650V IGBT4: The optimized device for large current modules with 10 µs short-circuit withstand time

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Abstract

This paper presents the new Infineon 650V IGBT4. Designed especially for medium and large current applications I_{nom}>300A, in comparison with the 600V IGBT3 the device offers a better softness during switch-off, and a higher blocking voltage capability. The measures used to realize these features were to increase the chip thickness, to reduce the MOS channel width, and to enhance the back-side emitter efficiency. As a consequence, also the short-circuit robustness is significantly improved.

1. Motivation

With the 600V IGBT3, including trench and field-stop technology, Infineon introduced an IGBT device in 2003 [1], which still offers benchmarking characteristics. However, the 600V IGBT3 has been optimized for smaller power applications, or higher power in very low stray inductance applications. The stray inductance in combination with the current gradient has an influence on the voltage characteristic during turn on and turn off, as V=L·dI/dt. Thus the over voltage increases when switching off with larger L_σ. In order to provide additional degrees of freedom in larger current applications in various setups, now a new chip, the 650V IGBT4, has been designed.

2. Design and Technology of the 650V IGBT4

As the 600V IGBT3, also the new 650V IGBT4 utilizes a trench MOS-top-cell, thin wafer technology, and a field-stop concept (see Fig.1). But compared to the 600V IGBT3, the chip thickness was increased by about 15%, and the width of the MOS channel was decreased by about 20% (as indicated in red in Fig. 1) Thereby, the softness during switch-off is improved to reduce the EMI effort, and a higher blocking voltage capability is achieved. The combination of trench cell and field-stop enables comparatively low on-state losses and turn-off losses. However, of course these measures also cause additional losses. So in order to compensate for these side effects, the efficiency of the backside emitter was increased by 50%. As a result, the new IGBT4 device features an improved softness during switch-off, i.e. a lower overshoot voltage and a reduced turn-off current slope dI/dt. In addition, the blocking voltage is increased to 650V. On the other hand, the forward voltage drop remains low, and the switching losses show only a moderate increase.

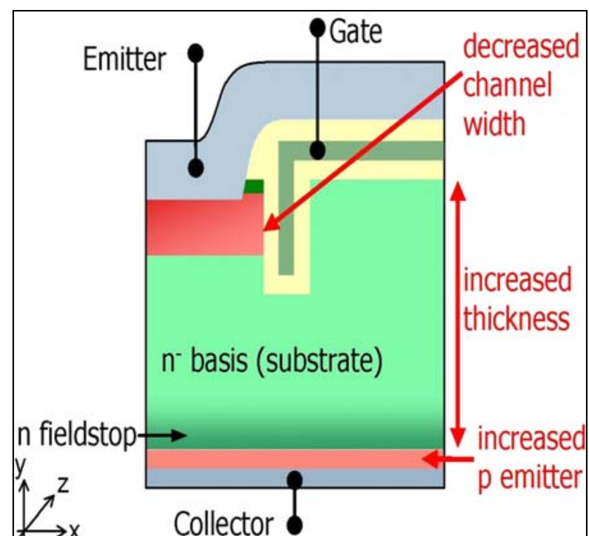

Fig. 1. Schematic cross section of the new 650V IGBT4, and the changes implemented compared to the 600V IGBT3: increased chip thickness (y), decreased channel width (z), and increased back-side p-emitter.

3. Features of the 650V IGBT4

3.1. Static and dynamic characterization

The saturation voltage $V_{CE,sat}$ is slightly increased for the new 650V IGBT4 (~100mV), as well as the E_{off} is increased compared to the 600V IGBT3, as the result of the softer switching behavior. The improved softness becomes obvious from Figs. 2 and 3.

