A Research on Transient Thermal Resistance Test Method of IPM Module

Hui Wei[a], Dafang Wang[b]

School of Automotive Engineering, Harbin Institute of Technology at Weihai, Weihai 264200, China

[a]18463101025@163.com, [b]wdflcjl@163.com

Keywords: IPM Module, thermal resistance, the saturation voltage drop

Abstract: IPM modules are currently widely used in household appliances and industrial production. However, since the thermal problem caused by power loss affects the performance of the device, it is crucial to obtain the thermal resistance of the IPM module. In this paper, a thermal resistance definition method based on transient process is proposed to test the thermal resistance of IPM module. The saturation voltage drop of IGBT chip is selected as the temperature sensitivity parameter to calculate the junction temperature. Using the relationship between the saturation voltage drop and the junction temperature under a small current, the saturation voltage drop of the IGBT chip in the IPM is collected in real time, and the junction temperature curve and the transient thermal resistance are obtained.

1. Introduction

The IPM (Intelligent Power Module) not only integrates the power switching device IGBT and the driving circuit, but also integrates fault detection and protection circuits such as overvoltage and overcurrent. IPM has been used more and more in power electronic converters due to its high integration and high reliability. It is especially suitable for inverters for driving motors and various inverter power sources, such as electric traction, servo drive, frequency conversion appliances, etc.

Due to the power loss of the IPM module in practical applications, the junction temperature will rise continuously, reducing performance, and even burning the IGBT chip. Therefore, it is crucial to obtain the thermal resistance and temperature rise of the IPM module. At present, there are two commonly used non-destructive thermal resistance test methods: finite element method and thermal parameter method [1, 2]. The finite element method requires accurate material and size of the IGBT module. This part of the data is the core data of the IGBT manufacturer, which is difficult to obtain, and it is difficult to avoid the calculation error caused by the aging of the device. In summary, based on the thermal resistance defined by the transient process, the thermal resistance is measured by the thermal parameter method to avoid the problem of the case temperature obtained by the traditional method.

2. Definition of transient thermal resistance

When the device under test is applied with power, the temperature of the transistor is continuously increased. At one moment, when the heat generated by the device under the applied power is equal to the amount of heat dissipated, the junction temperature of the device no longer rises, and the device enters the thermal stability. State. However, in the switching and pulse circuit, the dissipated power of the transistor changes with time, and the junction temperature and the case temperature of the transistor also change with time. The state is called thermal transient [3].

The traditional thermal resistance calculation formula is shown in (1) (taking the thermal resistance of the crust as an example) [4], which is based on the calculation method under steady-state heat transfer. The measurement method is to fix the device on the heat sink and obtain the junction temperature and power loss of the device.

$$R_{JC} = \frac{T_J - T_C}{P} \tag{1}$$

In which, T_J is the junction temperature, T_C is the case temperature, P is the power loss, R_{JC} is the steady-state thermal resistance of the case to PN junction. The method needs to measure the junction temperature and case temperature during the heat transfer stabilization phase, but the difficulty lies in the accuracy of the case temperature measurement. It is difficult to accurately place the thermocouple at the highest temperature of the shell temperature. Therefore, the definition of the transient thermal resistance (2) should be used to avoid the case temperature and measurement error of the measuring device.

$$Z = \frac{T_{J0} - T_J(t)}{P} \tag{2}$$

In which, T_{J0} is the initial value after the heating power is turned off, $T_J(t)$ is the junction temperature changes with time. The thermal resistance under this transient definition is no longer a fixed value, but an amount that varies with time, and the transient process thermal resistance curve can be calculated. We can use the advanced equipment area to sample the junction temperature at high speed, and obtain the transient thermal resistance curve according to formula (2). This paper selects the curve of the measured junction temperature drop process to calculate the transient thermal resistance. The cooling curve is more practical. Easy to acquire and does not affect the measurement results, and the temperature rise and temperature drop are symmetrical.

3. Transient thermal resistance test

3.1 Test principle

The thermal resistance of IPM is an important physical quantity representing thermal performance. As one of the important indicators for measuring power devices, the thermal resistance value reflects the heat dissipation capability of IPM. The characteristics of the semiconductor PN junction with a good linear relationship between voltage drop and temperature under constant small current conduction [5], this paper selects the saturation voltage drop as the temperature sensitivity parameter to calculate the junction temperature, which is also the commonly used temperature sensitivity parameters. Using the relationship between the saturation voltage drop and the junction temperature under a small current conduction, the saturation voltage drop of the IGBT chip is collected in real time to calculate the junction temperature curve and the transient thermal resistance.

