New 4500V SPT+ HiPak Modules

The next generation 4.5kV HV-HiPak IGBT modules employ the newly developed SPT+ IGBT and diode technologies. The new devices have significantly lower conduction and switching losses, while exhibiting higher SOA capability when compared to the previous generation modules. **A. Kopta, M. Rahimo, U. Schlapbach, ABB Switzerland Ltd, Semiconductors**

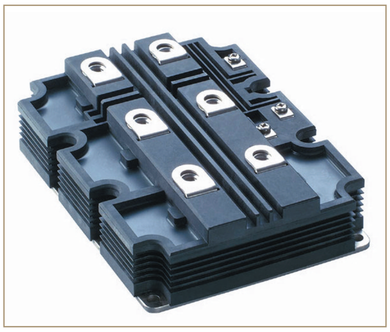


Figure 1: The 4.5kV HV-HiPak module comprising the newly developed SPT+ chip-set

Development trends in power electronic systems continue to demand power devices with continuously improving characteristics in terms of reduced losses, increased ruggedness and improved controllability. Following the introduction of the new generation of 1700 and 3300V SPT+ IGBT HiPak range, ABB now introduces the next generation 4.5kV HV-HiPak IGBT modules employing SPT+ IGBTs and diodes.

The SPT+ IGBT platform has been designed to substantially reduce the total semiconductor losses, while increasing the turn-off ruggedness above that of the current SPT technology. The SPT+ platform exploits an enhanced carrier profile through planar cell optimisation, which is compatible with ABB's rugged cell design.

The new cell technology significantly increases the plasma concentration at the emitter, which reduces the on-state voltage drop without affecting the turn-off losses. Due to the combination of the enhanced cell design and the soft-punch-through (SPT) buffer concept, the SPT+ IGBT technology enables ABB to establish a new technology-curve benchmark for the 4500V voltage class. The on-state losses of the new 4.5kV IGBT exhibit an approximately 30% reduction, as compared to the standard SPT device, while keeping the same Eoff value. The new 4.5kV HV-HiPak modules will provide high voltage system designers with enhanced current ratings and simplified cooling, while further enhancing IGBT and diode robustness.

4.5kV HV-HiPak module design

The 4.5kV HV-HiPak module (Figure 1) is an industry-standard housing with the popular 190 x 140mm footprint. It uses Aluminium Silicon Carbide (AlSiC) base-plate material for excellent thermal cycling capability as required in traction applications and Aluminium Nitride (AlN) isolation for low thermal resistance. The HV-HiPak version utilized for the 4.5kV voltage class is designed with an isolation capability of 10.2kVRMS.

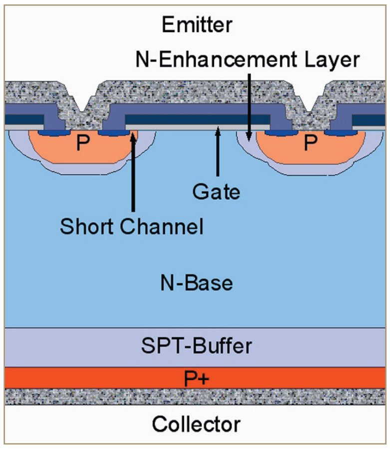
To achieve the high reliability required by its targeted applications (e.g. traction), the HV-HiPak module has been optimised for operation in harsh environments. This has been accomplished by designing the 4.5kV SPT+ chips to have smooth switching characteristics and rugged performance, qualities that are essential in the high-inductance environments of high voltage power electronic systems. The internal wiring and layout of the module were optimised to minimise oscillations and current imbalances between the chips. Finally, the whole design was qualified by standard reliability tests including HTRB (High Temperature Reverse Bias), HTGB (High Temperature Gate Bias), THB (Temperature Humidity Bias 85°C/85% relative humidity), APC (Active Power Cycling) and TC (Temperature Cycling).

4.5kV SPT+ chip-set technology

The SPT+ IGBT platform was developed with the goal of substantially reducing on-state losses while maintaining low switching losses, smooth switching behaviour and high turn-off ruggedness of the standard SPT (Soft-Punch-Through) IGBTs. This was achieved by combining an improved planar cell design with the already well-optimised vertical designed utilised in SPT technology (Figure 2).

The planar SPT+ technology employs an N-enhancement layer surrounding the P-well in the IGBT cell. The N-layer improves the carrier concentration on the cathode side of the IGBT, thus lowering the on-state voltage drop ($V_{CE,on}$) without significantly increasing the turn-off losses. A further reduction of $V_{CE,on}$ was achieved by reducing the channel resistance by shortening the length of the MOS-channel. By optimising the shape of the N-enhancement layer, the turn-off ruggedness (RBSOA) of the SPT+ cell could be increased even beyond the level of the standard SPT cell. In this way, SPT+ technology not only offers significantly lower losses, but also an increased SOA capability.

