Next Generation Planar IGBTs with SPT$^+$ Technology

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Following the successful introduction of the high voltage Soft-Punch-Through (SPT) IGBT range, ABB now introduces the next generation of planar IGBTs employing the newly developed SPT$^+$ technology. The new IGBTs exhibit significantly reduced on-state losses while maintaining low turn-off losses; smooth switching waveforms and a benchmark SOA performance associated with the well-established SPT IGBTs.

Until recently, it was widely believed that reductions in IGBT on-state voltage $V_{ce(sat)}$ could only be achieved using *Trench Gate* technology and that any loss reduction techniques would necessarily compromise the robustness of the planar technology. We now demonstrate that a high performance IGBT with much lower losses can be realised using an enhanced planar cell design combined with the well-established Soft-Punch-Through (SPT) concept. We have named the newly developed low-loss technology SPT$^+$. The correlation obtained by plotting the switching losses versus on-state voltage, strongly depends on the manufacturing technology. Therefore, a simultaneous reduction of both parameters can only be achieved by an improved cathode and/or silicon/buffer design. Compared to the current SPT platform, the new SPT$^+$ technology enables approximately a 15%-25% reduction in on-state losses for the same E_{off} depending on the voltage class as shown in figure (1).

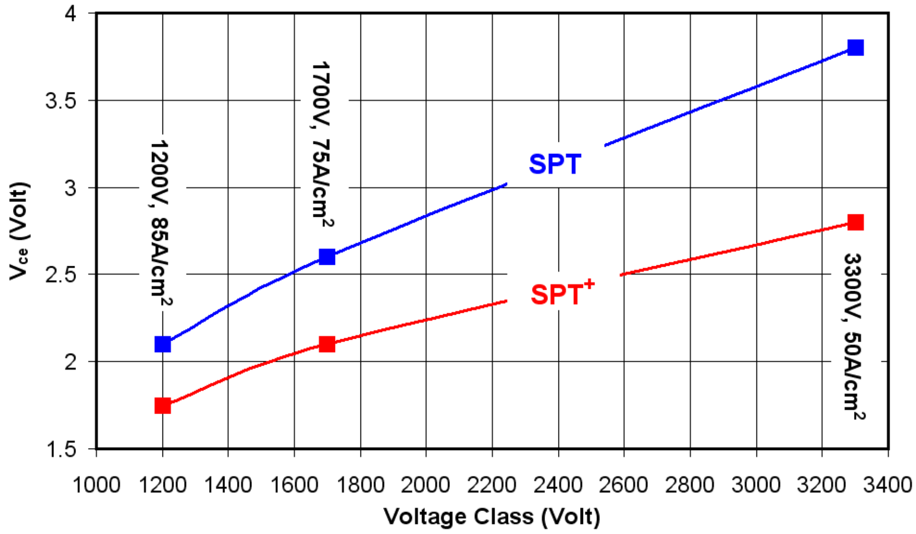

Figure 1: SPT vs. SPT$^+$ IGBT on-state losses at the indicated current densities for the 1200V, 1700V and 3300V chips at 125°C.

Furthermore, the results presented in this article show that despite the low on-state and switching losses of the SPT$^+$ IGBT, the world-class SOA performance of the current SPT generation have been maintained. The Soft-Punch-Through structure also ensures good switching controllability and soft turn-off waveforms.

SPT$^+$ IGBT Technology Platform

The next generation SPT$^+$ IGBT platform was specifically designed to substantially reduce the on-state losses while maintaining low levels of switching losses. However, this approach had to be combined with a carefully selected trade-off for providing high SOA capability, high immunity against cosmic ray induced failures and smooth switching behaviour. The new SPT$^+$ platform exploits an enhanced carrier profile technique through planar cell optimisation, which is compatible with our advanced and extremely rugged cell design as shown in figure (2). The new technology leads to a significant increase in plasma concentration at the emitter, thus, lower on-state losses are obtained without appreciably higher turn-off losses occurring. In addition, an optimised Soft-Punch-Through SPT buffer concept allows the collector current to smoothly decrease during the turn-off transient, hence, the term “Soft” in SPT. The new SPT-buffer, in combination with an optimal anode design, further ensures good short-circuit controllability with a high Short Circuit Safe Operating Area (SCSOA). Thanks to the combination of an enhanced cell design and the SPT concept, the new SPT$^+$ IGBT platform has enabled us to reach a new benchmark in the technology curve.