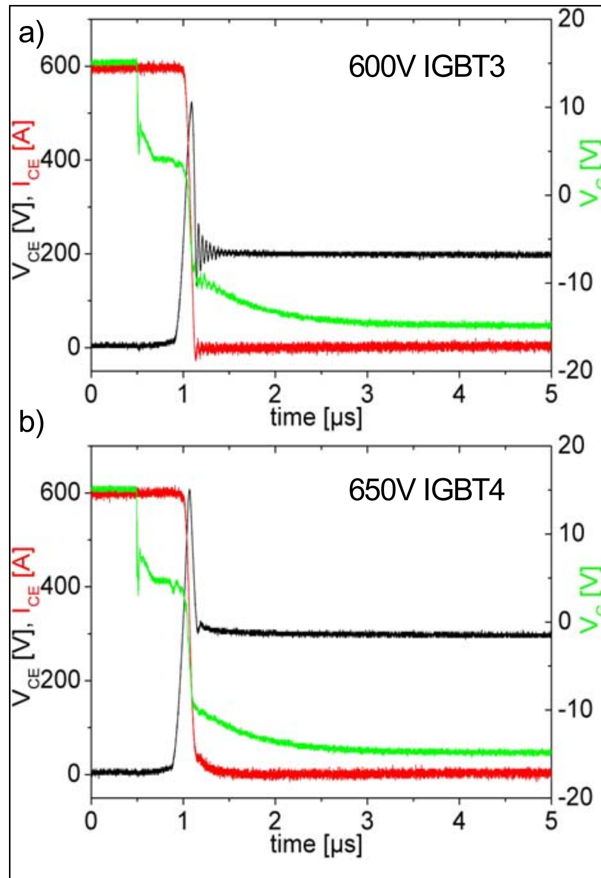

Fig. 2. Comparison of the softness during switch-off of a 600V IGBT3 (a) and the new 650V IGBT4 (b), measured in an EconoDUAL3 module. Shown are the voltage V_{CE} (black curves), the collector current I_C (red curves), and the gate-emitter voltage V_{GE} (green curves) during switching off a current of 600A at 25°C. For the IGBT3, oscillations occur already at a DC link voltage of 200V, while the new 650V IGBT4 shows soft switching even at 300V DC link voltage.

In Fig. 2 the switch-off process in EconoDUAL™3 modules is compared. This specific high current setup is not ideally suited for the 600V IGBT3 [4]. Consequently, the switch-off of 600A and a DC link voltage of 200V at 25°C effects a quite high overshoot voltage $V_{CE,max}$ and a snap-off with oscillations. In contrast, the new 650V IGBT4, especially designed for such high current applications and the corresponding module types, shows a smooth switch-off with a much lower $V_{CE,max}$, even at a DC link voltage of 300V.

This difference in the switching behavior also becomes obvious from Fig. 3, where the softness parameters $V_{CE,max}$ and current slope dI/dt are compared. Measurements were employed on DBC level at a temperature of 25 °C for the 600V IGBT3, and for several development variants of the new 650V IGBT4, including the final target design. Comparing the 600V IGBT3 to the final variant of the new 650V IGBT4, it turns out that the maximum overshoot voltage $V_{CE,max}$ is reduced by about 40V. The turn-off current slope dI/dt of the 650V IGBT4 could even be decreased by 20% as compared to the 600V IGBT3.