Figure 2: SPT+ IGBT technology



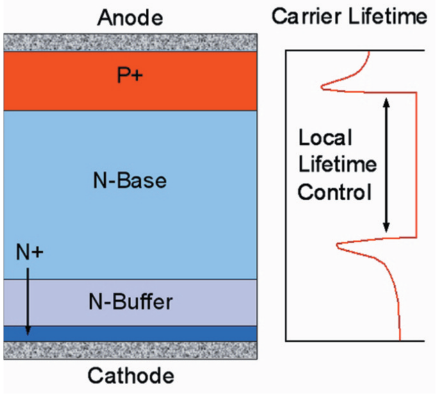
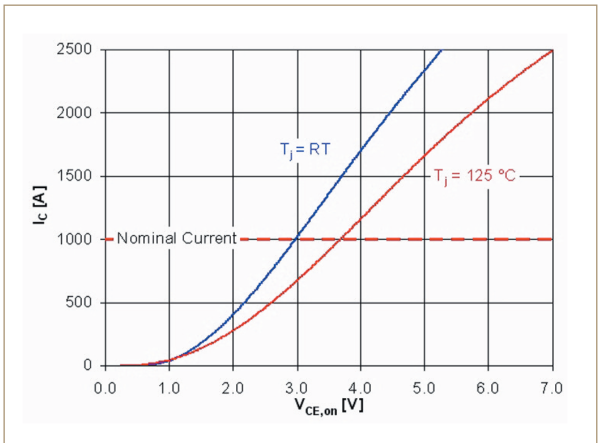
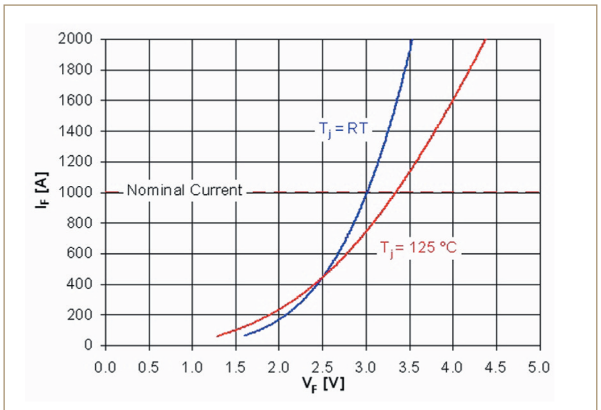


Figure 3: SPT+ diode technology





Figures 4a and 4b: **Forward characteristics of a) 4.5kV SPT+ IGBT (upper) and b) 4.5kV SPT+ diode**

Figure 3 shows a cross-section of the SPT+ diode. The new technology utilises a double local lifetime-control technique to optimise the shape of the stored electron-hole plasma. Due to the improved plasma distribution, the overall losses could be reduced, while maintaining the soft recovery characteristics of the standard SPT diode technology.

On the anode side, the SPT+ diode employs the same design as used in the standard SPT technology, utilising a high-doped P+-emitter. The anode emitter efficiency is adjusted using a first He++ peak placed inside the P+-diffusion. In order to control the plasma concentration in the
N-base region and on the cathode side of the diode, a second He++ peak, implanted deeply into the N-base from the cathode side is used. In this way, a double local lifetime profile as shown in Figure 3 is achieved. With this approach, no additional homogenous lifetime control in the N-base is necessary. Due to the improved shape of the stored electron-hole plasma, a better trade-off between total diode losses and recovery softness was achieved.

4.5kV/1000A HV-HiPak electrical performance

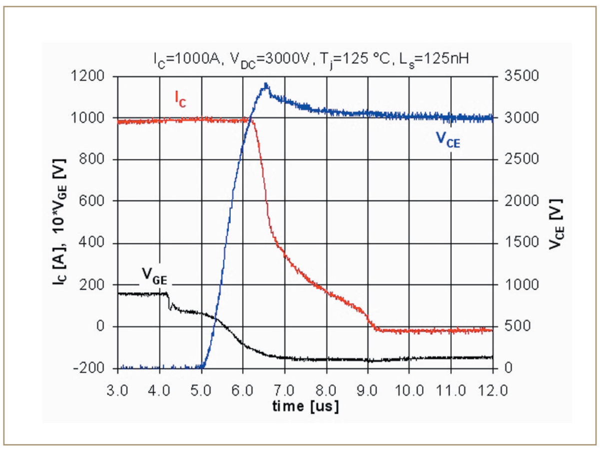
To verify the performance of the 4.5kV SPT+ chips and the HiPak module, extensive measurements were carried out. The nominal rated current of the 4.5kV HiPak module is 1000A, which corresponds to a current density of 50A/cm³ for the IGBT and 100A/cm³ for the diode. For dynamic measurements, the nominal DC-link voltage was 3000V, while SOA and softness measurements were carried out at 3600V.

