Power semiconductors
Product brochure 2017

ABB

Contents

Introduction

ABB is a leading supplier of power semiconductors with production facilities in Lenzburg, Switzerland, and Prague, Czech Republic, as well as a new research laboratory for wide bandgap semiconductors in Baden-Dättwil, Switzerland.

ABB's success story in power electronics began more than 100 years ago with the production of mercury-arc rectifiers in Switzerland. Over the past 60 years, ABB has played a pivotal part in the development of power semiconductors and their applications.

This product brochure compiles broad background information on ABB's full range of thyristor and IGBT power semiconductors, which – until recently – has been provided by various product flyers.

For information that's more technical please contact us or see our
- Product catalog
- Application notes
- Data sheets
- SEMIS – ABB's semiconductor online simulation tool

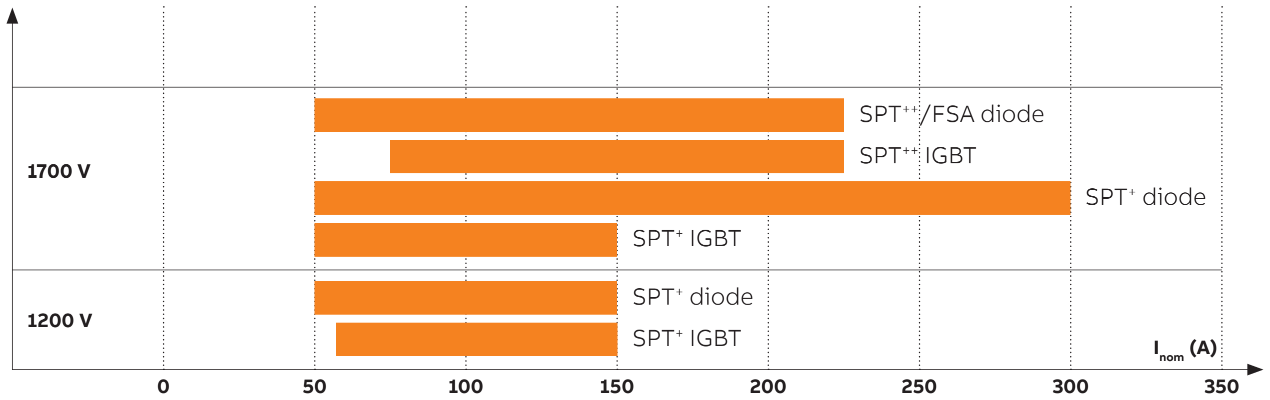
All of the above mentioned is available for download on our website www.abb.com/semiconductors.

IGBT and diode dies

ABB Semiconductors' range of SPT⁺ and SPT⁺⁺ (soft punch through) IGBT and diode chips is available at 1200 and 1700 V with currents ranging from 50 to 300 A.

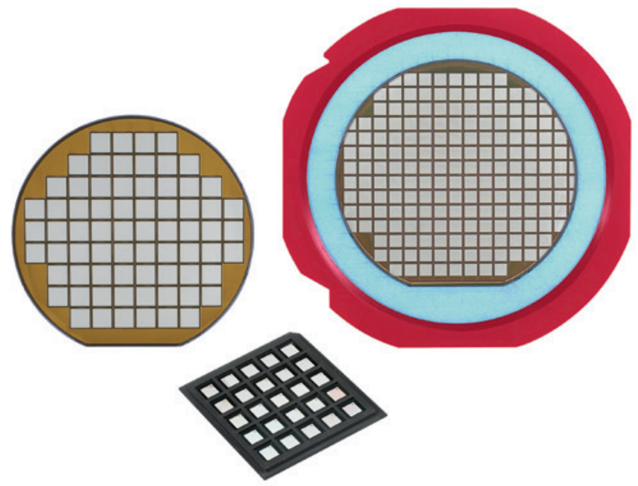
Their main applications include power converters for industrial drives, solar energy, battery backup systems (UPS) and electrical vehicles for 1200 V and industrial power conversion & drives, wind turbines and traction converters for 1700 V.

Power map



IGBT and diode dies

1. IGBT and diode dies



When looking for chipsets, featuring highest switching performance, ruggedness and reliability, ABB's IGBT and diode chips with state of the art soft punch through (SPT) planar technology are the preferred choice.

ABB Semiconductors has a well-established reputation in the field of high power semiconductors for switching devices. This is reflected in the most complete product portfolio of any supplier of high power semiconductors.

ABB's power semiconductor BiMOS chipsets, ie IGBTs and their accompanying free-wheeling diodes, are best in class in terms of switching performance, ruggedness and reliability. Thanks to a moderate chip shrinkage and thus larger die area, we are able to offer the highest output power per rated ampere in the industry.

The newly introduced 1700 V SPT⁺⁺ chipset is the world's first 1700 V chipset that offers an operational junction temperature of up to 175 °C. This allows the module designer to increase the power density of power modules significantly. The broad number of different current ratings and sizes supports the various requirements in package design and output power. All chipsets are for solder mount-down and wire bonding in modules.

The IGBT

ABB offers its IGBTs in the advanced SPT⁺ technology which means customers benefit from a conduction loss reduction of 20..30 % compared to the previous SPT technology.

Figure 1 shows the basic difference between SPT⁺ and SPT⁺⁺. The development target was to reduce the on-state losses by introducing an N-enhancement layer surrounding the channel-P-well. This improves the plasma concentration on the emitter side and therefore, lowers the on-state losses. With the introduction of the SPT⁺⁺, the profile of the said N-enhancement layer was further optimized with the main goal to make another step in conduction loss improvement. Together with thinner silicon, a reduction in $V_{CE\ SAT}$ of half a volt was possible.

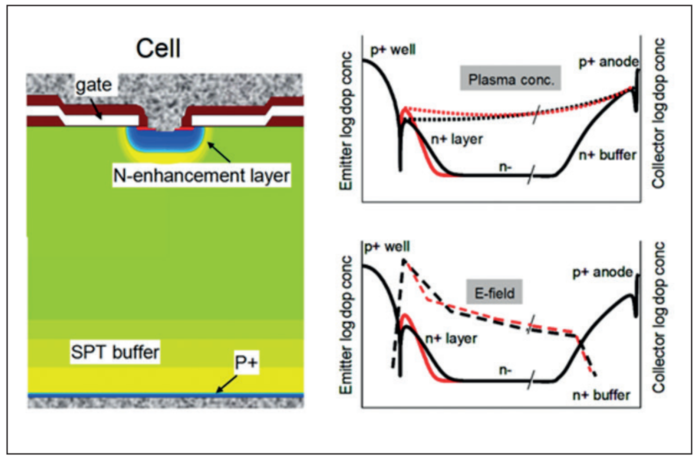


Fig. 1 SPT⁺ planar IGBT enhanced carrier profile

Figure 2 shows the on-state curves of the newest SPT++ IGBT chip with 150 A rating at different temperatures. The SPT+ IGBT shows a positive temperature coefficient of $V_{CE\,on}$, already at low currents, which enables a good current sharing capability between the individual chips in the module.

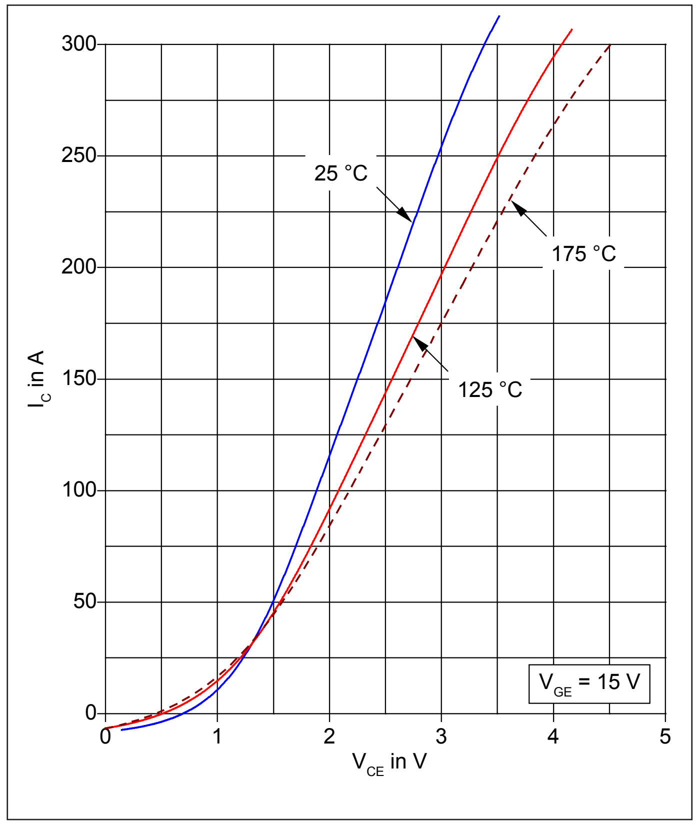


Fig. 2 On-state curves of the 150 A 1700 V SPT+ IGBT (module level measurements)

Figure 3 shows the turn-off of a 150 A 1700 V SPT++ IGBT under nominal conditions at 175 °C. The IGBT exhibits controlled switching characteristics as well as short current tails. This behavior is enabled by the combination of SPT buffer design and silicon resistivity used in SPT++ technology, which provides fast switching with low losses and low overshoot.

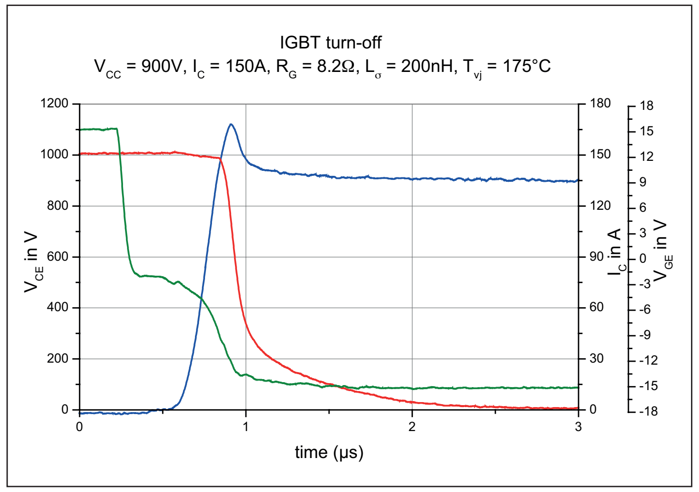


Fig. 3 IGBT turn-off of a SPT++ 150 A 1700 V IGBT

The diode

The diode of the new SPT++ chipset is based on an advanced pin-diode design using the FSA (field-shielded anode). A schematic cross-section is shown in figure 4. In contrast to more conventional design, the FSA diode has a double anode with a deep diffused P-well that shields the field from the anode and the irradiation. Thus a significant leakage reduction can be achieved without sacrificing the excellent robustness and low losses of the ABB diodes.

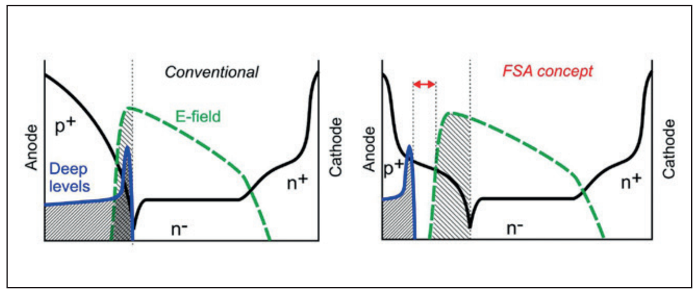


Fig. 4 Schematic cross-section of the diode

The typical forward characteristics is shown in figure 5. Figure 6 shows the reverse recovery characteristics of a 150 A 1700 V diode under nominal conditions at 150 °C. The current transients during switching are very smooth and soft.

