Next generation 1700V IGBT and emitter controlled diode with .XT technology

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Abstract

Increasing chip performance with respect to static and dynamic losses is an essential prerequisite to accommodate the continuous demand for higher power densities of inverters. Here, we present the superior performance characteristics of the new 1700V IGBT and diode generations of Infineon Technologies. At ≈30% higher current for the same module footprint, these 5th generation devices reach the same on-state voltages and switching losses per Ampere as the existing 1700V IGBT and diode generation. In the new 1700V power module generation, we implement the .XT technology [1], which provides the established module lifetime at the increased power density and higher junction temperature ($T_{vj,op}$ = 175°C) or, alternatively, can be employed to enable a strong enhancement of the lifetime.

1. The new 1700V IGBT and diode generation

1.1. Expanding the power range

An improved silicon performance is the basis to enable higher power densities in modules, which can be used to the advantage of inverter systems in a variety of applications. These are, for instance, wind turbines, where the power capacity per system has been continuously increasing throughout the last years. The steps to higher and higher power densities have been accompanied by an increasing junction temperature ($T_{vj,op}$). The 5th generation 1700V IGBT and emitter controlled diode are designed for continuous operation at $T_{vj,op}$ = 175 °C. In spite of the higher thermal stress, the power modules equipped with these devices provide the established lifetime of the previous generation at strongly enhanced power density, as they benefit from the implementation of the previously published .XT technology [1]. Alternatively, the .XT benefit can also be employed to realize a strong lifetime enhancement when the power density is kept unchanged. In the following, we discuss the performance characteristics of the new 1700V IGBT and diode including their static and dynamic losses as well as their switching behavior with respect to EMI friendly operation. In addition, we point out the short circuit ruggedness of the IGBT. Finally, we address to which extent the power range of the PrimePACK™ module in a typical inverter application can be increased utilizing the newly available silicon performance.

1.2. 1700V 5th generation IGBT

The 1700V IGBT5 is based on the successful trench-field-stop technology concept. As schematically shown in Fig. 1, the thickness of the IGBT has been reduced and the cell density has been increased compared to the previous 1700V IGBT in order to reduce the static and dynamic losses of the device. In Fig. 2, the output characteristics of the two technology generations is compared for room temperature and maximum $T_{vj,op}$. As known for the IGBT4, the collector emitter saturation voltage (V_{CEsat}) shows a positive temperature coefficient also for the 5th generation IGBT. It can be seen that the improved vertical device concept results in significantly reduced on-state voltages for the same current on the same module footprint, which allows for a strongly increased current density. Besides the on-state losses, of course, also the switching losses have to be taken into account in the discussion of the new IGBT generation.

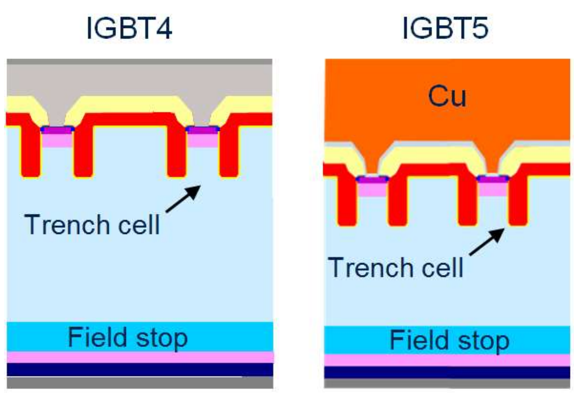

Fig. 1: Schematic drawing of a cross section through a 1700V IGBT4 in comparison with an IGBT5. The IGBT5 has a reduced device thickness, a higher density of trench cells and a thick copper front side metallization, while the IGBT4 has an aluminum front side.

