Introducing the 5.5kV, 5kA HPT IGCT

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The Power Point Presentation will be available after the conference.

Abstract

A 5.5kV asymmetric Integrated Gate Commutated Thyristor (IGCT) has been developed based on the High Power Technology (HPT) platform for very high SOA in large-area IGCTs. The device can safely control up to 3.6kA of current (actual destruction limit is higher - beyond 5kA), at DC-link voltages up to 3.9kV, while retaining important reliability aspects, as resilience towards cosmic-rays and load cycling. The device can handle frequencies up to 10kHz and an operating temperature of 125°C.

1. Introduction

The IGCT is a well-known and often preferred technology for handling very high power. The applications range from industrial drives (tens of MW), track-side supplies, power quality and high-current breakers. A picture of the device is shown in Fig. 1 below.

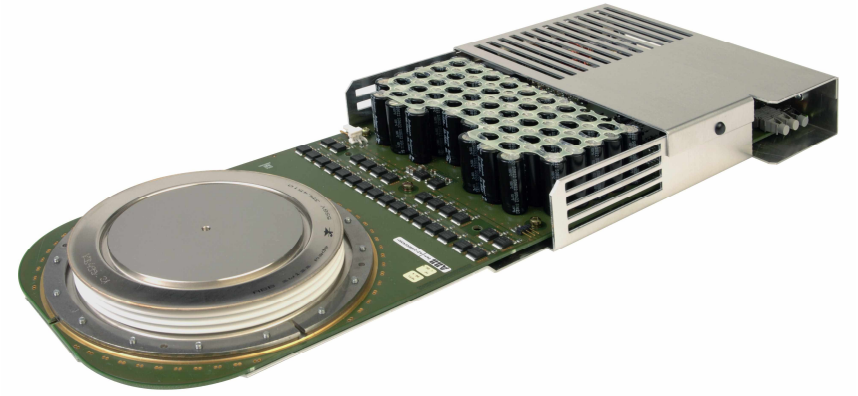

Fig. 1. The 5.5kV High-Power IGCT, consisting of the silicon switch in an hermetic ceramic housing to the left, intimately coupled to the gate driving circuit to the right.

The main strengths of the device lies in its thyristor-like on-state with maximal possibilities for engineering the on-state plasma distribution for optimal trade-off between on-state and turn-off losses, its rugged mechanical design and the good thermal coupling to the cooler. The main weakness compared to the IGBT, which is the only competitor device for the power range of the IGCT, is the relatively large effort needed to control the device - tens of Watts for the 3.6kA device - as well as the inability to control the anode voltage during turn-on as the IGBT does The former is due to the fact that it is a current-controlled device. The latter is due to it being a thyristor and as such it is, crudely, either off or on and the transition in between those states is only stable in theory. Hence, implementing it in most common inverter topologies means protecting the antiparallel diode at turn-on. Nevertheless, thanks to its low losses and efficient cooling, it is and continues to be the preferred choice for many manufacturers of very large power inverters. Other applications, such breakers for large currents, can only be conceived using the low on-state of the IGCT.

The maximal controllable current (MCC) of the IGCT does not scale linearly with device area. The reason is the inductive (and resistive) coupling to areas remotely placed from the gate contact. The area scales with the square of the diameter, whereas the MCC merely scales linearly, using the same technology. A graphical summary of this situation is presented in Fig. 2 below. The technology can be improved by decreasing the total inductance in the package (i.e. the minimum, 2nH, in Fig. 2), improving the local ruggedness to facilitate more current redistribution and increasing the driving gate voltage. The high-power technology was built using the first two.

