TH-Series: 7th Generation IGBT Modules for High-frequency Switching in Industrial Operation

Authors: *Satoshi Kawabata** and *Hiroki Muraoka**

1. Introduction

Power electronics that can use energy and other resources efficiently and effectively are becoming increasingly important in view of recent environmental trends and the social situation. This paper describes the development of the IGBT module TH-series. Mitsubishi Electric Corporation has already started mass-producing the latest seventh-generation industrial IGBT chips and fine-tuned their properties to provide the IGBT module TH-series with a high-speed switching specification. The TH-series can remarkably improve the efficiency of equipment that requires high-speed switching (fc = 20 kHz or higher). Regarding industrial equipment, the switching frequencies at which power devices are used vary (Fig. 1).

2. Characteristics of the TH-series

2.1 Technologies for the seventh-generation IGBT chips[1]

Mitsubishi Electric's IGBT chips have used the CSTBT structure having an electric charge storage layer (CS layer) since the fifth generation and the seventh-generation IGBT chips also have this structure. For the sixth generation, the pitch of the trench gate was narrowed compared to the fifth generation, which further improved the carrier storage effect. The high performance of the seventh generation was realized through ultrathin wafers, metal oxide semiconductor (MOS) structure, and improved structure of the back side. This time, the trade-off of the conventional seventh-generation IGBT chip was mitigated to create the TH-series chip and boost the efficiency of equipment used at a switching frequency (fc) of 20 kHz or higher.

2.1.1 Features of the TH-series[2]

The saturation voltage (VCEsat) of an IGBT has a trade-off relationship with the turn-off power loss (Eoff) and this is often used as an index of an IGBT's property. The seventh-generation industrial IGBT T-series is designed with a saturation voltage (VCEsat) of 1.55 V (@IC = rated current, Tvj = 25°C). If the structure or current density is the same, reducing the switching loss unavoidably increases the saturation voltage (Fig. 2). For equipment involving high-speed switching, the ratio of the switching loss is larger than that of the steady loss by the saturation voltage. Therefore, reducing the switching loss may make the equipment far more efficient even at the slight up of saturation voltage. However, there is a limit of the effect of reducing the total loss through the trade-off between saturation voltage and switching loss. The saturation voltage (VCEsat) of the TH-series was determined as 4.35 V (@IC = rated current, Tvj = 25°C) considering the service conditions of various types of equipment (Fig. 3).

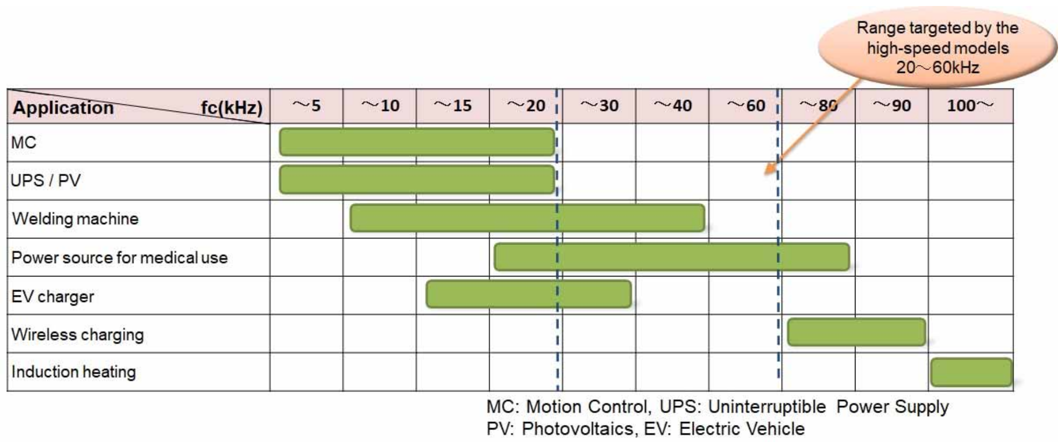

Fig. 1 Switching frequencies for industrial equipment

**Power Device Works*

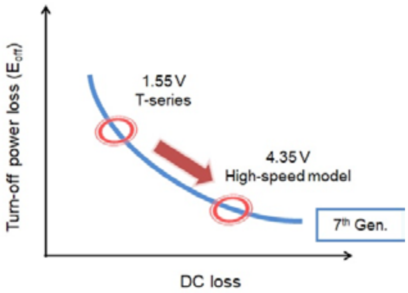

Fig. 2 IGBT trade-off

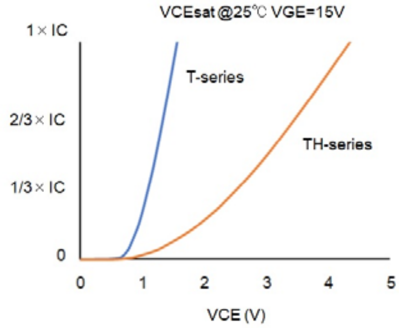

Fig. 3 Static characteristics of T-series and TH-series

The trade-off is adjusted by radiation of life time killers, but this adversely affects the breakdown endurance. Accordingly, this method can be applied only to equipment where it is important to reduce the switching loss at the cost of breakdown endurance and saturation voltage.