3.2 Calibration of temperature sensitive parameters

The design applies a test current of 10 mA to the IPM module (the article tests for Mitsubishi device module PM600CLA060). The power loss generated by such a small current is negligible, and it is considered that there is no influence on the junction temperature of the IGBT chip in this process.

The test procedure is as follows: place the IPM module in the thermostat, set the temperature is 20°C, wait for a long time, drive the IGBT to be on and conduct the current of 10 mA, measure and record the voltage Vce between the collectors, set the temperature of thermostat is stepped at 10°C (wait for more than 60 minutes each time the temperature is changed so that the junction temperature is equal to the ambient temperature) up to 60°C. If the collector voltage Vce changes during the measurement, it means that the junction temperature has not reached the internal temperature of the oven and needs to be placed for a longer time. The relationship between the saturation voltage drop and the junction temperature obtained at a constant small current is shown in Table 1.

Table 1. Junction Temperature-Saturation Voltage Drop.

Junction temperature (°C)	20	30	40	50	60
Voltage drop (mV)	497.1	472.85	450.3	424.22	401.5

3.3 Junction temperature measurement

After the calibration of the junction temperature and saturation voltage drop is completed, the junction temperature can be calculated. Next, the curve of the junction temperature with time is measured by the given heating power, and the thermal resistance of the device is calculated. Transient thermal resistance test platform is shown in Figure 1.

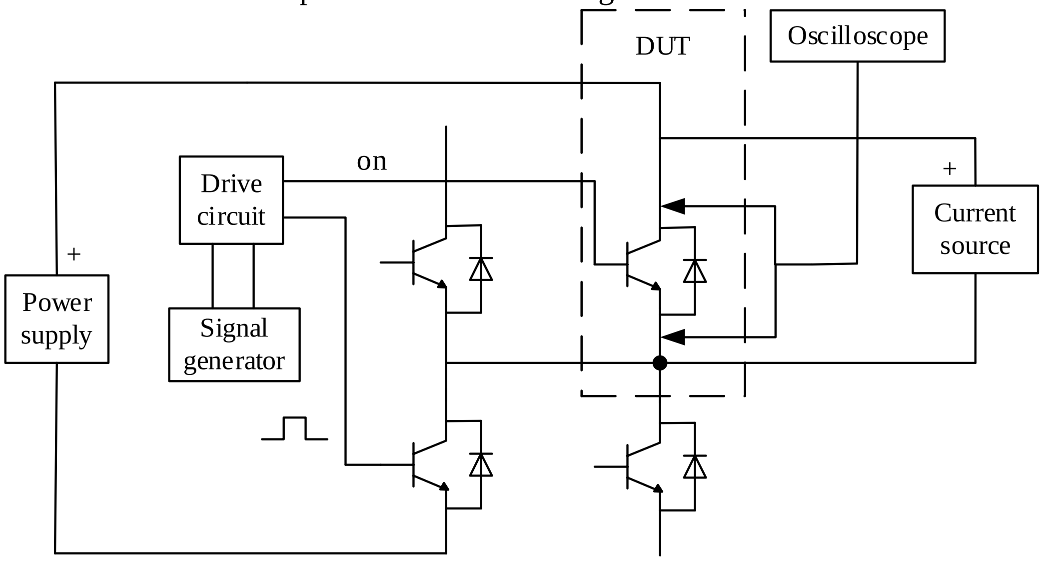

Figure 1. Transient thermal resistance test platform.

The power supply is to supply the heating current (power) to the DUT, while the current source is to provide a test current of 10 mA. The current selection and heating time are applied by controlling the left lower arm IGBT. Fix the IPM module on the heat sink, control the IGBT to conduct, and apply a load current of 75A. When observed in the oscilloscope, the saturation voltage drop curve of the device no longer changes, indicating that the device has reached steady state. Then the left lower arm IGBT is turned off, and the heating current is cut off. At this time, only 10 mA current flows through the IGBT and is recorded. After getting the Vce curve, the converted junction temperature is brought into (2), so that the thermal resistance of the transient process is obtained.

4. Analysis of results

Curve fitting of the data recorded in Table 1 can obtain the change curve of IGBT junction temperature and saturation voltage drop at a constant small current of 10 mA as shown in Fig. 2.

