Novel Soft-Punch-Through (SPT) 1700V IGBT Sets Benchmark on Technology Curve

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Abstract: *Following fast on the successful market introduction of the 1200V Soft-Punch-Through (SPT) IGBT range, ABB Semiconductors introduces the 1700V SPT IGBT line-up. In this paper, we demonstrate that the new 1700V SPT IGBT achieves the same desirable characteristics as the successful 1200V SPT generation. The results presented here show that despite the low on-state and switching losses of 1700V SPT IGBT, high levels of short circuit withstand capability and switching ruggedness have been realized. In addition, the unique Soft-Punch-Through structure achieves low levels of EMI. In parallel to the 1700V SPT IGBT, a new fast and soft recovery 1700V diode has been developed with very low reverse recovery losses and high ruggedness under all operating conditions. Both the 1700V IGBT and diode exhibit positive temperature coefficients for the forward voltage drop at nominal currents, making them ideally suited for safe parallel operation in high current modules. The new chip set will be introduced in the standard LoPak module range.*

1. Introduction

The introduction of the Soft-Punch-Through IGBT technology from ABB Semiconductors has set new standards in the IGBT medium power market [1]. The combination of this die technology with the new LoPak industry standard packaging [2], has given users the potential to develop more compact, higher power systems than ever before, on a packaging platform suitable for industrial and traction applications. Particular attention has been paid to reliability, applying ABB Semiconductors detailed knowledge of the subject, gained from long experience in high reliability applications [3].

In this paper we report on the new 1700V-SPT IGBT. Major improvements in terms of static and dynamic losses have been achieved when compared to current 1700V devices available in the market. The correlation obtained by plotting turn-off losses versus on-state voltage (i.e. technology curve), strongly depends on the manufacturing technology. Therefore, a simultaneous decrease of both parameters can only be achieved by an improved technology.

Until recently, the trench concept [4] was considered the only possibility to obtain a significantly improved performance with respect to currently available devices. We now demonstrate for the first time in the 1700V range, that a high performance IGBT with ultra low losses can be achieved using a standard planar technology combined with ABB Semiconductors' Soft-Punch-Through (SPT) concept as shown in figure (1). These values are comparable to those achieved using trench technology for the same current rated devices. However, the planar structure was chosen in order to keep cost per unit area low. In this way, the thermal resistance can be kept at a low level and the die cost reasonably low, while maintaining the high levels of ruggedness associated with the planar technology.

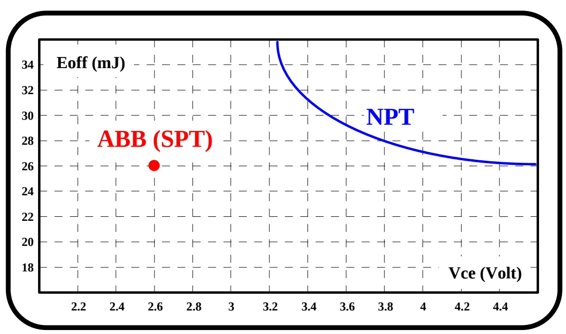


Figure 1: New 1700V SPT IGBT technology benchmark (Turn-off losses vs. on-state losses) for a 100A Chip with respect to an NPT equivalent structure. (V_{CC}=900V, I_c=100A, R_G=15Ω, @125^oC)

This paper will examine the key characteristics of the new 1700V SPT IGBT in detail as well as the application of the IGBT and anti-parallel diode in the new LoPak standard module range.

2. Soft-Punch-Through IGBT Concept

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 the boundary of this buffer region with the high resistivity n-base layer. Therefore, despite the much 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). The Soft-Punch-Through feature is especially applied with respect to the softness of the current and voltage curves during switching transients. Hence, the term “Soft” in SPT originates from this fact. In addition, the buffer acts as a field stopper for voltages higher than the DC-link voltage up to the nominal blocking voltage as shown in figure (2).

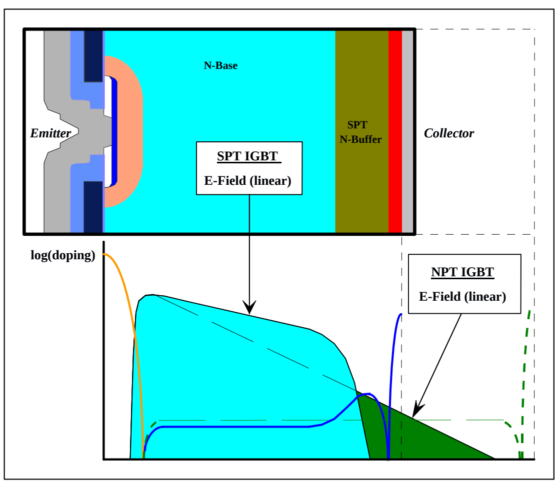


Figure 2: SPT IGBT doping profile and electric field distribution with respect to an NPT IGBT structure.

