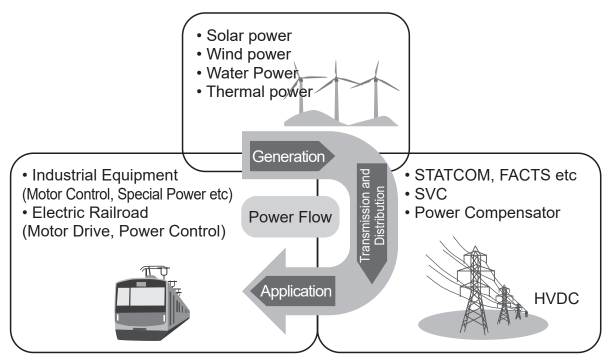
PPI Switching Devices for HVDC Systems

Reduction of the power consumption of equipment used in the power electronics field is an important issue as part of efforts to prevent global warming. Particularly for power transmission and distribution applications, high-voltage direct current (HVDC) transmission systems have been put to practical use as an energy-saving method suitable for long-distance, large-capacity power transmission.
Toshiba Electronic Devices & Storage Corporation has developed and released a line of injection enhanced gate transistors (IEGTs) known as press-pack IEGTs (PPIs) as switching devices for HVDC systems. These PPIs incorporate the following features: (1) an 18% reduction in energy loss through the introduction of a new trench structure, (2) an improved short-circuit failure mode (SCFM) allowing 50 hours of continuous current driving in the event of device failure, and (3) high rupture resistance through the application of a new package that achieves 1.7 times the rupture resistance of conventional packages.

1. Introduction

Semiconductor devices in the field of power electronics (hereinafter referred to as power devices) convert direct current to alternating current, alternating current to direct current, and control voltage, current, and frequency. Power devices are used in various fields ranging from renewable power generation, such as wind or solar systems, to utilization of electricity in familiar settings, including for railroads, automobiles, industrial machinery, home electric appliances and other applications (Figure 1). Toshiba Electronic Devices & Storage Corporation focuses on the development of high-power devices, which are key components for power conversion, and contributes to the efficient and stable usage of electric power through all phases of power generation, transmission, distribution, and consumption.

In order to manage power from generation to utilization, high efficiency and high reliability are also required. In particular, high-voltage direct current (HVDC) has attracted attention in recent years as a method suitable for large-capacity, long-distance power transmission, and has been put into practical use around the world. Compared with traditional high-voltage alternating current (AC) transmission, HVDC achieves higher transmission efficiency, the greater the distance the higher the efficiency, as well as savings in construction costs. In conventional HVDC systems, line-commutated converters (LCCs) that employ thyristors are commonly used. However, LCCs require supplementary equipment such as power compensators and harmonic filters, and the installation area required is an issue.



STATCOM: Static Synchronous Compensator
FACTS: Flexible AC Transmission System
SVC: Static var Compensator

(Figure 1) : Application fields for power devices

On the other hand, voltage source converters (VSCs) enable the control of active and reactive power independently. Since VSCs require power devices capable of turning themselves off, injection-enhanced gate transistors (IEGTs) are attracting attention as the devices most suited to HVDC transmission.

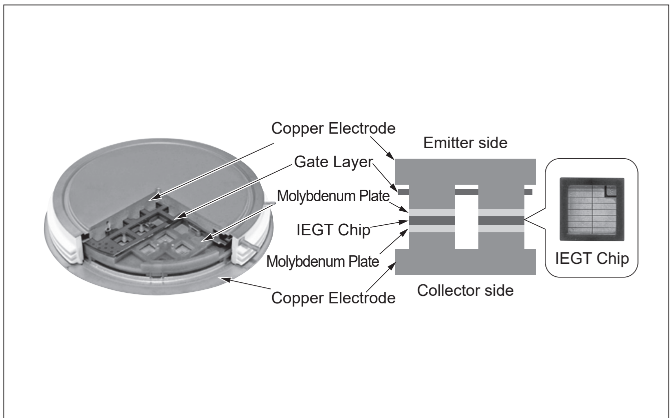
We have adopted the press pack IEGT (PPI), which is a suitable power device for a VSC thanks to its large cooling capacity achieved by double-sided cooling and the environmental resistance achieved by its hermetic sealing. Furthermore, we have improved the explosion resistance, continuous operating capability, and low energy loss for HVDC systems.

We describe the main points below.