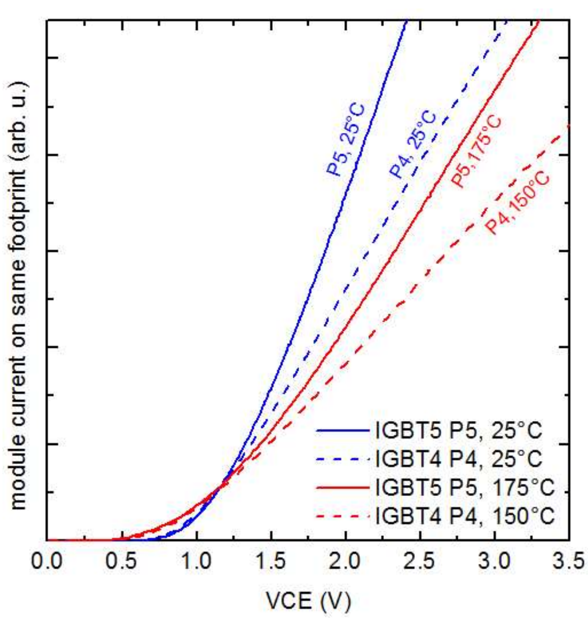

Fig. 2: Output characteristics of the 1700V IGBT5 compared with the 1700V IGBT4 (variant for high power applications P4), recorded at 25°C (blue curves) and their respective $T_{j,op,max}$ (red curves). Solid and dashed curves represent the IGBT5 and IGBT4, respectively. The output characteristics were measured for a positive gate voltage of V_{GE} = 15 V.

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IGBT	IGBT4 P4 @150°C	IGBT5 P5 @150°C	IGBT5 P5 @175°C
Current / PP3 footprint (%)	100%	130%	130%
Tj,op,max (°C)	150	175	175
VCEsat (V)	2.2	2.2	2.3
Esw/A (%)	100%	88%	95%

Tab. 1: Comparison of the electrical losses of the high power 1700V IGBT5 (P5) with its predecessor technology (P4) on the same module footprint (PrimePACK™ 3).

To this end, we compare the stationary and switching losses of the IGBT5 high power variant with the corresponding 1700V IGBT4 for a scenario, where the current on the same module footprint (PrimePACK™ 3) is increased by 30%. As can be seen in Tab.1, even at 25 K increased junction temperature, the IGBT5 shows total switching losses per Ampere (E_{sw}/A) which are at least as low as for the previous 1700V IGBT generation. Compared at the same junction temperature of 150 °C, the IGBT5 P5, shows the same V_{CEsat} and more than 10% reduced total switching losses per ampere compared to the P4 in spite of the 30% higher

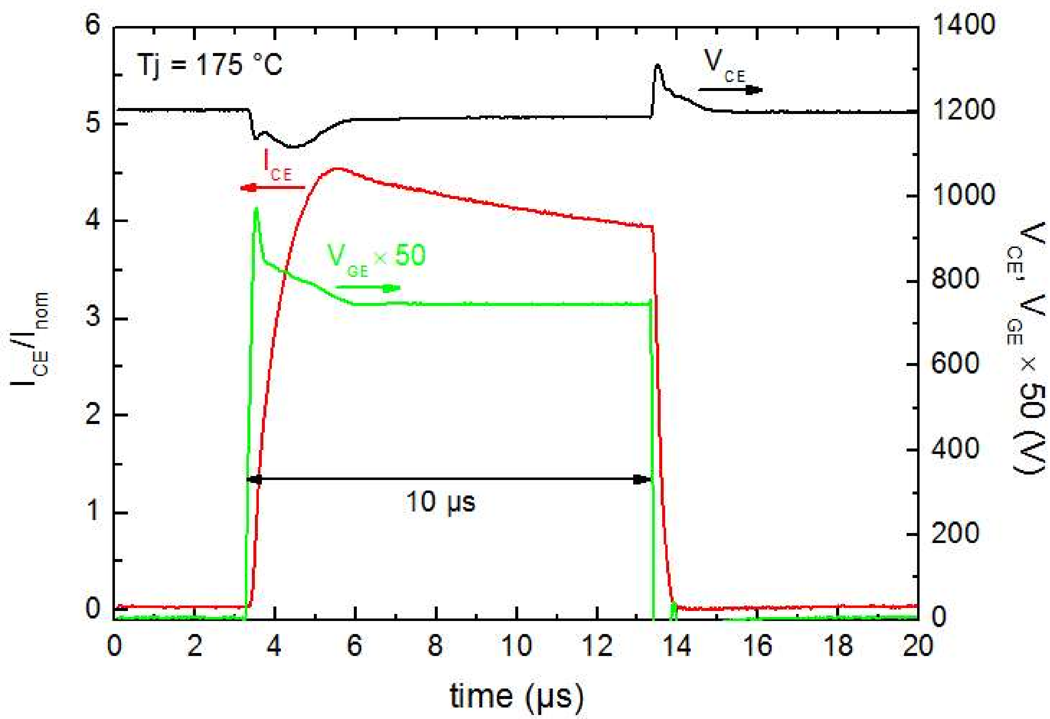

Fig. 3: Waveforms of a short circuit pulse measured on a single 1700V IGBT5 mounted on a direct copper bonded substrate using .XT technology. The collector emitter current (I_{CE}) and the collector emitter voltage (V_{CE}) are shown as red and black solid curves, respectively. The gate voltage (+15 V on-state) is shown as green solid curve. The DC-link voltage was 1200 V, the initial junction temperature was 175 °C, and the short circuit pulse length was 10 µs.

