HiPak Modules with SPT$^+$ Technology Rated up to 3.6kA

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Abstract

This paper presents the performance of a 3600A/1700V HiPak2 module using the recently developed SPT$^+$ IGBT technology. This new platform is being progressively implemented across the voltage range of 1200V to 4500V throughout 2006. Additionally, the smaller "HiPak1" which will also exploit SPT$^+$ technology, will be introduced. The SPT$^+$ IGBT HiPak modules achieve the same desirable switching characteristics and SOA performance of the current SPT generation, while exhibiting lower over-all losses and increased current ratings.

Introduction

The power electronics community continues to demand improvements in terms of losses, ruggedness and controllability. Recent SPT IGBT developments have produced major improvements in terms of ruggedness and softness [1]. The recent launch of the SPT$^+$ enhanced planar technology has finally combined solutions for the concurrent reduction of losses *and* the dramatic increase of SOA [2].
Results presented in this paper show that despite the low on-state and switching losses of the SPT$^+$ IGBT, the high levels of short-circuit withstand capability and turn-off ruggedness are maintained thanks to an enhanced planar technology. The loss trade-off of the new SPT$^+$ IGBT is comparable to that achieved using trench technology. In addition, applying our well-established Soft-Punch-Through (SPT) buffer structure ensures good switching controllability and soft turn-off waveforms, which is vital for very high current modules.

The HiPak Module Range

Lowering the overall losses for SPT$^+$ technology leads to higher current ratings for the HiPak modules, which sets new standards in both efficiency *and* ruggedness. The introduction of the new SPT$^+$ IGBT range will coincide with the introduction of the smaller HiPak1 in the industry standard 130 x 140 mm footprint. Along with the current single-switch and chopper configurations of the 190 x 140 mm housing (HiPak2), the HiPak1 will also offer dual IGBT and dual diode configurations in both standard isolation and high (V_{ISOL} = 10.2 kV) isolation housings. The HiPak module range is shown in Figure 1.

Figure 1: HiPak modules

SPT$^+$ IGBT Planar Technology

The next generation SPT$^+$ IGBT platform has been designed to substantially reduce the on-state voltage while maintaining low levels of switching losses. This approach combines a carefully selected trade-off for high immunity to cosmic ray failures and smooth switching behaviour while maintaining the high turn-off ruggedness (RBSOA) already achieved by the current SPT technology.
The new SPT$^+$ platform exploits an enhanced carrier profile through planar cell optimisation, which is compatible with our advanced and extremely rugged cell design as shown in Figure 2. This new technology leads to a significant increase in plasma concentration at the emitter and thus, a lower on-state voltage is obtained for the same turn-off loss. In addition, an optimised

base region combined with the Soft-Punch-Through (SPT) buffer allows the collector current to smoothly decrease during the turn-off transient due to the progressive and controlled manner in which the depletion layer is established. The SPT-buffer and an optimal anode design, further ensure good short-circuit controllability with a high Short Circuit Safe Operating Area (SCSOA).

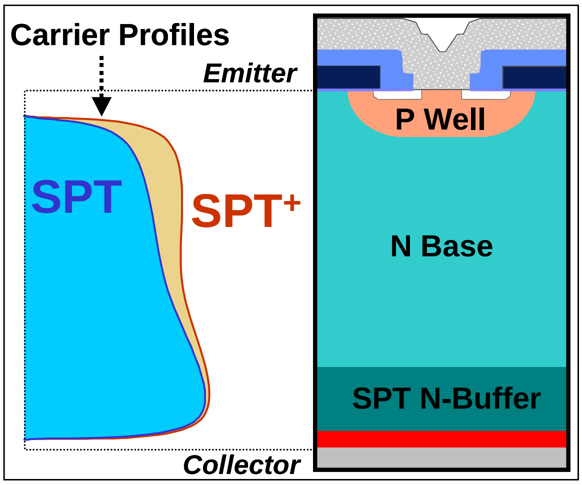

Figure 2: SPT+ planar IGBT enhanced carrier profile compared to the SPT standard profile