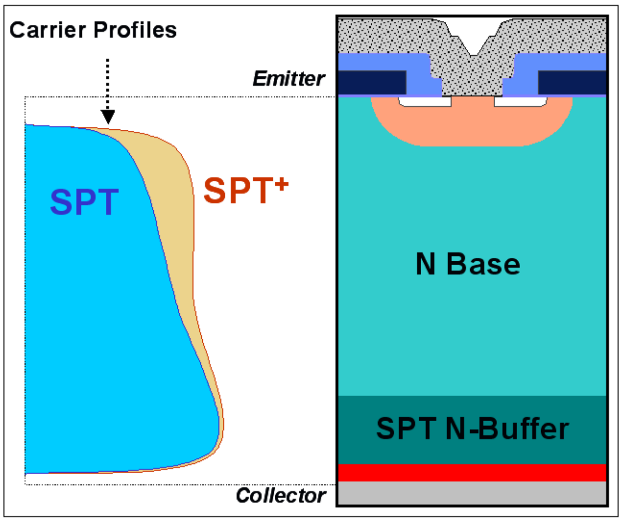

Figure 2: SPT+ planar IGBT enhanced carrier profile compared to the SPT standard profile.

SPT+ technology demonstrates the fact that an optimised planar technology is capable of matching the performance of the trench-gate cathode design for improving the carrier profile of an IGBT. It is necessary to point out that the lower losses were achieved without any substantial reductions in silicon thickness.

SPT+ IGBT Chips in the Medium Voltage Range

We will first discuss the results obtained for the next generation of 1200V and 1700V SPT+ IGBTs. The SPT+ technology retains all the desired SPT characteristics while simply reducing the conduction losses as shown in figure (1). Therefore, enabling us to increase the operating current density for both 1200V and 1700V SPT+ IGBTs, resulting in 25% in chip shrinkage (for a given current rating) or in other words, up to 30% more current (for a given chip size).
Table 1 compares the switching losses and current densities of the 1200 V/100 A SPT chip with those of the new SPT+ chip. It can be seen that for the same $V_{ce(sat)}$ and switching losses at 100A, the chip size was reduced from (12.6x12.6)mm^2 to (11x11)mm^2. Table 2 compares 1700V/100A chips and shows that *despite an increase in current density* of over 30%, the smaller SPT+ chip still allows reductions of 6 % and 4% in conduction and switching losses respectively.

Table 1: 1200V/100A	SPT	SPT+
chip length	12.6 mm	11.0 mm
chip area	159 mm^2	121 mm^2
current density (active area only)	85 A/cm^2	115 A/cm^2
on-state $V_{ce,on}$ (125°C, 100A)	2.1 V	2.1 V
E_{off}+ E_{on} =E_{sw} (125°C, 100A, 600V)	10 + 14 = 24mJ	10 + 14 = 24mJ

Table 2: 1700V/100A	SPT	SPT+
chip length	13.6 mm	11.9 mm
chip area	185 mm^2	141 mm^2
current density (active area only)	75 A/cm^2	100 A/cm^2
on-state $V_{ce,on}$ (125°C, 100A)	2.6 V	2.45 V
E_{off}+ E_{on} =E_{sw} (125°C, 100A, 900V)	28 + 26 = 54 mJ	26 + 26 = 52 mJ

The on-state characteristics of the 1200V and 1700V SPT+ IGBT are shown in figure (3) and (4) respectively. In addition to the extremely low on-state values, the curves exhibit a strong positive temperature coefficient even at low current levels. This feature is crucial for parallel operation of chips in order to avoid any current mismatch between the paralleled devices. Further optimisation of the final operating current densities and related chip sizes are still underway to provide the optimum performance in terms of maximizing the efficiency and output current of the new chip designs.
Figure (5) and figure (6) show the turn-off switching characteristics under nominal conditions at 125°C for the 1200V/100A and 1700V/100A SPT+ IGBT chips respectively.

