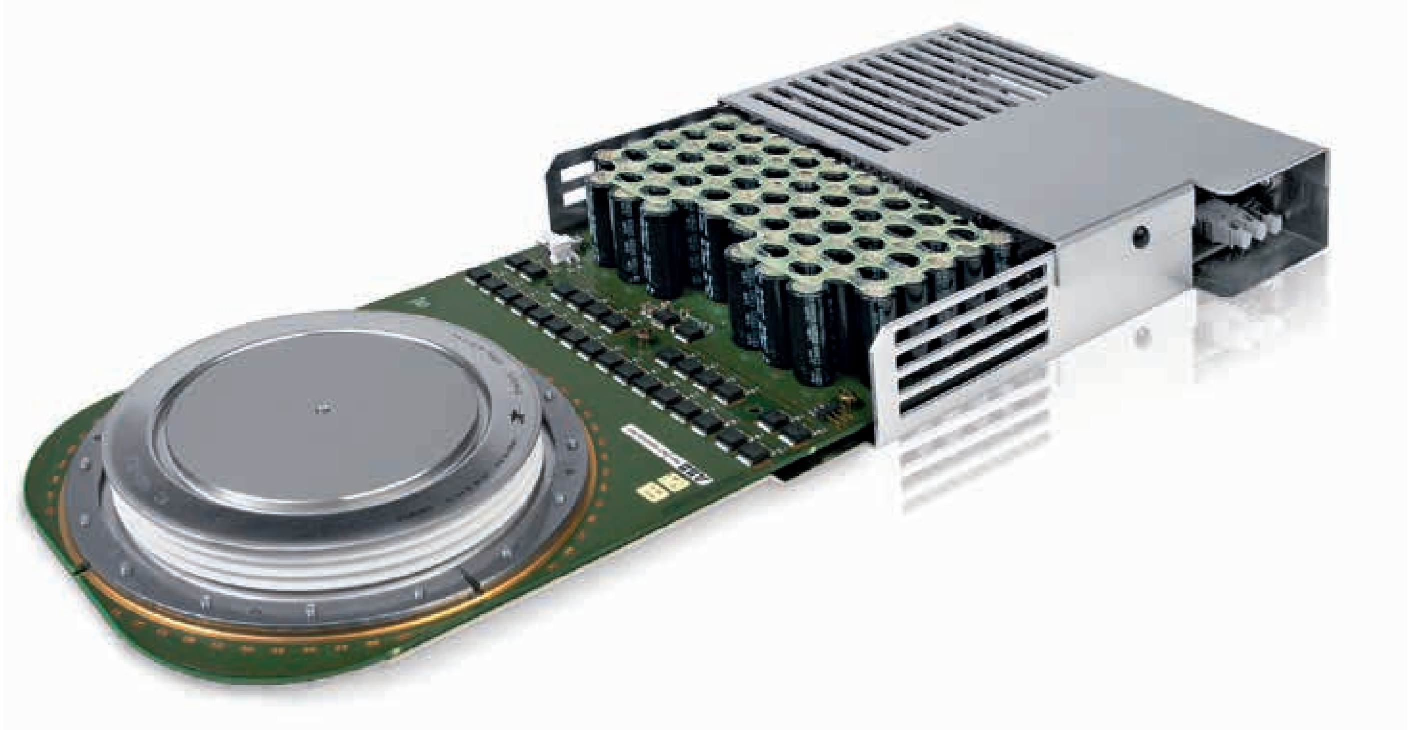
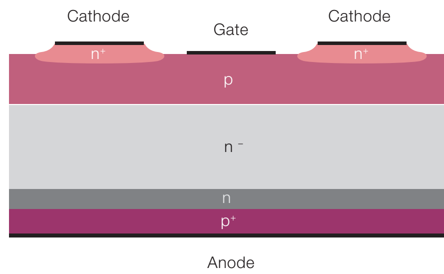


Switching the subject

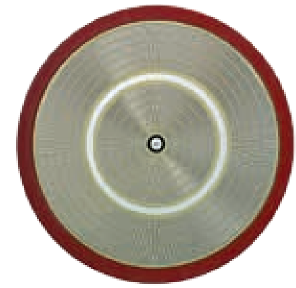
A look at recent advances in IGCT technologies for high-power electronics