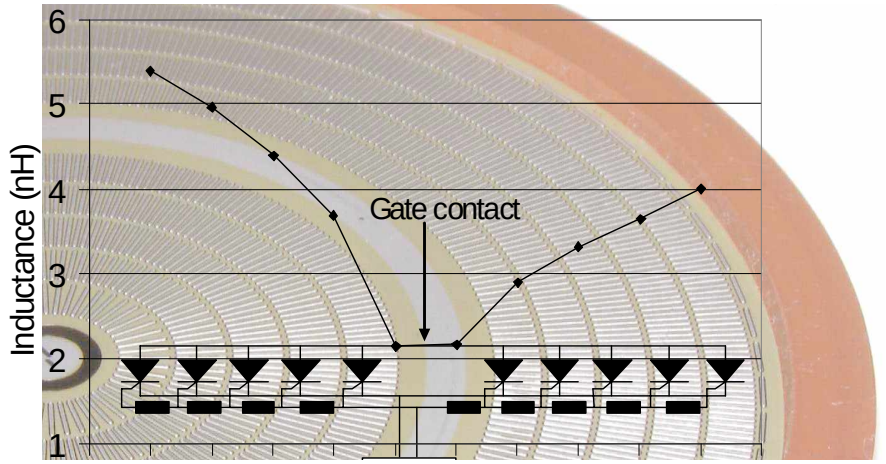

Fig. 2. A graphical representation of the inductive situation (simulated values) of the individual segment rings on an IGCT wafer – The circuit diagram shows how inductances can be distributed over the wafer. The rings far away from the gate contact are more heavily loaded by inductance than the rings in the vicinity. Hence, the gate signal will propagate at some finite speed and disfavour the gate-remote regions.

2. The high-power technology – design elements

The enablers for very high current turn-off is a combination of improving the local ruggedness of the silicon device itself by employing p-base corrugation, and increasing the gate's reach by minimizing the impedance, mostly in the gate driver circuit itself.

The p-base corrugation used for improving local ruggedness, albeit subject to optimizations for this voltage class, has been described in [1,2,3,4] and perhaps also elsewhere. Finding the optimum means trading off many parameters, such as blocking capability, thermal budget, process limitations and ruggedness. In general, the higher the device voltage, the deeper and more highly doped the p-base has to be made.

The improvements to the gate unit include improving aging of the capacitors used, using a 6- instead of 4-layered PCB substrate, increasing the parallel connection of the turn-off channel by increasing the number of MOSFET switches and capacitors, as well as optimizing the layout of the components on the gate unit.

A further improvement on the gate unit is the possibility to equip the IGCT with an anode-voltage sensing feature to improve the applicability of the device, facilitating early error detection.

For loss optimization, the IGCT technology can utilize all commonly used lifetime adjustment techniques. The 5.5kV device was designed using electrons and proton irradiation from the anode side, in which case the overall losses improve significantly.

3. 5.5kV Device capabilities

Dynamic electrical testing was carried out in a circuit displayed in Fig. 3. The clamp circuit used to protect the freewheeling diode is close to the application and facilitates rapid and reliable testing, as opposed to measuring replicas of inverters.

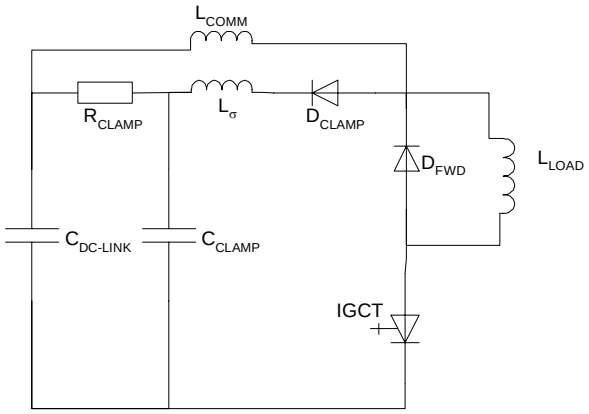

Fig. 3. The circuit used in dynamic testing of the IGCTs. Parameters : C_{CLAMP} = 8µF, L_{σ} = 300nH, R_{CLAMP} = 0.6 Ω, L_{COMM} = 6 µH.

Losses and SOA were evaluated in the dynamic circuit, both as single pulse as well as at burst frequency (10kHz) for special applications. Samples of waveforms from SOA measurements are presented in Fig. 4. Noteworthy is that SOA testing was interrupted as the maximal voltage reached 6kV during testing. Beyond 6kV, one would risk a blocking failure in the clamp-circuit discharge following the switching transient, which would not add any information, as this condition would be far beyond specified capabilities.