Due to the combination of an enhanced cell design and the SPT concept, the SPT+ IGBT technology platform has enabled ABB to establish a new benchmark in the technology curve over the whole IGBT voltage range. Figure 3 compares SPT+ with the current SPT technology for the voltage range 1200V to 4500V. The values for $V_{ce,sat}$ are obtained at the same current densities and for similar turn-off losses, for each voltage class. This demonstrates that SPT+ technology with an optimised planar structure can match the carrier profile of trench-gate cathode designs. It is important to stress that the reduction in on-state loss is achieved exclusively through enhancement of the carrier profile near the cell (emitter) while maintaining the same drift region thickness of the standard design. This is essential for ensuring controllable and "soft" switching behaviour, which in turn is necessary for very high current modules. The reduction in $V_{ce,sat}$ due to SPT+ cell enhancement ranges from 15% for a 1200V IGBT up to 30% for a 4500V device, allowing corresponding increases in current ratings.

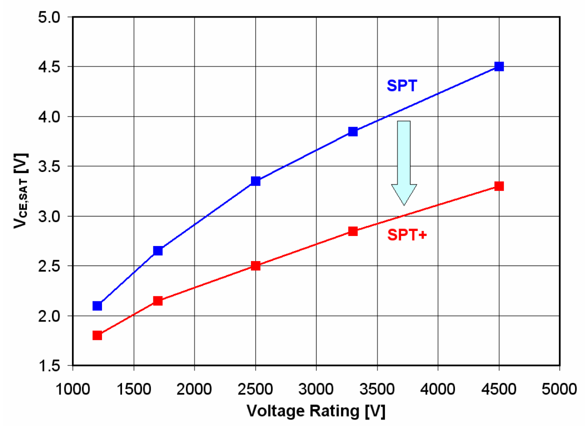

Figure 3: SPT and SPT+ IGBT on-state voltage vs. rated blocking voltage at 125°C

Considerations for High Current Modules

When designing high current modules, a number of issues must be considered with regards to the chip designs. Soft and controllable switching behaviour becomes a major target for device performance when the chips are utilised in high current modules. The combination of high currents and larger stray inductances will normally result in higher overshoot voltages and thus, increase the device tendency to snappy or oscillatory behaviour during turn-off. The device and circuit interaction can be explained with a simple approach. The stray inductance of the circuit is normally given by the converter layout. In such a system, the stored inductive energy E_L dissipated per chip (not including the voltage scaling factor) is given by:

$$E_{L\,(chip)} = \frac{L \times I^2}{2} \quad .$$

This equation is applied normally for discrete and low current components. However, for higher current modules with a number "n" of paralleled chips as shown in Figure 4, the equation for the effective inductive energy per chip is given as:

$$E_{L\,(chip)} = \frac{E_{L\,(module)}}{n} = \frac{L \times (n \times I)^2}{2 \times n} = \frac{n \times L \times I^2}{2}$$

In addition to the increase in the effective inductance "n x L" value, the stray inductance in high current applications is also somewhat larger anyway. Therefore, using typical discrete and module current ratings, dissipated energy levels per chip are shown in Figure 4. This represents one or two orders of magnitude more inductive stress per IGBT or diode chip when used in large modules, which clearly illustrates the importance of designing a chip for its housing as well as its application.

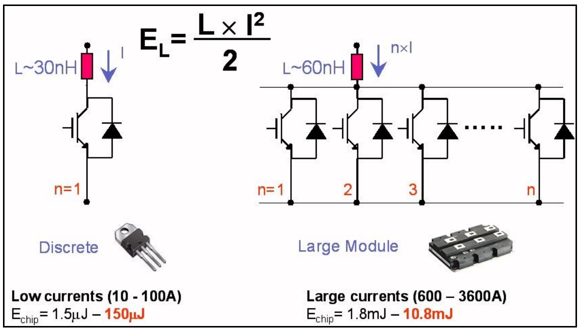

Figure 4: Effective stray inductance for discretes and modules

3600A/1700V SPT+ HiPak Module

We will now discuss the results obtained for the 3600A/1700V SPT+ HiPak module. The SPT+ technology retains all the desired SPT characteristics while simply reducing conduction losses. Thus, the new module is now rated at 3600A using same-sized chips or alternatively, the present 2400A module can be made with 30% smaller chips. The technology benchmark points are shown in Figure 5 below.