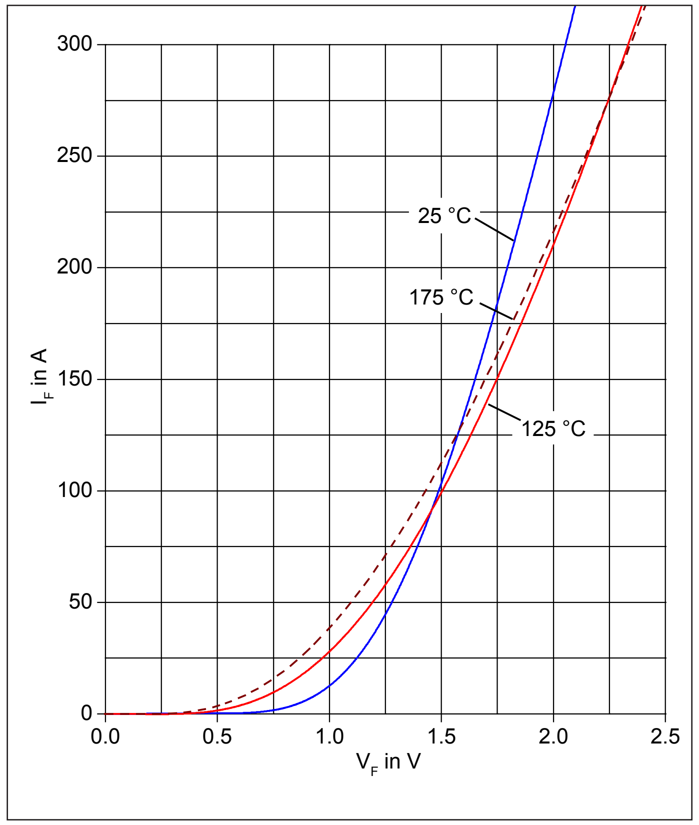


Fig. 5 V_F curve of a 150 A 1700 V FSA diode

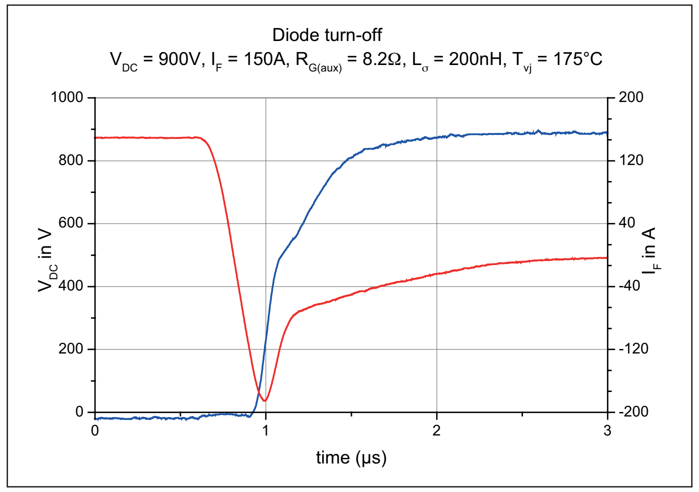


Fig. 6 Reverse recovery of a 1700 V 150 A diode

Reliability

The reliability of the chipsets is confirmed using a combination of standard tests including HTRB (high temperature reverse bias), HTGB (high temperature gate bias), THB (temperature humidity bias), cosmic ray test and a newly developed test, which combines high temperature, high humidity and high voltage.

To extend the reliability of the chipsets for extreme environmental applications, the chipset designs additionally feature a state of the art double-layer passivation of silicon nitride and polyimide. The polyimide layer has the advantage of mechanically protecting the first passivation layer, acting on the termination as a delay-barrier against humidity and ion-penetration from outside and preventing sparking across the termination during high-voltage operation.

Detailed technical information

More detailed product information is available in our latest Product Catalog, the data sheets or directly on the ABB Semiconductors website (www.abb.com/semiconductors). For further very valuable information, including data sheet user guide, testing, shipment, storage, handling and assembly recommendations please refer to our Application Note 5SYA 2059 «Applying IGBT and diode dies» which is also available on our website.

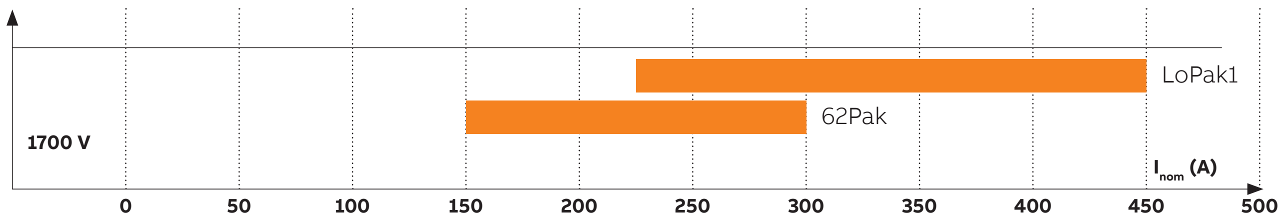
Medium-power IGBT modules

Coming from high-power semiconductors, ABB is regarded as one of the world's leading suppliers setting standards in quality and performance. ABB's unique knowledge in high-power semiconductors now expands to industry standard medium-power IGBT modules.

ABB launched its medium-power IGBT offering three 1700 V 62Pak phase leg modules, rated 150, 200 and 300 A. For 2017 the 1700 V LoPak1 dual/phase leg module will be launched with current ratings of 225, 300 and 450 A. The LoPak1 is 100 % mechanically compatible with EconoDual type modules. The portfolio will be further expanded with the 1700 V LoPak3 six-pack IGBT module being the next product to be launched.

Key benefits of the ABB medium-power IGBT modules are
– ultra low-loss and rugged SPT++ chipset
– smooth switching SPT++ chipset for good EMC
– Cu baseplate for low thermal resistance
– industry standard packages

Power map



Medium-power IGBT modules

2. 62Pak IGBT modules

The 62Pak modules feature industry standard housings and are designed for very low losses and highest operating temperatures.

Typical applications include:
– Variable speed drives
– Power supplies
– Power quality
– UPS
– Renewable energies

Feature	Customer value
Proven concepts from reliable traction rated HiPak modules are used	
Spacers for substrate solder – homogeneous solder thickness, less delamination	higher lifetime under cyclic loads (e.g. thermal cycles)
Pre-bowed and stamped baseplate – reduced gap and lower interface resistance to sink, less grease pump-out	higher themal utilization more power, higher lifetime
Spacers for main terminal solder – homogeneous and thus stronger solder layer	higher lifetime under cyclic load and more robust against vibrations

3. LoPak1 IGBT modules

The LoPak1 module is 100 % mechanically compatible with the Econo-type dual IGBT modules. The ABB LoPak1 sets a new benchmark with full switching performance up to 175 °C.

It is specifically designed for excellent internal current sharing offering optimal thermal utilization and increased robustness. Thus customers can expect larger safety margin and increased lifetime.

Typical applications include:
– Wind power converters
– Variable speed drives
– Power supplies
– Power quality
– UPS
– Renewable energies

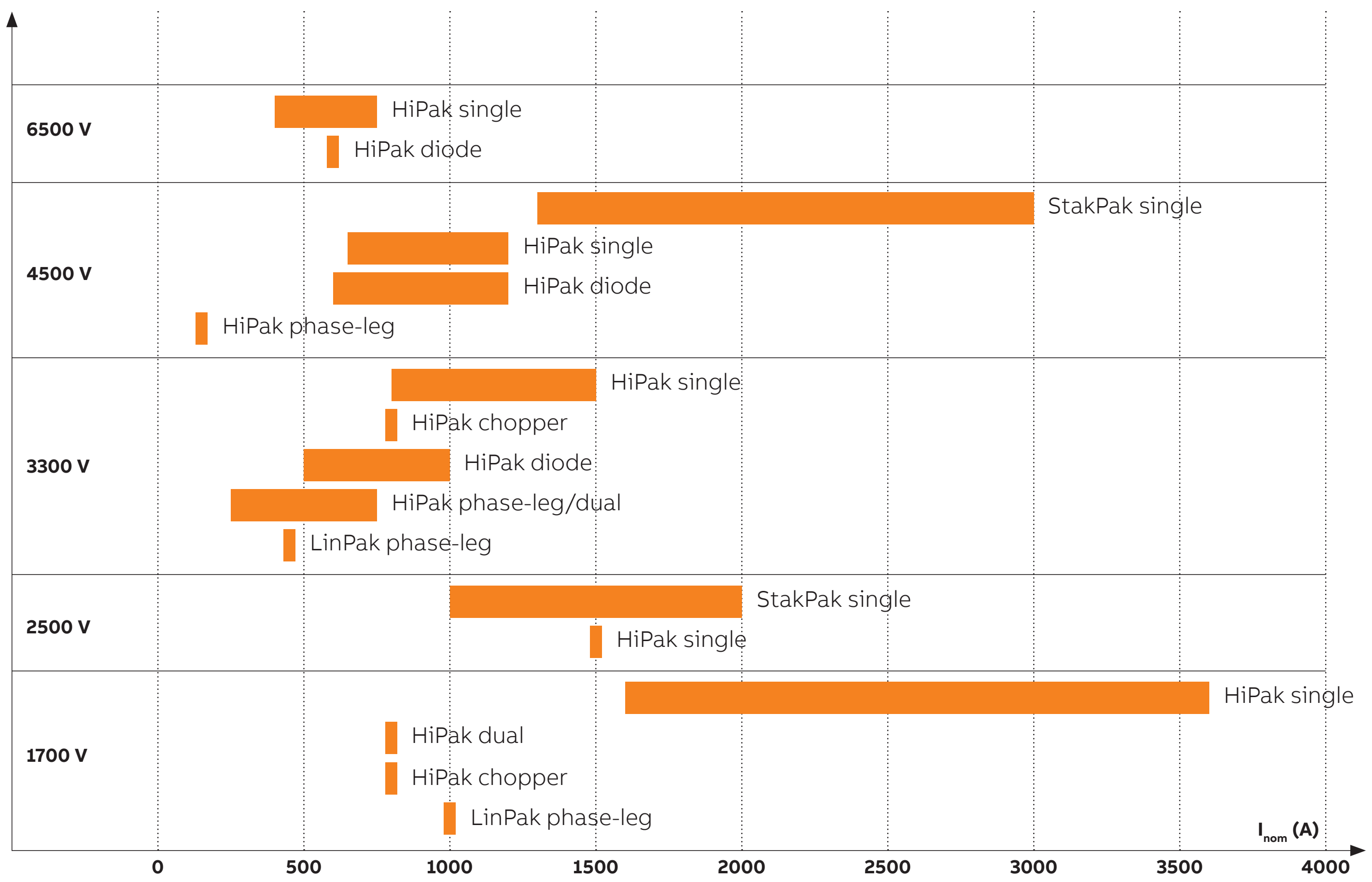
Feature	Customer value
Special treated Cu-baseplate – controlled bow and reduced airgap to heat sink. This yields to a lower thermal interface resistance and significantly reduce grease pump-out	higher thermal utilization, more power, higher lifetime
Spacers for substrate solder – homogeneous solder thickness, less delamination	higher lifetime under cyclic loads (e.g. thermal cycles)
Press-fit auxiliary connections – Press-fit auxiliary pins that allow a solder-free connection to the gate-driver PCB. – Press-fit pins can also be soldered	– Simplified attachment of gate-driver saves manufacturing costs. – Higher reliability compared to solder connection
Copper wire bonds for high current terminal and substrate inter-connects	– lower connection resistance/losses

High-power IGBT modules

ABB offers the three high-power IGBT and diode module families LinPak, HiPak and StakPak. They are available in various configurations including singles and duals, choppers and phase legs, covering voltage and current ranges from 1700 to 6500 V and 150 to 3600 A, respectively.

The LinPak is an enabler for more reliable, efficient and compact inverter designs in traction applications such as regional trains and metros but as well locomotives and high-speed trains and also serves markets such as OHV (off-highway-vehicle) and industrial converters for drives and wind power. HiPaks are the perfect match for demanding high-power applications such traction, renewable energy (wind, solar), industrial drives and T&D. The StakPak is ideally suited for use in multiple-device stacks as for instances in high-voltage DC transmission (HVDC) applications.

Power map



HiPak, StakPak and LinPak

4. LinPak IGBT modules

ABB presents a new open standard phase leg module, the LinPak. The innovative LinPak concept answers the market's request for a new package that offers exceptionally low stray inductance and, due to separated phase- and DC-connections, allows for simpler inverter designs. The low-inductive phase leg IGBT module LinPak is available at 1700 and 3300 V.

Features

The very low-inductive internal module design and the massive DC-connection enables both, a very low-inductive busbar design and a high current carrying capability. Both are desperately needed for state of the art silicon chipsets and even more for future SiC solutions. The LinPak module design results in excellent internal and external current sharing, making it ideally suited for paralleling. It thus renders possible a large range of current ratings with just one article. Derating-free paralleling is possible up to at least four modules. Moreover, the LinPak features an integrated temperature sensor and has a dedicated mounting area for a gate drive adapter board. For harsh environments in traction or off-highway vehicle applications, the adapter board can be additionally fixed with four screws in the module corners. This new open standard external module design can be freely used from all module manufacturers, as long as the outline and terminal positions are kept identical. So far at least two major suppliers are committed to this new high-power IGBT package.

The 3300 V / 2 x 450 A LinPak offers a fast and low switching loss SPT^{+} chipset that ideally fits to the LinPak module. The LinPak is the first 3300 V module with an integrated temperature sensor and offers unrivaled reliability thanks to well-matched materials such as AlN insulation and AlSiC baseplate, as well as advanced wire bonding techniques and particle free ultrasonic welded main connections.

The 3300 V LinPak is an enabler for more reliable, efficient and compact inverter designs in traction applications such as regional trains and metros but as well locomotives and high-speed trains. It also serves markets such as OHV (off-highway-vehicle) and industrial converters for drives and wind power.