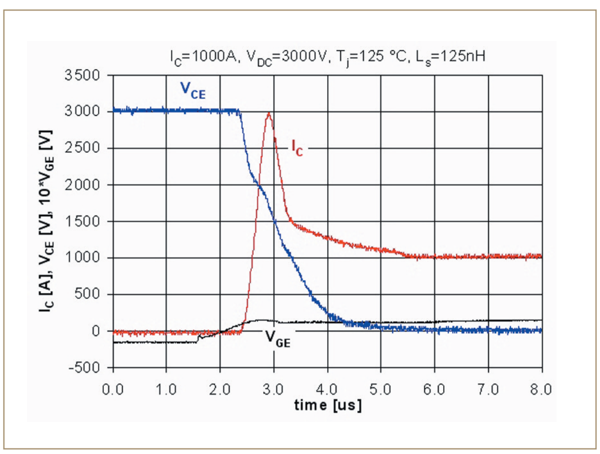
Static characteristics

In Figure 4a, the on-state curves of the 4.5kV SPT+ IGBT can be seen. The typical on-state voltage drop ($V_{CE,on}$) at nominal current and Tj=125°C is 3.65V. The SPT+ IGBT shows a positive temperature coefficient of $V_{CE,on}$, starting already at low currents, which enables a good current sharing capability between the individual chips in the module. In Figure 4b, the on-state characteristics of the 4.5kV SPT+ diode are shown. Due to advanced plasma shaping utilising a double He++ irradiation, the diode has a strong positive temperature coefficient of V_F already well below the diode's typical on-state voltage drop of 3.4V.

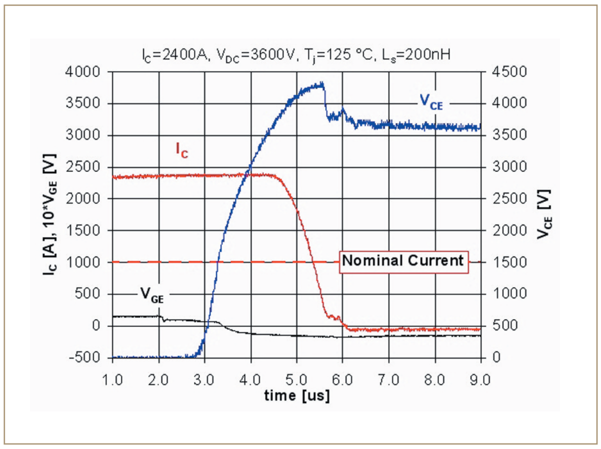
Switching characteristics

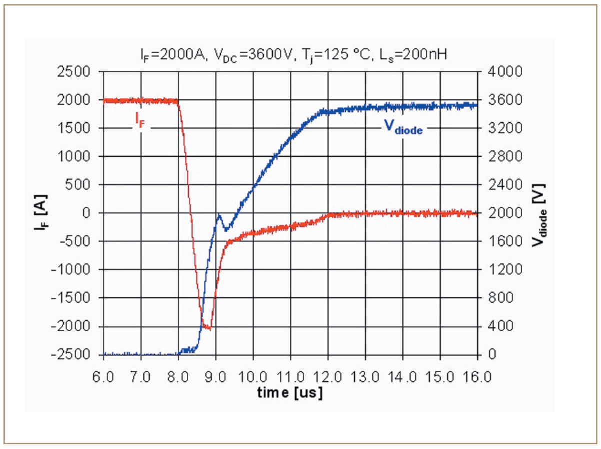
The switching characteristics are shown in Figure 5. Figure 5a shows the turn-off waveforms of the 4.5kV HiPak module measured under nominal conditions at 1000A and 3000V. Under these conditions, the fully integrated turn-off losses are 4.6J. The extremely rugged SPT+ cell enables the IGBT to be switched using a small gate-resistor,





Figures 5a and 5b: **Turn-on switching characteristics of a) 4.5kV SPT+ IGBT turn-off under nominal conditions measured on module level with E_{off} = 4.6J (upper) and b) turn-on under nominal conditions (E_{on} = 3.6J)**





