Application Note, V1.0, Oct. 2004

TrenchStop-IGBT -

Next Generation IGBT for Motor Drive Application

AN-TrenchStop-1

Author: Wolfgang Frank
http://www.infineon.com/IGBT

Discrete & Power
Management

Never stop thinking.

TrenchStop-IGBT - Next Generation IGBT for Motor Drive Application

Revision History: 2004-10 V1.0

Previous Version:

Page	Subjects (major changes since last revision)

For questions on technology, delivery and prices please contact the Infineon Technologies Offices in Germany or the Infineon Technologies Companies and Representatives worldwide: see our webpage at http://www.infineon.com.

TrenchStop^{TM}, DuoPack^{TM}, CoolMOS^{TM}, CoolSET^{TM} are a trademarks of Infineon Technologies AG.

Edition 2004-10

Published by Infineon Technologies AG,
St.-Martin-Strasse 53,
81669 München, Germany

© Infineon Technologies AG 2004.
All Rights Reserved.

Attention please!

The information herein is given to describe certain components and shall not be considered as warranted characteristics.

Terms of delivery and rights to technical change reserved.

We hereby disclaim any and all warranties, including but not limited to warranties of non-infringement, regarding circuits, descriptions and charts stated herein.

Infineon Technologies is an approved CECC manufacturer.

Information

For further information on technology, delivery terms and conditions and prices please contact your nearest Infineon Technologies Office in Germany or our Infineon Technologies Representatives worldwide.

Warnings

Due to technical requirements components may contain dangerous substances. For information on the types in question please contact your nearest Infineon Technologies Office.

Infineon Technologies Components may only be used in life-support devices or systems with the express written approval of Infineon Technologies, if a failure of such components can reasonably be expected to cause the failure of that life-support device or system, or to affect the safety or effectiveness of that device or system. Life-support devices or systems are intended to be implanted in the human body, or to support and/or maintain and sustain and/or protect human life. If they fail, it is reasonable to assume that the health of the user or other persons may be endangered.

Table of Contents Page

1 Short Description

This application note discusses the technological background of Infineon´s latest TrenchStop™-technology of Non-Punch-Through-IGBT (NPT-IGBT) for breakdown voltages of $V_{(Br)CES}$ = 600 V. The main topics are improvements in respect of both static and dynamic behaviour. Furthermore the paper explains the failure mode stability. This includes its short circuit capability in terms of short circuit withstand time t_{SC} and short circuit current capability I_{SC}. This is concluded by a section which works out basic considerations on the EMI-bahaviour of this family.

The TrenchStop-family for 600 V- and 1200 V-drive applications completes Infineon´s portfolio of high performance IGBT according to **Table 1**.

Table 1:Ranges of switching frequency and Infineon´s IGBT families

Hard switching: 0 - 20 kHz **Soft switching: 0 - 40 kHz**	**Hard switching: 20- 40 kHz** **Soft switching: 40 - 60 kHz**	**Hard switching: 40 - 100kHz** **Soft switching: 60 - 150 kHz**
TrenchStop 600 V **e.g. IKP10N60T**	Fast IGBT 600 V e.g. SKP10N60	HighSpeed 600 V e.g. SKB15N60HS
TrenchStop 1200 V e.g. IKW15T120 or IHW15T120	Fast IGBT 1200 V e.g. SKW15N120	HighSpeed II 1200V e.g. IKP03N120H2

2 The TrenchStop Concept

The development of IGBT technologies throughout the recent years showed several markable steps of performance enhancement. Two of them had been driven from Infineon and are now the most important ones.

2.1 The fieldstop technology [1]

Figure 1 shows the cross section of a conventional NPT-IGBT (left) and a fieldstop IGBT (right). The conventional technology is based on a rather large wafer thickness of roughly 200 µm for 1200 V class and 100 µm for 600 V. It can be seen in the curve of the electrical field, that the field decreases linearly until 0 within the substrate thickness. It is poorly doped in order to take over the field during off-state. This means that**,** the substrate has a rather large internal resistance and a change in the doping concept could affect other parameter negatively. The thickness is therefore the main contributor to the saturation voltage $V_{CE(sat)}$, which is the figure of merit in respect of the conduction losses. This means, that the thicker the substrate is the higher is the saturation voltage.

