1200V IGBT4 -High Power- a new Technology Generation with Optimized Characteristics for High Current Modules

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Abstract

In this paper the new 1200V IGBT4, Infineon´s new generation of IGBTs, is presented for the first time. The IGBT4 comes as a product family with optimized vertical structures for low, medium and high power applications respectively, balanced for the typical switching frequencies of the different power classes. In the following the focus is on the chip optimized for high current modules. The most important design targets for this power class are explained. Finally, the realisation is discussed by means of measured data.

I. Introduction

An Insulated gate bipolar transistor (IGBT) is a semiconductor component, which is increasingly used in the power electronics because it combines the advantages of a bipolar transistor (low saturation voltage capability, high reverse voltage) and the advantages of a field-effect transistor (almost powerless control) as one can read if one enters the keyword “IGBT” into the encyclopaedia Wikipedia [1]. Next it says "disadvantageous are the high switching losses in comparison to a MOSFET as well as the in principle existing voltage drop of some volt in the switched on condition".

That describes already rather comprehensively the goal of our further IGBT development. Reducing the saturation voltage and simultaneously reducing the switching losses of an IGBT means to find a new and better trade-off curve between static and dynamic losses. Today state off the art IGBTs are trench / field-stop devices.

Trench IGBT

The MOS channel of a Trench IGBT compared with a planar IGBT is rotated by 90°. Thus, a higher channel density can be realized at the chip top side which leads to a higher inundation of the top/emitter side with charge carriers. A maximum channel density would not only worsen the short circuit robustness but also increase the turn off losses dramatically. A good combination of a suitable trench density, a low backside emitter efficiency (collector doping) and a high charge carrier life time leads to a clear reduction of the saturation voltage without increase of turn-off losses [2].

Field-stop

In a field-stop IGBT, an additional n+ layer is introduced close to the collector. This layer, named field-stop, brings down the electric field within a very short spatial dimension. Therefore, it is possible to make the chips thinner and in such a way to reduce the static and dynamic losses. However, during switching events the silicon volume not affected by carrier extraction through the electric field is determining the amount of carriers contributing to the tail current. This tail carrier/charge is crucial for the softness of an IGBT. In case of high transient over voltages the space charge region reaches far into the field stop and the residual/tail charge is very small. For a critical voltage the tail current disappears and the current flow snaps off. Such a snap-off results in high and hardly controllable over voltages. This, so far, was a big challenge for the design-in of trench field stop modules in high power applications.

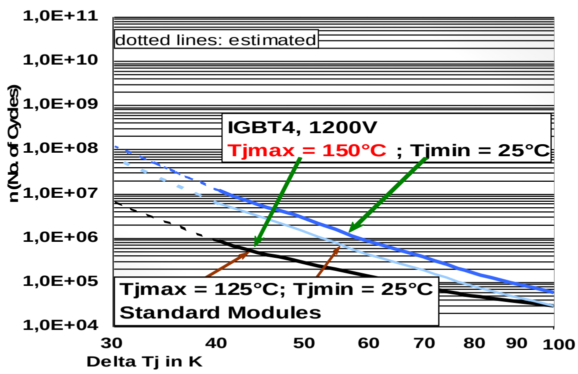

Figure 1: target power cycling curve: IGBT4 1200V vs. standard modules

II. Soft 1200V Trench + Field Stop IGBT 4 for High Power Modules

IGBT4 is Infineon´s new upcoming 1200V IGBT generation. As a main feature/advantage it allows a maximum junction temperature of 175°C. A maximum junction temperature of 175°C was introduced for the first time by Infineon at 600V power semiconductors of the third generation. A comprehensive discussion is given in [3, 4]. As main advantage one should name here the potential of higher output power (up to 20%, by use of the full temperature swing based on the same cooling condition). The higher temperature swing is supported by an improved power cycling reliability (Fig.1). For operation temperatures up to 150°C the target is to maintain the Power cycling capability of former Modules at 125°C.

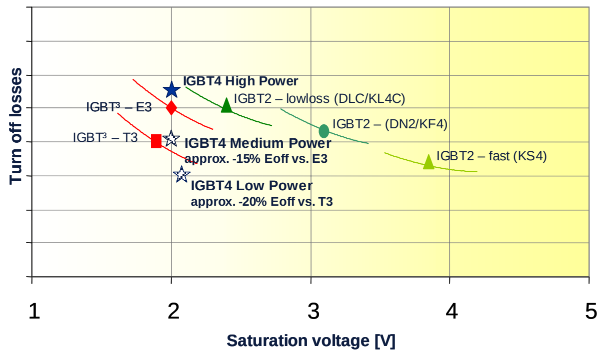

Figure 2: Turn-off losses vs. saturation voltage of different IGBT generations from Infineon

The 1200V IGBT4 comes as a product family with optimized vertical structures for low, medium and high power applications, respectively (Fig.2), balanced for the typical switching frequencies of the different power classes. This article focuses on High Power applications, namely modules with more then 1200A current rating. The following measurements were performed on a 2400A Infineon - eupec IHM single switch module.