Developments

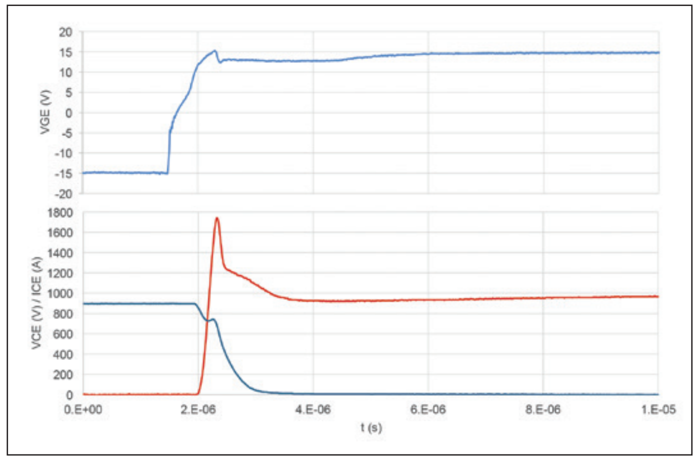
Based on the shown concept, ABB has developed highly reliable traction rated modules, starting with 1700 V / 2 x 1000 A followed by a 3300 V / 2 x 450 A module. Also Cu-based industrial versions at 1700 V and later 1200 V are targeted. High-voltage traction versions with the same footprint, but rearranged electrical connections in order to cope with the higher clearance and creepage requirements are also in consideration.

LinPaks	Voltage (V)	Current (A)
AlSiC[1] / (Cu*)	1700	2 x 1000
AlSiC[2]	3300	2 x 450

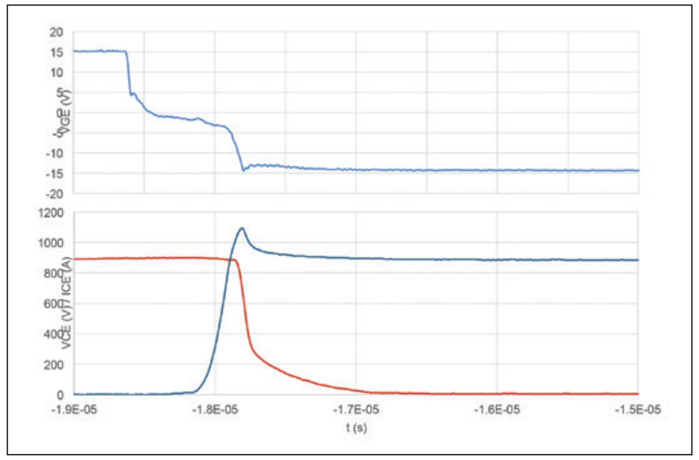
[1]Mass production Q2 2017
[2]Samples available. Mass production Q3 2107
*Copper version in consideration

Exemplary nominal switching waveforms

The exemplary switching waveforms at nominal current show the benefit of the low overall stray inductance. Despite the fast switching and the very low switching losses of the 1700 V SPT^{++} IGBT chipset, the overvoltage remains at a very low level and the current as well as voltage waveforms are free of oscillations. In the present setup, we achieved a total stray inductance including capacitors, busbar and module of less than 25 nH per 1000 A phase leg.



1700 V LinPak turn-on switching curves



1700 V LinPak turn-off switching curves

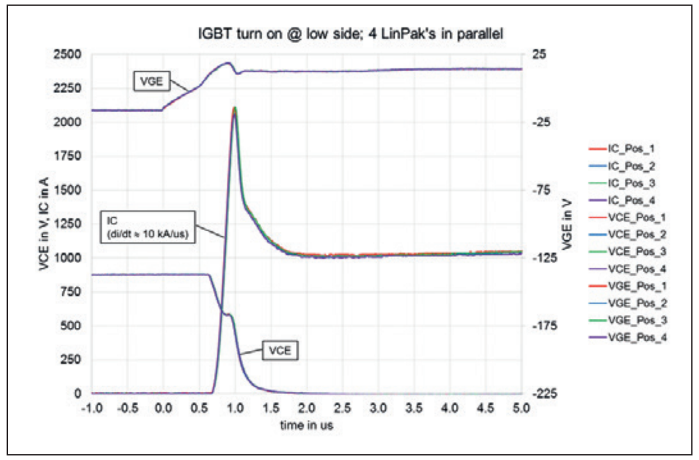
Outline drawing

ABB will offer both the 3300 V and 1700 V LinPak optionally with main emitter sense terminals. These additional auxiliary emitter contacts are connected to the DC – Minus power terminal for the bottom-switch and to the phase power terminal for the top-switch.

LinPak with basic configuration

Parallel connection

The LinPak is ideally suited for parallel connection. There is practically no current mismatch between paralleled modules. See the exemplary turn-on switching curve of four paralleled modules:



5. HiPak IGBT modules

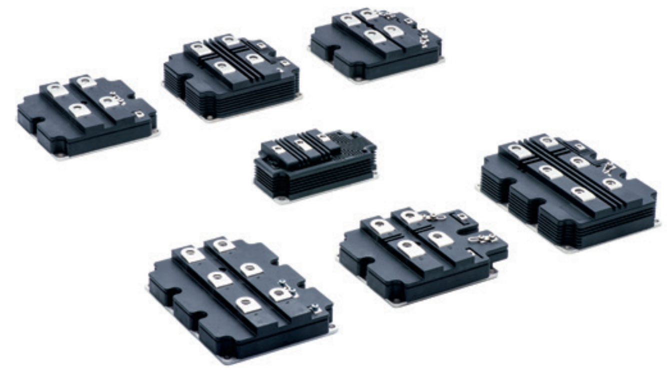


ABB Semiconductors' HiPak modules are a family of high-power IGBTs in industry standard housings using the popular 190 x 140 mm, 130 x 140 mm and 140 x 70 mm footprints. HiPak modules are the perfect match for demanding high-power applications such as traction, T & D, renewable energy (wind, solar) and industrial drives.

ABB's HiPak modules are available in three standard isolation voltages (4, 6 and 10.2 kV_{RMS}) and a variety of circuit configurations. These modules exclusively use aluminum silicon carbide (AlSiC) baseplate material and aluminum nitride (AlN) isolation with low thermal resistance. This specific material combination offers an excellent power cycling performance thanks to its matched thermal expansion coefficients (CTE). All HiPak modules feature ABB's advanced SPT and SPT⁺ (soft punch through) chip technology, which combines low losses with soft switching performance and record breaking Safe Operating Area (SOA). In keeping with ABB's reputation for offering high-power semiconductors of exceptionally high reliability, the HiPak SPT chips have been optimized for reliable operation under harsh conditions. This has been achieved through smooth switching characteristics – and through rugged operation (high SOA) as this translates into operational safety margins for the equipment. Furthermore, the SPT⁺ chipsets (IGBT and diode) at 1700 V and 3300 V blocking voltages have been improved to operate at higher junction temperatures up to 150 °C in the HiPak modules.

SPT technology

SPT is a well-established planar IGBT technology covering the voltage range of 1200 V to 6500 V. It is characterized by smooth switching waveforms and exceptional robustness which is of particular importance at higher voltages and currents where stray inductances are not easily minimized.

SPT⁺ technology

SPT⁺ retains all the features of the SPT technology but reduces $V_{CE\ SAT}$ by up to 30 % according to the curve in figure 1 – an achievement previously believed to be possible only with trench technology.

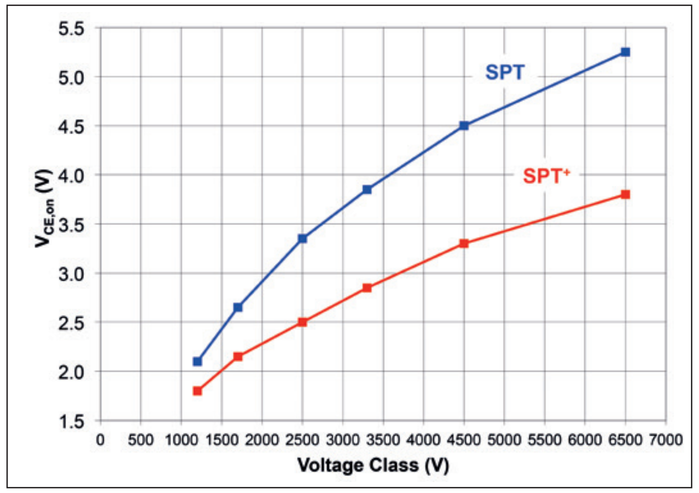


Fig. 1 $V_{ce\ sat}$ for different IGBT cell technologies on SPT silicon at 125 °C. (current density of SPT range, same E_{off})

High ruggedness at 6500 V

In the case of the new 6500 V SPT⁺ IGBT the on-state losses exhibit a reduction of approximately 30 % when compared to the standard SPT device. This, in combination with the improved ruggedness of the SPT⁺ IGBT has enabled an increase in the current rating from 600 A for the standard 6500 V HiPak up to 750 A for the new SPT⁺ version.

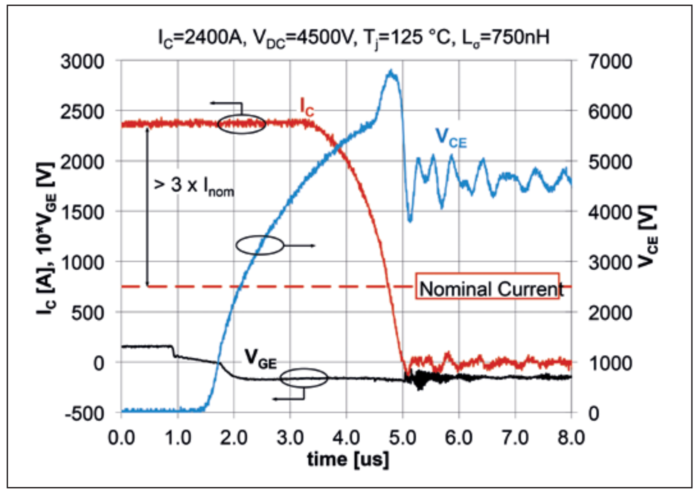


Fig. 2 6500 V SPT$^+$ IGBT turn-off under SOA conditions measured at module level, $P_{p\,off}$ = 11.7 MW

Figure 3 shows the reverse blocking SOA (RBSOA) test on the 1700 V 3600 A HiPak2 module where a current of 10500 A is turned off at a DC-link voltage of 1300 V, proving the ruggedness of the SPT$^+$ IGBT design when paralleled in the HiPak2 module.

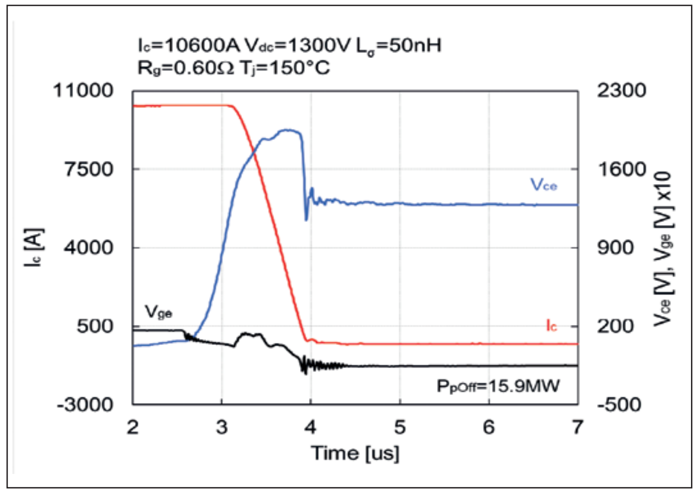


Fig. 3 1700 V / 3600 A HiPak RBSOA measured at Tj = 150 °C with active clamp

Figure 2 shows the extremely high turn-off ruggedness of the 6500 V SPT$^+$ IGBT, setting a new benchmark for this voltage class. A current of 2400 A – which corresponds to more than three times the nominal current – was switched-off against a DC-link voltage of 4500 V at a junction temperature of 125 °C. The stray inductance in this case was 750 nH, which is more than double the value that can be expected in the targeted application environment and shows that the specified SOA can be fulfilled with margin.

150 °C operation

ABB recently upgraded the 1700 V and 3300 V SPT$^+$ chipsets to be operational in HiPak modules at junction temperatures up to 150 °C. For the IGBT, this is achieved by improved device structures combined with new termination designs. This has resulted in excellent blocking characteristics and low reverse currents, which guarantee stable operation at 1700 V and 3300 V up to temperatures above 150 °C.

On the diode side, the plasma has been shaped for low forward voltage drop and soft reverse recovery by using both local and uniform lifetime control. The local lifetime control is obtained by proton (H^+) irradiation. The use of hydrogen particles has reduced the 150 °C leakage current by a factor of three when compared with the previous SPT diode platform.

The buffer and anode designs used in the SPT$^+$ IGBT have been optimized in order to obtain a high short-circuit SOA capability, even at gate voltages exceeding the guaranteed gate drive voltage of 15 V.

Increased reliability with improved HiPak

The improved HiPak modules will be a direct 1:1 replacement with identical electrical and thermal characteristics. The principal electro-mechanical layout remains unchanged. The improvements are realized by the following design features:

Housing construction:
For low-voltage (LV) HiPak modules we were able to remove the epoxy casting. This allows to increase the case temperature rating to $T_{C\,max}$ = 150 °C. The new package now complies with the latest fire and smoke requirements for traction applications. This for both the low-voltage and high-voltage version:
– NFF 16-101/102 I3 – F2,
– EN 45545-2 R23: >HL1, R24: >HL2

Internal auxiliary connections:
The internal solder connections between the gate-print and the substrate will be substituted by standard aluminum wire bonding. This well-established technology allows for higher reliability and offers a redundant double wire connection (figure 4).