As mentioned above, the major benefits of the SPT IGBT are resulting from a substantially (30%) thinner wafer thickness compared to a NPT IGBT of the same nominal blocking voltage. As a consequence, both on-state voltage and turn-off losses are reduced simultaneously establishing a new benchmark technology curve for 1700V IGBT devices. However, the main advantages of the NPT structure are also maintained with regard to extreme ruggedness, low temperature dependence during IGBT turn-off transient and finally, a positive temperature coefficient for $V_{ce(sat)}$ during on-state.

3. SPT IGBT Electrical Performance

The static and dynamic characteristics of the 1700V SPT IGBT have been verified confirming the electrical performance advantages achieved by employing the Soft-Punch-through concept for the 1700V IGBT range.

a) Static Performance:

Due to the large reduction in the base region thickness and optimized cell design, the new 1700V SPT IGBT achieves 20% less on-state losses compared to existing NPT structures. For the first time, we report on a 1700V (SPT) IGBT chip with a typical on-state voltage of 2.3V at (25°C) and 2.55V at (125°C) at a current density above 70A/cm^2. Even above 80A/cm^2 the on-state voltage has competitive values of 2.45V at (25°C) and of 2.75V at (125°C) as shown in figure (3).

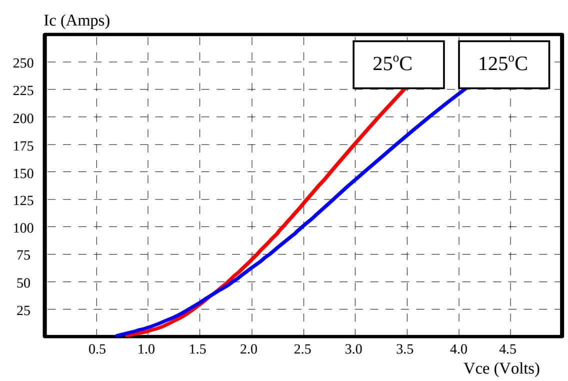


Figure 3: 1700V SPT IGBT output characteristics. (on-state voltage $V_{ce(sat)}$ against collector current I_c) at 25°C and 125°C.

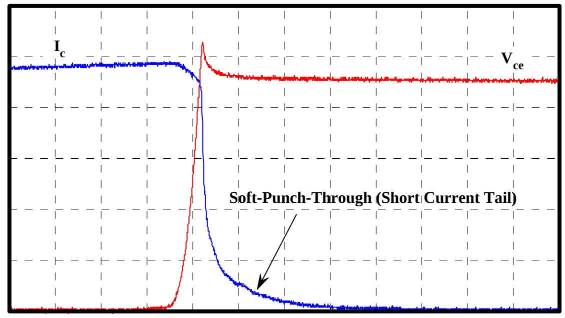
In addition to the extremely low on-state losses, the curves exhibit a strong positive temperature coefficient even at low current levels. This feature is crucial when utilizing the die for parallel operation especially in high current modules. It is important to have this type of behavior at low current levels as well as at nominal current to prevent any current mismatch during device operation. Also, the absence of any lifetime killing ensures a small spread of characteristics to add to the excellent sharing of current exhibited by the SPT IGBT die.

By implementing a reliable and effective junction termination technique with SIPOS passivation, the 1700V SPT IGBT has an extremely stable breakdown voltage at room temperature. Lower leakage currents, especially at higher temperatures, were also achieved due to the thinner base region and high lifetime values.