UMAMAHESWARA VEMULAPATI, MUNAF RAHIMO, MARTIN ARNOLD, TOBIAS WIKSTRÖM, JAN VOBECKY, BJÖRN BACKLUND, THOMAS STIASNY – In the mid-1990s, ABB introduced a new member of the power electronics family – the integrated-gate commutated thyristor (IGCT). Like the gate turn-off thyristor (GTO) from which it evolved, the IGCT is a fully controllable semiconductor switch that can handle the high currents and voltages prevalent in high-power electronics applications. The IGCT has a better performance than the GTO regarding turn-off time, size, the degree of integration, power density, etc. and this superiority has helped it become the device of choice for industrial medium-voltage drives (MVDs). It has also found use in many other applications such as wind-power conversion, STATCOMs and interties. IGCT technology development has made rapid progress over the past decade.

1 IGCT device



1a Schematic cross-section of an asymmetric IGCT



1b Top view of a 91 mm IGCT wafer

1c The IGCT wafer in a hermetic package and with its integrated gate unit

In many ways, an IGCT is similar to a GTO. Like the GTO, the IGCT is basically a switch that is turned on and off by a gate signal. However, IGCTs have advantages over GTOs: They can withstand higher rates of voltage rise (so no snubber circuit is needed); conduction losses are lower; turn-off times are faster and more controllable; cell size on the silicon wafer is smaller; and the solid gate connection used by IGCTs results in lower inductance. Furthermore, the IGCT drive circuit is integrated into the package [1] ➔ 1.

In the past couple of decades, IGCTs have become ubiquitous in high-power electronics and are now available in voltage ratings ranging from 4.5 kV to 6.5 kV and in three main types: asymmetric, reverse-conducting (RC-IGCT) and symmetric or reverse-blocking (RB-IGCT).

- Asymmetric IGCTs cannot block reverse voltages of more than a few tens of volts. Consequently, they are used where such a voltage would never occur – for example, in a switching power supply – or are equipped with an appropriate anti-parallel diode to conduct currents in the reverse direction. Asymmetric IGCTs have the highest power level for a given wafer size.
- RC-IGCTs have a diode integrated into the same GCT wafer to conduct currents in the reverse direction, but this uses wafer area that could otherwise be used for switching function capacity.
- Symmetrical IGCTs are inherently able to block reverse voltages, but conduct currents only in the forward direction.

The hermetic press-pack design of the IGCT has for years proven its reliability in the field.

The hermetic press-pack design of the IGCT has for years proven its reliability in the field with respect to power semiconductor device protection and load cycling capability. Consisting of a few layers of well-designed materials there are no issues with solder voids or bond liftoff, as is experienced by other technologies.

IGCT performance trends

In the past ten years, IGCT technology has seen major advances, especially regarding lower conduction losses and higher power densities ➔ 2. Power increases have come from achieving lower losses and/or higher operating temperatures, chiefly enabled by an increased device safe operation area (SOA) that allows higher turn-off current. Absolute power has been increased by enlarging the state-of-the-art 91 mm diameter wafer to 150 mm and integration concepts that provide full functionality with a single wafer device instead of employing two devices (IGCT and diode).

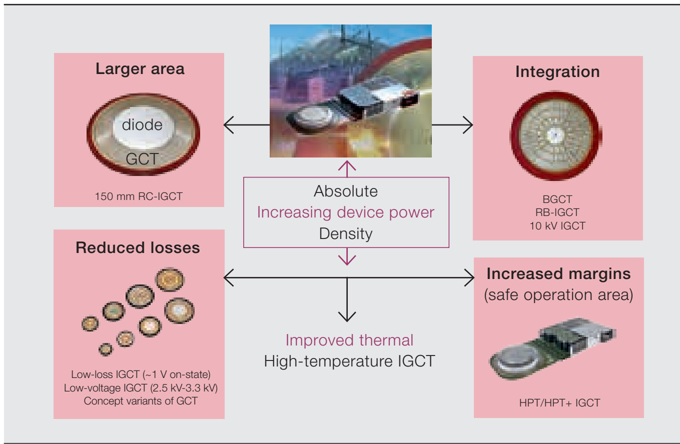
Increased margins: high-power technology

The main limiting factor in conventional IGCTs relates to the maximum controllable turn-off current capability and not losses or thermal constraints. Therefore, the introduction of the high-power technology (HPT) platform [2] has been hailed as a major step forward in improving IGCT SOA performance while providing an enabling platform for future development.