As described previously, adjusting and changing the target trade-off between turn-off loss and saturation voltage using life time killers can increase the efficiency of the equipment. However, there is turn-on power loss as a switching loss of IGBTs, in addition to turn-off power loss. Turn-on correlates with VGE(th) and thus reducing VGE(th) can reduce the turn-on power loss. However, equipment involving high-frequency switching may be more affected by noise. Considering the risk of malfunction and device destruction by noise as a result of merely reducing VGE(th), the chips' parasitic capacitance and built-in Rg of the TH-series were optimized accordingly, as is the case with the T-series.

In addition, regarding the high-speed switching specification, adjusting the free wheeling diodes (FWDs) included in the modules may work to reduce the loss, in addition to IGBTs. For diodes, saturation voltage (VF) has a trade-off relationship with the switching loss (Err) like turn-off of IGBTs. Accordingly, the target was changed as well.

As described above, the switching loss of the TH-series was reduced by changing the chip's target based on the T-series. Figure 4 compares the switching waveforms of the T-series and TH-series.

Table 1 lists the main properties of the seventh-generation industrial IGBT module T-series and TH-series for comparison.

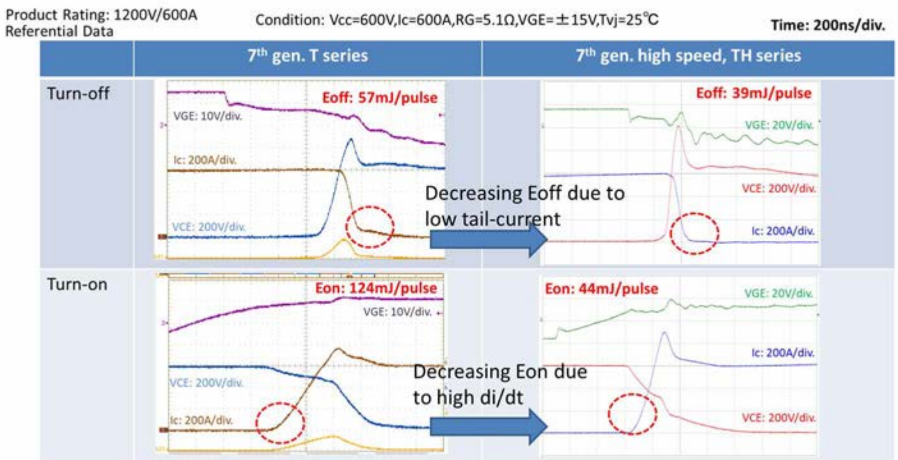

Fig. 4 Switching behavior comparison

Table 1 Comparison data (1200V/600A)

Item	Seventh-generation T-series	Seventh-generation high-speed TH-series[*1]
Type name	CM600DY-24T	CM600DU-24TH
V_{isol}	AC 4.0 kV	AC 4.0 kV
T_{vjmax}	175 °C	175 °C
Q_G	3700 nC	1500 nC
$V_{GE(th)}$ (typ)	6.00 V	6.00 V
V_{CEsat} (typ)	1.55 V	4.35 V
V_{EC} (typ)	1.65 V	2.35 V
E_{off} (typ)	64 mJ	35 mJ
V_{CCmax}	850 V	850 V

Note[1]: No short-circuit guarantee

2.1.2 Contribution of the high-speed switching specification to equipment

The loss of the seventh-generation T-series and TH-series was simulated to assess to what degree the high-speed specification could contribute to actual equipment. Figure 5 shows the comparison results. Because the high-speed switching specification targets equipment for which the switching frequency is 20 kHz or higher, 30 kHz was used for the calculation. The results show that the switching loss accounted for a large proportion for the T-series, but that it was remarkably reduced for the TH-series. Although the saturation voltage DC loss was increased as a result of reducing the switching loss, the total loss of the IGBT was reduced (Fig. 5).

Even when the switching frequency is increased, the DC loss is the same. Accordingly, the loss of the T-series may be increased at high-frequency operation compared to the TH-series because the switching loss of the T-series accounts for a large proportion (Fig. 6).

When the switching frequency is high, hybrid SiC (silicon carbide) modules and full-SiC modules are options. As an example, the loss of the seventh-generation T-series and TH-series was compared to that of such modules (Fig. 7). Although the TH-series is no match for SiC products as the figure shows, they are suitable for high-speed specifications as Si (silicon) products. We have therefore included them in our lineup as options that users can select.