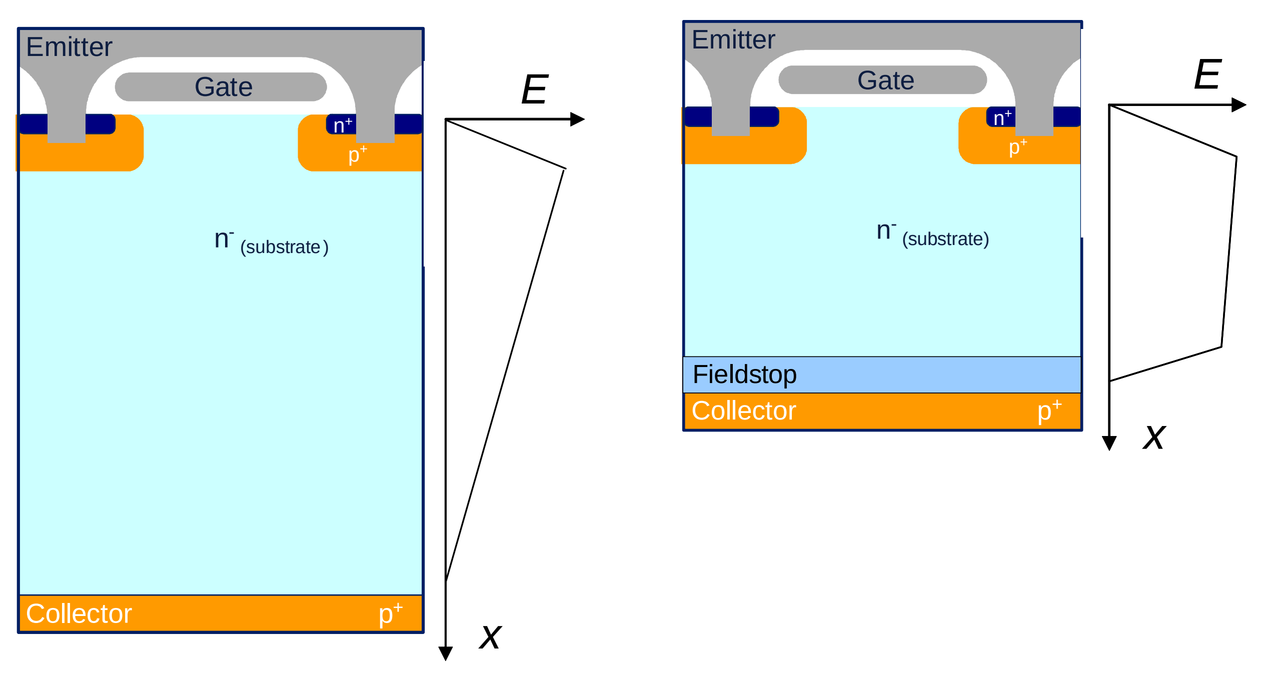

Figure 1 **Cross section and electrical field in the blocking state of a conventional NPT-IGBT and of a fieldstop-IGBT**

This is improved by implementing an additional layer between the substrate region and the collector layer. This is called fieldstop layer and has also an n-doping according to the right part of **Figure 1**. The dosis of this layer is designed to decrease the field within this layer to 0. This means, that the field drop in the substrate can be considerably low. The blocking capability of the IGBT is therefore not depending on the substrate thickness any more, which means, that the substrate can be grinded thinner. This results in very low saturation voltages and thus in low conduction losses.

The fieldstop concept offers also another advantage in hardly switched systems. The IGBT is able to switch-off much faster with virtually no tail current than conventional IGBT according to [2]. This leads to reduced switching losses, because the tail current contributes significantly to the total switching losses.

2.2 Trench gate

A characterising parameter of IGBT technologies is the saturation voltage $V_{CE(sat)}$. Both the turn-off energy and the saturation voltage are considered as socalled "Figures of Merit" (FoM). It can be shown, that the saturation voltage is influenced by the channel properties. The voltage drop over the channel is reverse proportional to the channel width and proportional to the length of the channel. The channel should therefore be as short as possible for low conduction losses. On the other hand the channel length must hold the breakdown voltage and is therefore limited to a minimum length. Secondly, it limits the short circuit current to avoid destruction of the device under short circuit conditions. This also limits the cell density of the overall IGBT chip.