Softness

It is important to mention that the tendency towards current snap-off is strongly dependent on the current rating of modules which are using the same IGBT chips. In today's high current modules as much as 24 150A IGBT dices are connected in parallel. Since the switching speed of the IGBTs is almost independent from the current rating, the current gradient dI/dt increases linearly with current rating to first order. As a consequence of parasitic stray inductances this leads to high dynamic over voltages favouring current snap-off. Moreover, even though the IGBTs in Infineon's high power modules are arranged in a highly symmetric manner any misbalance of current sharing

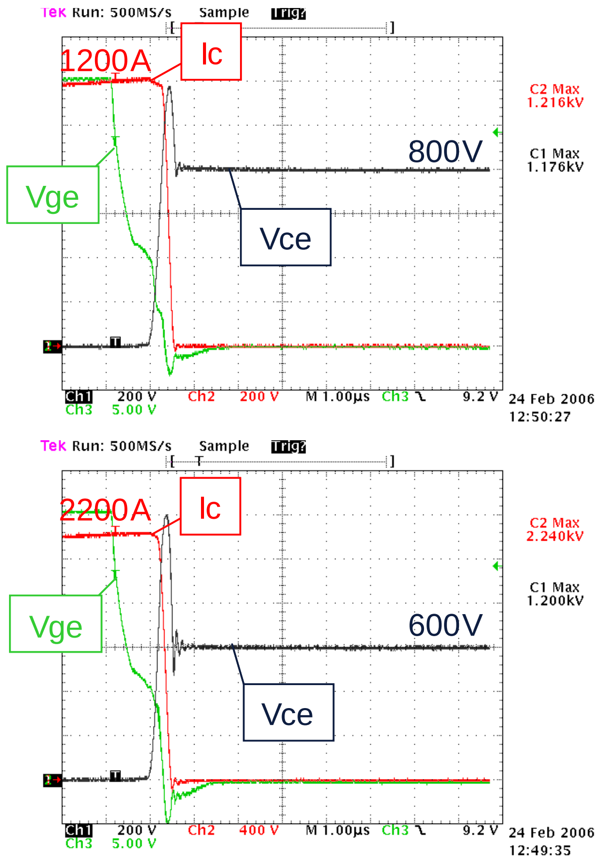

Figure 3: Turn-off curves at room temperature of an Infineon - eupec 2400A single switch IHM module from Infineon: stray inductance of the capacity bank = 50nH

worsens these effects. Consequently soft turn-off behaviour of the IGBT is a major prerequisite for safe and controllable operation of High Power Modules. Due to low switching frequencies lowering conduction losses is the main

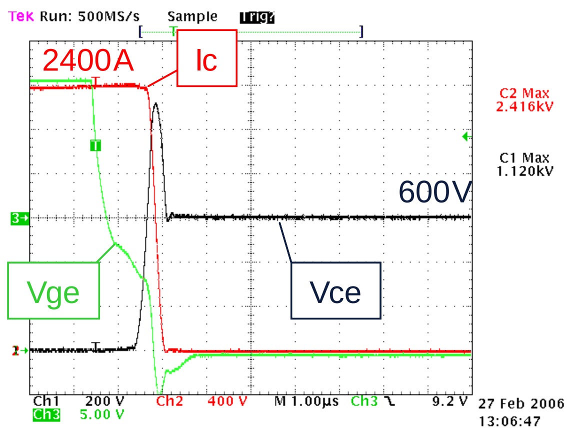

Figure 4: Soft turn-off behaviour of an Infineon - eupec 2400A single switch IHM module with IGBT4 at 125°C, stray inductance of the capacity bank = 50nH

development target. This also enables the optimization towards softness even if this is done at the cost of higher switching losses compared to chip optimizations for Low Power modules. The investigation of the IGBT4 on softness shows the most critical case is switching of high currents at high over voltage (Fig. 3). In case of the 600V measurement at room temperature and approximately 2200A a slight oscillation is to be observed. This could be interpreted as a beginning of current snap off.

