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Performance Evaluation of IGBT4 and IGBT7 in Servo Drive Design

Jia Zhao[1], Jianzhong Su[2], Zuange Liu[3]
1 Infineon Integrated Circuit (Beijing) Co., Ltd., China
2 Beijing Jingchuan Electronic Technology Development Co., Ltd., China
3 Wuhan Maxsine Electric Technology Co., Ltd., China

Corresponding author: Jia Zhao, jia.zhao@infineon.com
Speaker: Jia Zhao, jia.zhao@infineon.com

Abstract

IGBT (Insulated Gate Bipolar Transistor) is the key device of servo drive. IGBT type selection and losses is directly related to the system performance, cost, and size. As the latest generation IGBT technology platform of Infineon, IGBT7 has the characteristics of ultra-low conduction voltage drop, dv/dt controllable and 175℃ overload junction temperature. Through the test of FP35R12W2T4 and FP35R12W2T7 in the same platform servo drive, the junction temperature comparison of IGBT4 and IGBT7 under the same working conditions is obtained. The experimental results show that the junction temperature of IGBT7 is lower than that of IGBT4 in the comparison continuous high-power load condition and inertia disk load condition.

1 Introduction

Motors are widely used in areas such as home appliances, transmission, transportation, new energy, industrial robotics, and others. Servo can be considered as a drive with special requirements, mainly focusing on:

- The response time, the output torque, and the rotational inertia of the system should be comparatively large.
- High control accuracy, in terms of position detection, current detection, and torque pulsation of the motor is more demanding.
- Wide range of speed control. A high-performance servo control system can reach over 1:100000.
- Intelligent, networked, and collaborative control.

To cater to these application characteristics of servo drives, Infineon has introduced IGBT7 modules. In this paper, the advantages of IGBT7 over IGBT4 for servo drives are discussed and experimental results shared.

2 The IGBT7 Chip Technology and Applications

In modern power electronics system designs, the general trend is to reduce the losses in power devices and increase their power density. The losses in power devices consist of switching losses and conduction losses. For IGBTs, increasing carrier concentration in the drift region can reduce the on-state resistance, but removing excessive carriers during turn-off inevitably increases the tail current, thus increasing turn-off losses. Therefore, the turn-off losses and conduction losses in IGBTs are usually conflicting parameters. When designing the device, it is necessary to consider the trade-off in this correlation carefully. In terms of motor drive application characteristics, considering the impact of voltage slew rate (dv/dt) on motor windings and

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cables, the dv/dt is mostly below 10 kV/µs, with a typical target of 5 kV/µs. This means that in power semiconductors for motor drives, conduction losses are the largest portion of the total losses and switching losses are secondary. IGBT7 is optimized for these characteristics of motor drives. They significantly reduce conduction losses while maintaining the turn-off losses at the same level as its predecessors.

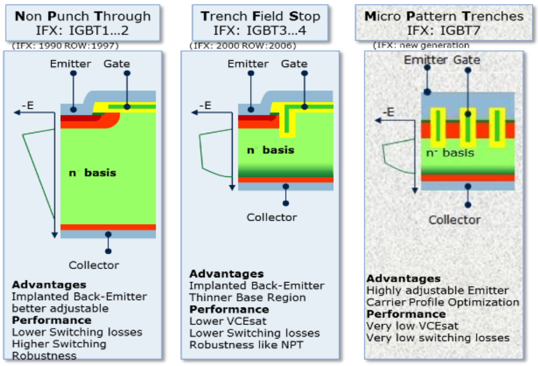

Fig. 1. Cell structure of different generations of IGBTs from Infineon

Figure1 is a cross-sectional view of Infineon's various generations of IGBTs. IGBT 3 and 4 adopted the Trench + FieldStop technology, replacing the previous Planar + NPT technology of IGBT 1 and 2, which was a revolutionary leap. Similarly, IGBT7 is also a technological leap over IGBT4. Unlike the mainstream IGBT4 trench technology currently in the market, IGBT7 adopts the micro pattern trench (MPT) technology with higher channel density, thinner chip thickness, a carefully designed cell structure and spacing, and optimized parasitic capacitance parameters. Thus, achieving optimal switching performance at 5 kV/µs. In terms of specific application aspects, the advantages of IGBT7 are displayed as follows:

- Due to the thinner chips and optimized carrier distribution, conduction loss of IGBT7 is significantly lower, with a 20% reduction in the saturation voltage drop compared to IGBT4. For example, the $V_{ce(sat)}$ of FP25R12W2T7 at 25℃ is only 1.6 V. At the same time, the turn-off losses are maintained at the same level as that of IGBT4. Thus, the goal of reducing total losses is achieved.
- Based on the optimized power module design, the maximum transient junction temperature (T_j) of IGBT7 has been increased to 175°C, which is 25°C higher than that of IGBT4. This characteristic helps meet the actual overload requirements of inverter operations.
- IGBT7 has various forms of trenches. The most common ones are used as active gates. There are also emitter trenches and dummy trenches in the MPT structure, both of which are inactive trenches. The number of these three types of trenches determines the controllability of IGBT7. It enables controllable dv/dt over a wide range through gate resistance and helps achieve the lowest losses within the typical dv/dt range of inverters (2 to 10 kV/µs).