Figures 6a and 6b: Turn-off switching characteristics of a) 4.5kV SPT$^+$ IGBT turn-off under SOA conditions measured on module level (upper) and b) 4.5kV SPT$^+$ diode reverse recovery under SOA conditions

resulting in a fast voltage rise, which reduces the turn-off losses. In the test shown, the module was switched off using an $R_{g.off}$ of 2.7Ω, which results in a voltage rise of 3100V/µs. The optimised N-base region combined with the Soft-Punch-Through (SPT) buffer allows the collector current to decay smoothly, ensuring soft turn-off behaviour without any disturbing voltage peaks or oscillations even at high DC-link voltages and stray inductances.

Figure 5b shows the turn-on waveforms under nominal conditions. The low input capacitance of the planar SPT$^+$ cell allows a fast drop of the IGBT voltage during the turn-on transient. Thanks to high ruggedness and soft recovery behaviour, the diode can be switched with a high di_F/dt, which significantly reduces the IGBT turn-on losses. This, combined with the low-loss SPT$^+$ diode brings the turn-on switching losses down to a typical value of 3.6J, while the diode recovery losses are 2.4J.

Turn-off and reverse recovery ruggedness

One of the advantages of the new 4.5kV SPT$^+$ IGBT is its extremely high turn-off ruggedness, setting a new benchmark for this voltage class. Figure 6a shows a turn-off waveform at module level, where a current of 2400A was switched against a DC-link voltage of 3600V. The test was conducted with a gate resistance of 2.7W, without using any clamps or snubbers. This harsh test has been implemented as the standard SOA test made during the final outgoing production-level module testing. This is to ensure high quality and reliability of all shipped 4.5kV HiPak modules. Figure 6b shows the corresponding production level test of the diode reverse recovery SOA.

Short-Circuit SOA

The short circuit waveforms of the 4.5kV HV-HiPak module can be seen in Figure 7. The IGBT was designed to withstand a short circuit at VGE=15.0V for all DC-link voltages up to 3600V and junction temperatures between –40 and 125°C.

The results presented demonstrate that by using the lower losses and higher SOA of the new 4.5kV HV-HiPak modules in future inverters, a 10 to 20% increase in total output current is predicted from simulations as shown in Figure 8. The new 4.5kV SPT$^+$ technology will ultimately allow 1200A rated modules to be realised. The new modules will provide high voltage system designers with enhanced current ratings, simplified cooling and higher SOA margins.

The developmental product described in this article is intended for release in 2008. A full description of this product including surge current capability will also be presented at the PCIM Conference 2007.

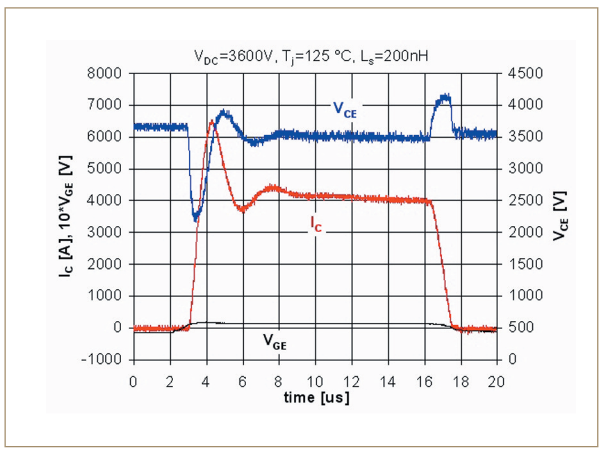


Figure 7: 4.5kV SPT$^+$ IGBT short-circuit characteristics

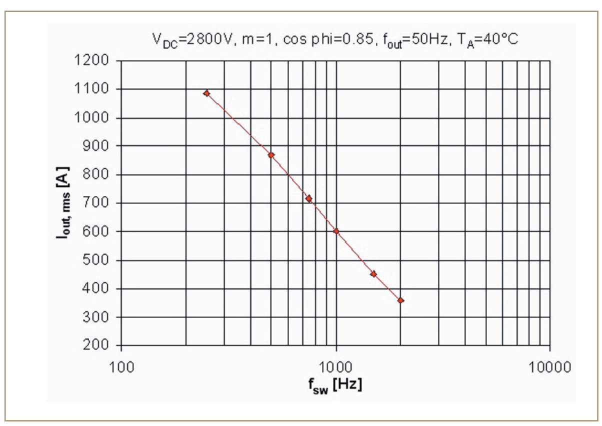


Figure 8: 4.5kV HV-HiPak module output current as a function of the switching frequency