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nominal current.

This degree of performance increase could not be realized without substantially increasing the level of the short circuit current. In order to handle the higher level of power dissipation during a short circuit event in a way that the well-established short circuit withstand time of 10 µs can be maintained, the thermal capacity of the device is increased by means of a thick copper metallization on the front side of the IGBT (cf. Fig. 1). This concept to increase the short circuit withstand time has been introduced previously in detail [2,3]. Exemplarily, Fig. 3

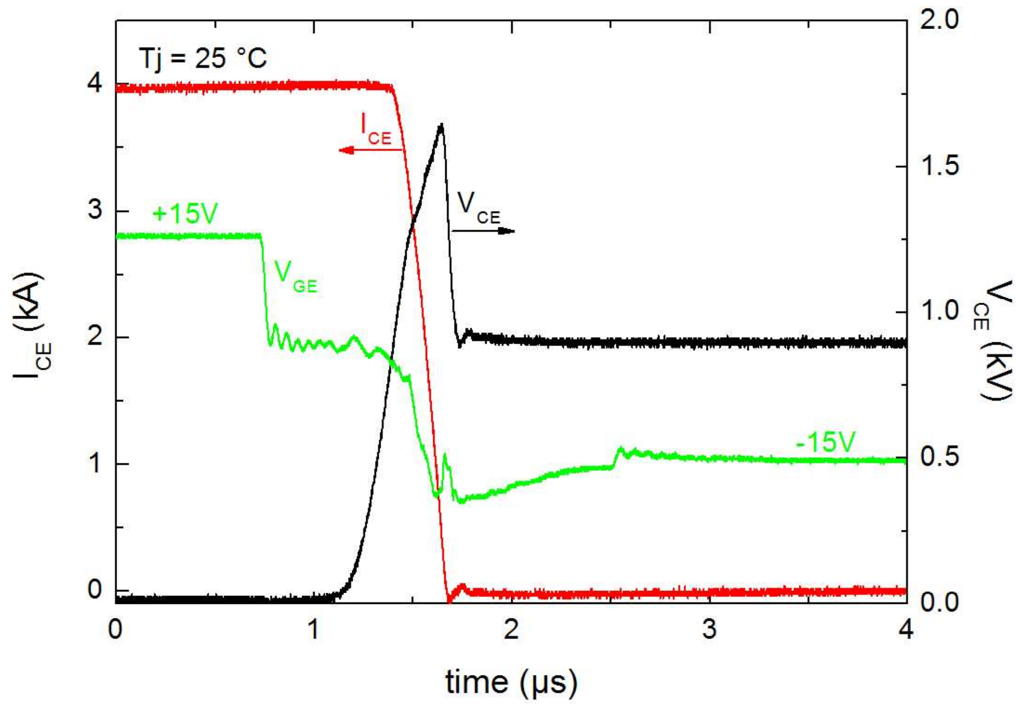

Fig. 4: Turn-off curve of a PrimePACK™ prototype module equipped with the new IGBT5 at 4000 A, more than twice the nominal current (1800 A), T_j = 25 °C and an external gate resistor of 0.52 Ω. Red curves represent the collector emitter current, green and black curves represent the gate-emitter and collector-emitter voltage, respectively.

shows the waveforms of a short circuit pulse that has been measured on a single IGBT5 chip mounted on a direct copper bonded substrate using .XT technology. The initial junction temperature was 175 °C and the pulse was recorded for a DC-link voltage of 1200 V, and at a gate voltage of 15 V with a pulse length of 10 µs.