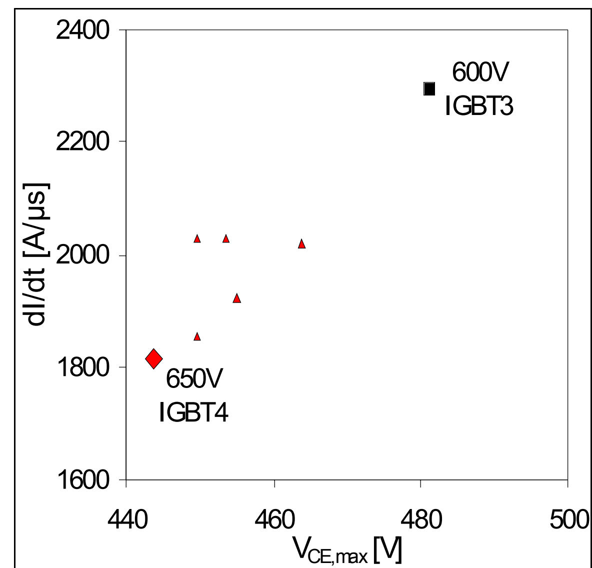

Fig. 3. Comparison of the turn-off softness parameters, current slope dI/dt versus the maximum overshoot voltage $V_{CE,max}$, for the 600V IGBT3 and the new 650V IGBT4 (red rhombus), including different developed variants (small red triangles). All data is measured at 25°C on DBC level under identical conditions. For the final variant of the 650V IGBT 4, $V_{CE,max}$ is reduced by about 40V, and dI/dt even by 20% as compared to the 600V IGBT3.

On the other hand, this softer switching behaviour has to be paid with higher losses during switch-off. But taking into account common switching frequencies, this increase plays no major role. This fact is visualized in Fig. 4: there a simulation with IPOSIM is shown. This tool, the Infineon Power Simulation program, can be found on the Infineon homepage (www.infineon.com). It performs a calculation of switching and conduction losses for all components, taking into account conduction and switching losses as well as thermal ratings. As can be seen in Fig. 4, the reduction of the RMS module current due to increased losses of the 650V IGBT4 is only moderate, between 3 and 7% up to 12kHz, a typical range of switching frequencies for common applications.

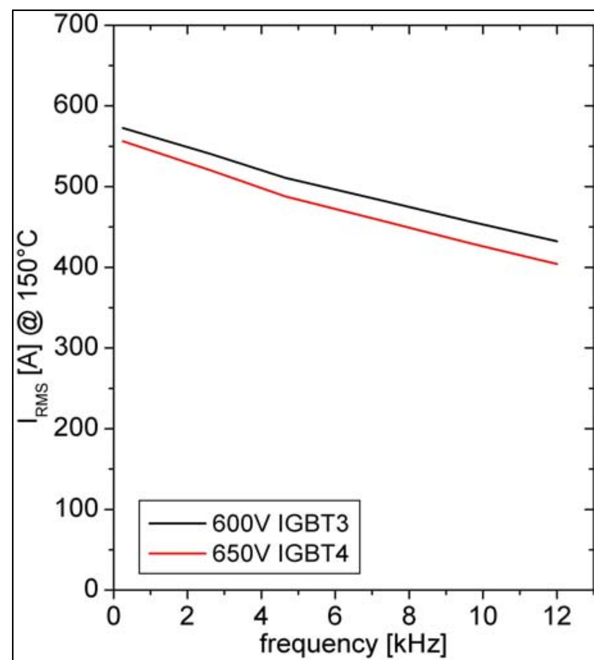

Fig. 4. Calculation of the RMS current as function of the switching frequency of the 600V IGBT3 (black line) and the new 650V IGBT4 (red line), calculated in 600A EconoDUAL™ modules. Calculations were perfomed with IPOSIM (tool can be found at www.infineon.com; simulation conditions: R_{th}(heatsink)=0.09K/W, T(ambient)=40°C, $T_{vj,op}$=150°C, cos(φ)=0.85).

3.2. Short circuit robustness

Despite the considerably reduced silicon thickness of field-stop devices as compared to non-punch-through designs, field-stop IGBTs are

known to feature a good short-circuit robustness [2,3]. With the new 650V IGBT4, the short-circuit robustness is significantly enhanced compared to the 600V IGBT3. The increased thickness of the chip offers a larger thermal budget due to the heat capacity of the silicon volume. In addition, the decreased channel width reduces the level of the short-circuit current (this effect is shown vice versa in [4]). In sum, the 650V IGBT4 can resist a higher short-circuit energy, and therefore the device is able to withstand a longer short-circuit pulse time without getting destroyed.