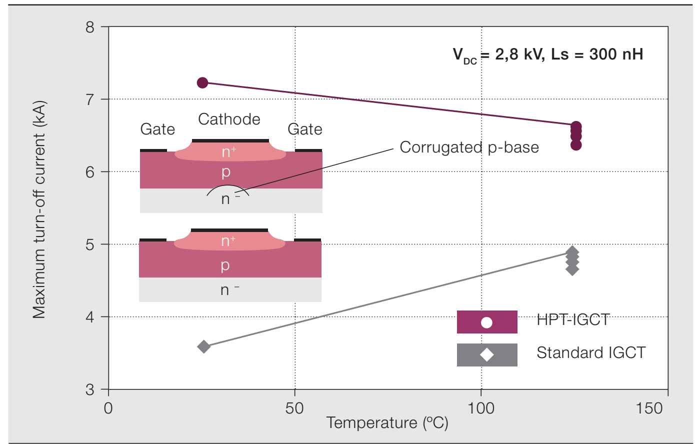
An HPT-IGCT gives an increase in the maximum turn-off current of up to 40 percent at 125 °C. HPT-IGCTs incorporate an advanced corrugated p-base design – compared with a standard uniform p-base junction – that ensures controlled and uniform dynamic avalanche operation with better homogeneity over the diameter of the wafer during device turn-off ➔ 3. The HPT has been proven for IGCT products with voltage ratings of up to 6.5 kV. In tests, 91 mm, 4.5 kV HPT-IGCTs have turned off currents in excess of 5 kA, withstanding extreme conditions with a large stray inductance.

Title picture
The invention of IGCTs has changed the rules in the power electronics landscape. Pictured is an ABB IGCT with gate unit.

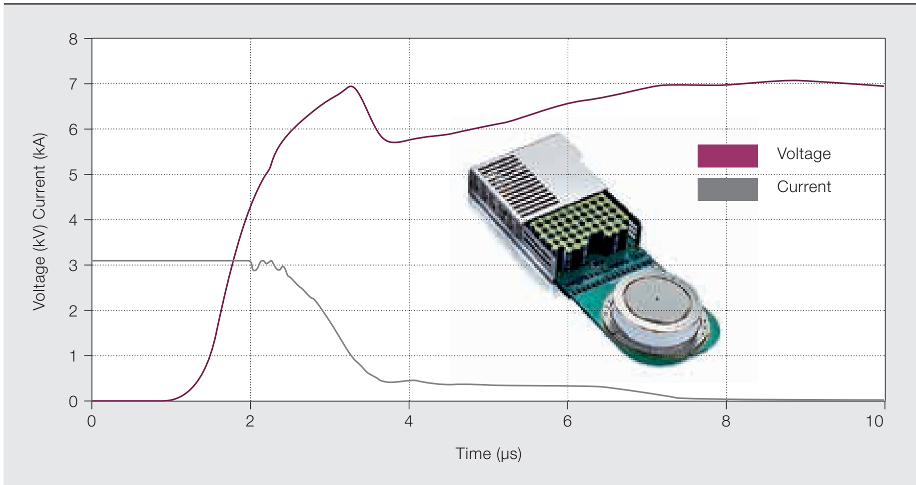
2 IGCT development trends for achieving lower losses and/or higher power handling capabilities



3 Experimental results of the HPT-IGCT maximum controllable turn-off current capability against a standard IGCT



4 91 mm, 10 kV IGCT and its measured turn-off waveforms at 3.3 kA, 5.5 kV and 125 °C