In the next section, the junction temperatures of IGBT4 and IGBT7 are compared, under the same operating conditions, on a servo drive platform.

3 Performance Comparison between IGBT7 and IGBT4

3.1 Platform Setup for Experiments

A 3.5 kW servo drive based on Infineon semiconductors was selected as the testing platform. The drive IC for the IGBT was Infineon's coreless transformer, 1EDI20I12MH. Due to its unique gate structure and low Miller capacitance, IGBT7 can greatly suppress a parasitic turn-on. This allows for a unipolar power supply design, which greatly simplifies the drive design. The main control unit had XMC4700/4800 as the microcontroller, and the motor position detection was done by using TLE5109,

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enabling precise control of speed and position.

Fig. 2(a). The 3.5 kW servo drive test platform

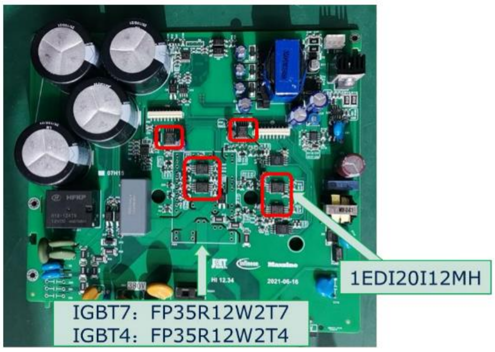

Fig. 2(b). The 3.5 kW servo drive power board

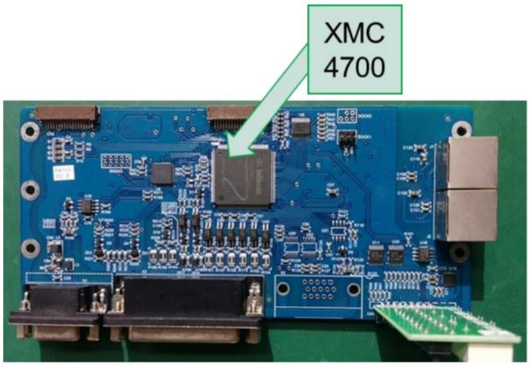

Fig. 2(c). The main control board of the 3.5 kW servo drive

IGBT modules used in this test were FP35R12W2T7 and FP35R12W2T4. Both had thermocouples attached to the IGBT chips. Since the two modules have the same package and pins, it was possible to test them on the same bench. Thermocouples were attached to the IGBT chips at the same position in both FP35R12W2T7 and FP35R12W2T4. This facilitated a direct comparison of the junction temperatures of IGBT4 and IGBT7.

To compare the performance of IGBT4 and IGBT7 in servo drives, two servo drives with the same setup were used, equipped with FP35R12W2T4 and FP35R12W2T7 separately. The tests were conducted under the same dv/dt conditions (dv/dt = 5600 V/us).

For the experiment, discussed in this paper, two typical operation modes were designed to compare the junction temperatures of IGBT4 and IGBT7 under the same conditions, including continuous heavy load mode test and inertia load mode test.

3.2 Results

3.2.1 Continuous Heavy Load Test

Two motors were used for the mutual drag load. The motor under test was operated in electric mode, and the load motor system was operated in the power generation mode. These motors were driven by drivers based on IGBT4 and IGBT7, with the same switching frequency, output current, and power rating. A power analyzer was used to test the input power and output power of the driver, and to calculate the driver's losses and efficiency.

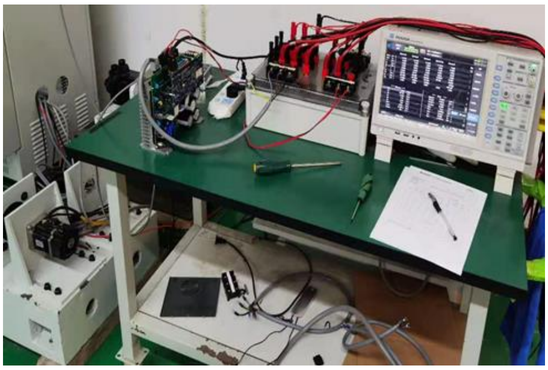

Fig. 3. Experimental platform for continuous large load testing

Figure 4 shows a comparison between the junction temperatures of IGBT4 and IGBT7 under continuous heavy load conditions.

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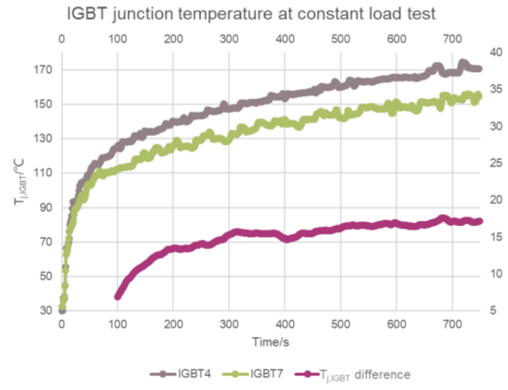

Fig. 4. Comparison between the junction temperatures of IGBT4 and IGBT7 under continuous heavy load conditions

After 13 minutes of the loading test at 8 kHz switching frequency, the junction temperature of IGBT7 was 17°C lower than that of IGBT4. When the loading time was extended, the difference between the junction temperatures enlarged.