One further important requirement, which has to be considered during the optimization of the new IGBT technology, is a sufficiently soft switching behavior, providing an EMI friendly operation. In Fig. 4, a turn-off curve measured for a PrimePACK™ prototype module is shown, which was recorded at more than twice the nominal current and at room temperature. As can be seen, we could already demonstrate that the 1700V IGBT5 is designed to provide a soft switching behavior in power modules with nominal currents up to 1800 A.

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1.3. 1700V 5th generation emitter controlled diode

The maximum gain for a new power module generation can only be reached, when also the 1700 V power diode is improved and matched to the IGBT5. The optimization path for power diodes is a reduction of the silicon thickness. As schematically shown in Fig. 5, the 1700 V emitter controlled 5th generation diode, the silicon thickness has been further reduced compared to the predecessor technology. This is the basis for the strongly reduced stationary and dynamic losses, which are summarized in Tab. 2. Similar to the IGBT, we achieve the same forward voltage (V_f) and reverse recovery losses (E_{rec}) per Ampere as the previous diode generation, however, at 30 % higher current on the same PrimePACK™ 3 module footprint and at 25 K increased junction temperature.

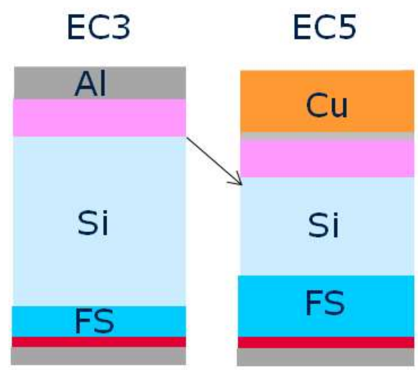

Fig. 5: Schematic drawing of a cross section through a 1700V 5th generation emitter controlled diode in comparison with the previous generation device. The EC5 diode has a reduced device thickness, an optimized field stop and a thick copper front side metallization.

Despite the relatively large reduction of the diode thickness, the switching softness of the 5th gen. emitter controlled diode is very similar to its predecessor. In Fig. 6, the commutation characteristics of the two diode generations at 1/20th of the nominal current are compared. The measurements have been performed at room temperature for a PrimePACK™ prototype module equipped with 5th generation emitter controlled diodes. The improvement has been achieved by the optimization of the field stop design of the diode.

In order to avoid a loss of surge current capability in spite of the 25 K increased $T_{vj,op}$, also the next generation diode is equipped with a thick copper metallization on its front side [3], which is illustrated in Fig. 5.

Diode	3rd gen. @150°C	5th gen. @150°C	5th gen. @175°C
Current / PP3 footprint (%)	100%	130%	130%
Tj,op,max (°C)	150	175	175
Vf (V)	1.8	1.8	1.8
Erec/A (%)	100%	90%	100%

Tab. 2: Comparison of the electrical losses of the 5th generation 1700V emitter controlled diode with its predecessor technology on the same module footprint (PrimePACK™ 3).

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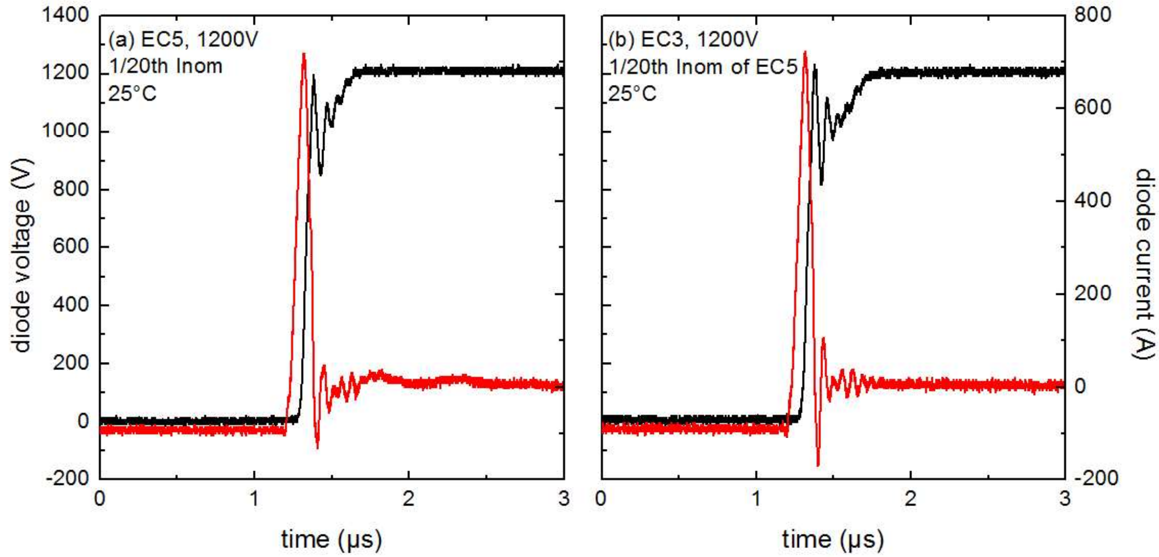