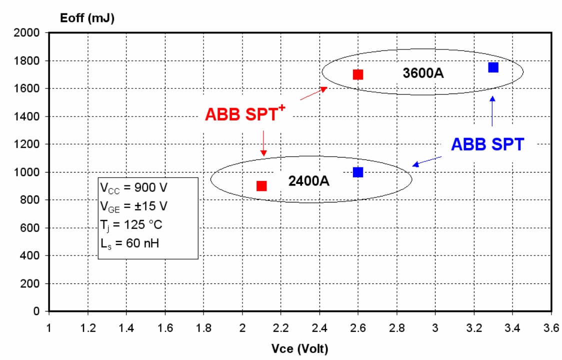

Figure 5: 1700V SPT and SPT+ IGBT HiPak on-state voltage vs. turn-off losses at 125°C

Table 1 compares the current densities and losses of the standard SPT HiPak with those of the new SPT+ module. It can be seen that for the same $V_{ce,sat}$ (at rated current), the module rating is increased from 2400A to 3600A.

Table (1) 1700V HiPak2	ABB SPT I_{CN}=2400A	ABB SPT+ I_C=2400A	ABB SPT+ I_{CN}=3600A
V_{cesat} (V)	2.6	2.1	2.6
E_{off} (J)	1.0	0.9	1.7
E_{on} (J)	0.7	0.4	0.7
E_{sw} (J)	1.7	1.3	2.4
Conditions:			
I_c (A)	2400	2400	3600
V_{cc} (V)	900	900	900
$R_{g\ on/off}$ (Ohm)	0.56/ 0.56	0.39 / 0.47	0.39 / 0.47
L_s (nH)	60	60	60
T_j (°C)	125	125	125

Table 1: Comparison of 1700V HiPak2 with SPT and SPT+ IGBTs

Static Characteristics:

The output characteristics of the module are shown in Figure 6 at 125°C. The SPT+ module has an on-state voltage drop of 2.6V and 2.8V at 3600A at chip and module level respectively. The new IGBT also exhibits the same strong positive temperature coefficient of $V_{ce,sat}$ similar to the present types as shown in Figure 7, which is essential for ensuring good current-sharing in demanding paralleling conditions.

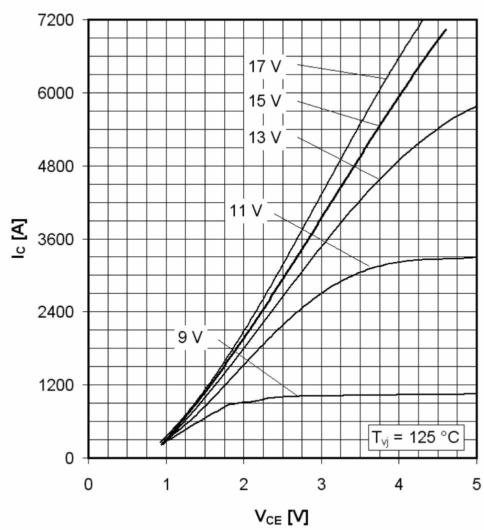

Figure 6: 3600A/1700V SPT+ IGBT HiPak module output characteristics at 125°C

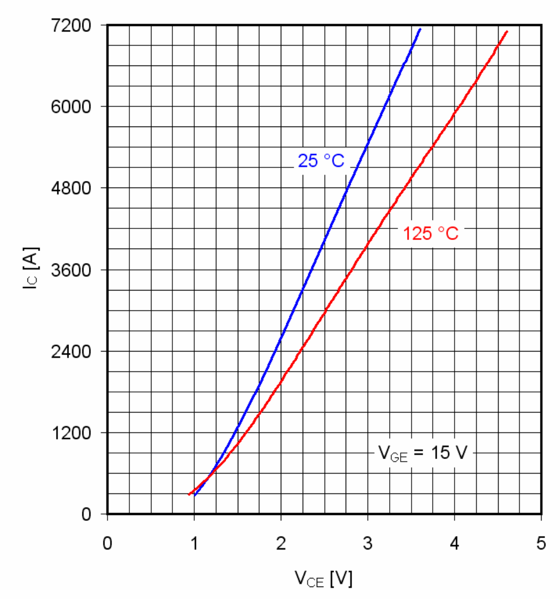

Figure 7: 3600A/1700V SPT+ IGBT HiPak module on-state characteristics

Dynamic Characteristics:

The 3600A/1700V SPT+ modules were subjected to a series of dynamic tests to demonstrate their electrical capability. In Figure 8 and Figure 9, the turn-on and turn-off waveforms respectively, under nominal conditions (900V/3600A) at 125°C can be seen. Figure 10 shows the diode reverse recovery waveforms at 125°C. The IGBT and the diode both exhibit controlled switching characteristics as well as short current tails. This behaviour is the combined result of the SPT buffer design and silicon specification used in SPT+ technology, which allows fast switching, low losses, low overshoot voltages and low EMI levels.