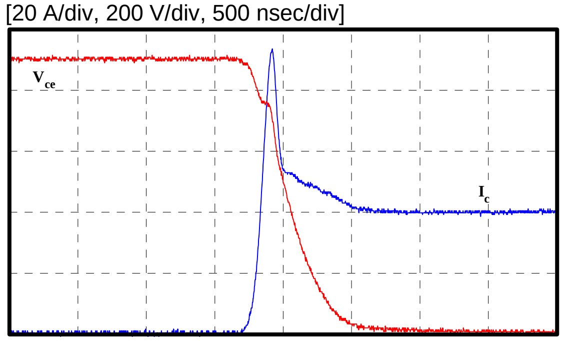
b) Switching Performance:

Figure (4) shows the switching characteristics of the 1700V SPT IGBT chip during (a) turn-off and (b) turn-on. The tests were carried out at a nominal current of 100A and a DC bus voltage of 900V. As can be seen in Figure (4.a), the current switching transients of the 1700V SPT are very smooth with a short tail. This behaviour is due to the buffer layer in front of the anode and the thin wafer specification. Since less plasma needs to be extracted, the tail phase of the current during turn-off is short and 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. Therefore, a perfect balance is achieved resulting in fast switching speeds with low losses, short tail current, low overshoot voltage and low EMI levels.

Figure (4.b) shows the switching waveforms during turn-on. The IGBT and diode were designed for low turn-on switching losses due to an optimised design for the new 1700V diode, which will be discussed later in this paper. In addition, faster fall times for the IGBT voltage reduce the IGBT losses during turn-on.



(a) Turn-off current and voltage waveforms
[20 A/div, 200 V/div, 500 nsec/div]



(b) Turn-on current and voltage waveforms
[50 A/div, 200 V/div, 500 nsec/div]

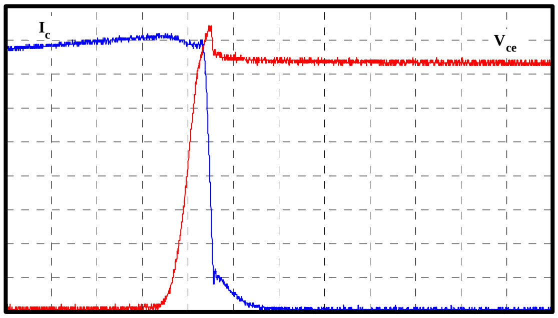
Figure 4: 1700V SPT IGBT switching characteristics. (V_{cc}=900V, I_c=100A, V_{ge}=15V, R_G=15Ω, @125°C)

c) SOA Performance:

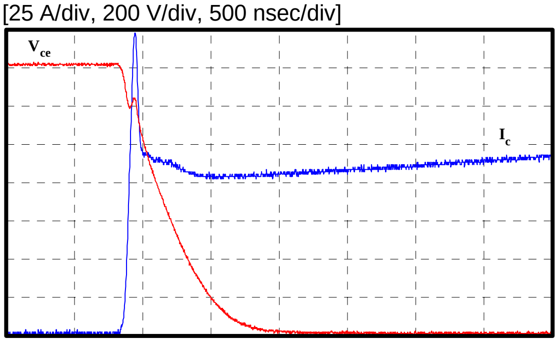
The new SPT IGBT show very good rugged performance and a wide SOA during the IGBT turn-off (RBSOA) and under short circuit conditions (SCSOA).

Figure (5) shows the (RBSOA) switching characteristics of the 1700V SPT IGBT chip during (a) turn-off and (b) turn-on. The devices were tested at a current of 200A and DC rail voltage of 1450V at (150°C). A peak overshoot voltage of 1700V can be observed during the turn-off period. Rugged performance is also demonstrated during turn-on for both the IGBT and diode. Turn-on waveforms show a di/dt current ramp of 3000 A/µsec and a diode reverse recovery peak current of 400A.

The waveforms in figure (6), show the 1700V SPT IGBT in short circuit mode at a DC rail voltage of 1300V at (125°C). The current waveform shows a reasonable maximum short circuit current of approximately 500A for a chip with a nominal current of 100A.



(a) Turn-off current and voltage waveforms
[25 A/div, 200 V/div, 500 nsec/div]



(b) Turn-on current and voltage waveforms
[50 A/div, 200 V/div, 1 µsec/div]

Figure 5: 1700V SPT IGBT RBSOA switching characteristics.
(V_{cc}=1450V, I_c=200A, V_{ge}=15V, R_G=15Ω, @125^{o}C)