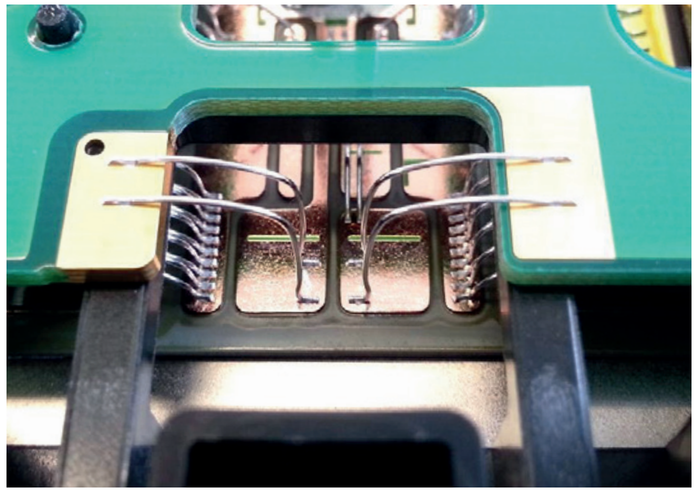


Fig. 4 New redundant aluminum wire bond connection of gate and auxiliary emitter

Terminal foot:
The main terminals offer an improved solder foot with specifically designed spacers in order to achieve a homogenous solder layer thickness. This allows for an improved temperature cycling performance.

Wire bonding:
The emitter side wire bonding parameters have been improved and so called stich-bonds (figure 5) are used. This results in an improvement of factor 4 in intermittent operating life (IOL) (target 2 Mcycles T = 60 K, $T_{vj\,max}$ = 150 °C).

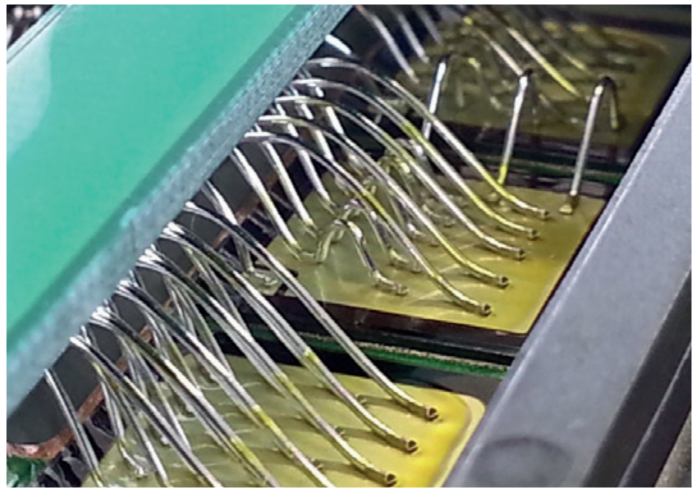


Fig. 5 Stich-bond layout and improved bonding parameters boost the power cycling capability

The new design has been qualified with all the relevant tests: shock and vibration, temperature cycling, IOL and Temperature Humidity Biased (THB). During 2016, the improvements will be made available for the high-voltage housings (G, J and P).

Summary

As illustrated above, ABB's HiPak family of IGBT modules continues to set new standards of robustness for high reliability applications. Robustness translates to higher operating safety margins and allows low gate drive resistance at turn-off which, in turn, allows lower turn-off losses. SPT chip technology with its smooth switching behavior allows users the greatest freedom of design by not imposing dv/dt or peak-voltage restrictions at turn-off. The new SPT$^+$ technology allows further loss reductions without compromising any of the existing features of SPT. Further improvements on the cell design allow chipsets to operate at junction temperatures up to 150 °C.

6. StakPak press-pack IGBT modules

StakPak is a family of high-power IGBT press-pack modules in an advanced modular housing that guarantees uniform chip pressure in multiple-device stacks.

Although the insulated module is the most common package for IGBTs, for applications requiring series connection, press-pack modules are preferred because of the ease with which they can be connected electrically and mechanically in series and because of their inherent ability to conduct in the shorted state – an essential feature where redundancy is required.

Since IGBT modules feature multiple parallel chips, there is a challenge – with conventional press-packs – in assuring uniform pressure on all chips. ABB has solved this problem with an advantageous spring technology.

The StakPak, optimized for series connection, features a modular concept based on submodules fitted in a fiberglass reinforced frame (figure 1), which allows a flexible realization of a range of products for different current ratings and IGBT / diode ratios.

StakPak product range

Unlike standard IGBT modules, StakPak modules fail into a stable short-circuit failure mode (SCFM). SCFM capable StakPaks are ideally suited for applications with series connections with redundancy; in such applications, additional devices are inserted in the series string so that a device's failure will not interrupt converter operation. The failed device will continue to conduct current for a time period greater than the planned service interval of the equipment. This period of time, during which load current must flow in the failed device without external degradation of the housing or internal degradation of the electrical contact, is a function of the load current time-dependence. ABB offers SCFM ratings for users requiring this feature and who are able to specify the load current waveforms and profiles. For applications not requiring a stable short over a longer period, ABB can provide non-SCFM rated modules. Still also, non-SCFM rated StakPak modules fail into a short – but a stable short can only be guaranteed up to one minute. This is still sufficient time to engage an external bypass or take other measures.

Fig. 1 Submodules in a 6-pocket StakPak module

Press-pack technologies

Two basic multichip press-pack technologies exist: chips contacted by common pole-pieces (figure 2: conventional technology) and chips contacted by individual springs (figure 3: ABB StakPak technology).

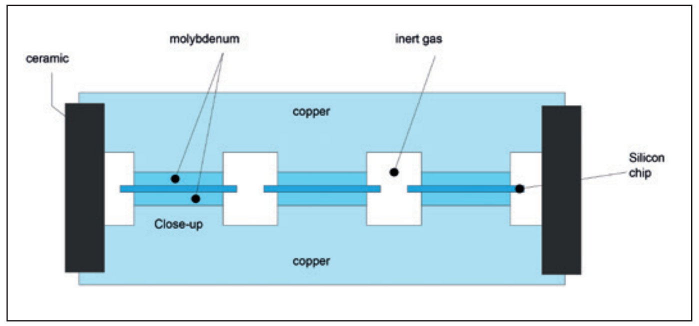


Fig. 2 Sectional view of conventional multi-chip press-pack with common pole-pieces: each chip bears the device force divided by the number of chips.

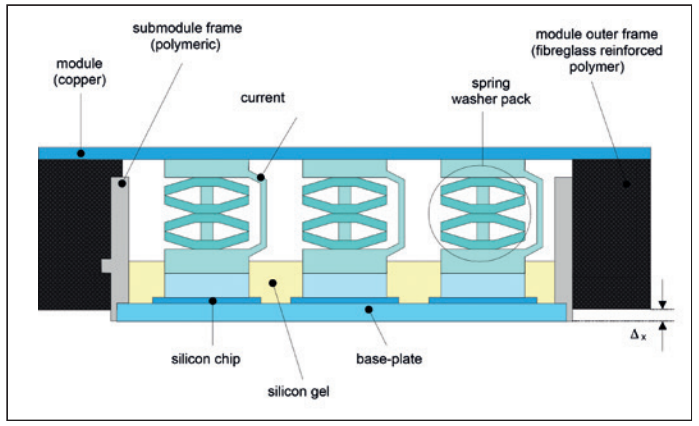


Fig. 3 Sectional view of ABB multichip press-pack with individual spring contacts: the chip bears the force determined by the spring; excess force is borne by the housing walls. The drawing illustrates one multichip submodule in one press-pack housing.

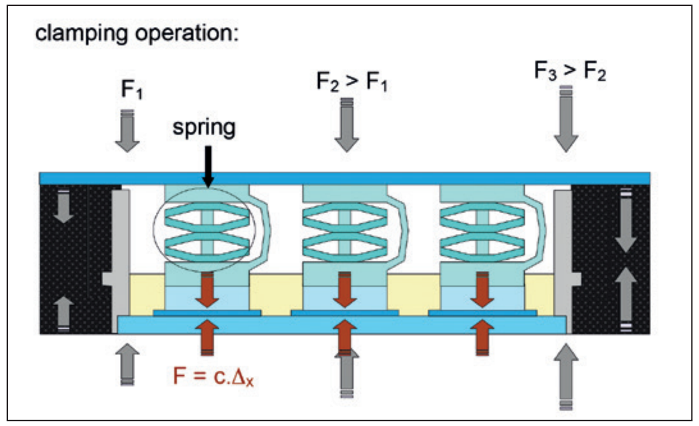


Fig. 4 Principle of individual emitter pressure contacts. F is the force, c the spring constant and Δx the travel distance.

The individual spring contacts reduce the heat sink flatness tolerance and the pressure uniformity requirement within the stack that would otherwise be needed. This, in turn, reduces the mechanical construction costs of the stack and greatly increases field reliability. Thanks to this «independent suspension», only the correct force is applied to each chip allowing excess force to be transferred to the StakPak's housing wall (figure 4). The force needed for a long stack may indeed be far higher than that tolerated by the silicon chips being contacted via their sensitive surface microstructures. The rigidity and stability of a stack subjected to shock or vibration in service or during transportation depends on a mounting force that may not always coincide with that required by the encapsulated chips. It is therefore important to decouple the two forces, allowing the optimal force on the chips to be lower than the optimal force on the stack: the individual springs of ABB's StakPak allow this.

Applications

Press-pack modules are favored in applications where devices are series-connected mechanically and/or electrically and where redundancy is required. A classic example of a long stack requiring SCFM can be seen in the HVDC valve of figure 5. Other press-packs applications include:

- HVDC & FACTS (Flexible AC Transmission Systems)
- Topologies in which open circuits are not possible (eg current-source systems)
- Multi-level inverters with 6 or more devices mechanically in series
- Frequency converters operated directly from the 15 or 25 kV AC traction catenary
- Pulse-power applications, such as thyratron replacement

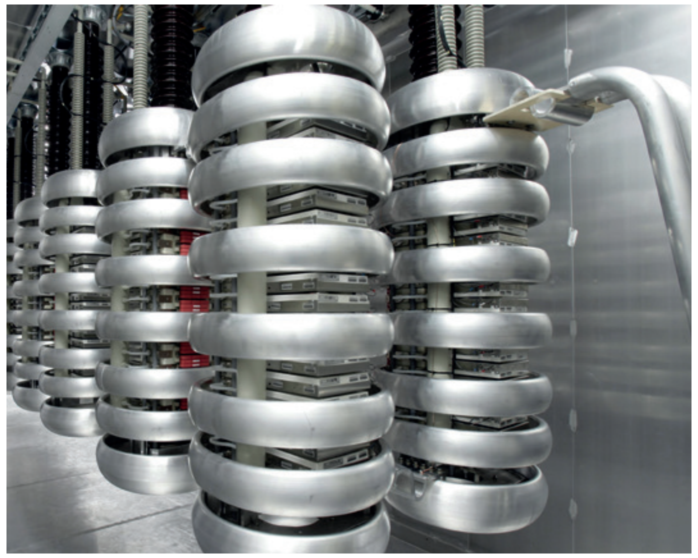


Fig. 5 Standard IGBT valve for VSC, HVDC and STATCOM

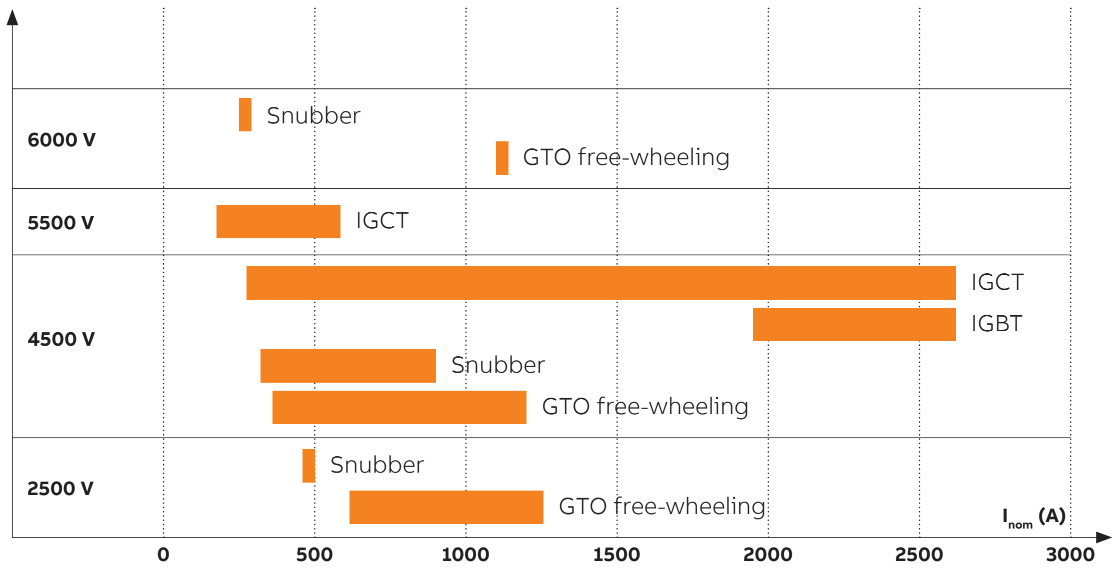
Summary

StakPak technology is a well proven concept in IGBT press-pack technology, conceived to reduce cost and enhance reliability in systems requiring several press-packs in one stack. The modularity of StakPak allows the product range to be configured from a number of standard parts allowing rapid response to market needs. The newly introduced 4500 V rated modules feature the state of the art SPT+ chipset for lowest system losses and highest ruggedness and reliability.