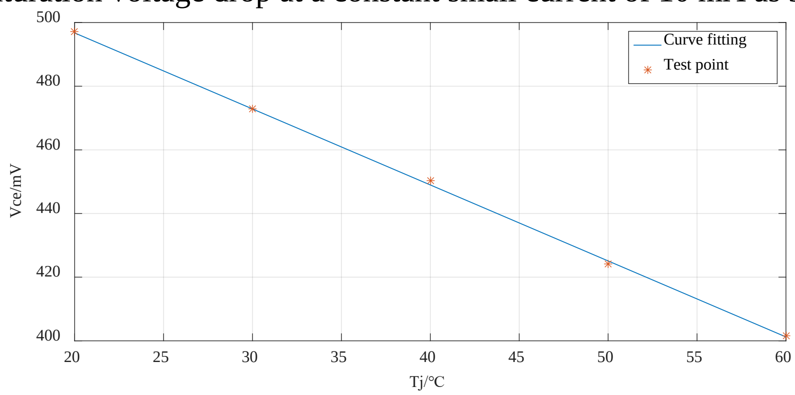

Figure 2. Tj-Vce calibration curve.

It can be seen from Fig. 2 that the saturation voltage drop of the IGBT is linearly negatively correlated with the junction temperature at a small current of 10 mA. A linear relationship (3) can be obtained by data fitting.

$$V_{ce} = -2.388T_J + 544.53 \quad (3)$$

The junction temperature and time delay curve and transient thermal resistance curve are shown in Figure 3.

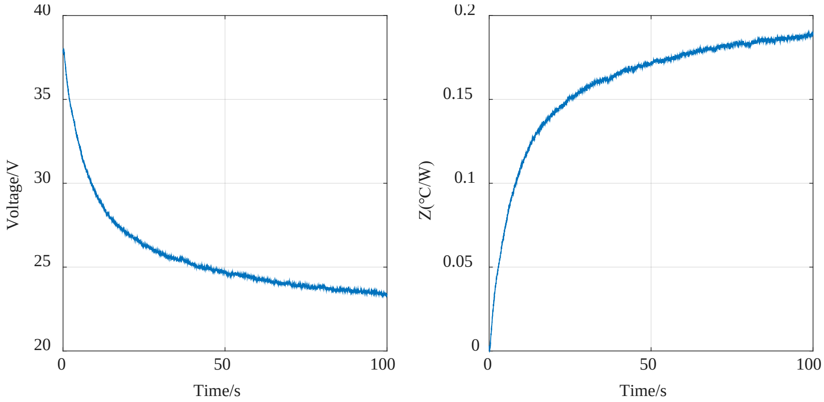

Figure 3. Temperature drop and thermal resistance curve.

The measured Vce curve is converted into the junction temperature drop curve on the left side of Fig. 3 by the equation (3), and the junction temperature curve is brought into the equation (2) and divided by the power to obtain the transient thermal resistance, as shown in the right side of Fig. 3 Shown. From the data sheet, it can be known that the steady-state thermal resistance of the junction-case and the heat sink is 0.07°C / W and 0.12°C / W, which is close to the measured thermal resistance, respectively, verify the accuracy of the method.

5. Conclusion

In this paper, the thermal resistance of the IPM module is tested based on the definition of thermal resistance in the transient process. The saturation voltage drop is chosen as the temperature sensitivity parameter to calculate the junction temperature, which is linearly negatively correlated with the junction temperature. A test platform is built to collect changes in the saturation voltage drop of the IGBT chip in real time and convert it into a junction temperature to calculate the transient thermal resistance. Difficulties in measuring case temperature and device measurement errors are avoided compared to conventional steady state based thermal resistance test methods.

Acknowledgments

This work was financially supported by the Fundamental Research Funds for the Central Universities (HIT.NSRIF.201705) and Natural Science Foundation of Shandong Province (ZR2017MEE011).

References

[1] Chen M, Hu A, Wang B, et al. Test of IGBT Junction-Case Steady State Thermal Resistance and Experimental Analysis [C]// International Conference on Intelligent System Design & Engineering Application. IEEE Computer Society, 2010.
[2] LAKHSASI A, HAMRI Y. Transient thermal analysis of fast switching devices by partially coupled FEM method [C]// Canadian Conference on Electrical and Computer Engineering, Ottawa, Canada. New York: IEEE, 2006: 1098 - 1103.
[3] Joiner B, Adams V. Measurement and simulation of junction to board thermal resistance and its application in thermal modeling [C]// Fifteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium (Cat. No.99CH36306). IEEE, 2002.
[4] Qiu Z, Zhang J. Validation of transient dual interface measurement method of IGBT Rth-JC[C]// 2016 IEEE 8th International Power Electronics and Motion Control Conference

(IPEMC 2016 - ECCE Asia). IEEE, 2016.
[5] Luo Y, Kajita Y, Hatakeyama T, et al. Thermal Transient Test Based Thermal Structure Function Analysis of IGBT Package [C]// 2014 International Conference on Electronics Packaging (ICEP). IEEE, 2014.