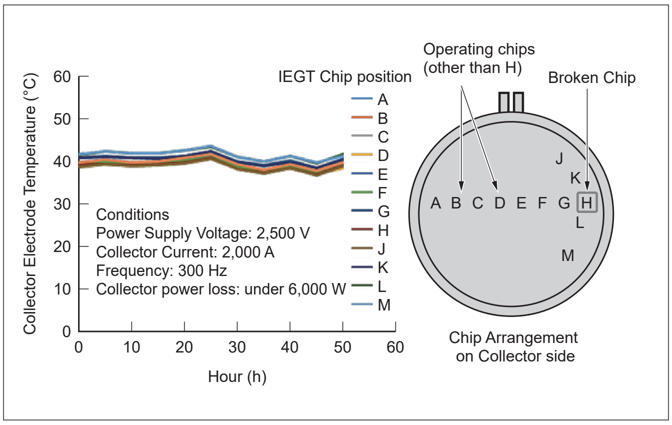
2. Operational continuity of PPI

In the field of transmission and distribution, which includes HVDC, it is desirable that the system as a whole be able to continue operating even after a device failure. Since plastic case modules use bonding wires, if a device fails, the bonding wires will break and the circuit may electrically open, meaning the HVDC system can no longer operate. On the other hand, since PPIs adopt pressure contact to make an electrical connection, they are less likely to result in an open circuit after a failure. Even in the unlikely event of the device failing because of an accident, the short-circuit state can be maintained and current can continue to flow (Figure 2). Taking advantage of this, PPIs can be connected in series to provide redundancy and allow continuous operation. Since no soldering or bonding is employed, deterioration due to thermal degradation is slight and high reliability is maintained.

In order to confirm the continuity of operation of a PPI, we conducted tests on the stability of the current conduction (Figure 3). An intentionally broken IEGT chip (at position H) was mounted in the PPI together with normal chips. A continuous pulse current corresponding to the operation of the converter was applied for up to 50 hours, and the temperature was measured at each position from A to M located just under each IEGT chip on the collector electrode. The differences in temperature between each measurement point were small. Based on this result, it can be concluded that current will continue to flow stably after a device failure. The PPI is shown to be a power device suitable for HVDC operation that requires a continuous supply of stable current and can withstand a device failure.



(Figure 2) : Structure of PPI



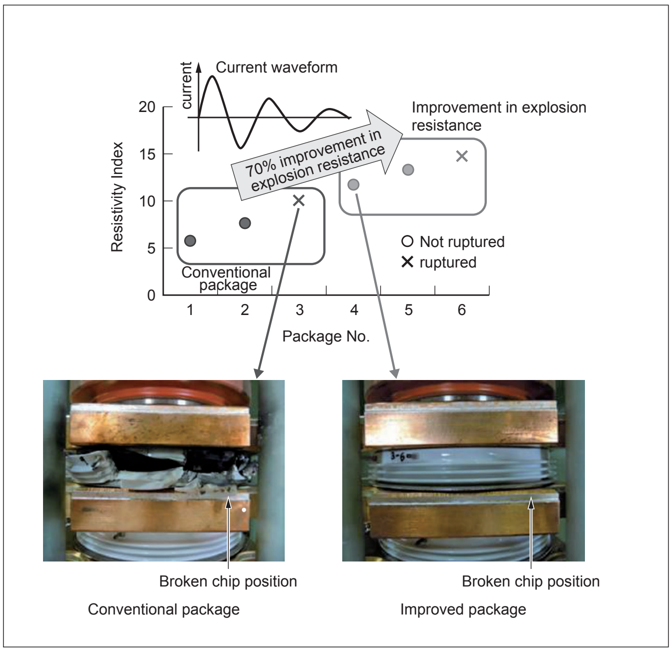
(Figure 3) : Changes in collector electrode temperature measured in SCFM test

3. Explosion resistance of PPI packages

If the package ruptures when an IEGT chip breaks, it may damage the cooler unit and other nearby equipment, resulting in the shutdown of the entire system. Thus, an explosion-resistant package is important to ensure stable operation. PPI packages use ceramic, which is unlikely to rupture, and we have developed an improved explosion-resistant package using a ceramic material.

Figure 4 shows the test result of an explosion-resistant package versus a conventional package. The test was conducted as follows: we assembled an intentionally broken chip on each package and injected current as shown in the waveform in the figure. The current was set to around 300 kA, a normal current level when a device is short-circuited. The vertical axis of the graph represents the resistivity index of the explosion. The explosion-resistant package has raised the index by 70%, meaning that the package can withstand a DC voltage 1.3 times higher with the same capacitor and the same stray inductance.

These results demonstrate that a more reliable system has been realized using an explosion-resistant PPI package.