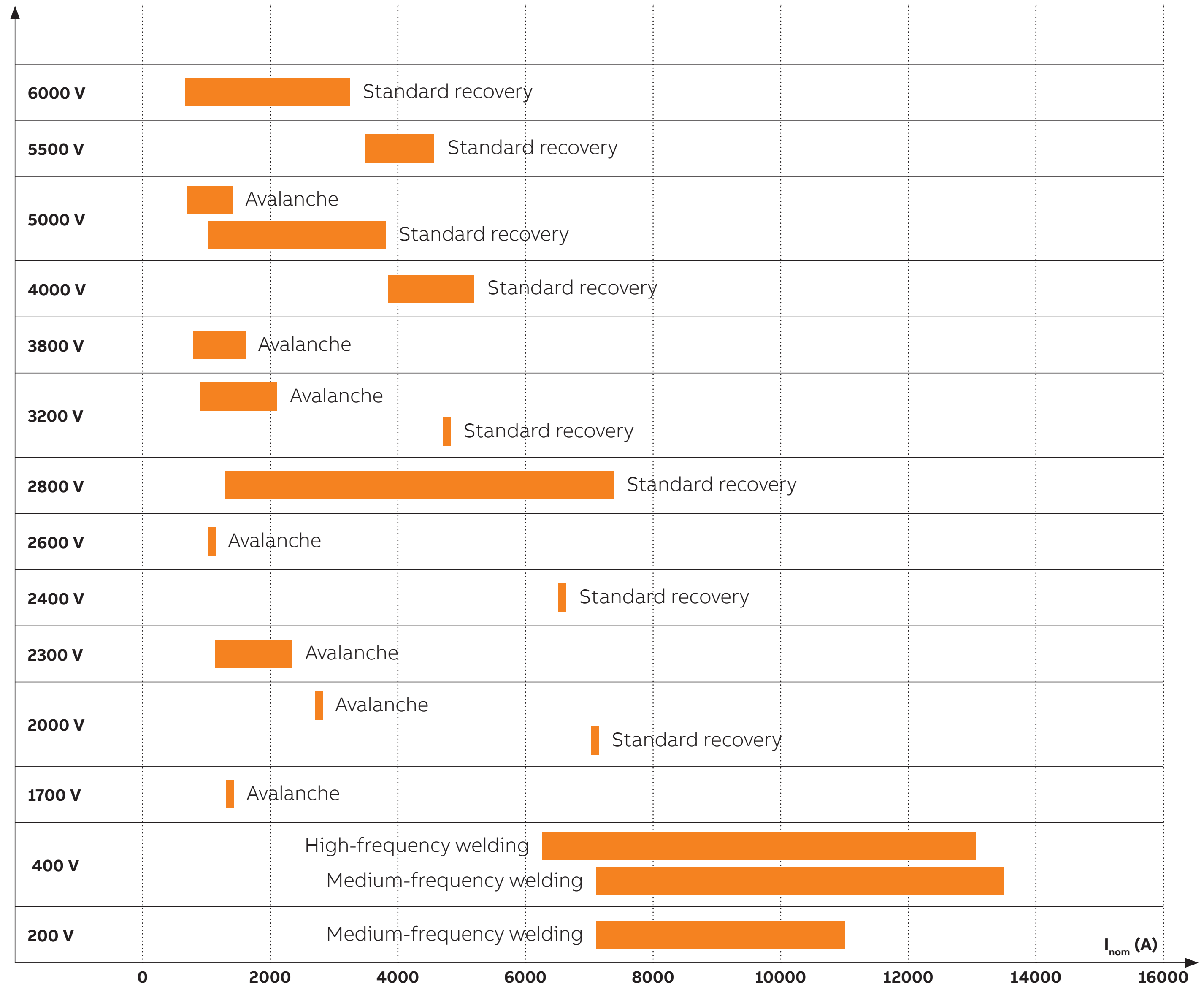
Diode press-packs

ABB's range of press-pack diodes covers
- Fast recovery diodes from 2500 to 6000 V and 175 to 2620 A (GTO free-wheeling, snubber, IGBT and IGCT diodes)
- Standard rectifier and avalanche diodes from 1700 to 6000 V and 662 to 7385 A
- Welding diodes for medium and high frequencies at 200 and 400 V and from 6.2 to 13.5 kA.

Power Maps

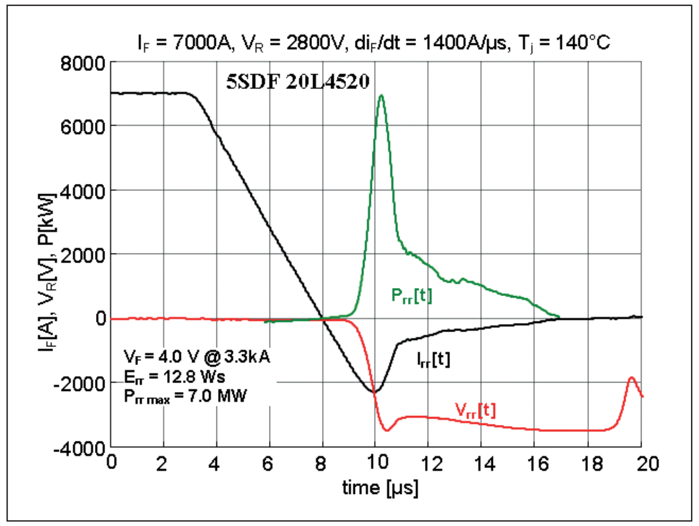


Fast recovery diodes



Rectifier and welding diodes

7. Fast recovery diodes



Typical diode turn-off in IGCT circuit.

ABB Semiconductors offers a wide range of fast recovery, low loss diodes such as snubber, clamping and free-wheeling diodes in various configurations to enable full performance of the IGCTs, IGBTs and GTOs in demanding applications.

Fast recovery diodes, though an integral part of inverter design, have seldom received the same attention as turn-off devices such as IGBTs, IGCTs or GTOs. As a result, snubber, clamp, neutral-point clamping (NPC) and free-wheeling diodes (FWDs) have too often limited optimal equipment design. Recognizing this and the growing trend to eliminate voltage snubbers on semiconductors, ABB has developed a full range of fast diodes offering enhanced safe operating areas (SOA) and controlled (soft) recovery at very high di/dt and dv/dt levels. The growing demand for switching capability (ratings) and not just recovery charge or losses (characteristics) imposes new constraints on diode design and production test equipment to ensure cost-effective delivery of robust and reliable components. In contrast to turn-off devices, thyristors and diodes have traditionally been tested for their characteristics only and classified accordingly. New generations of high-performance fast diodes, as 5SDF 11H4505, 5SDF 20L4520 / 21 and 5SDF 28L4520 / 21, are now tested for their dynamic characteristics and ratings on production test equipment that accurately reproduces the main commutation modes required of today's fast diodes. The fast diodes 5SDF 20L4521 and 28L4521 have been developed to operate safely in power electronic circuits employing IGBT and IEGT press-packs, where di/dts up to 5 kA/µs are especially required.

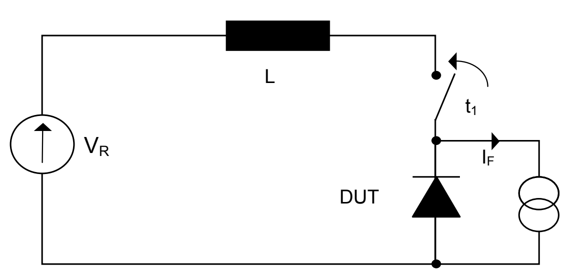
Features:
- Free-wheeling diodes
- Clamp and snubber diodes
- Snubbered types
- Unsnubbered types
- Soft recovery
- High SOA
- Cosmic ray resistance capability

Benefits:
- high operating temperature range up to 140 °C
- optimized forward and reverse recovery characteristics
- excellent softness and enhanced SOA
- cosmic radiation withstand rating
- press-pack devices

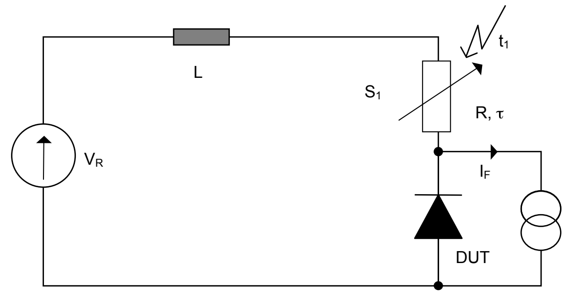
Applications

Fast diodes of a given blocking voltage and silicon wafer diameter are designed using five basic variables: resistivity, thickness, uniform lifetime control, profiled lifetime control and emitter efficiency. Combining these variables allows diodes to meet the requirements of five different commutation modes encountered in voltage source and current source inverters (VSIs and CSIs). These are defined in table 1. One of the basic principles influencing the nature of a commutation is the origin of the di/dt. There are two types of commutation:

- **inductive commutation**
  whereby the active switch is considered «perfect» (eg a thyristor) and an inductance determines di/dt



- **resistive commutationn**
  whereby the active switch is considered as a time-dependent resistor (eg a transistor) and this controls di/dt.



Category	Application	Snubber type	Commutation characteristics	Required diode characteristics
I	FWD and NPC diodes for GTOs and IGCTs in low frequency VSIs	RCD	– inductive – unclamped – snubbered – low dv/dt	– uniform lifetime – high cosmic ray resistance capability – low V_{FM}
II	Snubber diode in RCD circuits	R	– inductive – unclamped – snubbered	– profiled lifetime – soft recovery at low I_F
III	– Snubber diodes in Undeland, Marquardt and McMurray VSIs – Clamp diodes	none	– resistive – unclamped – unsnubbered	– profiled lifetime – soft recovery at low I_F
IV	– Commutation diodes in CSIs – High frequency series-connected IGCTs	RC	– inductive – unclamped – snubbered	– profiled lifetime – medium cosmic ray resistance capability
V	FWD and NPC diodes in snubberless high frequency VSIs	none	– inductive – clamped – high dv/dt	– profiled lifetime – high cosmic ray withstand capability – high SOA – soft recovery at low I_F

Cosmic ray resistance capability

An important parameter for the rating of any semiconductor in a converter is the voltage to which it is exposed. This has two reasons: the stability of the leakage current at rated temperature and the potential failures provoked by ionizing cosmic particles – events whose probability of occurrence increases exponentially with field strength but only linearly with voltage duty cycle. The various functions within power conversion equipment may be exposed to different voltages and duty cycles even though the peak voltages might be the same. Thus, an inverter containing 4.5 kV GTOs, free-wheeling diodes, snubber diodes and clamp diodes operating from a 2.8 kV DC link, would require that the GTOs and snubber diodes have a 2.8 kV DC rating.

The snubber and clamp diodes, however, due to their infrequent exposure to the DC link (duty cycle of approximately 5 %), would be better served with diodes of lower DC rating (thinner silicon), thus endowing them with superior dynamic properties (fast forward and reverse recovery, low losses, no snap-off). For further information see application note 5SYA2061 «Failure Rates of Fast Recovery Diodes due to Cosmic Rays».

8. Rectifier diodes

ABB Semiconductors' reliable high-power rectifier diodes are first choice in many demanding applications in industry and traction.

ABB offers two families of high-power rectifier diodes, standard rectifier diodes and avalanche diodes, both with the following features:
- Reverse repetitive voltage from 1700 V to 6000 V
- High average forward current rating from 700 A to 7400 A
- Excellent surge current capabilities up to 87 kA
- Operating temperature from -40 °C to 190 °C
- High current handling capabilities
- Diodes for parallel or series connection available
- Hermetically sealed press-pack devices

Standard rectifier diodes
Optimized for line frequency and low forward losses.
Applications:
- Input rectifiers for large AC-drives
- Aluminum smelting and other metal refining
- Rectifier traction substations

Avalanche diodes
Self-protected against transient over-voltages, offering reduced snubber requirements and maximum avalanche power dissipation.
Applications:
- Input rectifiers in traction converters
- High voltage power rectifiers

9. Welding diodes

ABB Semiconductors has accumulated impressive expertise in the design and manufacturing of rectifier diodes for high-current-resistance welding machines. The diodes operate at frequencies beyond 1 kHz with welding currents over 10 kA. Despite these severe conditions, a load cycle capability of millions of cycles, corresponding to years of device operation, is achieved.