In Fig. 5, a short-circuit pulse measurement of the 650V IGBT4 is displayed. As the graph shows, the pulse time short-circuit event was 15 µs, and the short-circuit current typically is about 4.5 times the nominal current of the 200A device. This short-circuit event finally led to a destruction of the device at a later stage (not shown) due to thermal runaway, how well the switch-off of the short-circuit event itself was successful. While the thermal destruction limit is reached for a typical device at 15 µs under these conditios pulse lengths up to 14.5 µs typically are survived without failure. Taking into account the requirements of process capabilities this leads to an increase of the specified maximum short-circuit pulse withstand time at $T_{vj}=T_{vj,op}$ from 6µs (IGBT3) up to now 10µs for the new 650V IGBT4.

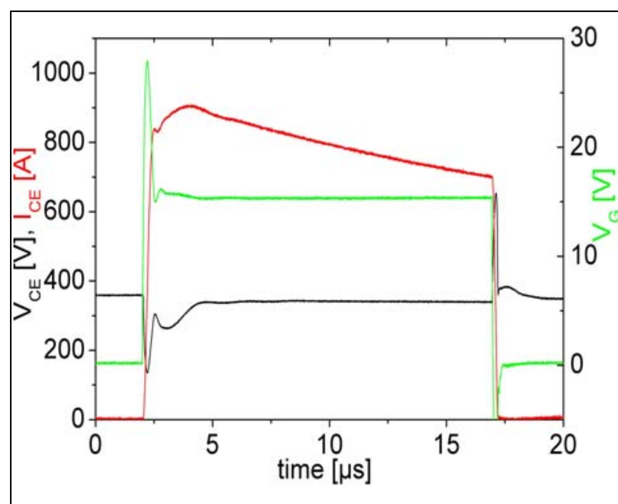

Fig. 5. Measurement of a short-circuit pulse event of the 650V IGBT4. Shown are the collector-emitter voltage V_{CE} (black curve) and collector current I_C (red curve), and the gate-emitter voltage V_{GE} (green curve, right axis). Test conditions were V_{CE} =360V, V_{GE} =±15V, T_{vj} =150°C.

4. Conclusion

With the new 650V IGBT4, an IGBT device especially designed for large current applications, to be employed in the corresponding modules, such as 62mm, EconoDUAL™3 and EconoPACK™4, is offered. The device features an improved switch-off softness, i.e. significantly reduced values of overshoot voltage $V_{CE,max}$ and current slope dI/dt. To turn off an EconoPACK™4 at higher DC Link voltage and/or connected to higher inductances is possible. In addition, the 650V IGBT4 offers an enhanced short-circuit robustness of 10µs pulse time. Next to better switching behavior with still moderate losses, this allows a better management of short-circuit events: using the withstand time of 10µs, a current detection of the short-circuit case, e.g. by means of an open-loop Hall sensor, becomes possible.

Additionally the optimization of the assembly technology within Infineon IGBT modules shows a noteworthy power cycling (PC) improvement. This ensures at least excellent PC lifetime expectation at junction operation temperature of $T_{vj,op}$=150°C or enhanced PC lifetime at a lower junction temperature which can be chosen by the user. The 650V IGBT4 provides design engineers effective degrees of freedom in their applications.

The new generation of semiconductors will be utilized in well known and also in future IGBT module packages. With all these improvements the new IGBT4 module generation will be an excellent choice for the requirements of the different applications.

5. Literature

[1] H. Rüthing et al.: "600V-IGBT3: Trench Field Stop Technology in 70µm Ultra Thin Wafer Technology", Proc. 15 th ISPSD, 66 (2003).

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[3] T. Laska et. al.: “Short Circuit Properties of Trench-/Field-Stop-IGBTs – Design Aspects for a Superior Robustness”, Proc. 15th ISPSD, 152 (2003).

[4] P. Kanschat, H. Rüthing, F. Umbach, F. Hille: “600V-IGBT3: A detailed Analysis of Outstanding Static and Dynamic Properties”, Proc. PCIM Europe, 436 (2004).