal resistance of RC-IGBT is proposed, which avoids test errors caused by snap-back effect during forward test. The test results of the two test methods are compared, and the new method can effectively improve the test accuracy.
2. Traditional test circuit and method
Generally, $V_{CE}$ is a thermal-sensitive parameter for IGBT thermal resistance test [9-12]. The traditional test circuit [13-14] is shown in Figure 3. During the measurement of K-factor, put the test circuit into the incubator, disconnect S, and adjust different temperatures to obtain the corresponding $V_{CE}$. When heating, close S and adjust different $I_{C2}$ to get different heating power. To get the thermal response curve, the device under test is saturated by adjusting $V_{GE}$, and the test current and heating current are provided by $I_{C1}$ and $I_{C2}$ respectively[15-16].

![Figure 3. Standard thermal resistance test circuit in IEC60747-9 [14].](image)

3. Proposed test circuits and methods
A new test circuit and method for extracting the thermal resistance of RC-IGBT is proposed. As shown in Figure 4. T1 and T2 are both RC-IGBT. T1 is auxiliary. T2 is DUT. T1 and T2 are the same devices. T1 and T2 are heated together in the heating phase, and in the test phase only the junction temperature change of T2 was tested. In the circuit, $I_{sense}$ and $I_c$ are controlled by switches to provide the test current and the heating current respectively. During heating, IGBT is saturated by adjusting $V_{GE}$. During testing, the voltage drop $V_{ec}$ of the body diode is taken as the temperature sensitive parameter since RC-IGBT is integrated with FRD. The thermal response curve is obtained basing on the change of $V_{ec}$ with temperature.

![Figure 4. Proposed thermal resistance test circuit.](image)

4. Test results
The test results of the new method and the traditional method are compared. The test circuits of Figure 3 and Figure 4 were respectively used to perform the thermal resistance \( R_{\text{thjc}} \) test on the RC-IGBT by the double interface method \([17-18]\).

4.1. Temperature Sensitive Characteristics \((K\text{-factor})\) Test

Junction temperatures of the devices are controlled by the oil tank from 25\(^\circ\)C to 125\(^\circ\)C. And the test currents \((I_{\text{sense}})\) are set from 5mA to 100mA. Temperature sensitive characteristics are tested at different test currents.

4.1.1. Temperature sensitive characteristics test results by traditional method

By traditional method, test current is applied from C to E with the gate voltage of 15V. The junction temperature of the device is controlled by oil tank. The voltages of \( V_{\text{CE}} \) at different temperatures and currents are tested. The curve of IGBT conducting voltage drop \( (V_{\text{CE}}) \) and junction temperature at different currents is shown in Figure 5.

![Figure 5. Curve of \( V_{\text{CE}} \) and \( T_j \) at different currents.](image)

4.1.2. Temperature sensitive characteristics test results by proposed method

The test current is from E to C with the gate voltage of 0V. The junction temperature of the device is controlled by oil tank. The voltages of \( V_{\text{EC}} \) at different temperatures and currents are tested. The curve of FRD conducting voltage drop \( (V_{\text{EC}}) \) and junction temperature at different currents is shown in Figure 6.
Figure 6. Curve of $V_{EC}$ and $T_1$ at different currents.

We can see from the curves of Figure 6 and Figure 7 that the linearity and consistency of the temperature sensitive characteristics curve based on $V_{ac}$ by new method are better than those by traditional method.

4.2. Junction-to-case Thermal Resistance ($R_{thjc}$) Test

$R_{thjc}$ is tested by the new method and traditional method respectively. The heating currents are from 10A to 25A and $R_{thjc}$ is tested every 5A. The test current ($I_{sense}$) is 100mA.

The $R_{thjc}$ testing curves by two methods and circuit under different heating currents are as follows:

- Heating currents is 10A:

Figure 7. $R_{thjc}$ testing curve by traditional method (when heating current is 10A).

Figure 8. $R_{thjc}$ testing curve by new method (when heating current is 10A).

- Heating currents is 15A:
Figure 9. $R_{thjc}$ testing curve by traditional method (when heating current is 15A).

Figure 10. $R_{thjc}$ testing curve by new method (when heating current is 15A).

- Heating currents is 20A:

Figure 11. $R_{thjc}$ testing curve by traditional method (when heating current is 20A).

Figure 12. $R_{thjc}$ testing curve by new method (when heating current is 20A).

- Heating currents is 25A:

Figure 13. $R_{thjc}$ testing curve by traditional method (when heating current is 25A).

Figure 14. $R_{thjc}$ testing curve by new method (when heating current is 25A).
From above test results, it can be seen that under different heating currents, the new method can obtain accurate separation points of the $R_{thjc}$, while the traditional method cannot obtain clear separation points. Moreover, the higher the heating current is, the more obvious the trend is.

