Enhanced Trench 3300V TSPT+ IGBT Module Brings Highest Current Density and Robustness

With the arrival of the Enhanced Planar (SPT+) IGBT cell technology, ABB set a benchmark in device performance that still today competes with Trench cell IGBTs. Nevertheless, the market continuously demands increased performance. ABB has thus combined the merits of the Enhanced Planar cell with Trench technology and created the Enhanced Trench TSPT+ IGBT. The new 3300V TSPT+ represents the latest generation IGBT cell technology, enabling a further loss reduction and hence the possibility to increase the current density.

By Raffael Schnell, Chiara Corvasce and Silvan Geissmann, ABB Semiconductors

Technology IGBT cell technology
The Enhanced Trench cell IGBT builds on the N-type enhancement layer, known from the SPT+ technology, and combines it with the Trench technology [1]. The combination is the resulting Enhanced Trench cell or TSPT+ technology (Figure 1).

The TSPT+ cell is implemented as a stripe design. To achieve the targeted enhanced carrier concentration near the trench emitter, aimed to reduce conduction losses, the TSPT+ cell is combined with the characteristic N-enhancement layer. This greatly reduces the hole drainage through the cell. The P-well between the trenches is designed to achieve a low input capacitance and hence an optimized IGBT turn-on behavior and to support the blocking voltage. The P-well is resistively coupled to the emitter node in order to optimize the trade-off of controllable turn-on and conduction losses.

Diode technology
The 3300V 1800A TSPT+ IGBT module uses a Field Charge Extraction (FCE) diode with a Field Shielded Anode (FSA) design (Figure 2).

The FCE [2] concept aims at a better losses versus softness, as it allows a reduction in the diode thickness. This reduces the losses without sacrificing the softness during diode recovery. This is achieved by introducing P+ islands at the diode cathode. During the tail-phase of the diode reverse recovery, the electrons are deflected around the P+ islands causing a lateral voltage drop (DV). At the end of the tail-current phase this voltage drop exceeds the built-in junction voltage (~0.6V) and the P+ islands inject holes that avoid a sudden snap-off of the tail current.

The FSA [3] technology features a double anode design with a shallow doped P- layer that blocks the electric field during diode off-state from the deep-level proton irradiation. Hence, the deep levels generated by the proton irradiation are shielded from the electric field. Its impact to the hot leakage current are thus heavily minimized, enabling the diode to be rated at 150°C.

Mitigation of Trench degradation
Trench cells especially for high-voltage applications are known to suffer from degradation effects [4]. During IGBT turn-off at an elevated current and voltage, the IGBT enters into dynamic avalanche. This means charge carriers get accelerated enough from the high local electric field to generate electron hole pairs. Due to the high local field in the IGBT, the generated charge can have enough energy and momentum to get injected into the gate-oxide. Since the oxide of trench cells is much more exposed (Figure 1) than that of planar IGBTs, trench IGBTs are prone to so called "hot carrier injection" into the oxide, especially at the exposed trench bottom. Consequently, charges are trapped within the oxide which alters and degrades the oxide properties. This has measurable impact on device parameters like...
gate-threshold change, gate leakage increase, capacitance change and, as a further consequence of this, an increase of the IGBT turn-on switching speed.

Avoiding trench cell degradation means that the oxide of the trench needs to be protected and shielded from the hot carriers. In the most consequent extent this probably could be done, but would set back performance of the trench design to that of an enhanced planar cell. This would render the practical benefit of trench obsolete. Hence it is important to mitigate the effect of trench cell degradation to such an extent that it is moved out from the regular range of operation.

This can be done by protecting the trench cell to a reasonable amount from the hot carriers and by moving the position of the dynamic avalanche by way of a 3D optimization of the trench layout, together with a high quality gate oxide. In addition, dynamic avalanche can be reduced by the gate-driving conditions, such as using a higher turn-off gate resistor.

Trench degradation is mainly influenced by turn-off current and voltage and accumulates with the number of turn-off events. ABB has optimized the trench cell design to avoid degradation in the nominal operation conditions as there one has to practically account for infinite turn-off events during life time. In addition, the degradation effects at elevated conditions like IGBT turn-off at SOA with countable events during an IGBT life time, have to be minimized and characterized for a better understanding.

Figure 3 shows the effect of trench degradation for the ABB devices and an identical rated other trench based device. Both devices are subjected to 125,000 turn-off events at 1.5 times nominal current and an increased DC-voltage of 2300V. For the driving the recommended datasheet turn-off gate-resistor is used for both tested IGBTs. The ABB device shows an identical turn-on behavior prior to and after the 125,000 turn-off events, hence no degradation. The other trench cell design shows a significant increase in turn-on speed after being subjected to 125,000 turn-off events. As a result of the faster switching, the IGBT turn-on current respectively the diode IRR is significantly higher. This means the diode is more stressed and a further degradation of the trench cell yields to an even faster turn-on. The diode could finally fail due to operating outside of its safe operating area.

So far the tests with the optimized ABB TSPT+ IGBT have shown no degradation if operated at nominal current or below. The tests with several hundred thousand to millions of cycles have also shown that degradation is mostly dependent on the switched turn-off current and the dissipated dynamic avalanche energy [5], therefore a higher turn-off gate resistor reduces the degradation to some extent. This can be also one reason why manufacturers of the latest trench-based IGBT modules typically recommend rather large turn-off gate resistors compared to planar devices.

