New Industry Standard LoPak Modules with 1700V SPT-IGBT and Diode chip set

M. Rahimo, A. Kopta, R. Schnell, G. Debled, J. de Oñate, S. Linder
ABB Switzerland Ltd Semiconductors, Fabrikstrasse 3, CH – 5600 Lenzburg, Switzerland

Abstract: In this paper, we are introducing the 1700V SPT-IGBT LoPak module line-up. In order to fully exploit the performance benefits of the new 1700V SPT-IGBT and diode chips, the devices were implemented in a range of 1700V LoPak4 and LoPak5 modules rated above 150A. The LoPak packages offer themselves a high level of mechanical integration into the user’s system. The combination of this, with the low losses and thermal characteristics of the 1700V SPT die set, allows extremely compact, high power density and efficient systems to be built. In this paper, the performance of the new 1700V LoPak product range is discussed, with particular reference to the low on-state and switching losses, high ruggedness, low cosmic ray failure rate, and easy parallel operation.

1. Introduction

With the introduction of SPT (Soft Punch Through) technology [1], new standards in IGBT design and performance were reached especially for the medium power market. The combination of traditional NPT ruggedness with low losses has made SPT the 1200V benchmark product. Now, the SPT range is expanded by the introduction of the 1700V range [2]. The 1700V SPT-IGBT die also achieves 20% improvement in both on-state and switching losses when compared to standard NPT chips, without increasing thermal resistance or sacrificing ruggedness. Also, a new 1700V fast and soft diode was developed to complement the performance advantages offered by the SPT-IGBT die. Both the 1700V SPT-IGBT and diode exhibit a positive temperature coefficient for the on-state voltage making them ideal for parallel connection in the LoPak module range.

The lower losses offered by the new chip set, combined with the LoPak4 and LoPak5 industry standard packaging shown in figure (1), has given users the potential to develop more compact, higher power systems on a packaging platform suitable for both industrial and traction applications. The concept of modularity, (where phases are built up in a building block approach to achieve higher power ratings) allows a range of inverter power ratings for the 690V AC line to be manufactured using only two part numbers. Furthermore, due to the package concept, and validated by an extensive reliability qualification program, the LoPak module family package design offers high reliability for inverter circuits in industrial (up to 690V AC) and traction (up to 750V DC) applications [3].

![LoPak4 and LoPak5 package outline of 1700V Industry Standard Modules.](image)

Since the design, construction and mechanical performance of the LoPak modules has been reported in detail previously [4] for the 1200V series, we will only outline briefly the main features and advantages of the LoPak packages. However, this paper will mainly examine the key electrical characteristics of the 1700V SPT LoPak range. This includes the static and dynamic performance, turn-off and short circuit ruggedness, parallel operation and cosmic ray failure rate. In addition, different circuit layouts and thermal resistance options offered for the 1700V voltage range will be presented briefly.
2. 1700V SPT IGBT and Diode Chip Set

In recent years, the trench concept in IGBT cell design [5] has been presented to be the only possibility to obtain a significantly improved performance in terms of on-state losses. In contrast, we previously demonstrated [1][2], that a high performance IGBT with lower losses (20% vs. NPT) can be achieved using a standard planar technology combined with the Soft-Punch-Through (SPT) concept shown in figure (2). The on-state losses obtained are comparable to those achieved using trench technology for the same current rated devices. The planar design was chosen in order to keep cost per unit area low using a mature processing technology. Moreover, the thermal resistance can be kept at a low level, while maintaining the high levels of ruggedness associated with the planar cell concept.

![Figure 2: 1700V SPT-IGBT structure, doping profile and electric field distribution.](image)

The SPT concept is based on using a low doped n-buffer profile at the anode side of the IGBT. At a normal DC-link operating voltage, the space-charge region does not reach this buffer region with the high resistivity n-base layer. However, at higher voltages, the SPT (Soft-Punch-Through) buffer layer ensures the softness of the current and voltage curves during switching transients. Therefore, despite a 30% thinner base region, the dynamical electrical properties of the SPT-IGBT are almost comparable with those of a thicker Non-Punch-Through IGBT (NPT-IGBT).

Also, a new 1700V fast and soft recovery diode was developed to add to the advantages of the 1700V SPT-IGBT. The diode was designed using a combination of modern design techniques and lifetime killing methods to achieve very low static and dynamic losses along with very soft recovery characteristics and low levels of Electromagnetic Interference (EMI). In addition, a positive temperature coefficient during on-state for both the IGBT and diode was obtained to ensure good current sharing of the paralleled die operating in the high current module. The 1700V / 75A chip set implemented in the LoPak modules is shown in figure (3) below.

![Figure 3: Top view of 1700V/75A SPT-IGBT and diode chip set for LoPak modules](image)

The many advantages of the chip set layout design for wire bonding and module manufacturing in general has been reported in previous articles [4] especially with regard to the special gate corner position and large emitter bondable area.