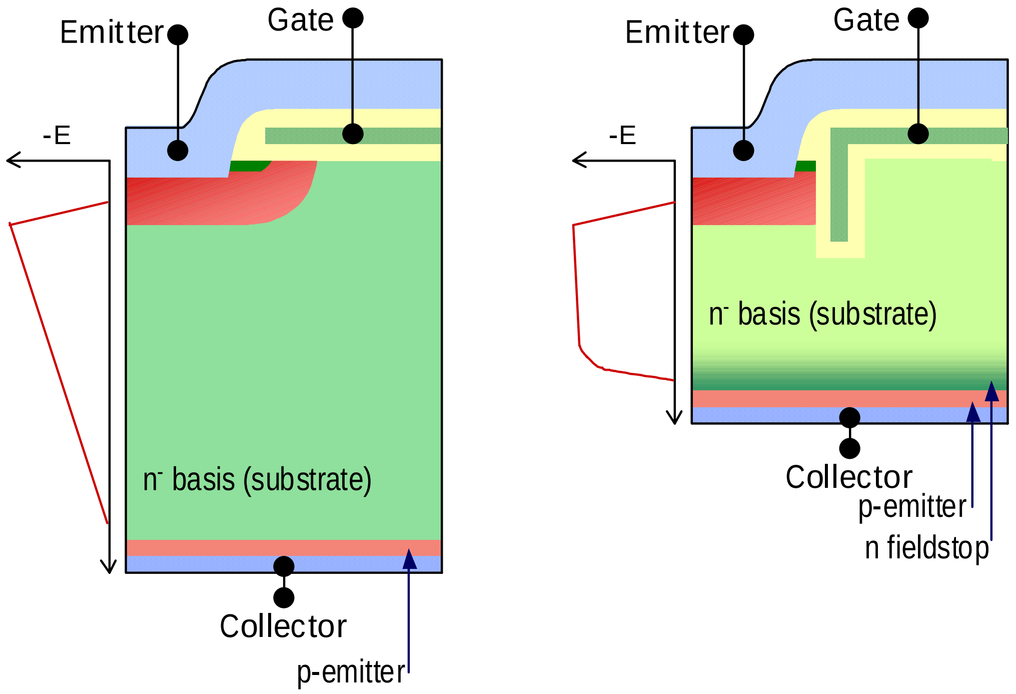

Figure 2 Conventional IGBT technology (left) and trench gate technology combined with fieldstop layer (right)

A trenched gate now implements not a horizontal gate but a vertical gate. This means, that the channal can be designed in an optimised way which achieves a lower saturation voltage while having a sufficient breakdown voltage simultaneously.

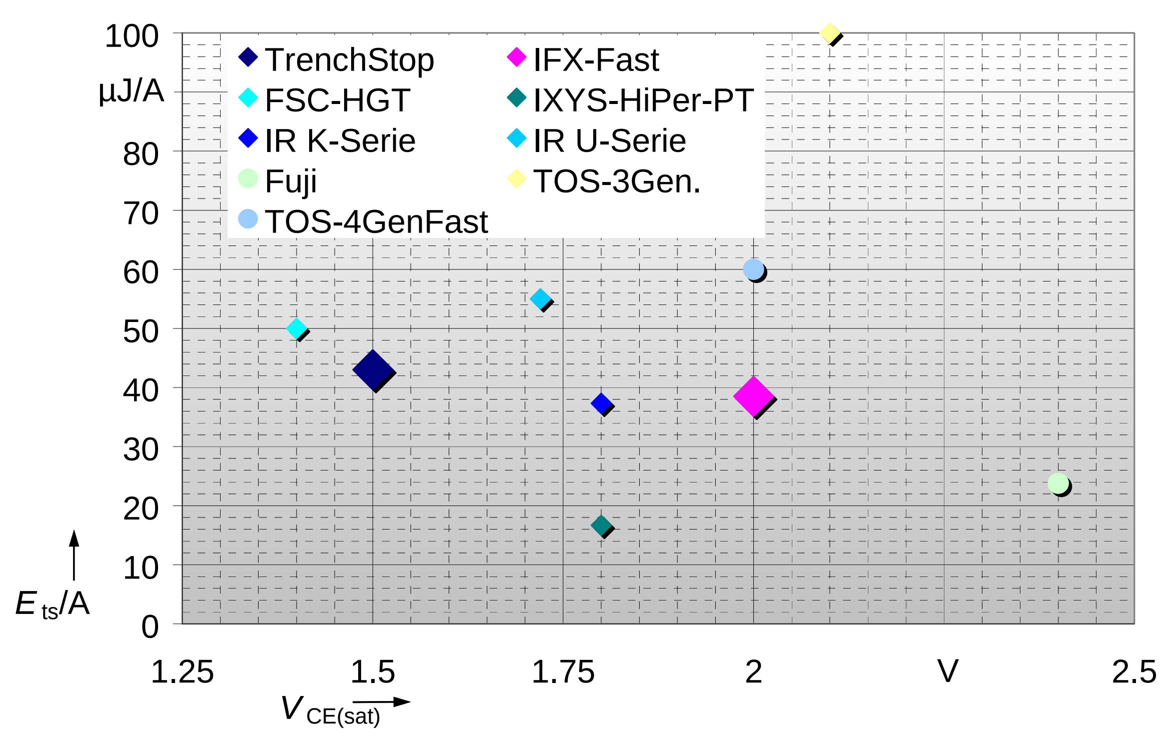

Figure 3 **FoM-plane of switching Energy E_{ts} and saturation Voltage $V_{CE(sat)}$**