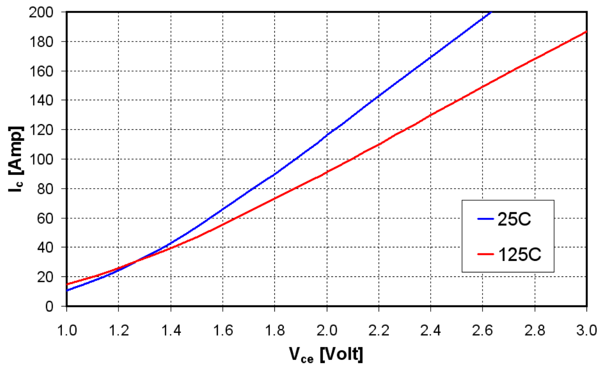

Figure 3: 1200V/100A SPT+ IGBT on-state characteristics at 25°C and 125°C.

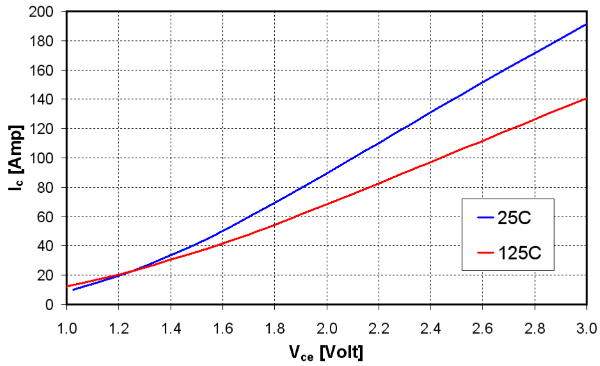

Figure 4: 1700V/100A SPT+ IGBT on-state characteristics at 25°C and 125°C.

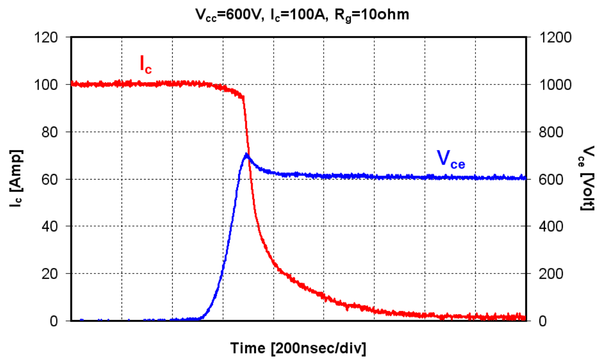

Figure 5: 1200V/100A SPT+ IGBT turn-off waveforms at 125°C.

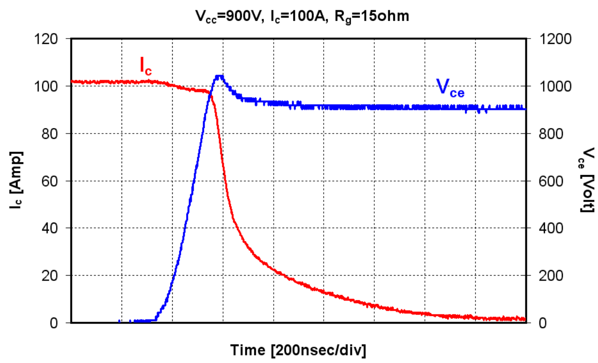

Figure 6: 1700V/100A SPT+ IGBT turn-off waveforms at 125°C.