ABB has been cooperating with most of the major welding equipment manufacturers for years. Through this cooperation, ABB has gathered great experience in the utilization of diodes to reach optimal reliability and electrical performance. The product range of ABB welding diodes (WD) includes encapsulated, hermetically sealed WDs as well as housing-less welding diodes (HLWD) in different sizes and ratings.

Encapsulated and hermetically sealed
The semiconductor diode chips are alloyed to a molybdenum disk. Due to the low voltage rating of 200 or 400 V only, it is possible to use thin silicon to reduce the conduction losses of the devices. The silicon-molybdenum disk is placed inside the hermetic housing between two copper electrodes. Since the requirements for air strike and creepage distance are low, thin housings with low thermal resistance are used. An added advantage is the small size and low weight of WDs, a welcome feature, e.g. for welding equipment mounted on a robot arm in the automotive industry.

Housing-less
The housing-less welding diodes are constructed with a reduced number of layers to improve their thermal performance. In HLWDs, the silicon chips are covered by a copper electrode on the cathode side, which works as a mechanical buffer, the anode side is the hard molybdenum disk, which serves as a HLWD case. Although HLWDs are more susceptible to environmental conditions, their advantages are higher current densities, lower weights and geometric sizes compared to WDs.

Medium- and high-frequency welding diodes
The medium-frequency welding diodes can operate at frequencies up to 7 kHz. However, their optimal and reliable frequency range is up to 2 kHz. To meet the demands of higher frequencies up to 10 kHz, a new group of high frequency welding diodes with high current capabilities combined with excellent reverse recovery characteristics has been developed. They offer the following features:
- high operating frequency up to 10 kHz
- high operating temperature up to 190 °C
- high current capability combined with excellent reverse recovery characteristics
- available in standard or housing-less versions
- excellent surge current ratings
- very low thermal resistance
- press-pack devices

Load cycling capability and welding current
The load cycling capability of the welding diodes is crucial for the choice of application components. Each welding cycle represents a load cycle for the diode used in the application. The load cycling capability is determined by the temperature swing the diode undergoes during the cycle. To keep the temperature swing as low as possible during the welding cycle, the diodes must be designed for lowest possible losses and thermal impedance.

Figure 1 demonstrates the number of load cycles as a function of ΔT_{jh} obtained experimentally in collaboration with welding equipment manufacturers. The dependence is valid for the whole welding diode product range. The lifetime curve indicates how many cycles it is possible to reach in case of right mounting and proper cooling of diodes under test. Since the experiment is time consuming, the number of tested devices is limited. This fact could slightly affect the accuracy of the lifetime trend.

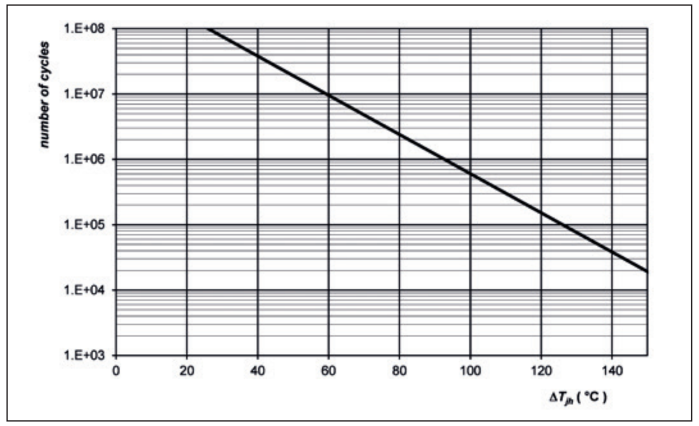


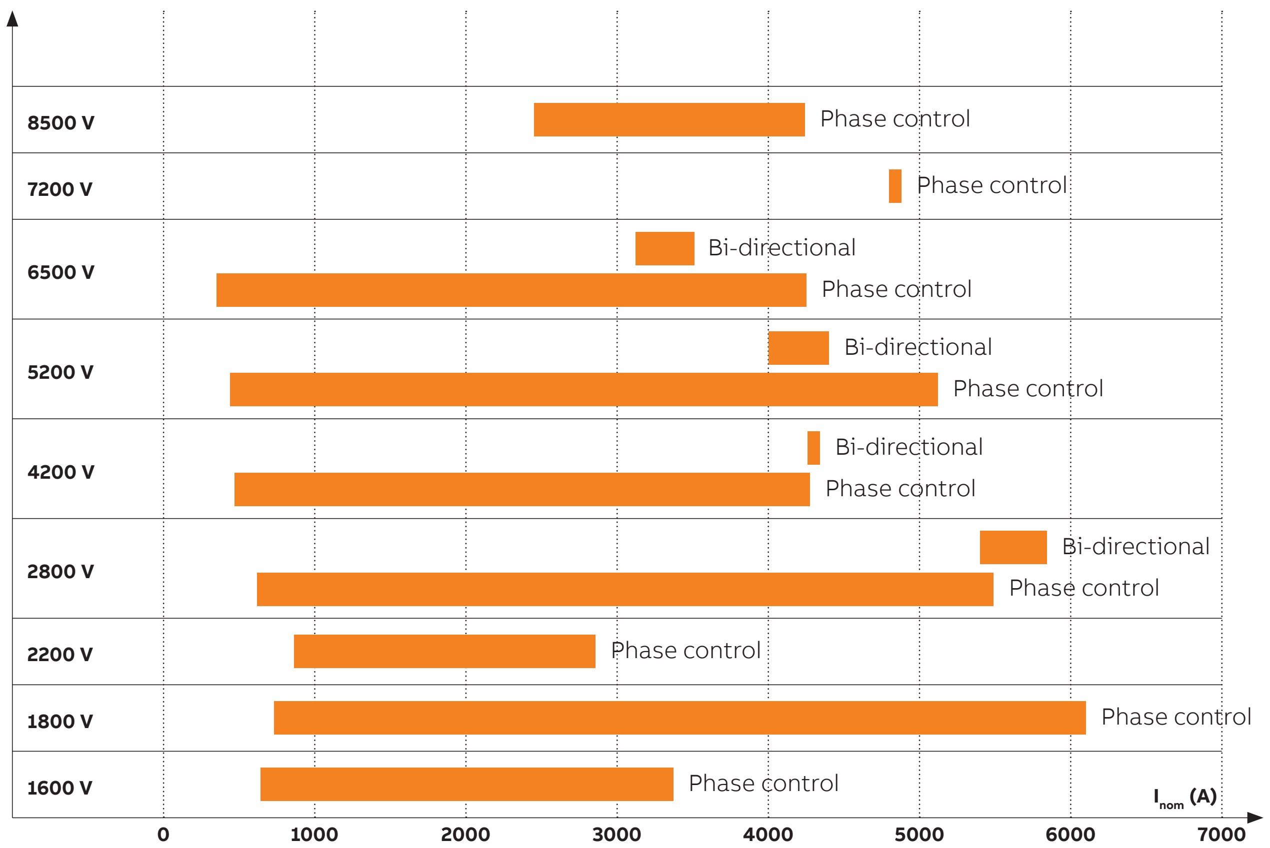
Fig.1 Achievable load cycling capability of welding diodes produced in ABB Ltd. Semiconductors, as a function of diode's junction to heat sink temperature (ΔT_{jh}).

Thyristor press-packs

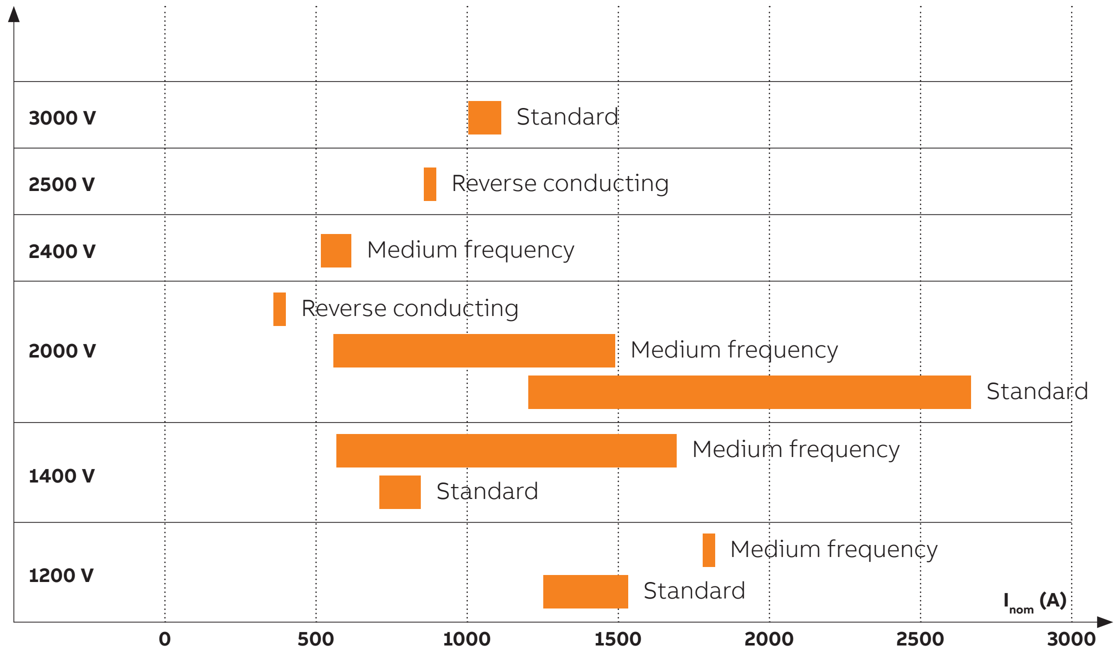
ABB offers a full range of thyristors including
- Phase control thyristors (PCTs), from 1600 to 8500 V and 350 to 6100 A.
- Bi-directionally controlled thyristors (BCTs) from 2800 to 6500 V and 3120 to 5840 A.
- Fast switching and reverse conducting thyristors from 1200 to 3000 V and 360 to 2667 A.

Their field of applications ranges from kW DC-drives and MW rated load commutated frequency converters to GW converters for HVDC transmission.

Power maps



Phase control thyristors (PCT) and bi-directional controlled thyristors (BCT)



Fast thyristors

10. Phase control and bi-directionally controlled thyristors (PCT, BCT)

ABB Semiconductors' phase control thyristor has been the backbone of the high-power electronics industry since its introduction almost 50 years ago. Its field of application ranges from kW DC-drives and MW rated load commutated frequency converters to GW converters for HVDC transmission.

Due to the growing demand for energy efficiency, the thyristor remains at the heart of much of the equipment needed for energy transmission and distribution, as it allows the best performance in terms of cost, reliability and efficiency.

ABB was the first company to introduce 6" thyristor products for HVDC applications and offers the most complete range of high-power thyristors. New thyristor products continue to be developed with focus on minimizing overall losses and maximizing the power rating of the device.

ABB's PCT product range includes press-pack devices with ratings of 1600 V – 8500 V and 350 A – 6100 A used in demanding applications such as HVDC, FACTS and DC-drives. These components have set benchmark reliability records over many years.

The bi-directionally controlled thyristor

Since many medium and high voltage applications use anti-parallel connected thyristors as AC controllers, ABB has introduced the bi-directionally controlled thyristor (BCT) which consists of two monolithically integrated antiparallel thyristor functions on one silicon wafer. The two thyristor halves are individually triggered and have a separation region enabling the design of high voltage devices with the dynamic capability of discrete devices. Figure 1 shows a cross-section of the BCT's silicon wafer.

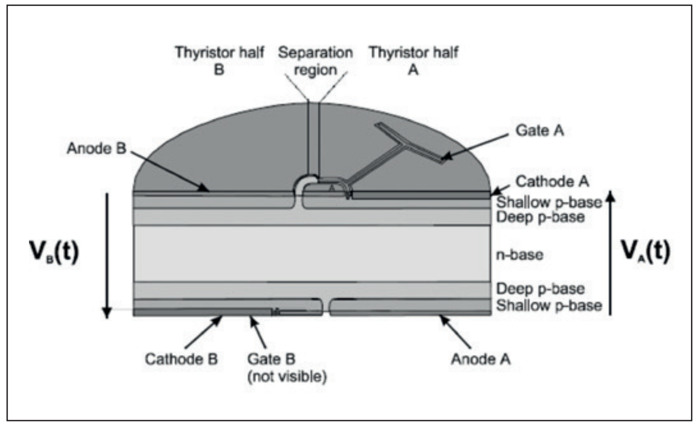


Fig. 1 Cross-section of a BCT.

The BCT is designed, manufactured and tested using the same philosophy, technology and equipment as the well-established PCT, thus reaching the same levels of performance and reliability. This enables manufacturers of equipment for applications such as

- SVC
- 4-quadrant DC-drives
- soft starters

to reduce part count and equipment size without jeopardizing reliability and performance by introducing the BCT instead of a conventional PCT. Examples show volume improvements and part count reductions for equipment with BCTs in the magnitude of 25 % compared with equally rated PCT solutions.

BCT product range includes two wafer sizes available in three different housings with ratings of 2800 V – 6500 V and 3120 A – 5840 A. The ratings I_{TSM}, and R_{thjc} are given for one «thyristor-half» of the device. I_{RMS} is the rms-current for a device operating in an AC-switch application.