Figure 3 shows the plane of the FoM which is defined by the normalised typical switching energy per rated ampere E_{ts}/A (T_J = 25°C) and the typical saturation voltage $V_{CE(sat)}$ at T_J = 25°C. It can be seen, that the TrenchStop technology offers the best combination of switching energy and saturation voltage. However, the HiPer-Family from IXYS offers also good performance and low switching losses. Please note here, that this is a Punch-Through-IGBT with a strong increase of switching energy over temperature and a negative teperature coefficient in $V_{CE(sat)}$ which makes paralleling almost impossible.

A few other competitor part also offer slightly lower switching energy, but this is compensated by the superior performance of TrenchStop in saturation voltage.

2.3 Conclusion

The combination of both the fieldstop and the trench gate technoplogy lead to highly improved FoM. Other important parameters such as the short circuit capability or latch-up robustness are not or only marginally influenced.

3 Static performance of TrenchStop-IGBT

Both, trench top-cell and field stop concept lead to a significant improvement of the static as well as the dynamic performance of the device. **As will be shown in the following the combination with an increased junction temperature leads to reduced power losses and / or increased inverter output power despite of a considerable chip shrink**. **Figure 4** shows the output characteristics of TrenchStop- and Fast-IGBT in comparison. Here the characteristics of components with a current rating of I_C = 10 A at a case temperatuer of T_C = 100°C are compared.

Figure 4 shows clearly, that the new TrechStop-technology reduces the saturation voltage V_{CEsat} dramatically by 0,5 V which is almost 30% compared to the Fast-IGBT of the same current rating. This effect even increases for higher junction temperatures to a difference of 0,6 V due to the higher temperature stability of the TrenchStop technology. Please note here, that **Figure 4** only shows the curves for 150°C, although TrenchStop is characterised until 175°C. This is done in order to gain a direct comparability with the Fast technology in this figure.

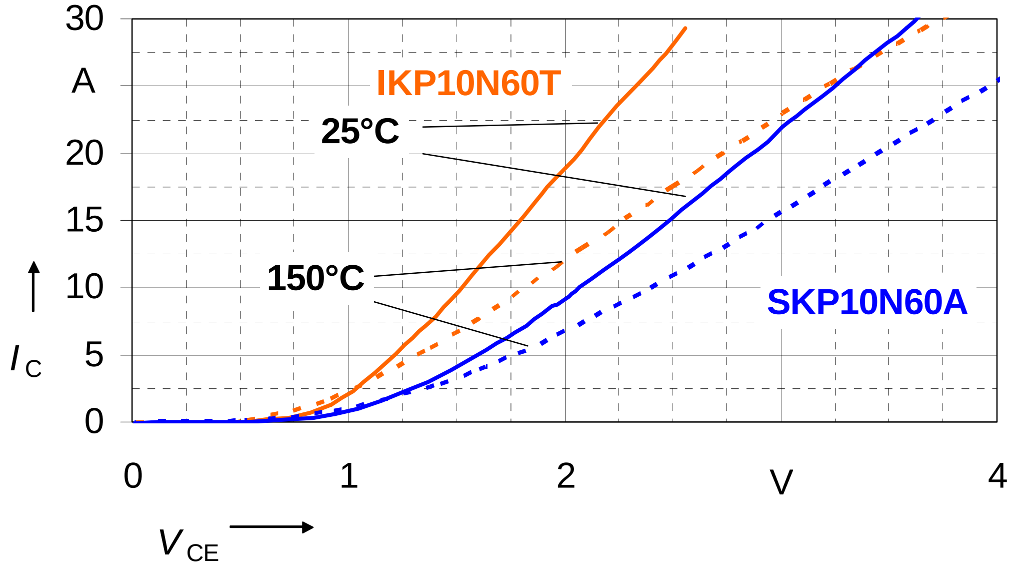

Figure 4 **Output characteristic of TrenchStop-IGBT (IKP10N60T, orange) and Fast-IGBT (SKP10N60A, blue) at 25°C (solid line) and 150°C (dotted line)**

4 Dynamic behaviour

The switching losses are highly influenced by the dynamic behaviour of the transistor. On one hand the switching times such as fall time or rise time characterise the transition from on-state to off-state and vice versa. On the other hand bipolar devices like IGBT suffer from the socalled “current tail”, which results from slow recombination and removal of carriers during turn-off and causes significant losses.

It is reported in **[2]** that the fieldstop technology is able to nearly eliminate this current tail. This results in excellently low turn-off losses.