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Integration: RB-IGCT

In some cases – such as with a solid-state DC breaker, in AC applications or in current source inverters (CSIs) – a symmetrical blocking switching device is required. Although this could be accomplished by using an asymmetric IGCT connected in series with a fast diode, the preferred solution is a symmetric IGCT in a single wafer. Since the required performance and some modes of operation are different from other IGCTs, device design optimization is needed to achieve the reverse-blocking performance along with low losses and robust switching performance. Both 6.5 kV RB-IGCTs for CSI applications and 2.5 kV RB-IGCTs for bi-directional DC breaker applications have been developed. A 91 mm, 2.5 kV RB-IGCT, for example, has been demonstrated with an on-state voltage drop as low as 0.9 V at rated current (1 kA) at 125 °C and a maximum controllable turn-off current capability up to 6.8 kA at 1.6 kV, 125 °C [3].

Integration: high voltage ratings (10 kV IGCT)

It would be possible to make a three-level inverter without series connection for line voltages of 6 to 6.9 kV if IGCTs with a voltage rating in the range of 8.5 to 10 kV were available. Such a device offers simple mechanical design, less control complexity and high reliability compared with the series connection of two 4.5 or 5.5 kV devices for line voltages of 6 to 6.9 kV. To prove the feasibility of this approach, devices rated at 10 kV have been manufactured using the HPT platform and the concept has been shown to work [4] ➔ 4.

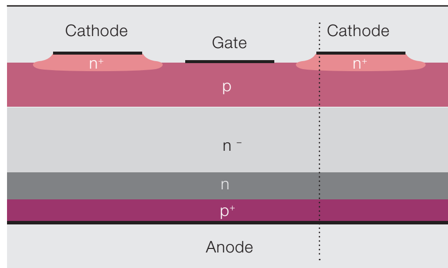
Improved thermal performance: high-temperature IGCT (HPT+)

One way to increase the output power of an existing converter design is to increase the temperature rating of the power semiconductor device used. For continuous operation, however, the cooling system capabilities may limit this increase. For intermittent high-power operation, though, a temperature increase can be a valid option and the HPT-IGCT can be improved to accommodate this. Accordingly, the corrugated p-base doping profile was further optimized to allow a full SOA in the whole temperature range up to 140 °C. Also, the internal interfaces, such as the metallization on the wafer, were improved to reach a higher thermomechanical wear resistance. The verification of these improvements has started and the first results look promising. Also, this so-called HPT+ technology has a clearly improved technology curve compared with HPT-IGCT due to its optimized corrugated p-base design [5].

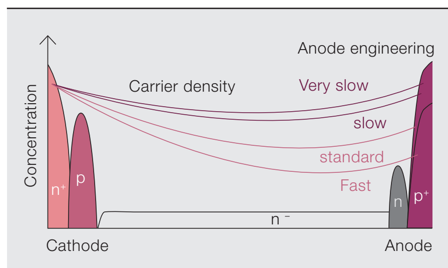
Reduced conduction losses: toward a 1 V on-state, 3.3 kV IGCT

In recent years, there has been a clear trend toward using multilevel topologies in many power electronics applications. Such products often operate at fairly low switching frequencies but at the same time require high current-carrying capabilities and/or high efficiency. Due to its inherent low-conduction-loss thyristor