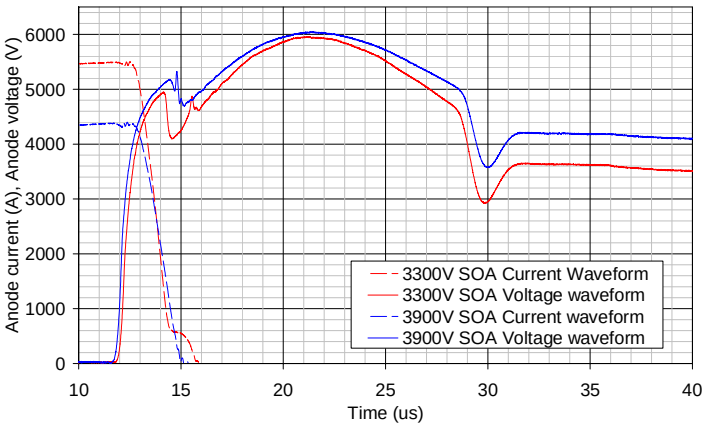

Fig. 4. The current handling capability of the 5.5kV HPT IGCT. At 3.3kV DC-link voltage, more than 5.5kV can be controlled (device testing stopped without destruction). At 3.9kV, the tests stopped at around 4.4kA.

The burst capability of the device was tested – five pulses at 10 kHz. As the temperature coefficient of the MCC is negative, the failures always occur at the fifth pulse. Due to limitations in the test circuit, it is not possible to test at constant current and voltage. Instead, the current increases and the voltage decreases as the pulse train progresses. In this mode, the IGCT withstands a current of around 4kA at a voltage of around 3 – 3.3kV. Of course, when switching at this speed, the process is more or less adiabatic which means that the wafer temperature is significantly higher than the allowed 125°C after pulse number 5, if the starting temperature is 112°C. A typical pulse pattern from the burst tests is presented in Fig. 5.

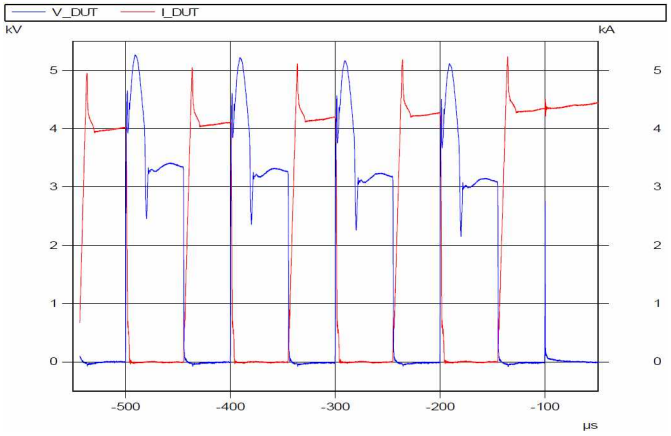

Fig. 5. Waveforms from the 10kHz burst measurement. This example failed at the fifth pulse, at 4.4kA.

The IGCT offers flexibility in loss optimization. Using electron irradiation, proton irradiation, or both, one can tailor the electron-hole plasma distribution to the best shape and tune the trade-off between static and dynamic losses to the best fit to the application. Thanks to the vast surplus of charge in the on-state, lifetime attenuating techniques can be utilized within a broad range. An example of this is presented in Fig. 6, where both proton- and electron irradiation were put to use.

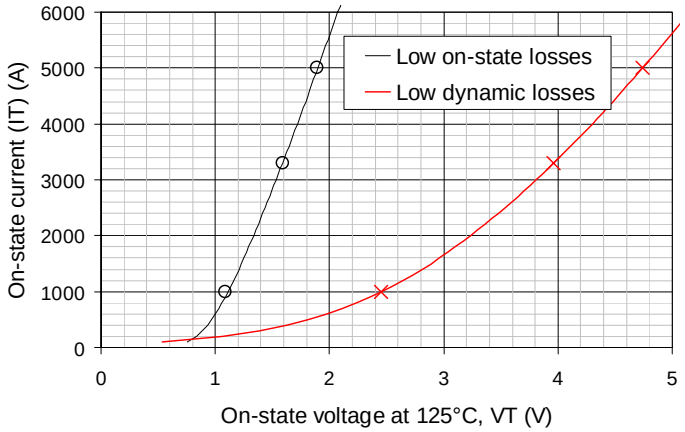

Fig. 6. Flexibility of On-state voltage tailoring in IGCT technology.

Using these lifetime tailoring techniques, a profound influence can be seen on the loss trade-off.