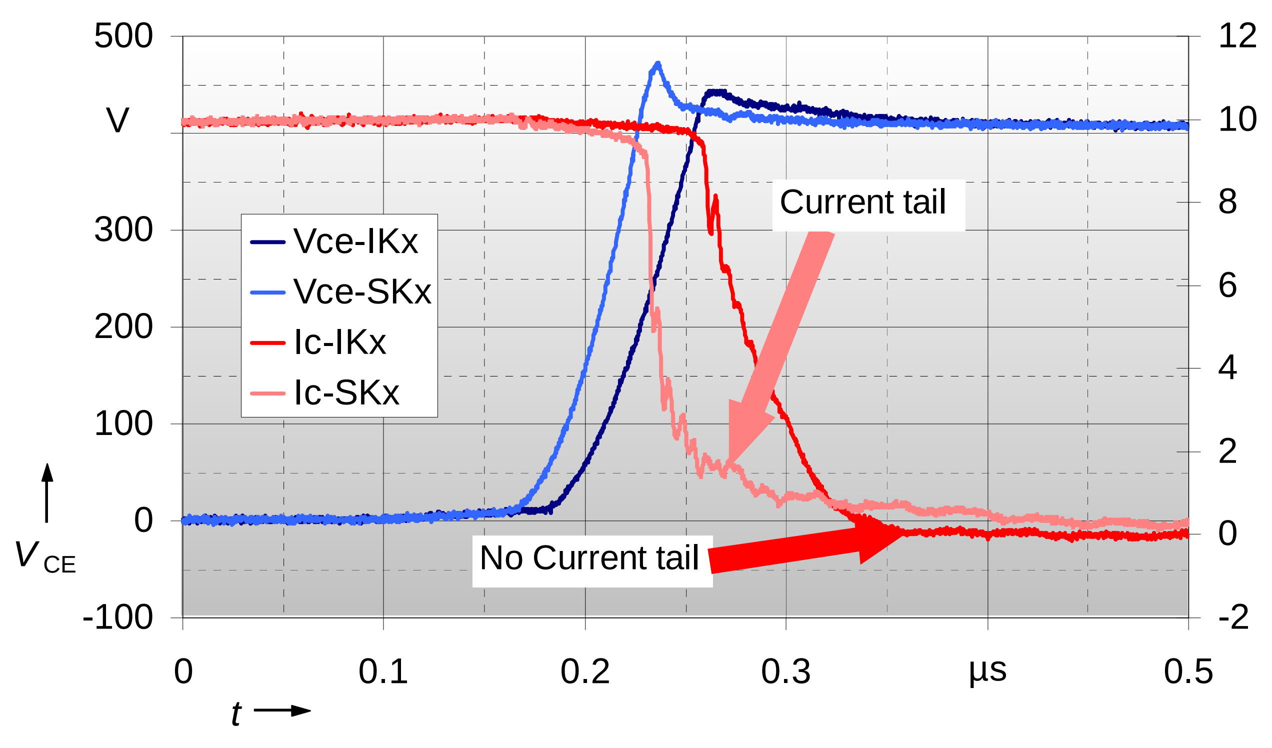

Figure 5 **Voltage (blue) and Current (red) Waveforms of IKP10N60T (dark colours) and SKP10N60A (light colours)during turn-off**

The turn-off energy of IKP10N60T (TrenchStop) is typically 350 µJ compared to 280 µJ of SKP10N60A (Fast). This is only about 25% more than the Fast-technology. Please note here, that according to the definition of the turn-off energy the SKP-device is still generating losses when the current tail is below 10% of rated current. These losses are not considered in the datasheet. The real losses are therefore slightly higher which is not the case wih TrenchStop-devices.

Another important point here is that the turn-on capability of the TrenchStop-IGBT is still very high. This results in an optimal use of the properties of the duopacked EmCon-diode, which minimises the turn-on losses. Turn-on with a rise time of t_r = 11 ns is still very fast, so that this switching speed benefits most from the soft recovery behaviour of the EmCon-diode. This results in lower reverse recovery currents of a freewheeling diode and therefore in low reverse recovery losses in the IGBT.

This can be verified in the datasheet: The fall time of SKP10N60A (Fast) is typically 26ns, IKP10N60T (TrenchStop) has typically 63 ns which is more than 100% longer both at elevated temperature of 150°C. This would usually imply, that the total switching losses are roughly in the same ratio. A glimpse into the datasheet unveils, that the total switching losses of the TrenchStop-device has only about 15% higher than the Fast-device!