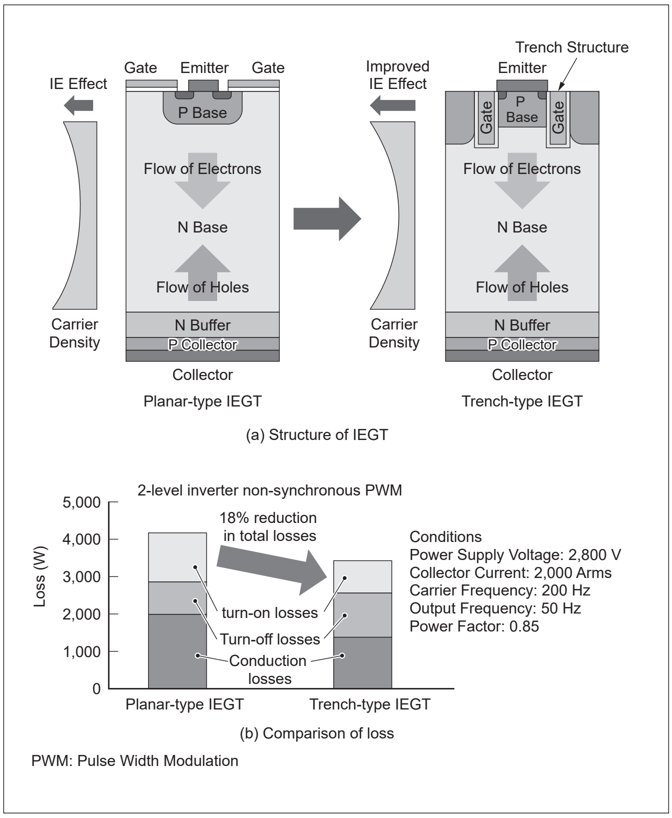


(Figure 4) : Results of package rupture tests

4. Low-loss characteristics of IEGT and improvements of RBSOA

In the IEGT, by suppressing outflow of holes injected from the P (P-type semiconductor) base on the emitter side, the carrier density on the emitter side is increased by the injection enhancement (IE) effect[1], achieving a low ON-voltage. However, for the conventional planar structure, this effect is limited. Therefore, for the case of a 4,500 V IEGT for HVDC, we have developed a chip having a gate with a trench structure. The IE effect was further enhanced by optimizing the P base layout (Figure 5 (a)). In addition, by adjusting the hole injection efficiency from the collector side on the backside of the device, the current conduction loss and the turn-on loss were reduced, with the total loss improving by about 18% (Figure 5 (b)).

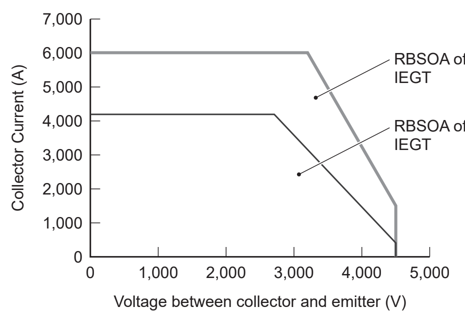
For a high-current switching device, the reverse bias safe operating area (RBSOA) for high current turn-off is also important. In order to improve the RBSOA of IEGTs, one needs to suppress the gain of the parasitic NPN transistor that exists in the metal oxide semiconductor (MOS) gate structure and to adjust the amount of holes injected from the P-type collector on the backside. It is also known that suppressing holes injected from the



(Figure 5) : Comparison of structure and inverter loss of conventional planar and newly developed trench IEGTs peripheral region is effective in improving RBSOA. For a 4,500 V trench-type IEGT chip, by reducing the impurity concentration of the peripheral region, it is possible to suppress the hole injection from this region and to enable shutdown of a larger current compared with the case of a conventional planar-type IEGT. As a result, the RBSOA is expanded (Figure 6).

5. Conclusion

While power saving is an important requirement for all areas of power electronics, maintaining the reliability of the system is particularly important in the power transmission and distribution field. In addition to reducing power loss, we will continue to contribute to energy saving and improve system reliability by focusing both on packaging and the semiconductor chip technologies.



(Figure 6) : Comparison of reverse bias safe operating area (RBSOA) of conventional planar and newly developed trench IEGTs

References

(1) Kitagawa, M. et al. "A 4500 V injection enhanced insulated gate bipolar transistor (IEGT) operating in a mode similar to a thyristor" . IEDM Tech. Dig. IEEE International Electron Devices Meeting, 1993. Washington DC, USA, 1993-12, IEEE 1993, P679 – 682