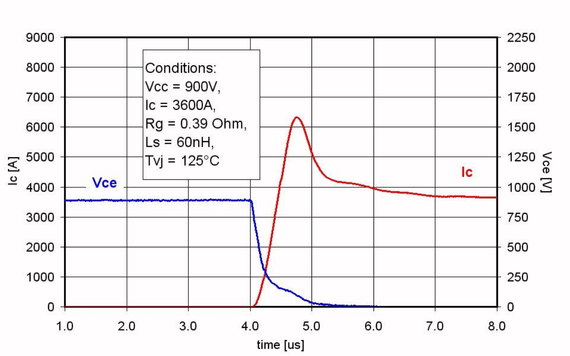

Figure 8: 3600A/1700V HiPak nominal IGBT turn-on waveforms at 125°C

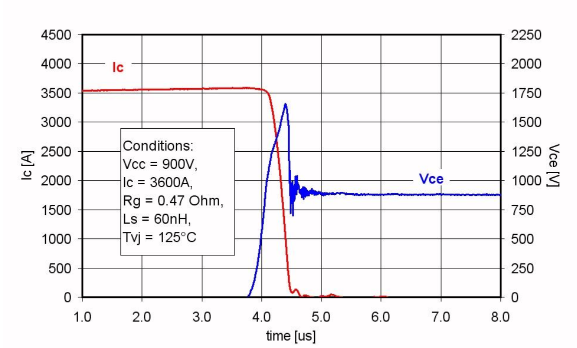

Figure 9: 3600A/1700V HiPak nominal IGBT turn-off waveforms at 125°C

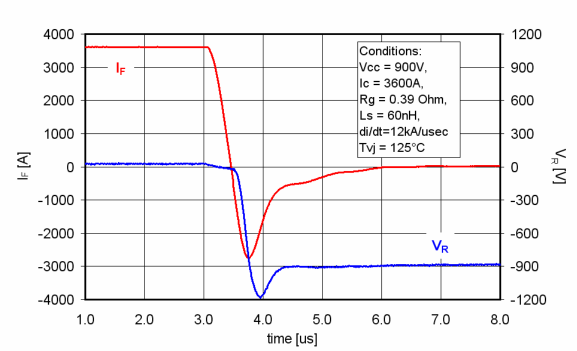

Figure 10: 3600A/1700V HiPak nominal diode reverse recovery at 125°C

SOA Performance:

The 3600A/1700V HiPak module RBSOA turn-off waveforms are shown in Figure 11 and Figure 12 for the IGBT and diode respectively. The IGBT was tested at a DC-link voltage of 1200V with a collector current value of 8000A at 125°C. A self-clamp overshoot voltage of 2000V can be observed during the turn-off period. The diode was also successfully tested at a DC-link voltage of 1200V for a forward current value of 7200A at 125°C.