3. 1700V SPT-IGBT LoPak Module Range

The 1700V LoPak range takes full advantage of the exceptional characteristics of the 1700V SPT IGBT and diode die to offer a range of 6-pack and 2-pack configurations as shown in table (1). Lower thermal resistance packages are also available on request.

<table>
<thead>
<tr>
<th>Module</th>
<th>Part Number</th>
<th>Type</th>
<th>Ic/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoPak4</td>
<td>5SNS 0150V170100</td>
<td>6-pack</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-pack</td>
<td>450</td>
</tr>
<tr>
<td>LoPak4*</td>
<td>5SNS 0150V172100</td>
<td>6-pack</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-pack</td>
<td>450</td>
</tr>
<tr>
<td>LoPak5</td>
<td>5SNS 0225U170100</td>
<td>6-pack</td>
<td>225</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-pack</td>
<td>675</td>
</tr>
<tr>
<td>LoPak5*</td>
<td>5SNS 0225U172100</td>
<td>6-pack</td>
<td>225</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-pack</td>
<td>675</td>
</tr>
</tbody>
</table>

*Low Rth

| table(1): 1700V SPT LoPak module line-up. |
The 1700V LoPak4 and LoPak5 modules aim to extend the current rating in six-pack topology to 150A and 225A respectively. Also, the modules are designed so that by parallel connecting the phase outputs the same device is then usable as a two-pack (phase-leg) at three times the current rating (up to a 675A in LoPak5). The circuit schematics for both LoPak4 and LoPak5 are shown in figure (4).

![Circuit schematics for LoPak 4 and 5](image)

Figure 4: Circuit schematics for LoPak 4 and 5

By further paralleling “2-packs”, multi-MW inverters can be realized. In this way a user can manufacture a complete range of inverters in 690V AC from 40kVA to perhaps 5MVA using only two packages, three 1700V article numbers. The footprint of the LoPak4 and LoPak5 modules is designed to enable the replacement of existing standard modules without major changes to the heatsinks used. System or equipment assembly with LoPak is extremely fast and easy compared to previous solution in force, as well as reliable. The concept behind the LoPak4 and LoPak5 modules is that the best place for the gating and control circuitry is on a PCB as close as possible to the IGBTs. Therefore, minimizing the inductance between the driver and the chips themselves. In this way the user can achieve gate circuitry with high noise immunity and optimize the switching of the device to his application. The module is designed to take a PCB, which snaps on top to avoid any irreversible soldering. In addition pins have been provided for connection of auxiliary collector signals into the control circuitry. These can be used for short circuit detection and control or alternatively for active dv/dt control to optimize switching losses, and EMC performance. Also, for ensuring that the power- and control-circuit connections to the module are completely separated from each other.

4. 1700V LoPak5 Electrical Performance

1700V/225A SPT LoPak5 modules have been verified and tested confirming the electrical performance advantages achieved by employing 1700V SPT-IGBT and diode chip set. The modules were tested for the static and dynamic characteristics, Safe Operating Area SOA, parallel operation and cosmic ray failure rate measurements.

a) Static Performance:

Figure (5) shows the on-state characteristics of the 1700V/225A LoPak5. Due to the large reduction in the base region thickness and optimized cell design of the 1700V SPT-IGBT chip, 20% less on-state losses were obtained compared to equivalent NPT structures. The 1700V/225A LoPak5 module had an on-state voltage of 2.3V at 25°C and 2.6V at 125°C rated current as shown in figure (5:a).

![IGBT on-state voltage against collector current](image)

Figure 5: 1700V/225A LoPak5 module on-state characteristics for both (a) SPT-IGBT and (b) diode at 25°C and 125°C.
The curves also exhibit a strong positive temperature coefficient even at low current levels to prevent current mismatch during parallel device operation due to thermal imbalance. The diodes also maintain low on-state voltages of 1.9 at 25°C and 1.95V at 125°C (figure 5:b) providing a positive temperature coefficient and making it a perfect match with the IGBT inside the module. Both the SPT-IGBT and diode have a very reliable and effective junction termination technology implemented, providing extremely stable breakdown voltages at room temperature and low leakage currents for the module, especially at higher temperatures. The typical blocking voltage for the chip set is 1850V to ensure a sufficient margin for the required voltage of 1700V at room temperature. Also, an optimized silicon design was aimed for reducing cosmic ray induced failure rates for the IGBT and diode. Measurements have shown that the initial design goal of 10 FIT per chip at 25°C and 900V DC link voltage is met.