5. Conclusions
In this paper, a new circuit and method for thermal resistance test of RC-IGBT are designed to solve the problem of inaccuracy of the traditional thermal resistance test method caused by snap-back effect. By inputting the reverse test current, the voltage drop $V_{ce}$ of the body diode is taken as the temperature sensitive parameter. The thermal response curve is obtained basing on the change of $V_{ce}$ with temperature, which avoids the influence of snap-back effect during forward conduction. At the same time, the same T1 devices in series can shield the interference of large heating current to small test current and reduce the test noise. Through comparison of actual test results, it is found that:

- the linearity and consistency of the temperature sensitive characteristics curve based on $V_{ce}$ by new method are better than those by traditional method.
- under different heating currents, the new method can obtain accurate separation points of the $R_{thjc}$, while the traditional method cannot obtain clear separation points. Moreover, the higher the heating current is, the more obvious the trend is.

It can be seen that the new method proposed in this paper can effectively test $R_{thjc}$ of RC-IGBT and improve the test accuracy.

Acknowledgments
The project is supported by the Key Realm R&D Program of Guangdong Province under Grants of 2018B010142001, 2020B010173001, 2019B010143002.

References
[1] Liu Z and Sheng K 2020 A Novel Self-Controlled Double Trench Gate Snapback Free Reverse-Conducting IGBT with a Built-in Trench Barrier Diode *IEEE Transactions on Electron Devices* **67**(4) 1705-11
[2] Findlay E M and Udrea F 2019 Reverse-Conducting Insulated Gate Bipolar Transistor: A Review of Current Technologies *IEEE Transactions on Electron Devices* **66**(1) 219-31
[3] Chen W, Huang Y, Li S, Huang Y and Han Z 2019 A Snapback-Free and Low-Loss RC-IGBT With Lateral FWD Integrated in the Terminal Region *IEEE Access* **7** 183589-95
[4] Wu Y, Liu C L, Jin R, Wang Y H, Liu Y Y and Wen J L 2018 Review of reverse conducting IGBT technology development *High Voltage Engineering* **44** 3221-30
[5] Liu G, Li K, Wang Y, Luo H and Luo H 2020 Recent advances and trend of HEV/EV-oriented power semiconductors – an overview *IET Power Electronics* **13**(3) 394-404
[6] Li L et al. 2018 Temperature dependency of the on-state voltage of IGBT and its application in thermal resistance test *IEEE Applied Power Electronics Conf. and Exposition* (San Antonio, USA) pp 2786-91
[7] Chen Y et al. 2020 Study on Electrothermal Characteristics of the Reverse-Conducting IGBT (RC-IGBT) *Inter. Conf. on Electronic Packaging Technology* (Guangzhou, China) pp 1-5
[8] Huang X, Ling C, You X and Zheng T Q 2017 Research of the loss and gate desaturation control for RC-IGBT used in vehicle power converters *IEEE International Conference on Industrial Technology* (Toronto, Canada) pp 201-206
[9] Mohamed Sathik M H, Sundararajan P, Sasongko F, Pou J and Natarajan S 2020 Comparative Analysis of IGBT Parameters Variation Under Different Accelerated Aging Tests *IEEE Transactions on Electron Devices* **67**(3) 1098-1105
[10] Schueuermann U and Schmidt R 2009 Investigations on the $V_{ce}(t)$–Method to determine the junction temperature by using the chip itself as sensor *Proc. Int. Exhibition and Conf. for Power Electronics* (Nuremberg, Germany) pp 802–7
[11] Zheng S, Du X, Zhang J, Yu Y, Luo Q and Lu W 2018 Monitoring the Thermal Grease Degradation Based on the IGBT Junction Temperature Cooling Curves IEEE Inter. Power Electronics and Application Conf. and Exp. (Shenzhen, China) pp 1-4

[12] Deng E, Zhao Z, Zhang P, Li J and Huang Y 2017 Study on the methods to measure the junction–to-case thermal resistance of IGBT modules and press pack IGBTs Microelectronics Reliability 79 248–56

[13] Górecki K and Górecki P 2015 The analysis of accuracy of selected methods of measuring the thermal resistance of IGBTs Metrology and Measurement Systems 22 455–64

[14] Semiconductor devices – Discrete devices – Part 9:Insulated–gate bipolar transistors (IGBTs) International Electrotechnical Commission IEC60747–9, 2019

[15] Integrated Circuit Thermal Measurement Method – Electrical Test Method IAJEDEC Standard,Electronic Industries Association JESD51–1, 1995

[16] Zhang Y, Deng E, Zhao Z, Fu S and Cui X 2020 A Physical Thermal Network Model of Press Pack IGBTs Considering Spreading and Coupling Effects IEEE Transactions on Components, Packaging and Manufacturing Technology 10(10) 1674-1683

[17] Transient Dual Interface Test Method for the Measurement of the Thermal Resistance Junction–to–Case of Semiconductor Devices with Heat Flow Through a Single Path EIA/JEDEC Standard JESD51–14, 2010

[18] Schweitzer D, et al 2011 Transient dual interface measurement – A new JEDEC standard for the measurement of the junction–to-case thermal resistance Proc. IEEE Semiconductor Thermal Measurement and Management Symp. (San Jose, CA, USA) pp 222–229