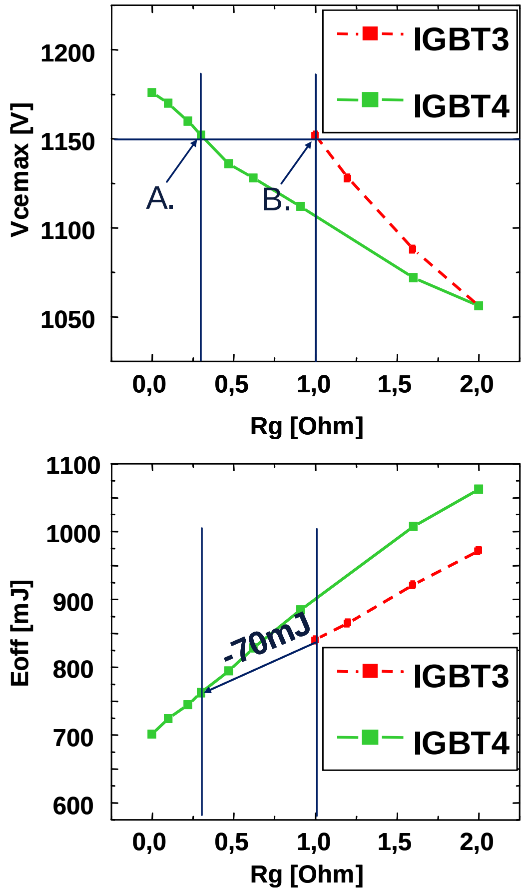

Figure 5a: Controllability of IGBT 3 and 4 (Vce=800V; Ic=2400A; Tj=25°C; active Clamping Vbr=900V); top: over voltage peak vs. Rg – the over voltage of IGBT4 can handled with 0Ohm for an IGBT3 a gate resistor > 2Ohm is needed; bottom: Turn off losses vs. Rg → improved controllability leads to reduced turn-off losses (both characteristics apply only for driver circuits with an active clamping, where the collector voltage is coupled to the gate through a zener diode with a defined break-trough voltage of Vbr = 900V, for example);

But, on the one hand, at working temperatures of 125°C or 150°C this oscillation disappears (Fig. 4) and - as the following section shows - this slight snap off at room temperature has no influence on the controllability of the IGBT. In contrast to the former Trench Field stop generation, the new High Power IGBT4 shows no snap off under operation conditions.

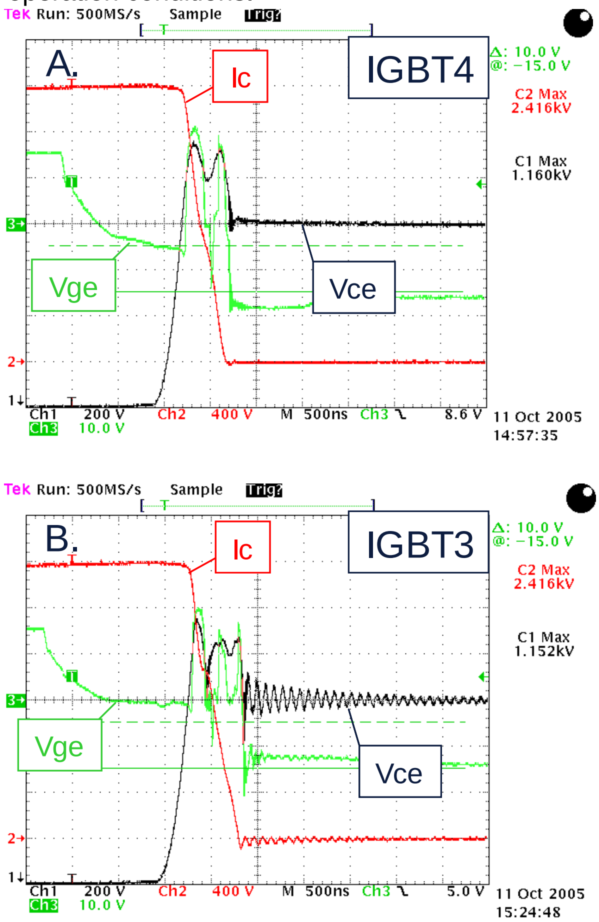

Figure 5b: Turn-off behaviour with active gate control corresponding to Fig 5a top (Vce=800V; Ic=2400A; Vbr(active clamping)=900V)