5 EMI considerations

The influence of switching transistors on the EMI-spectrum is mainly defined by the slew rates of collector-emitter voltage $v_{CE(sat)}(t)$ and collector current $i_C(t)$. The EMI-behaviour of a switch can therefore often be estimated by the analysis of the switching waveforms. The steeper the current or voltage transition is the higher are the high frequency amplitudes in the EMI-spectrum.

The analysis of the turn-off waveforms according to **Figure 5** and the corresponding turn-on waveform results in values of di_C/dt and dv_{CE}/dt during turn-on and -off which are given in **Figure 6**. The junction tempertature is T_J = 150°C.

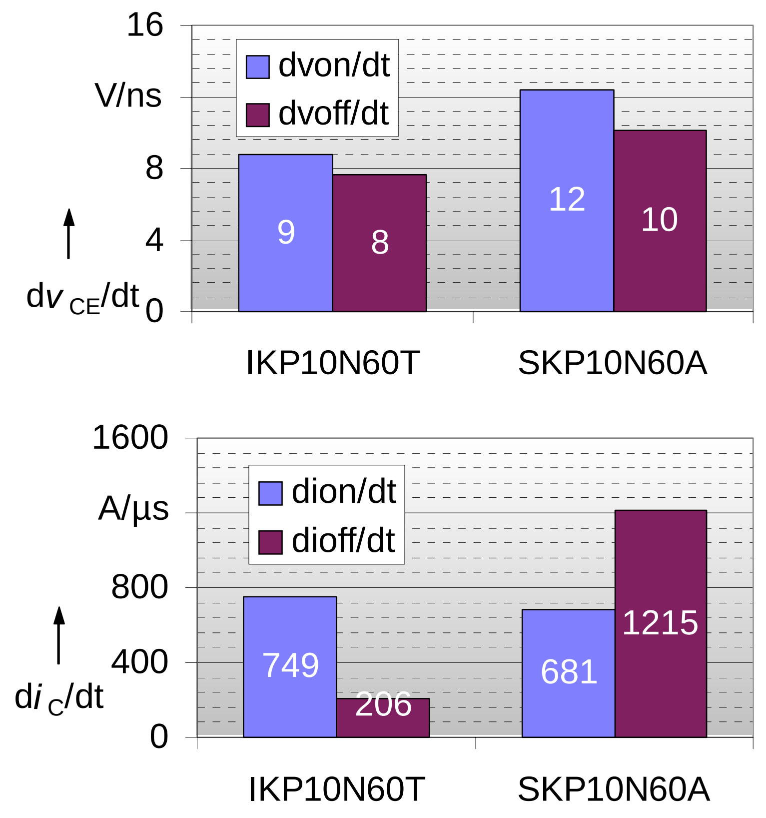

Figure 6 **Slew rates of voltage (top) and current (bottom) waveform during turn-on (blue) and turn-off (purple)**

It can be easily seen, that the at turn-off the current slew rate of IKP10N60T is dramatically lower than the slew rate of the Fast-IGBT which is correlated with **Section 4**. This leads to a significantly lower over-voltage peak and improved EMC behavior. Also the other values are lower for TrenchStop compared with the Fast-technology. This means, that all parasitic oscillators which are inherently available on any PCB are only softly excited and therefore the EMI-spectrum should be lower.

The EMI-behaviour is one of the key features of TrenchStop technology. It is very important for the application, because a soft transition from conduction state into blocking state and vice versa is essential for the design of the EMI-filter.

Nevertheless it is important to know, that general layout rules for EMI-minimisation must be fulfilled, such as minimisation of ground loops, minimisation of drain-, gate- and source-tracks and placement of (passive) filter components as close to the switches as possible.

6 Short Circuit Capability

The occurrance of short circuit generates immediately a large amount of heat, which is almost entirely dissipated in the silicon chip.

The 600V TrenchStop IGBT is specified with a short-circuit robustness up to t_{SC} = 5 µs at T_J = 150°C, V_{GE} = 15 V and V_{CC} = 400 V. Please note here, that the reduction of the short circuit withstand time to 5 µs is not an indicator of reduced short circuit robustness of the TrenchStop technology. Instead it is a well chosen operational point on a trade-off curve between device performance (i.e. losses under operation conditions) and short circuit withstand time.

In order to understand short circuit capability properly, the known destruction mechanisms shall be discussed. It has been reported in [3] that principally three mechanisms of short circuit destruction are known:

a) destruction during turn-off due to a latch-up which is related to the device over-temperature,

b) destruction during the current pulse (current destruction mode) which is not related to the device temperature. Up to now this destruction mode is not fully understood but design measures are known to avoid this kind of destruction mode,

c) destruction after a successful turn-off (energy destruction) due to thermal run-away of the device as a consequence of the dissipated energy within the pulse. This destruction mode obviously largely depends on the device temperature prior to the short circuit.