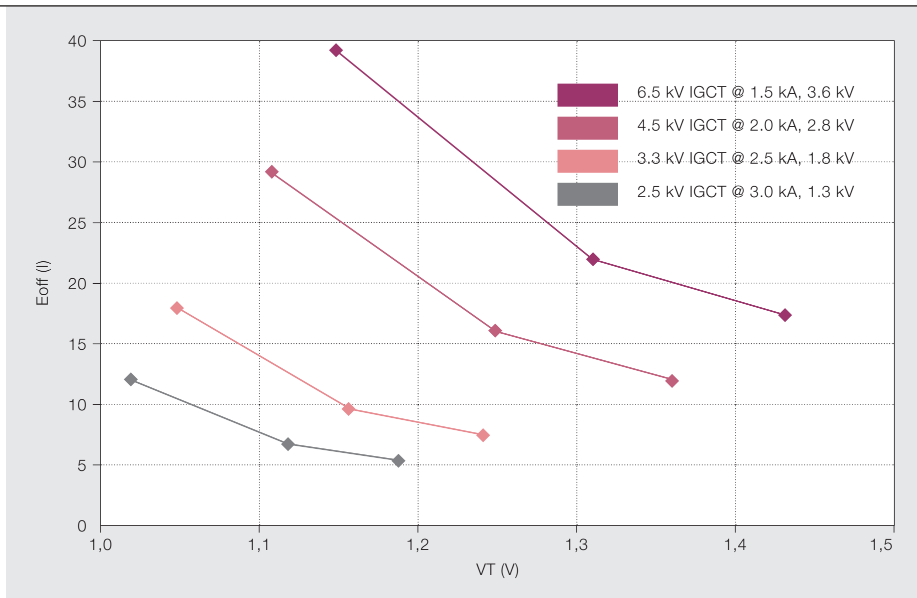
5 IGCT anodic engineering



5a IGCT structure



5b IGCT doping and anode engineering carrier profiles along the section a'–a



5c Technology curves of different voltage class 91 mm IGCTs at 125 °C achieved through anode engineering

Power increases have come from achieving lower losses and/or higher operating temperatures, chiefly enabled by an increased device SOA that allows higher turn-off current.

properties and hard-switched functionality, the IGCT is predestined for these applications. Therefore, further optimization is required to achieve very low on-state voltages (~1 V) through anode engineering while maintaining good overall performance ➔ 5.

Since there is a certain amount of freedom in selecting the device voltage for a multilevel system, a number of simulations and experiments have been performed for a wide range of voltage classes to see what performance can be achieved [6]. The available results are summarized in ➔ 5 and give input to the designers of multilevel converters to see how the systems can be optimized with respect to the minimum total inverter losses for a given topology, voltage rating and current rating.

Furthermore, first prototype samples of 3.3 kV RC-IGCTs were manufactured to verify the simulation results. Three different anode injection trials were carried out (A1, A2 and A3) to ensure the potential of 3.3 kV RC-IGCTs to achieve very low conduction losses even at higher currents with reasonable switching losses [7].

Larger area: 150 mm RC-IGCT

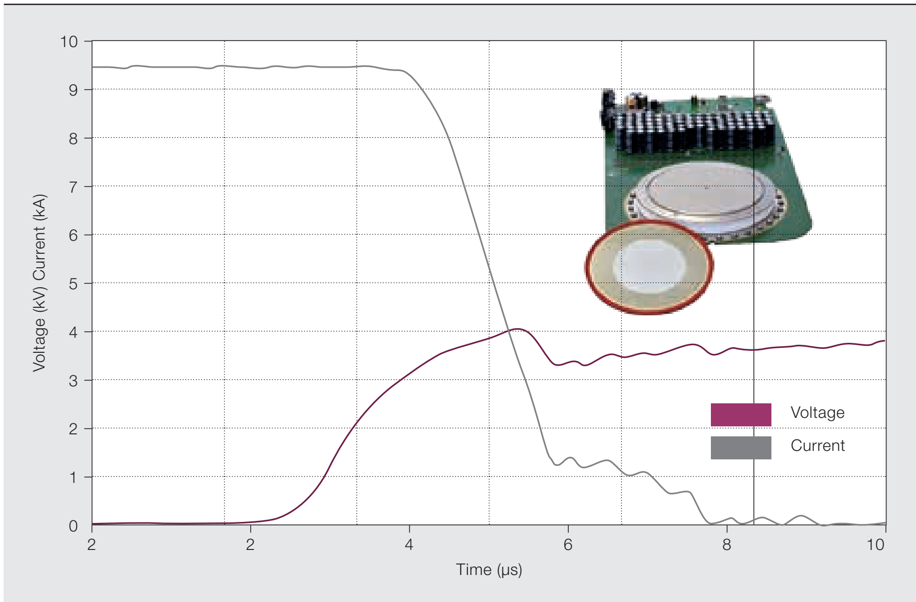
The quest for ever-greater power ratings makes larger silicon diameters inevitable. Compared with the previous technology, HPT has an improved scalability that enables the design of devices beyond the standard 91 mm wafer size. The first 150 mm, 4.5 kV RC-IGCT prototypes based on HPT+ technology have recently been manufactured. With these devices, it will be possible to make three-level inverters up to about 20 MW without the need for series or parallel connection of power semiconductor devices [8] ➔ 6.