Temperature rise in IGBT7 and IGBT4 at the same output power (5.8 kVA) under different switching frequencies was also investigated. Figure 5 shows a comparison between the temperature rise in IGBT4 and IGBT7. The horizontal axis represents the IGBT's switching frequency, the left side of the vertical axis shows the rise in the NTC temperature compared to the initial temperature. The right vertical axis represents the difference in temperature rise between IGBT4 and IGBT7. At higher switching frequencies, the rise in NTC temperature of IGBT7 and IGBT4 was also higher. At 10 kHz switching frequency, the NTC temperature rise of IGBT7 was 19°C lower than that of IGBT4. As IGBT7 is able to operate at higher junction temperatures, it achieves a higher output power rating, or manages power jumping in the same housing compared to IGBT4.

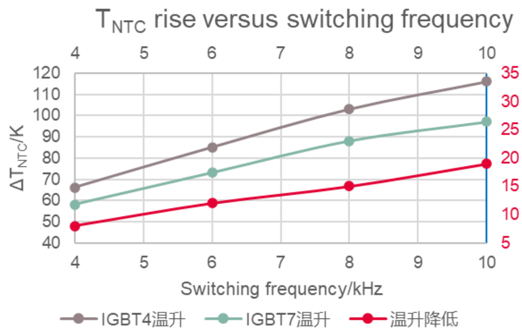

Fig. 5. Comparison between the temperature rise in IGBT4 and IGBT7 at different switching frequencies

3.2.2 Inertia Load Comparison Test

Two servo motor drives were equipped with IGBT4 and IGBT7, with the motor carrying the same inertia disk load. The rotational speed switch time from 1500 rpm to -1500 rpm was 250 milliseconds, and the steady-state operation time was 1.2 seconds. At steady-state operating conditions, the phase output current was less than 0.5 A. Therefore, the average power rating was relatively small. The heat dissipation condition for two motors was identical, with a switching frequency of 8 kHz.

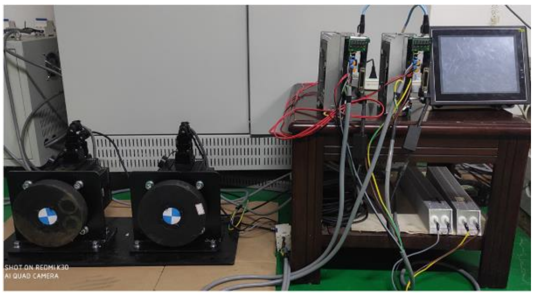

Fig. 6(a). Experimental platform for inertia load comparison test

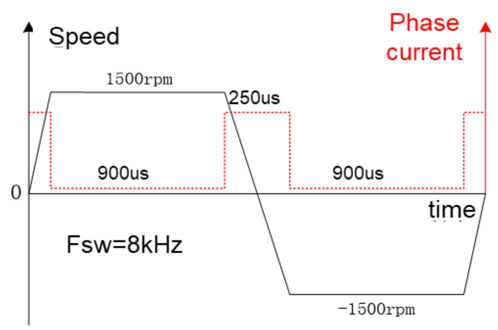

Fig. 6(b). Speed profile of the inertia load test

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The measured junction temperature profile is shown in Fig. 7.

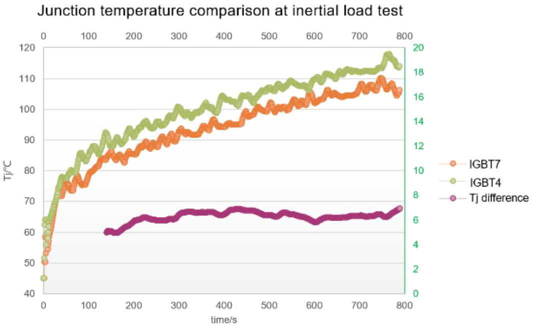

Fig. 7. Comparison between the junction temperatures under inertia load conditions

As can be seen, under accelerating and decelerating conditions with the inertia disk, the junction temperature of IGBT7 was lower than that of IGBT4. Even after running for 13 minutes, the temperature rise did not reach a steady state. At that point, the difference between the junction temperatures was approximately 7°C.

4 Conclusions

The performance of IGBT7 (FP35R12W2T7) and IGBT4 (FP35R12W2T4) was investigated based on a 3.5 kW servo drive platform. The junction temperature of IGBT7 was found to be significantly lower than that of IGBT4 in two operating modes. The lower T_{vj} of IGBT7 allows for a smaller heatsink and reduced overall dimensions of the servo drive. Under the same heat dissipation conditions, IGBT7 can give a higher power output. Additionally, a maximum allowable T_{vj} of 175° C in IGBT7 can help servo drives achieve higher power ratings.

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