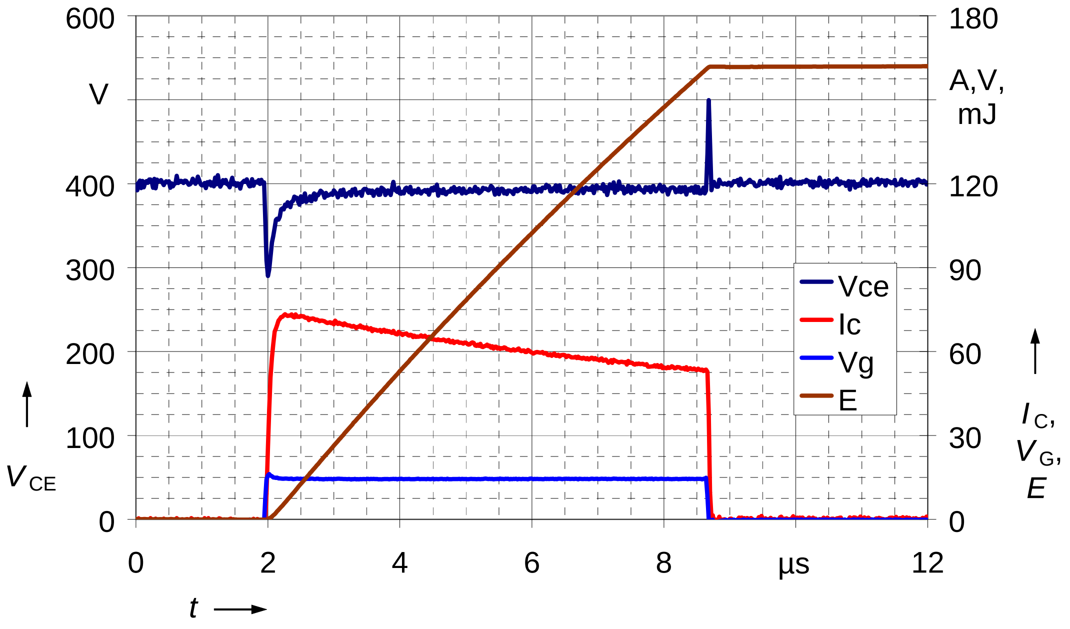

Figure 7 **Short Circuit of IKP10N60T**

With 600 V TrenchStop exclusively the destruction mode c) can be observed, demonstrating the robust and latch-up free device design. **Figure 7** shows a non-destructive short circuit pulse for a TrenchStop IGBT with a DC current rating of I_C = 10A at V_{GE} = 15 V. Note that the waveforms show conditions well above the specified short circuit capability.

The above discussion clarifies that once the IGBT technology is short circuit robust the further adjustment of a short circuit withstand time is a matter of definition. State-of-the-art short circuit detection methods are fast enough to recognize and turn off a short circuit within 5 µs. Therefore the specified short circuit withstand time has been set to 5µs in order to provide products with the best price-performance ratio achieving the biggest advantage for the user.

7 Device Impact on Motor Drives

The static losses have been much reduced with the TrenchStop-generation while the switching losses increase only slightly. Still, with this optimization the switching losses contribute about only 40% of the total inverter losses for switching frequencies of 16 kHz and full output power of the inverter (cos ϕ = 0.7). This contribution decreases to only 25% at a switching frequency of 8 kHz. It can be seen, that the sum of the conduction losses of IGBT and diode (P_{vcI} + P_{vcD}) are still contributing most to the overall losses P_{vtot}. Especially the switching losses P_{vsD} of the diode is very small. Please note here, that a portion of the dynamic diode losses are generated in the IGBT, as well. In **Figure 8** the dissipated power of each IGBT and diode is shown for IKP20N60T (TrenchStop) and SKW20N60 (Fast-IGBT) for two switching frequencies of 8kHz and 16 kHz.

The IGBT losses at high output currents are 10 - 20 % lower with the TrenchStop devices than compared to the Fast-IGBT. Looking at this comparison from another point of view reveals that with IGBT3 the maximum output power - especially at an elevated heat sink temperature of 125 °C - is about 10 - 15% higher. Note that this calculation already has taken into account the increased thermal junction-ambient resistance R_{thJA} due to the chip shrink.