The current switching transients of the SPT+ IGBTs maintain very smooth waveforms with a short current tail. This behaviour is due to the SPT buffer region and the optimal silicon wafer specification employed in the new designs. Therefore, a good compromise was achieved resulting in fast switching speeds with low losses, low overshoot voltage and low EMI levels.
The new SPT+ IGBTs show very high ruggedness and a wide SOA during the IGBT turn-off (RBSOA) as well as under short circuit conditions (SCSOA). In this article we present the SOA results obtained for the 1700V SPT+ IGBT. However, similar robust performance was also obtained for the 1200V chip. Figure (7) shows the

(RBSOA) switching characteristics of the 1700V/100A SPT+ IGBT chip during turn-off. The devices were capable of surviving the test at a current of 600A (6 x time nominal) and a DC rail voltage of 1400V at 150°C. A peak overshoot voltage of 1900V can be observed during the turn-off period. No active clamp was utilized in the test setup. The high short-circuit capability of the new SPT+ IGBT was also demonstrated at 25°C as shown in figure (8). The waveforms show the 1700V/100A SPT+ IGBT in short-circuit mode at a DC rail voltage of 1300V for a current pulse of 10µsec. The current waveform shows a reasonable average short-circuit current of approximately 400A for a chip with a nominal current of 100A. 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 withstanding the short circuit conditions at gate voltages exceeding the standard gate drive voltage of 15V.

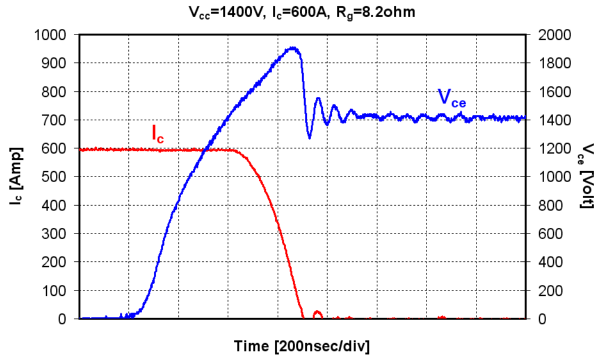

Figure 7: 1700V/100A SPT+ IGBT RBSOA waveforms at 125°C.

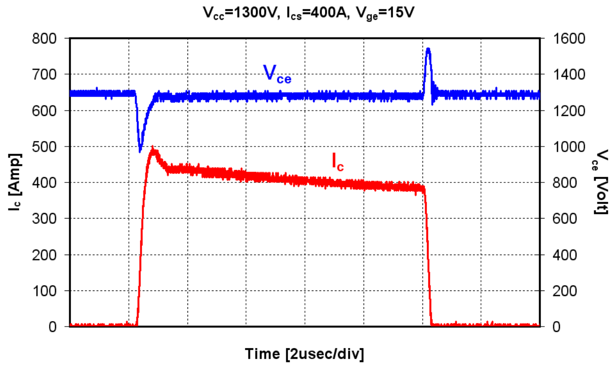

Figure 8: 1700V/100A SPT+ IGBT SCSOA waveforms at 25°C.

SPT+ IGBT Chips in the High Voltage Range

Compared to existing state-of-the art 3300V SPT IGBTs, the newly developed SPT+ IGBT offers 25% lower on-state losses while still maintaining low turn-off losses, thereby setting a new benchmark for 3300V IGBT performance. Furthermore, the HV- SPT+ IGBT also achieves the high short circuit and turn-off ruggedness as well as the *Switching Self-Clamping Mode* (SSCM) capability as for the current HV-SPT IGBT range [1]. The typical on-state voltage at a rated current density of 50A/cm^2 was 2.2V at 25°C and 2.7V at 125°C, while maintaining low turn-off losses of approximately 90mJ/cm^2. In order to confirm the extremely high turn-off current capability and SSCM for a single 3300V/50A SPT+ IGBT chip, an RBSOA test was carried out as shown in figure (9). The device was capable of turning-off more than 7 x nominal current at 360A with a DC link voltage of 2700V at 125°C.