BCT designs offer considerable volume and part count reductions over conventional PCTs. Table 1 summarizes expected improvements by application and power level and table 2 shows the table of replacement of PCTs by BCTs.

Application	Power level	Anticipated average volume improvement (*)	Anticipated average parts count reduction (*)
DC-drive	800 kw	30%	30%
DC-drive	2000 kw	30%	25%
Soft starter	250 kw	25%	20%
Soft starter	450 kw	30%	20%
SVC	50 MVAr	35%	35%

Tab. 1 Summary of anticipated advantages when replacing a PCT solution with a BCT solution.
(*) Compared to conventional PCT solutions.

Replacement of PCTs by BCTs		
5STB 24Q2800	replaces two	5STP 24H2800
5STB 24N2800	replaces two	5STP 24H2800
5STB 18N4200	replaces two	5STP 18H4200
5STB 17N5200	replaces two	5STP 17H5200
5STB 13N6500	replaces two	5STP 12K6500
5STB 25U5200	replaces two	5STP 25L5200
5STB 18U6500	replaces two	5STP 18M6500

Tab. 2 One BCT replaces two PCTs.

Voltage rating definitions

The development of high-voltage thyristors has lead to increased values of dissipated power in the off-state (due to higher voltages) even if the leakage currents themselves have remained at similar levels to devices with lower blocking capability. This can cause problems when such devices are characterized and measured in outgoing inspection at elevated temperature (eg 125 °C) because the whole device is heated to a constant temperature (not just the junction) and no temperature gradient exists to sink the generated heat away from the junction, resulting in thermal runaway during testing. Here the applied voltage causes a leakage current and the product (V x I) heats the device. As the device gets hotter, leakage current increases exponentially and so does the heating. If the cooling of the device is not adequate, the device will get progressively hotter and will ultimately fail.

This is in strong contrast to real-world applications where the junction temperature may indeed reach a maximum value of 125 °C but the case temperature never exceeds, say, 110 °C, allowing leakage current losses to be cooled away across the temperature gradient between junction and case.

A more realistic method of measuring power semiconductors is to have a sinusoidal 50 or 60 Hz wave of peak value V_{DWM}/V_{RWM} and to superimpose a narrow pulse of amplitude V_{DRM} as per figure 2. This pulse corresponds to repetitive voltage peaks as typically caused by commutation transients (though the RC-circuit limiting them should be designed to give a peak voltage below rated V_{DRM} and V_{RRM}).

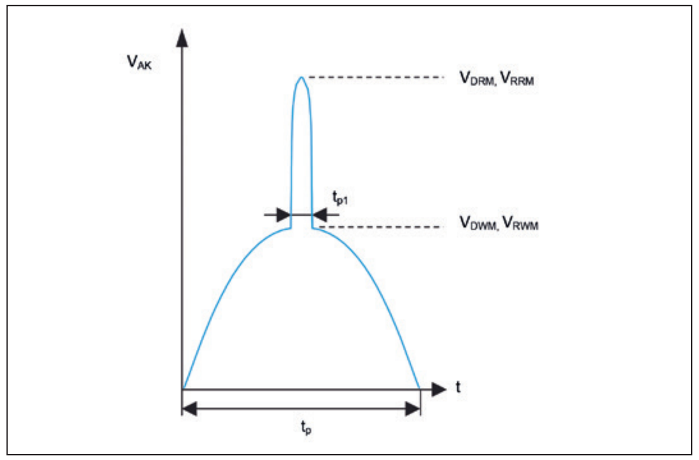


Fig. 2 Voltage definitions for high voltage PCTs and BCTs.

By using this method, the voltage capability is tested at application-like conditions and in conformance with international standards, without thermal runaway. This method of rating is applied to ABB's high-voltage thyristors, V_{DRM}/V_{RRM} > 4500 V. In the datasheets, the level for V_{DWM}/V_{RWM} is selected as the maximum expected working voltage for a device chosen according to the recommendations in Application Note 5SYA2051 «Voltage ratings for high power semiconductors».

11. Fast thyristors

ABB offers three lines of fast switching thyristors: the standard fast thyristor, the medium frequency fast thyristor and the reverse conducting fast thyristor.

All fast switching thyristor types feature optimized and very short turn-on and turn-off times, large critical rates of on-state current rise, high surge current ratings and a wide operating temperature range. Further features are:
- Blocking voltage from 1200 V to 3000 V
- Average forward current from 360 A to 2700 A
- Turn-off time from 7 to 100 microseconds (µs)
- Critical rate of rise of on-state current 800 A/µs
- High surge current ratings up to 47 kA
- Operating temperature from -40 °C to 125 °C

Standard fast thyristors
Fast switching thyristors feature an amplifying gate structure and a special lifetime control technology. Their optimized design ensures low on-state voltage drop and switching losses, low reverse recovery and high di/dt performance. Devices for serial or parallel connection are available on request.

Medium frequency fast thyristors
Medium frequency fast thyristors are fast thyristors with an extended distributed gate technology. They feature a special cathode and gate design for effective operation in the medium frequency range up to 10 kHz.

Reverse conducting fast thyristors
The reverse conducting fast thyristors feature a monolithically integrated free-wheeling diode. Several types of this thyristor are available as spare and replacement parts.

Applications
Fast thyristors are typically used in induction heating resonant inverters, DC chopper drives, UPS and pulse power, to name a few.

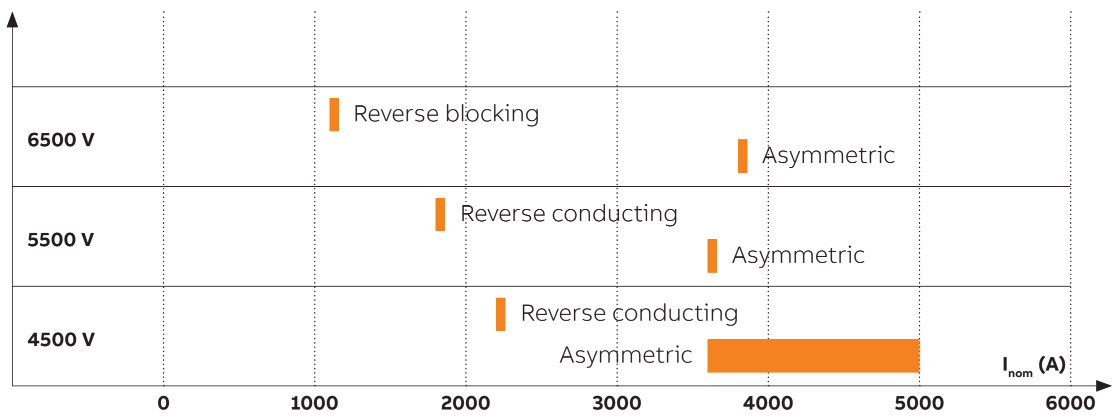
Induction smelting, typical application for fast thyristors.

IGCT and GTO press-packs

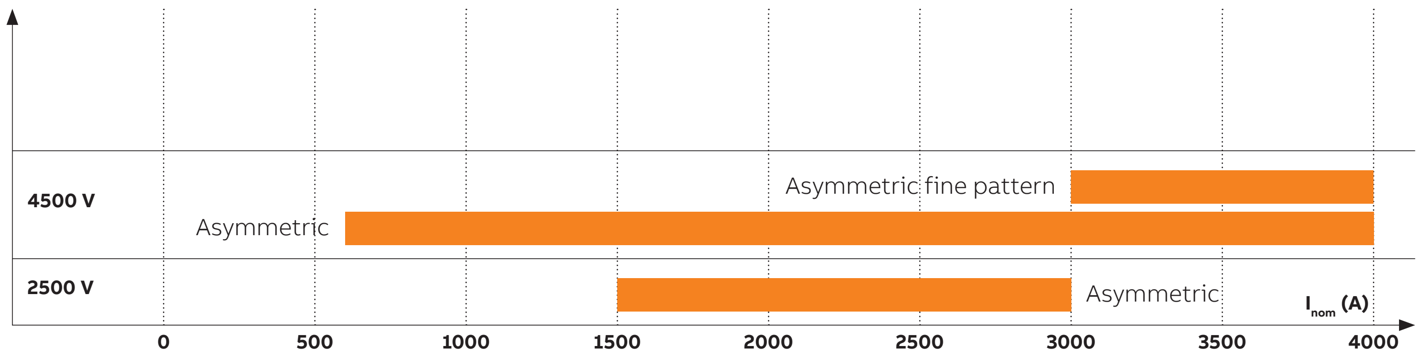
ABB Semiconductors’ IGCT portfolio offers both symmetric, asymmetric and reverse blocking IGCTs in the voltage and current ranges of 4500 to 6500 V and 1100 to 5000 A, respectively. GTOs are offered as asymmetric types at 2500 or 4500 V and between 600 and 4000 A.

The number of applications featuring IGCTs is manifold: medium voltage drives (MVDs), co-generation, wind power converters, STATCOMs and rail power supply. GTOs are typically used in different traction and industrial applications.

Power maps



Integrated gate-commutated thyristors (IGCT)



Gate turn-off thyristors (GTO)

12. Integrated gate-commutated thyristors (IGCT)

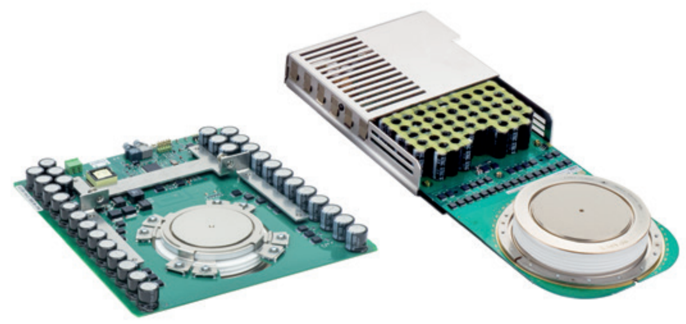


ABB Semiconductors’ IGCTs are used in a multitude of applications due to their versatility, efficiency and cost-effectiveness. With their low on-state voltage, they achieve the lowest running costs by reaching inverter efficiencies of 99.6 percent and more.

The IGCT is a gate-controlled turn-off switch, which turns off like a transistor but conducts like a thyristor with the lowest conduction losses. Figure 1 shows turn-off at 3000 A.
GCTs are the only high power semiconductors to be supplied already integrated into their gate units. The user thus only needs to connect the device to a 28 – 40 V power supply and an optical fiber for on/off control. Because of the topology in which it is used, the IGCT produces negligible turn-on losses. This, together with its low conduction losses, enables operation at higher frequencies than formerly obtained by high power semiconductors.

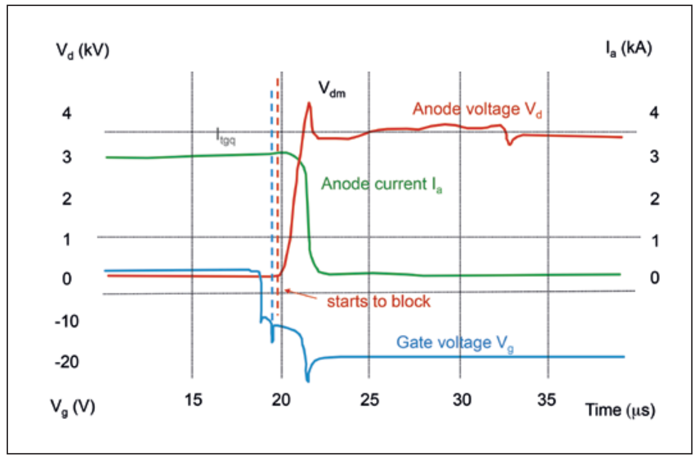


Fig. 1 IGCT turn-off exhibits same waveform and losses (E_{off}) as transistor

IGCTs are available as reverse conducting (RC), reverse blocking (symmetrical) and asymmetric devices. The low losses allow hard-switched operating frequencies of up to 600 Hz for 6.5 kV devices and 1 kHz for 4.5 kV devices in the steady state and over 5 kHz in burst mode.

Figure 2 illustrates the basic IGCT voltage source inverter (VSI) topology. It can be seen that diode commutation is controlled by the inductance L. The free-wheel circuit of figure 2 minimizes the turn-on energy in the semiconductor by storing it in L. The inductance is the most logical fault limitation technique in the event of catastrophic failure since, as opposed to resistors and fuses, it has the benefit of «already being there». The press-pack construction of the IGCT, combined with the inductance, makes the system resistant to explosion, even when the device’s surge rating is exceeded.

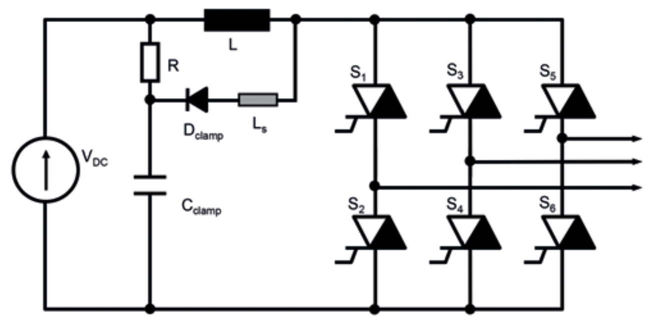


Fig. 2 Basic IGCT inverter circuitand auxiliary emitter

Turn-off dv/dt is also not gate-controlled, but programmed at the device manufacturing stage by anode design and lifetime engineering. The absence of dv/dt and di/dt control functionality simplifies the gate-unit design and allows a high degree of standardization. Some sixty publications exist on the use of IGCTs in many applications. These can be downloaded from the ABB Website www.abb.com/semiconductors.