Controllability and turn-off losses

In addition to the important softness an easy controllability of the turn off dI/dt is crucial because in this performance category an active (dI/dt) control is generally present at least to limit the over voltage peak for inverter overload conditions. We have used a simple active clamping as active control for the characterization of a 2400A single switch in Infineon´s – eupec´s IHM module (Fig.5). The measurements show that the new chip is easily controllable which was formerly (with IGBT3) only possible with high Rg at the cost of drastically increased losses due to reduced dV/dt. At the nominal current of 2400A and 800V dc, the improved softness leads to a reduction of the turn off losses of approximately 70mJ. On the other hand, there is a trade off relation between softness and current tail and therefore the optimization towards softness is linked with an increase of turn off losses at low current. At low collector currents the tail current influences the turn off losses more than the dI/dt- and dV/dt,

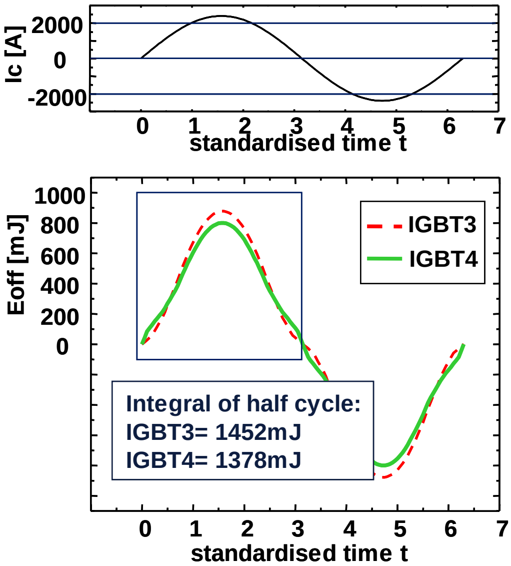

Figure 6: Turn-off losses of a sinusoidal current (Vce=800V; Tc=25°C; active clamping Vbr=900V; Rg(IGBT4)=0,47Ohm and Rg(IGBT3)=1,2Ohm are chosen for Vcemax<1150V); Eoff(IGBT4)<Eoff(IGBT3) for Ic>1000A → in sum the IGBT4 produces approximately 5% fewer turn-off losses than the IGBT3

where dI/dt and dV/dt is mainly determined by the gate resistor. Generally applications are thermally limited at high current levels and moreover the overall losses throughout a whole sine wave have to be considered (Fig.6). Here the IGBT4 shows a benefit of about 5% compared to IGBT3.

Turn-on losses

For turn-on the diode behaviour is most decisive for optimized losses at tolerable EMC (electromagnetic compability) behaviour. IGBT4 High Power comes with a kind of EmCon4 which is also optimized for extreme soft behaviour. Therefore the IGBT can turn on much faster. Taking benefit from the diode softness the turn-on losses may be reduced by up to 20%.

III. Conclusion:

With the optimized high power IGBT4 Infineon makes a trench field stop component available which is soft enough, so that large nominal currents up to 3600A can be controlled with a small gate resistor. During operation with an active gate control the total turn off losses (in sum over the complete operation range) decrease by 5% at a DC link voltage of 800 V and through the improved diode the turn-on losses decrease too (~20%). Taking into account the plus of 25°C in operation temperature this means a plus of approximately 20% higher inverter output power compared to an IGBT3 module assuming the same heat sink (Fig. 7).

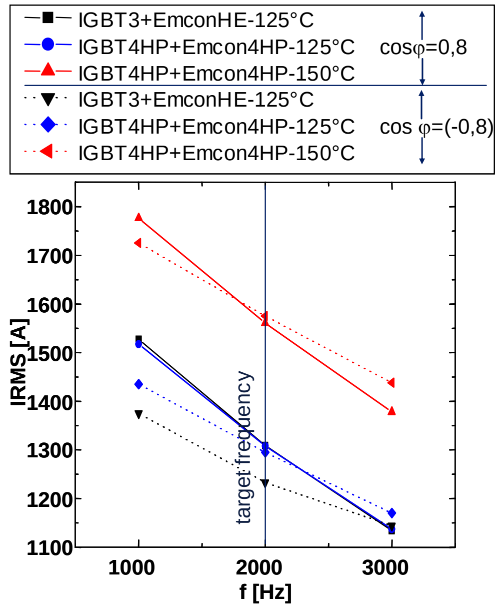

Figure 7: maximal RMS output current vs. switching frequency of a 2400A single switch IHM module at 600V DC link (calculated with IPOSIM [5] heat sink- Rth=0,03K/W; Tambient=40°C (dynamic losses from measurements with active gate control)

An optimization of the assembly technology furthermore ensures the same lifetime expectation in spite of increased operation temperature – or enhanced lifetime at comparable output power as can be chosen by the customer.

References

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