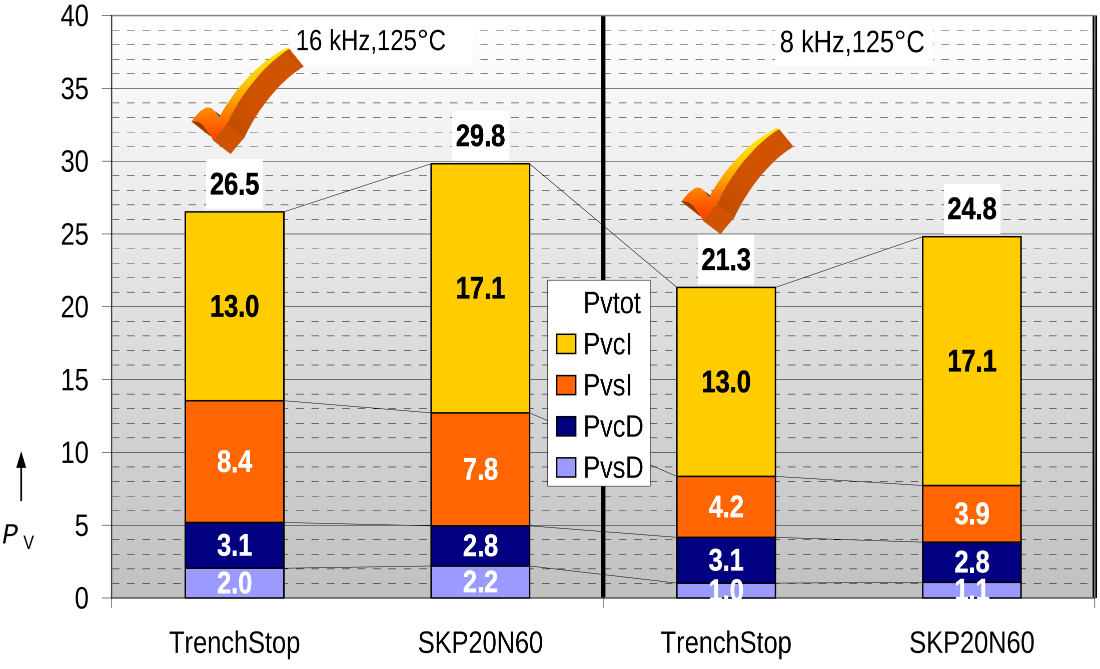

Figure 8 Comparison of losses per inverter leg of IKP20N60T (TrenchStop) and SKW20N60 (Fast-IGBT) for $I_{out,rms}$ = 20 A, cos ϕ = 0.7

Thus the disadvantageous increase of R_{thJA} is over-compensated by the reduced losses and the increase of the maximum junction temperature by 25 °C. As a consequence the customer may either choose a smaller heat sink for the same output power rating or decide to draw considerably more power by using TrenchStop-IGBT. For further considerations of the thermal management of TrenchStop-IGBT DuoPack, please refer to AN-TrenchStop-2.

8 Summary of Used Nomenclature

Physics:

General identifiers:

A	cross area
b, B	magnetic inductance
d, D	duty cycle
f	frequency
i, I	current
N	number of turns
p, P	power
t, T	time, time-intervals
v, V	voltage
W	energy
η	efficiency
K_1, K_2	ferrite core constants

Special identifiers:

A_L	inductance factor
$V_{(BR)CES}$	collector-emitter breakdown voltage of IGBT
V_F	forward voltage of diodes
V_{rrm}	maximum reverse voltage of diodes

big letters:	constant values and time intervals
small letters:	time variant values

Components:

C	capacitance
D	diode
IC	integrated circuit
L	inductance
R	resistor
TR	transformer

Indices:

AC	alternating current value
DC	direct current value
BE	basis-emitter value
CS	current sense value
OPTO	optocoupler value
P	primary side value
Pk	peak value
R	reflected from secondary to primary side
S	secondary side value
Sh	shunt value
UVLO	undervoltage lockout value
Z	zener value

fmin	value at minimum pulse frequency
i	running variable
in	input value
max	maximum value
min	minimum value
off	turn-off value
on	turn-on value
out	output value
p	pulsed
rip	ripple value
1, 2, 3	on-going designator

9 References

[1] **T. Laska, L. Lorenz, A. Mauder:** The New IGBT Generation – A Great Improvement Potential for Motor Drive Systems

[2] **H. Hüsken, F. Stückler:** Field Stop IGBT with MOS-like (tailless) turn-off, accepted at ISPSD 2003

[3] **T. Laska, G. Miller, M. Pfaffenlehner, P. Türkes, D. Berger, B. Gutsmann, P. Kanschat, M. Münzer:** Short Circuit Properties of Trench-/Field-Stop-IGBTs - Design Aspects for a Superior Robustness", Proc. 15th ISPSD, Cambridge 2003

www.infineon.com

Published by Infineon Technologies AG