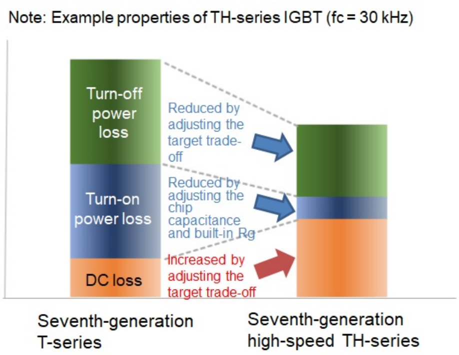

Fig. 5 Comparison for IGBT loss

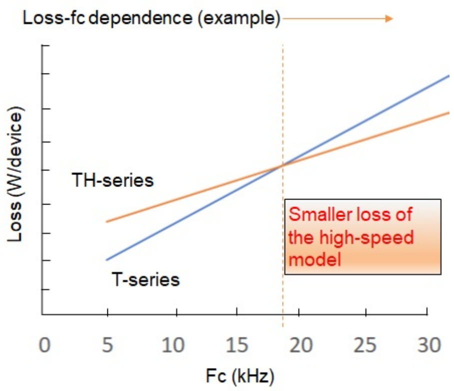

Fig. 6 Loss – fc (per 1 device)

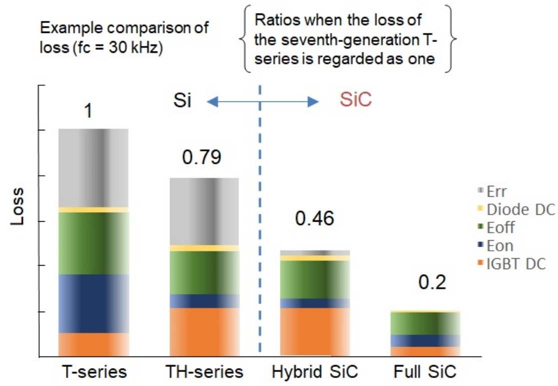

Fig. 7 Loss data for various IGBT modules

2.2 Packaging technologies

The seventh-generation industrial T-series standard type adopted the thick metal substrate (TMS) technology. For the TH-series, ceramic substrates and a copper base structure, which were used for the old generations (up to the six-generation standard type), were used instead of TMS. We focused on ensuring compatibility with our hybrid SiC and securing heat dissipation and thermal capacity because the loss would be considerably large due to high-speed switching (Fig. 8).

2.3 Product lineup

As our product lineup, we offer 1,200 V/200 A, 1,200 V/400 A, and 1,200 V/600 A (all 2-in-1) models (Table 2). For the 1,200 V/400 A model, two types of packages are provided: one is for designing compact equipment and the other is for designing when much heat will be generated due to high loads. The forms were designed such that they can be used as replacements, considering compatibility with currently-used packages.

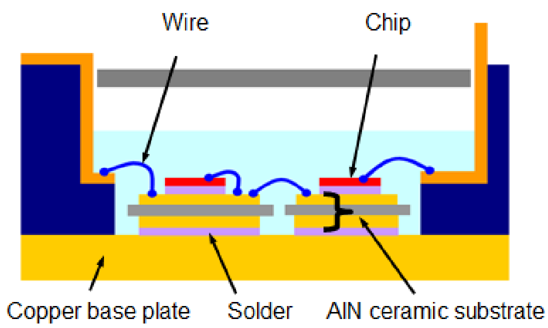

Fig. 8 Internal structure (TH-series)

Table 2 Line-up (TH-series)

V_{ces}	Topology	Package	I_c[A]		
			200	400	600
1200V	2in1	48x94mm² 	■ CM200DY-24TH		
		62x108mm² 		■ CM400DY-24TH	
		80x110mm² 		■ CM400DU-24TH	■ CM600DU-24TH

3. Conclusion

This paper described the seventh-generation industrial IGBT module TH-series with the high-speed switching specification. To make equipment more efficient, it is important to reduce the loss of the power devices. However, there are many applications of industrial equipment and service conditions also vary. Accordingly, there is no single specification that can cover all power devices and improve the efficiency of all equipment. It is important to optimize the properties of power devices based on the service conditions of equipment in order to make best use of it. In recent years, to enhance the performance of equipment, wide band gap (WBG) devices can also be selected because they may work well to reduce the loss. Meanwhile, Si devices, which are reaching the upper limit to improvements to their properties, may still contribute to equipment for which they are used by adjusting the IGBT's properties. We will continue to develop products to support various service conditions and various circuit configurations of equipment in the future.

References

(1) R. Kamibaba, et al.: 7th Generation Power Chip Technologies for Industrial Applications, Mitsubishi Denki Giho, 90, No. 5, 287–290 (2016)

(2) Masaomi Miyazawa, et al.: 7th Generation IGBT Module "T Series" for Industrial Applications, Mitsubishi Denki Giho, 90, No. 5, 295–298 (2016)