b) Switching Performance:
Figures (6) and (7) show the switching characteristics of the 1700V/225A LoPak5 during turn-off and turn-on respectively. The tests were carried out at rated current and a DC bus voltage of 900V. It can be observed that the turn-off current switching transients of the 1700V SPT are very smooth. A short tail can be observed due to a thinner base region and the SPT buffer. Therefore turn-off losses are kept low. The results of the turn-off losses are a reduction of 25% when compared to an equivalent NPT-IGBT module. This also results in faster switching speeds with low losses, short tail current, low overshoot voltage and low EMI levels. Figure (7) shows the switching waveforms during turn-on. Thanks to an optimized diode design, the IGBT turn-on losses were reduced substantially. The diode reverse recovery waveforms are shown in figure (8). The input capacitance of the SPT-IGBT has also been optimized to provide good controllability of the turn-on di/dt with respect to varying the gate resistance. In addition, faster voltage decay for the IGBT was obtained, further reducing the IGBT losses during turn-on. A curve showing di/dt and dv/dt against $R_G$ at 125°C is shown in fig. (9).
c) SOA Performance:
The 1700V LoPak5 show very good rugged performance and a wide SOA during the IGBT turn-off RBSOA and under short circuit conditions SCSOA. Figure (10) shows the RBSOA turn-off switching behaviour of the 1700V/225A LoPak5 module, while figure (11) shows the LoPak5 under the same RBSOA conditions during turn-on. The devices were tested at 2.5 x rated current of 575A and DC rail voltage of 1450V at 125°C. Rugged performance is also demonstrated during turn-on for both the IGBT and diode. Turn-on waveforms show a di/dt current ramp of 4000 A/μsec and a diode reverse recovery peak current of 170A. The 1700V diodes dynamic behaviour ensures soft recovery, high ruggedness and reliable performance under all operating conditions especially at low current levels and low temperatures. The turn-off and turn-on energy losses of the SPT-IGBT and the reverse recovery charge and current of the diode during turn-on are all plotted against the collector current as shown in figure (12: a and b).

![Figure 10: 1700V/225A LoPak5 RBSOA switching characteristics during turn-off.](image1)

![Figure 11: 1700V/225A LoPak5 RBSOA switching characteristics during turn-on.](image2)

Figure 12: 1700V/225A LoPak5 IGBT losses and diode reverse recovery parameters against Ic

The waveforms in figure (13), show the 1700V LoPak5 in short circuit mode at a DC rail voltage of 1300V at (a)25°C and (b)125°C for 10μsec. The current waveform shows a reasonable maximum short circuit current of approximately 1400A at 25°C and 1200A at 125°C for a 225A module.

![Figure 13: LoPak5 1700V IGBT short circuit behaviour.](image3)
5. Parallel Operation of 1700V LoPak5

As discussed previously, the mechanical design allows the LoPak5 module to be easily converted from a 6-pack to a 2-pack device by simply connecting the three phase-terminals together. Easy paralleling requires a carefully designed chip set. Both 1700V SPT-IGBT and diode are manufactured with narrow parameter distributions. Therefore, for both IGBT and diode the difference in on-state voltage between the 3 single branches of a LoPak module is typically below 100mV. Additionally, the IGBT and the Diode offer a positive temperature coefficient of $V_{CEsat}$ and $V_F$ respectively. Thus, avoiding thermal runaway due to static imbalance. To check the easy paralleling, thorough investigations were carried out. As a result, we observed that the static current mismatch is below 5% for the diode and IGBT as shown in figure (14).

In case of switching the device on and off, the sharing of the switching losses depends on the connection of the phase terminals. Completely symmetrical connection results according to our investigations in a maximum mismatch of the switching losses of 5%. Using a more simple approach by connecting the phases closer together, results in our set-up to a mismatch in switching losses of 10%, due to the different impedance of the single branches.

Figure 14: 1700V/225A LoPak5 IGBT operated as a dual pack in a double pulse test.
($V_{cc}=900V, I_c=450A, V_{ge}=15V, R_G=5Ω, @125^oC$)

In order to visualise how the static and dynamic current imbalance translates into thermal derating, a typical drive application with naturally sampled PWM has been simulated. A model of an ideal LoPak5 1700V without any current imbalance in parallel operation and a model of a "real live" LoPak5 1700V with 5% static current imbalance and 10% higher switching losses have been simulated. Figure (15) shows the comparison of the two models against switching frequency. The derating of LoPak5 1700V operated as a dual-pack depends on the switching frequency and varies from 1.8% at 250Hz up to nearly 9% at 20kHz.

Figure 15: Derating against switching frequency for 1700V/225A LoPak5 operating as dual pack.
($f_{out}=50Hz, m=1, \cos \phi=0.85, \Theta_h=70^oC, @125^oC$)

Conclusion

The new 1700V LoPak module range utilizing the new 1700V SPT-IGBT and diode chip set has been introduced. The excellent electrical performance of the new SPT-IGBT and diode with regard to the lower on-state and switching losses, and high ruggedness, combined with LoPak packaging with the high level of mechanical integration into the system, will realize the concept of higher power from smaller systems.

References