Fig. 6: Comparison of the turn-off of the 5th gen. emitter controlled diode (a) and the 3rd gen. emitter controlled diode (b) in a PrimePACK™ prototype module measured at 1/20th of the nominal current and T_{vj} = 25°C. Red curves represent the diode current, black curves the diode voltage. Voltage and current are displayed at the same scale for (a) and (b).

2. Module performance

2.1. Inverter output current calculation

Based on the data concerning the electrical performance of the new 1700V IGBT and diode generation discussed so far, we can now estimate the expected increase of the maximum inverter output current for the same module footprint. To this end, the IPOSIM simulation tool from Infineon Technologies AG has been used [4]. For our calculations, we have assumed the same silicon placement in a module with PrimePACK™ 3 footprint. We address two cases of application. First, we have simulated the maximum inverter output current for an application in a central solar inverter, where the IGBT is the limiting device. Second, we have considered an application in a generator side wind power inverter.

2.2. Solar inverter application

For the solar inverter application, we have assumed a forced air heat sink with an R_{th} heat sink-to-ambient ($R_{th,h\text{-}a}$) of 0.07 K/W per module arm and an ambient temperature of 50°C. The DC-link voltage was 900 V, the output frequency was 50 Hz, and the modulation factor was 0.65. The simulation was performed for a cosφ = 0.90. In Fig. 7, the achievable inverter output current at these operation conditions is plotted vs. the switching frequency. For both, IGBT5 and IGBT4, the curves represent the current calculated for the maximum $T_{vj,op}$ of 175 °C and 150 °C, respectively.

The black curve shows the results for the IGBT4 in the PrimePACK™ 3 module FF1400R17IP4. The red curve shows the respective curve for the IGBT5. For a typical switching frequency in the range between 1.5 kHz and 2 kHz, the maximum inverter output current can be increased by approximately 33% to 37% for the specific switching conditions under evaluation.

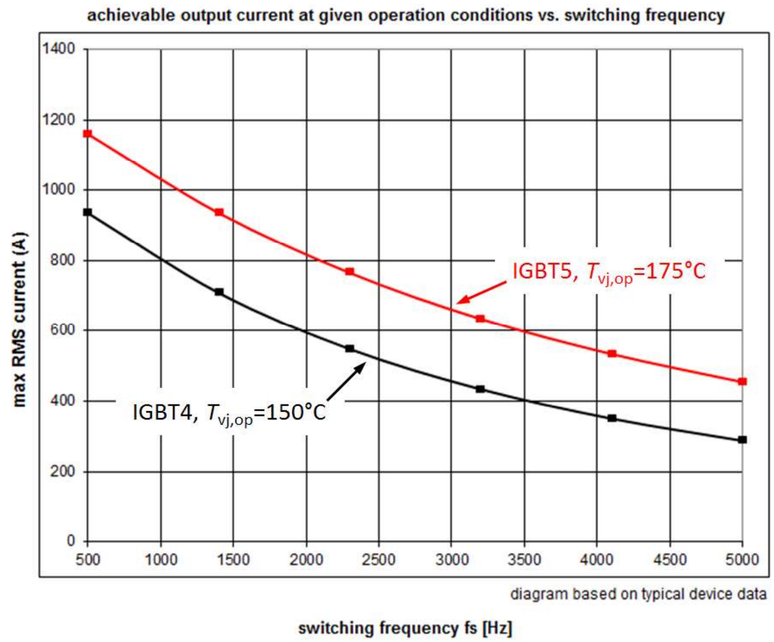

Fig. 7: Comparison of the achievable output current for two modules with PrimePACK3™ footprint equipped with IGBT4 and IGBT5 assuming same silicon placement. The simulation has been performed for a forced air heat sink with an $R_{th,h\text{-}a}$ of 0.07 K/W per module arm and an ambient temperature of 50 °C. The DC-link voltage was 900 V, the output frequency was 50 Hz, the modulation factor was 0.65 and cosφ = 0.90. The curves represent the current calculated for the IGBT5 (red solid line) at $T_{vj,op}$ = 175 °C and IGBT4 (black solid line) at $T_{vj,op}$ = 150 °C.