The investigations on trench degradation are continuing in order to improve the understanding of the impact of various application parameters.

Device characteristics
The new 3300V TSPT+ IGBT offers a significant reduction in conduction losses compared to the previous generation. This has enabled, a 140 x 190mm² sized HiPak2 module to be rated at 1800A. In order to lift the diode performance to the same performance level than that of the TSPT+ IGBT, ABB has re-designed the internal module layout and increased the FCE/FSA diode chip area by 20 percent. This gives a reduction of both the diode conduction losses and thermal resistance.

The key characteristics of the 3300V 1800A TSPT+ module are shown in table 1:

<table>
<thead>
<tr>
<th></th>
<th>25 °C</th>
<th>150 °C</th>
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<tbody>
<tr>
<td><strong>Conduction losses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{CEsat}$</td>
<td>2.4 V</td>
<td>3.0 V</td>
</tr>
<tr>
<td>$VF$</td>
<td>2.1 V</td>
<td>2.2 V</td>
</tr>
<tr>
<td><strong>Switching losses</strong></td>
<td></td>
<td></td>
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<tr>
<td>$V_{on} = 1800V$, $I_{off} = 1800A$</td>
<td></td>
<td></td>
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<tr>
<td>$R_{on} = 12 Ohm$</td>
<td>2.7 J</td>
<td>3.95 J</td>
</tr>
<tr>
<td>$E_{off}$</td>
<td>3.2 J</td>
<td>3.9 J</td>
</tr>
<tr>
<td>$E_{on}$</td>
<td>1.6 J</td>
<td>2.55 J</td>
</tr>
</tbody>
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Table 1: Key characteristics of the 3300V, 1800A TSPT+ HiPak2 IGBT module
The new TSPT+ IGBT is suitable for many applications, including 2-level and 3-level inverters. For 3-level topologies, the DC-link stray inductance typically has higher values compared to the 2-level counterparts. This increases the requirements on inherent soft switching characteristics of both the IGBT and especially the diode. The TSPT+ IGBT features a stronger anode compared to its SPT+ predecessor. This ensures a softer IGBT turn-off with less overvoltage. Figure 4 shows the 3300V 1800A TSPT+ module at extreme turn-off conditions with double nominal current of 3600A to 2600Vdc. The switching characteristics is very smooth and without excessive overvoltage.

For a soft diode switching characteristic a field charge extraction (FCE) diode design is chosen. The FCE diode implementation in the new 3300V 1800A TSPT+ HiPak2 module sets a new benchmark in terms of softness combined with record low losses. Figure 5 illustrates the soft switching characteristics over the full current range at the critical extreme low temperature of -40°C and an increased DC voltage of 2300V. In addition, the switching speed is faster than the datasheet recommendation with an RGon of 0.67Ohms instead of 1.2Ohms.

Application performance
The new 3300V 1800A TSPT+ IGBT offers significant reduced losses compared to previous generations. Its inherent soft switching characteristics makes it suitable for a variety of applications such as 2-level, 3-level topologies used in propulsion inverters for railway applications, renewables like wind-turbines or industrial drives. Optimization for low conduction losses means the TSPT+ IGBT is ideally suited for modular multi-level (MMC) inverters with rather low switching frequency such as those used in HVDC and FACTS applications.

A good measure of IGBT performance in real applications is the so-called performance plot [6]. Figure 6 shows the inverter output current for a 2-level inverter as used for instance, in traction propulsion drives. It compares three generations of 190 x 140mm sized HiPak2 modules. The new TSPT+ module shows close to 15 percent improvement compared to the previous SPT+ generation and even more than 50 percent improvement compared to the 1200A rated SPT generation. This provides the potential to replace a 1200A rated 190 x 140mm SPT HiPak2 module with a third smaller 130 x 140mm 1200A rated HiPak1 TSPT+ module. This is a significant reduction of inverter volume.

The benefit of the larger diode area and the FCE/FSA diode of the TSPT+ IGBT module is shown in the rectifier mode performance (fig. 7). The new module outperforms its SPT+ predecessor by more than 20 percent and the SPT module by a healthier 65 percent. This is highly important in case of regenerative breaking or for line-side converters in traction applications. It also enables a full 4-quadrant operation in HVDC and FACTS applications.

Summary
The new 3300V enhanced Trench TSPT+ IGBT module from ABB offers significantly reduced losses compared to previous generations. Thus, the current density can be increased to 1800A for 190 x 140mm sized HiPak2 module. This lets customers make more compact inverter designs with up to a third volume savings compared to earlier generations.
The TSPT+ IGBT and the new FCE/FSA diode offer excellent robust and soft switching characteristics, making it the device of choice for a large variety of applications.

ABB will present the 3300V 1800A TSPT+ HiPak2 IGBT module at PCIM 2018 in Nuremberg. It will be the first module with the enhanced Trench technology, followed by a 3300V 1200A 130 x 140mm sized HiPak1 module beginning of 2019 and other voltage classes like a 4500V 1500A rated 190 x 140mm HiPak2 module in the coming years.

References