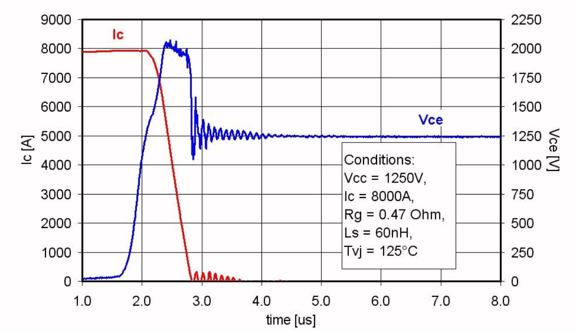

Figure 11: 3600A/1700V HiPak IGBT RBSOA at 125°C

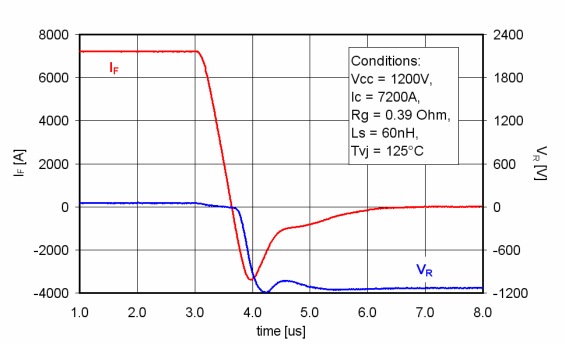

Figure 12: 3600A/1700V HiPak diode RBSOA at 125°C

The short circuit SOA test at 125°C and at a DC-link voltage of 1300V can be seen in Figure 13. The current waveform shows a reasonable average short-circuit current of approximately 12kA. The SPT buffer and anode designs employed in the SPT+ IGBT have been optimised in order to obtain a high short-circuit SOA capability, even at gate voltages exceeding the standard gate drive voltage of 15V. The high SOA obtained under such extreme conditions confirms the module's robustness.

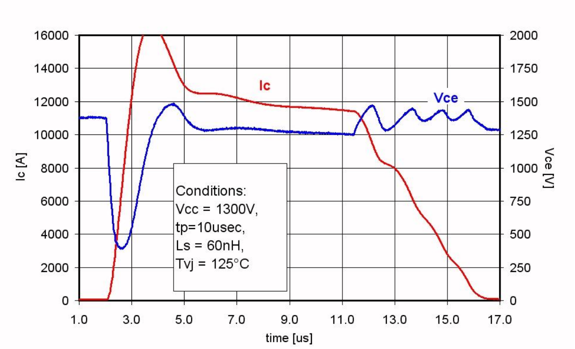

Figure 13: 3600A/1700V HiPak short circuit waveforms at 125°C

1700V SPT+ HiPak Frequency Performance

To obtain the maximum allowable output current of the new 1700V SPT+ module, simulations were carried out to provide the frequency performance chart. Figure 14 shows a simulated curve for the inverter output current against the switching frequency at 125°C for the SPT+ 1.7kV HiPak module compared to the current SPT generation. The SPT+ curve shows a clear increase in output current capability over the whole range of switching frequencies. With SPT+ IGBTs, the output current can be increased by approximately 10% to 20% within a switching frequency range of 250Hz to 1000Hz in a typical water-cooled application.

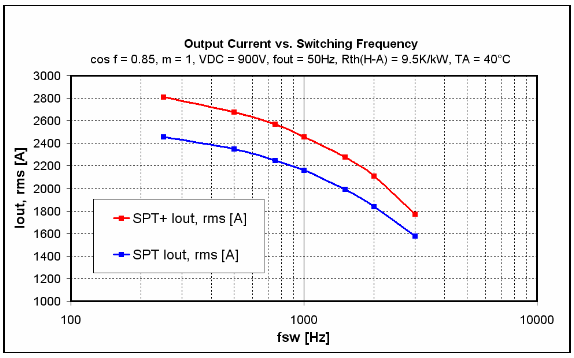

Figure 14: Inverter output current vs. frequency for 1700A HiPak modules

Conclusions

When compared to the current SPT IGBTs, the newly developed SPT+ IGBT technology offers 15%-30% lower on-state losses while still maintaining similar turn-off losses. In addition, the SPT+ achieves the same extreme ruggedness during switching and short-circuit conditions. The electrical characteristics of the 1700V HiPak module were presented confirming the superior performance of the SPT+ generation. The new range of SPT+ HiPaks will give system designers greater freedom in achieving higher power and better efficiency for their applications. HiPak products with SPT+ IGBT chips will become commercially available in 2006 in voltage classes ranging from 1200V to 4500V. In addition to the 1700V range, the 3300V module now being sampled will be the first commercially available 1500A version of this popular voltage class. It will be followed in mid-year by the 4500V class accompanied by the general release of the new HiPak1 family.

References

[1] M. Rahimo et al., "2.5kV-6.5kV Industry Standard IGBT Modules Setting a New Benchmark in SOA Capability" Proc. PCIM'04, pp 314-319, NURNBERG, GERMANY, 2004.

[2] M. Rahimo et al., "SPT+, The Next Generation of Low-Loss HV-IGBTs" Proc. PCIM'05, pp 361-366, NURNBERG, GERMANY, 2004.