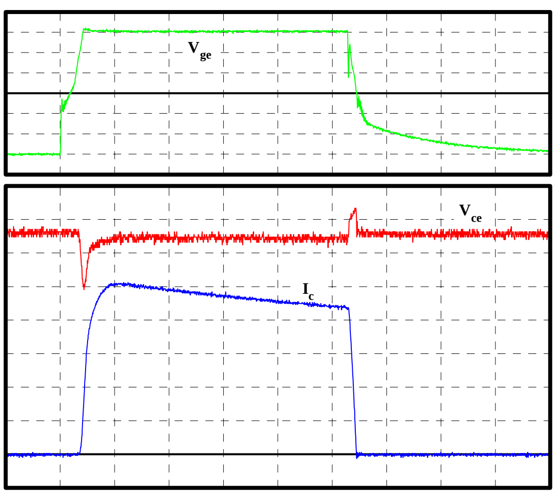


Figure 6: 1700V SPT IGBT short circuit behaviour.
(V_{cc}=1300V, I_{sc}=500A, V_{ge}=15V, @125^{o}C)
[100 A/div, 200 V/div, 2 µsec/div, (V_{ge})5 V/div]

4. Fast-Soft Recovery 1700V Diode

A new family of 1700V planar fast and soft recovery diodes were developed to add to the advantages of the 1700V SPT IGBT. The new diodes were designed using a combination of modern design techniques and lifetime killing methods to achieve very low switching losses along with very soft recovery characteristics and low levels of Electromagnetic Interference (EMI). The diode reverse recovery waveforms are shown in figure (7).

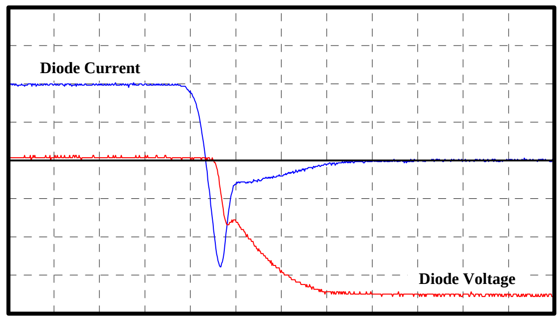


Figure 7: 1700V Diode reverse recovery characteristics at nominal current and voltage.
(V_R=900V, I_F=100A, *di/dt*=1500A/µs, @125^{o}C)
[50 A/div, 250 V/div, 250 nsec/div]

The 1700V diodes dynamic behaviour ensures high ruggedness and reliable performance under all operating conditions. The new diodes also maintain low on-state voltages of 1.85V at (25°C) and 2.0V at (125°C). Due to optimum lifetime control method employed in the design of the diode, a positive temperature coefficient during on-state is achieved making the diode a perfect match for the SPT IGBT for providing good parallel sharing for the current inside the module.

5. 1700 SPT IGBT in LoPak Modules

In order to fully exploit the performance benefits of the new 1700V SPT IGBT and diode chips, the devices will be implemented in a new range of 1700V LoPak4 and LoPak5 modules rated above 150A.

The LoPak module range shown in figure (8), 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 and efficient systems to be built. In addition, 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 in for 690V AC line to be manufactured using only two part numbers [2]. The LoPak line-up is available from ABB Semiconductors as well as from Semikron (under the brand name SKiM).

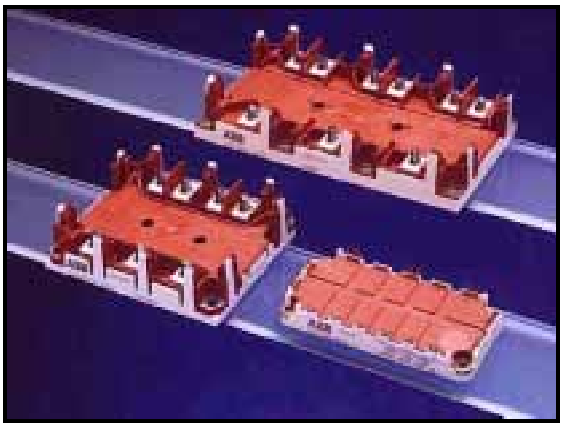


Figure 8: The LoPak range of 1200V - 1700V Industry Standard Modules.

6. Conclusion

Compared to existing state of the art 1700V NPT IGBTs, the new 1700V SPT IGBT from ABB Semiconductors offers 20% less on-state losses and 25% lower turn-off losses setting a new benchmark for 1700V IGBT performance. In addition, The SPT devices exhibit extreme ruggedness during turn-off and short circuit conditions and offer low EMI levels due to the soft punch-through buffer structure.

Also, a new 1700V fast and soft diode has been presented to complement the performance advantages offered by the SPT IGBT die. Both the IGBT and diode exhibit a positive temperature coefficient for the on-state voltage making them suitable for parallel connection in ABB Semiconductors LoPak4 and LoPak5 module range.

References

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