2.3. Wind power application (generator side)

For the wind power application, we have considered a water cooled system with an $R_{th,h\text{-}a}$ of 0.015 K/W per module arm and an ambient temperature of 50 °C. Further, we have assumed a DC-link voltage of 1080 V, a base frequency of 15 Hz, a modulation factor of 1.00 and a cosφ = -0.82. In Fig. 8, the results of the calculations are shown. The achievable inverter output current is plotted vs. the switching frequency. The black and red curves show the current calculated for the 5th generation devices at $T_{vj,op}$ = 175 °C and the 4th generation devices at $T_{vj,op}$ = 150 °C, respectively. Under the conditions considered here, the diode is the limiting device.

For an assumed switching frequency of 2 kHz, the maximum inverter output current can be increased by approximately 30% by the use of the new technology. The blue curve represents the maximum output current calculated for the 5th gen. module where $T_{vj,op}$ has been limited to 150 °C. Under these conditions, where the full potential of the .XT based lifetime improvement is realized [1], in particular with respect to power cycling, being essential for low frequency application considered here, the maximum achievable output current is still increased by approximately 10%.

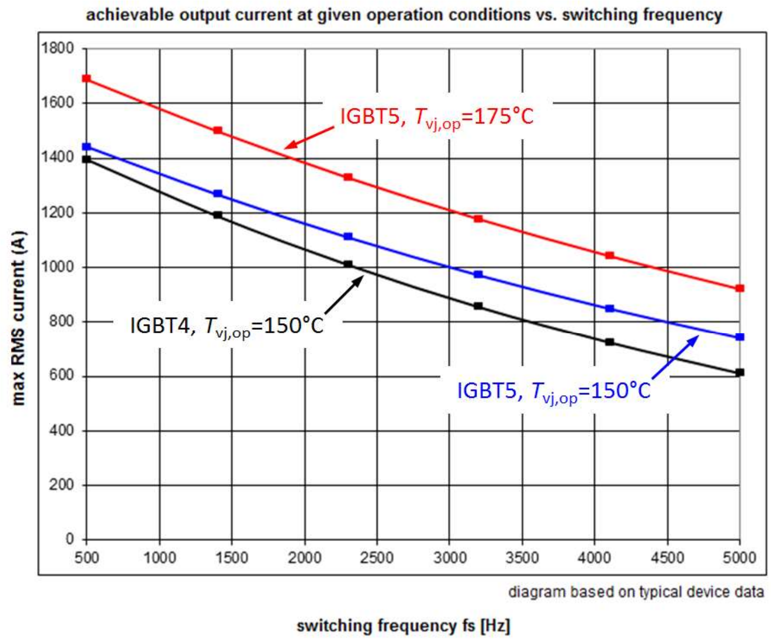

Fig. 8: Comparison of the achievable output current for two modules equipped with 5th generation and 4th generation 1700V IGBTs and diodes, assuming same silicon placement. The simulation parameters were $R_{th,h-a}$ = 0.015 K/W per module arm, T_a = 55 °C, 1080 V DC-link voltage, 15 Hz base frequency, modulation factor 1.00, and cosφ = -0.82. The curves represent the current calculated for the 5th gen. module at $T_{vj,op}$ = 175 °C (red solid line), the 5th gen. module at $T_{vj,op}$ = 150 °C (blue solid line) and the 4th gen. module at $T_{vj,op}$ = 150 °C (black solid line).

3. Conclusion

In summary, the 5th generation 1700V IGBT and emitter controlled diode from Infineon Technologies, which are designed to operate at $T_{vj,op}$ = 175 °C, enable a strongly enhanced power density for a new generation of 1700V power modules. Utilizing the .XT technology, these new devices fulfill the requirements established concerning lifetime, short circuit and surge current events, as well as EMI friendly operation, even at the increased current density and higher thermal stress. Alternatively, the .XT advantage can be employed to enable a strong enhancement of the lifetime, when the power density is only moderately increased.

4. References

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