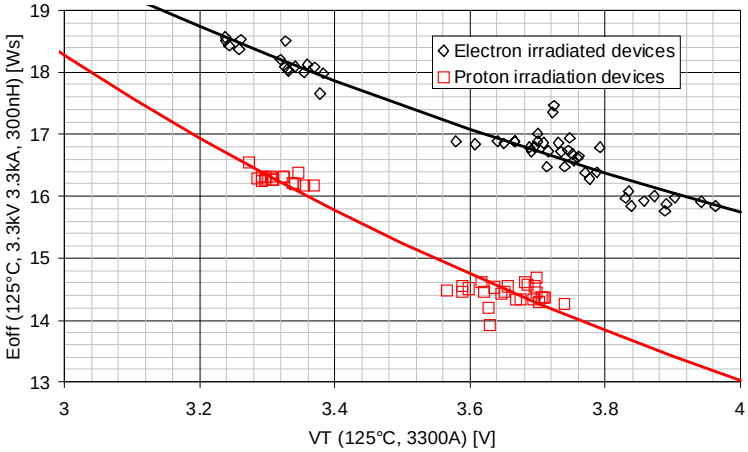

Fig. 7. Loss trade-off for the 5.5kA IGCT switching 3.3kA at 3.3kV with a Tj of 125°C. The rest of the circuit parameters are listed in the caption of Fig. 3.

The developed device was also subjected to extended reliability testing. Especially of interest with new silicon specifications and thyristor designs is the performance of the device in the presence of cosmic rays. The testing was done in a proton beam, for which a sound correlation to actual cosmic rays has been established, with the obvious advantage that the testing is done in a matter of hours instead of years.

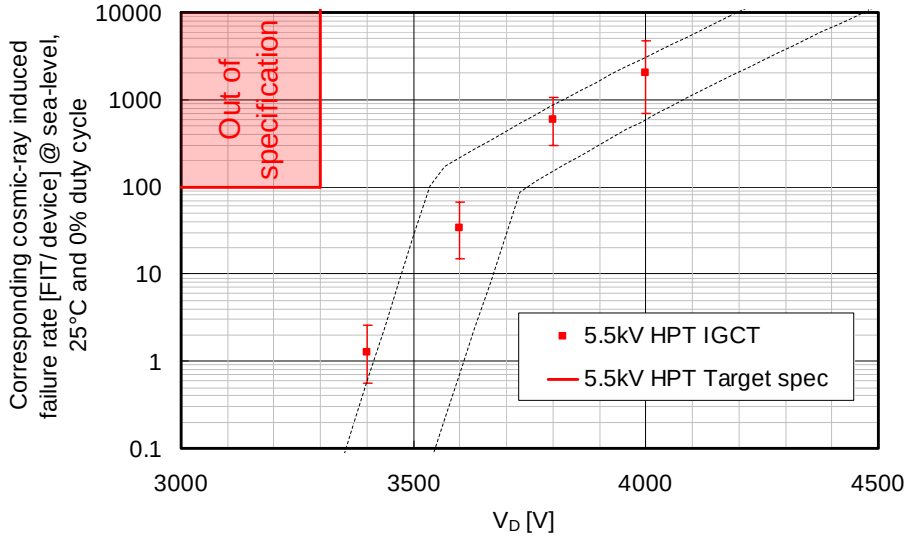

Fig. 8. Corresponding failure rates due to cosmic rays measured using biased devices in a high-energy proton beam. The specification can of course be used arbitrarily, however, the 100 FIT level has developed as a standard where failures due to cosmic rays will be a significant mechanism in the field.

4. Conclusion

A High-Power IGCT has been presented for application at 3.3kV DC-link, maximally 5.5kV peak. The device has a maximally controllable current specified to 3.6kA, but in reality exceeding 5.5kA and 3.9kV. The device shows significant flexibility in tuning to specific requirements, as well as applicability in very harsh conditions, such as the 10kHz pulse burst.

5. Literature

[1] Stiasny, „Large area IGCTs with improved SOA", in Proc. ISPSD 2004
[2] Wikström, „The High performance corrugated p-well IGCT - a new landmark in large area SOA scaling", Proc. ISPSD 2007
[3] Nistor, „An IGCT chip set for 7.2 kV (RMS) VSI application", in Proc. ISPSD 2008
[4] Arnold, „High-Temperature Operation of IGCTs", in Proc. PCIM, 2011