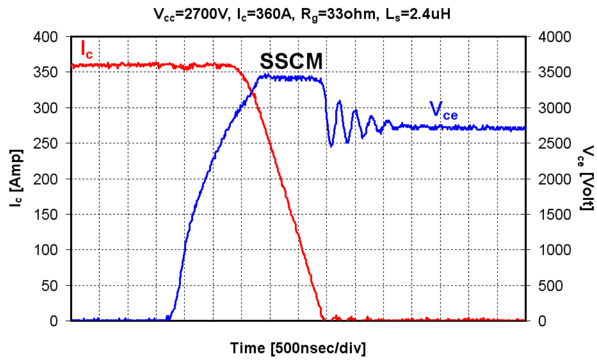

Figure 9: 3.3kV/50A SPT+ IGBT chip RBSOA waveforms at 125°C with "SSCM".

Successful operation in SSCM was obtained with a self-clamp voltage of 3450V. The duration at which the device remained in SSCM was approximately 1.5µsec. By enabling the IGBT module to withstand SSCM, the device will exhibit a square SOA capability up to the self-clamp voltage level. The high dynamic ruggedness, combined with smooth switching behaviour gives users the greatest freedom in designing their systems without the need for any dv/dt or peak-voltage limiters such as snubbers or clamps. Another major advantage of an extremely rugged IGBT is that it offers the possibility of operating the device with significantly lower gate-resistance values than those required by conventional technologies. This results in shorter delay times during device turn-off, which not only lowers the turn-off losses but also improves the current sharing between individual IGBT chips in the module. To demonstrate the superior performance of the new chip, detailed electrical characteristics of the 3300V/1200A SPT+ HiPak module were recently published [2].

The low losses and high levels of ruggedness will enable us to benefit from the higher efficiency obtained from the semiconductor component. Figure (10) shows a calculated curve for the inverter output current against the switching frequency at 125°C for the new low-loss SPT+ 3.3kV IGBT HiPak module compared to the current generation HV-SPT. The SPT+ curve shows a clear increase in output current capability over the whole range of switching frequencies. Without any changes to the inverter design except the use of SPT+, the output current can be increased by 10%-20% within a switching frequency range from 250Hz up to 1000Hz in a typical forced-air cooled application.

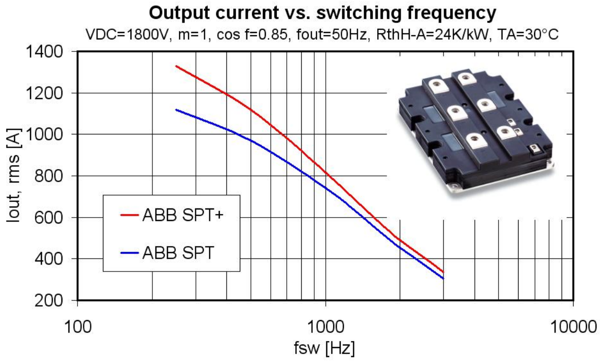

Figure 10: Inverter output current vs. Frequency for 3300V/1200A modules.

Conclusions

Compared to existing state-of-the-art SPT IGBTs, the newly developed SPT+ IGBT from ABB offers significantly lower on-state losses while still maintaining low turn-off losses, thereby setting a new benchmark for IGBT performance. SPT+ IGBTs also achieve extreme ruggedness during switching and under short-circuit conditions and offers the same low EMI levels as for the current SPT platform.

The new chips will undergo minor optimisations, which may result in further improvements by the time of their release. Products with SPT+ technology including chips and packages such as our standard HiPak range will be commercially available in 2006 in several voltage classes and ultimately be implemented across the full voltage range of the current SPT products namely from 1200 V to 6500V.

References

1) M. Rahimo et al., “2.5kV-6.5kV Industry Standard IGBT Modules Setting a New Benchmark in SOA Capability” Proc. PCIM’04, NURNBERG, GERMANY, 2004.
2) M. Rahimo et al., “SPT+, the Next Generation of Low-Loss HV-IGBTs” Proc. PCIM’05, NURNBERG, GERMANY, 2005.