Future trend: Full integration with bi-mode gate-commutated thyristor

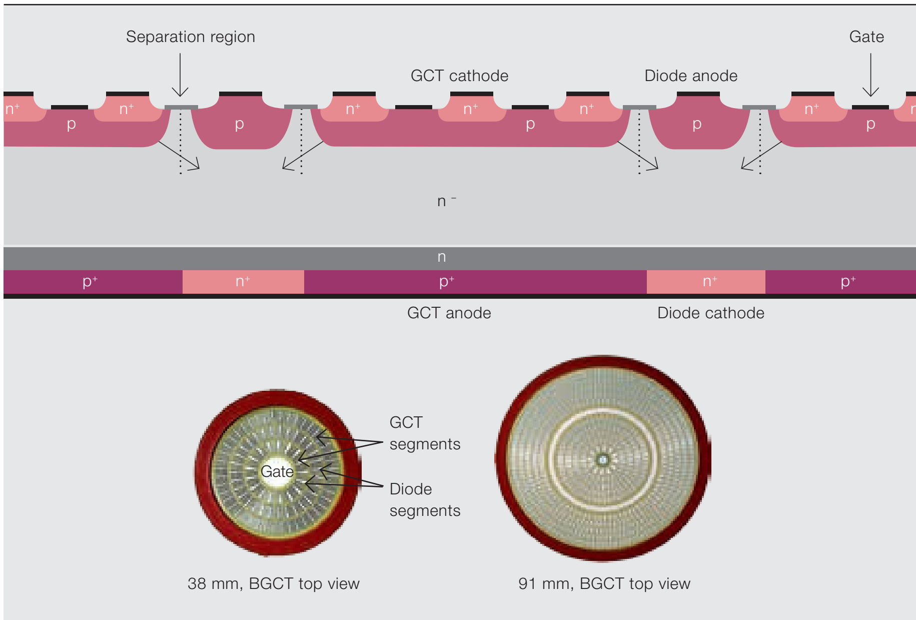
The conventional RC-IGCT enables better component integration in terms of process and reduced parts count at the system level, and therefore improved reliability. As explained above, in an RC-IGCT the GCT and diode are integrated into a single wafer, but they are fully separated from each other as shown in ➔ 2. Consequently, in the RC-IGCT, the utilization of the silicon area is limited in the GCT region when operating in GCT mode and in the diode region when operating in the diode mode. Therefore, a new fully integrated device concept (interdigitated integration) was developed that resulted in the bi-mode gate-commutated thyristor (BGCT), which integrates IGCT and diode into a single structure while utilizing the same silicon volume in both GCT and diode modes [9] ➔ 7. Each segment acts either as GCT cathode or diode anode.

This interdigitated integration results not only in better usage of the diode and GCT areas but also better thermal distribution, softer reverse recovery and lower leakage current compared with conven-

6 150 mm, 4.5 kV RC-IGCT and its measured turn-off waveforms at 9.5 kA, 2.8 kV and 125 °C



7 Schematic cross-section of the BGCT and fabricated 38 mm and 91 mm, 4.5 kV BGCT prototypes



The introduction of the HPT platform has been hailed as a major step forward in improving IGCT SOA performance.

tional RC-IGCTs. The BGCT concept has been demonstrated experimentally with 38 mm, 4.5 kV as well as 91 mm, 4.5 kV prototypes [10] and the results confirm the potential advantages of the BGCT over conventional RC-IGCT.

This review of recently introduced IGCT technologies with improved performance and functionalities provides only a glimpse of the promising field of IGCT technology. Power electronics systems designers face an exciting future of further device improvements, with the prospect of devices with even higher operational temperatures, even better reverse blocking and reverse conducting functionalities, lower losses delivered by a 1 V on-state, a wider range of voltage ratings and larger areas up to 150 mm and beyond.

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