Applications

The integrated gate-commutated thyristor is the power-switching device of choice for demanding high-power applications such as:

- MVD (medium voltage drives)
- Marine drives
- Co-generation
- Wind power converters
- STATCOMs
- DVRs (dynamic voltage restorers)
- BESS (battery energy storage systems)
- SSB (solid state breakers)
- DC traction line boosters
- Traction power compensators
- Interties

Outlook

The expansion of power electronics into the new fields of energy management, renewable energy sources and cogeneration is driving semiconductor requirements towards higher frequency, higher voltage and higher efficiency while increasing demands for reliability and lower costs. The IGCT is capable of still higher currents, voltages and frequencies without series or parallel connection and the first products are introduced as «High Power Technology» devices. This latest family of IGCTs exhibit up to 30 % higher turn-off capability compared to standard devices.

Currently in development are technologies to increase the rated temperature for a number of devices and to increase the current rating with larger silicon diameters.

Within 10 years of its introduction, the IGCT has established itself as the power device of choice for high power at high voltage by meeting the demands of a growing power electronic market. Single inverters of over 15 MVA can now be realised without series or parallel connection achieving the highest inverter power densities in the industry.

13. Gate turn-off thyristors (GTO)

One might be assuming that the rapid advance of the IGCT and IGBT would spell an equally rapid end to the GTO era. The demand for these devices, however, is still strong today.

Production of GTOs commenced in the mid 1980s. A GTO is a thyristor that can be turned off by applying a current to the gate in the reverse direction to that required to turn it on.

GTOs are optimized for low conduction losses. The typical on-off switching frequency is in the range of 200 – 500 Hz for most applications. GTOs are, by nature, relatively slow switches.

Typical transition times from on to off state and vice versa are in a range of 10 to 30 microseconds. All GTOs require protective networks called «snubbers» for turn-on and turn-off. The turn-on snubber circuit, in essence an inductor, limits the rate of current rise. For turn-off, the GTO requires a device that limits the rate of voltage rise, in essence a capacitor.

All ABB GTOs are press-pack devices. They are pressed onto heat sinks, which also serve as electrical contacts to the power terminals.

ABB offers a broad portfolio of asymmetric GTOs with proven field reliability in various traction and industrial applications.

Asymmetric GTOs

Asymmetric GTOs are divided in two categories: buffer layer and standard. Buffer layer GTOs have exceptionally low on-state and dynamic losses. Fine pattern types (5SGF) are optimized for fast switching and transparent emitter (5SGT) for low on-state losses. The Standard GTOs have excellent trade-off between on-state and switching losses.

14. Test systems

ABB Switzerland Ltd., Semiconductors, designs and manufactures test systems for high power semi-conductors.

With more than 30 years of experience, ABB designs and manufactures CE compliant customized test systems, cover-ing the entire range of high power semiconductors. Presently, over 70 test systems are in operation for routine and reliability measurements of power semiconductors. Some test systems have been in operation for more than 15 years.

Thanks to our close proximity to semiconductor development, application and production, we are in an ideal position to provide test systems to meet customers' needs. Automation, efficient handling and safety are among the designed-in features of the test equipment.

Dynamic IGCT, GTO and diode test system

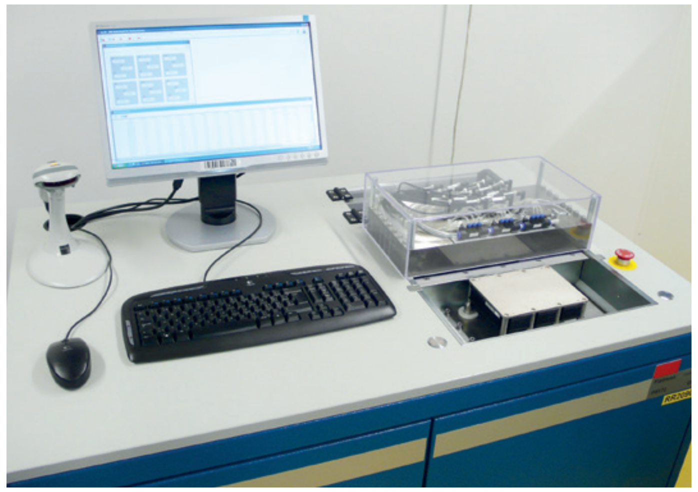
Power semiconductor test systems

ABB offers static and dynamic test systems for diodes, phase control thyristors (PCTs), bi-directionally controlled thyristors (BCTs), switching and reverse conducting thyristors, gate turn-off thyristors (GTOs), integrated gate-commutated thyristors (IGCTs), as well as insulated gate bipolar transistor (IGBT) dies, substrates, submodules and modules.

Our test systems cover the range of up to 14 kilovolts and 10 kiloamperes and use state of the art configurable stray inductances down to 60 nanohenry. During testing, the clamped device can be precisely heated up to 200 °C for production systems or cooled down to -40 °C in an environ-mental chamber for engineering systems. The clamping units can handle devices up to 240 millimeter in diameter and can apply a clamping force of up to 240 kilonewton.

Automated IGBT and diode dies test system

ABB recently installed the next generation of IGCT test system in production, able to test devices with the highest current and voltage ratings on the market.



Baseplate flatness tester. Mechanical measurement under pressure (resolution up to 0.1 micrometer)

Features:

– Available for various application environments (production, laboratory, failure analysis, research and development)
– Highest quality assurance during engineering and manu-facturing
– Safe operator handling
– Remote and on-site service
– Automated handling
– European standard compliance

Test systems

ABB offers the following specialized solutions

	Blocking voltage AC or DC	Gate characteristics	On-state, forward voltage	Reverse recovery charge	Critical dV/dt	Circuit-commutated turn-off time	V_{cesat} / $V_{pinch-off}$	Turn-on / turn-off
Bipolar test systems								
Thyristor and diode static / dynamic	X	X	X	X	X	X		
Gate turn-off thyristor and diode static	X	X	X					X
Gate turn-off thyristor and diode dynamic	X			X				X
IGBT test systems								
IGBT and diode dies static	X	X					X	
IGBT and diode substrates static / dynamic	X	X		X			X	X
IGBT and diode modules static	X	X					X	
IGBT and diode modules dynamic				X				X
Baseplates flatness								

Reliability test systems

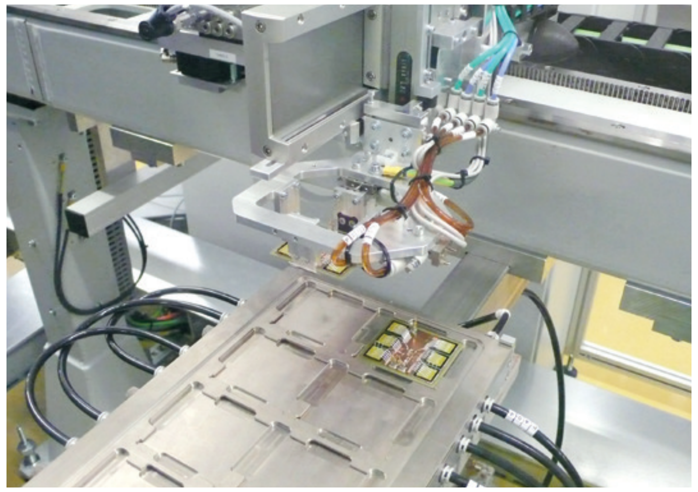
– High temperature reverse bias
– Intermittent operating life
– Surge current

Automation

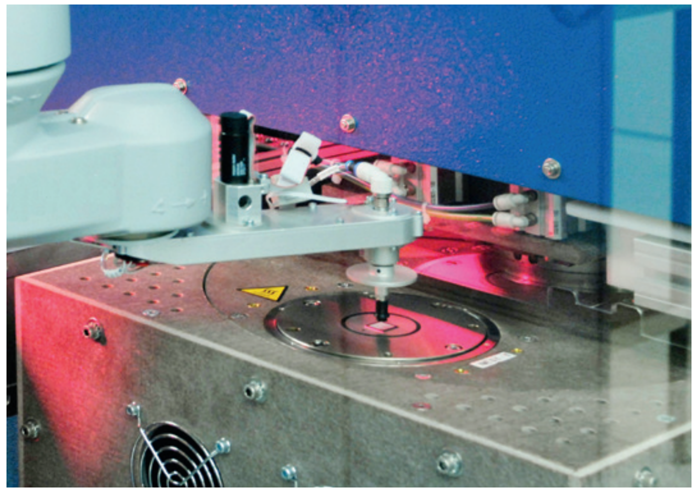
Our test systems are designed for easy integration into automated handling equipment. Its software is compatible to commercial control systems as manufacturing execution systems (MES) and computer-aided quality assurance (CAQ).

Auxiliary unit

– Clamping unit
– Capacitor discharge unit
– Preheating unit
– Programmable IGBT and thyristor gate units
– Data acquisition and parameter extraction units



Substrate handling



Die handling

Documentation

Product catalog, application notes and data sheets as well as SEMIS – ABB's semiconductor online simulation tool – are available on ABB's website www.abb.com/semiconductors.

Additional documentation required for the reliable application of ABB's power semiconductors is available on the same site. An overview is given here.

IGBT dies and modules

Document title	Document number
Mounting instructions for StakPaks	5SYA 2037
Mounting instructions for HiPak modules	5SYA 2039
Failure rates of HiPak modules due to cosmic rays	5SYA 2042
Load-cycling capability of HiPak IGBT modules	5SYA 2043
Thermal runaway during blocking	5SYA 2045
Voltage ratings of high power semiconductors	5SYA 2051
Applying IGBTs	5SYA 2053
IGBT diode safe operating area	5SYA 2057
Surge currents for IGBT diodes	5SYA 2058
Applying IGBT and diode dies	5SYA 2059
Thermal design and temperature ratings of IGBT modules	5SYA 2093
Paralleling of IGBT modules	5SYA 2098
Mounting Instructions for 62Pak	5SYA 2106

Diodes

Document title	Document number
High current rectifier diodes for welding applications	5SYA 2013
Design of RC snubbers for phase control applications	5SYA 2020
High power rectifier diodes	5SYA 2029
Mechanical clamping of press-pack high power semiconductors	5SYA 2036
Field measurements on high power press-pack semiconductors	5SYA 2048
Voltage ratings of high power semiconductors	5SYA 2051
Failure rates of fast recovery diodes due to cosmic rays	5SYA 2061
Applying fast recovery diodes	5SYA 2064
Parameter selection of high-power semiconductor for series and parallel connection	5SYA 2091

Thyristors

Document title	Document number
Bi-directionally controlled thyristors	5SYA 2006
Design of RC snubbers for phase control applications	5SYA 2020
Gate-drive recommendations for phase control and bi-directionally controlled thyristors	5SYA 2034
Mechanical clamping of press-pack high power semiconductors	5SYA 2036
Field measurements on high power press-pack semiconductors	5SYA 2048
Voltage definitions for phase control and bi-directionally controlled thyristors	5SYA 2049
Voltage ratings of high power semiconductors	5SYA 2051
Switching losses for phase control and bi-directionally controlled thyristors	5SYA 2055
Parameter selection of high-power semiconductor for series and parallel connection	5SYA 2091
Surge currents for phase control thyristors	5SYA 2102

IGCTs

Document title	Document number
Applying IGCT gate units	5SYA 2031
Applying IGCTs	5SYA 2032
Mechanical clamping of press-pack high power semiconductors	5SYA 2036
Failure rates of IGCTs due to cosmic rays	5SYA 2046
Field measurements on high power press-pack semiconductors	5SYA 2048
Voltage ratings of high power semiconductors	5SYA 2051

GTOs

Document title	Document number
Mechanical clamping of press-pack high power semiconductors	5SYA 2036
Field measurements on high power press-pack semiconductors	5SYA 2048
Voltage ratings of high power semiconductors	5SYA 2051

Environmental specifications

Document title	Document number
Storage of diodes, PCTs, GTOs	5SZK 9104
Transport of diodes, PCTs and GTOs	5SZK 9105
Operation of pressure contact IGCTs	5SZK 9107
Storage of IGCTs	5SZK 9109
Transport of IGCTs	5SZK 9110
Storage of HiPaks	5SZK 9111
Transport of HiPaks	5SZK 9112
Operation of industry HiPaks	5SZK 9113
Handling, packing and storage conditions for sawn wafer dies and bare dies	5SZK 9114
Operation of industry press-pack diodes, PCTs and GTOs	5SZK 9115
Operation of traction press-pack diodes, PCTs and GTOs	5SZK 9116
Operation of traction HiPaks	5SZK 9120

Notes

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