IGBT Press-Packs for the Industrial Market

The standard Press-pack IGBT (PPI) basically uses the same packaging concept as Bipolar high power semiconductor devices. The main difference is that the high power semiconductor content in the package is square IGBT chips arranged on a round molybdenum disc instead of large, round bipolar devices matched in size to the molybdenum disc and ceramic housing. The Press-pack IGBT comes under the name StakPak™ in a pseudo-square frame package that allows for much better utilization of the squared IGBT chips and for a modular platform in power scaling of the device. **Bülent Aydin, Franc Dugal, Evgeny Tsyplakov, Raffael Schnell, Liutauras Storasta and Thomas Clausen, ABB Switzerland Ltd, Semiconductors, Lenzburg, Switzerland**

Originally, it was thought that the PPIs would replace Gate Turn-Off Thyristors (GTOs) in both medium voltage drives and traction drives and be an alternative to the insulated IGBT modules. In 2011, PPIs have become an established part of the high power semiconductor market segment serving the industry in medium voltage drives, but PPIs have only marginally penetrated the traction segment. For propulsion drives, the development of rugged and reliable insulated IGBT high power modules have allowed for new platforms and topologies and virtually all new propulsion drive designs feature insulated IGBT modules.

ABB Semiconductors has many years of experience in manufacturing Press-pack IGBTs for power transmission & distribution applications. For many years, the StakPak has proved its outstanding reliability and ruggedness by serving as the principle switching device in the ABB HVDC light application. In the HVDC transmission link high voltage, direct current is transported either over long distances or via sea cables with very low transmission link losses. More than 15 of the HVDC light transmission links using StakPak devices for valves are currently in operation carrying more than 10 GW of power, and five projects are planned to add an extra 5 GW. The first link began operation in 1997 and, as of today, no field failures related to the StakPak device have been reported. This proves the device's capabilities in ruggedness and reliability.

The StakPak is well suited for series connection. With both 2.5 and 4.5 kV switches, there are a multitude of industrial applications that can benefit from the use of StakPak devices. Static VAR Compensation (SVC) systems and multi-level high power inverters with several devices in series to match industrial line voltages > 6 kV are the most obvious applications. Also, Pulse Power applications requiring high voltage level and fast repetition rates between the pulses will benefit.

Package outline

What makes the StakPak PPI unique as a high power switch is foremost the modularity of the package combined with the flexibility of the IGBT/diode ratio in the module. For high power PPI products the package size increases to support the high amount of chips. As the number of chips per unit operation increases, so does the probability of failures during subsequent device manufacturing steps and early failures in the field. The StakPak PPI consists of a number of standard rectangular sub-units, called submodules. The number of chips per submodule is limited to 12 and each submodule is tested for full functionality before it is inserted into the frame. In this way, power is configured into the switch based on the number of submodules in the frame. The frame is pseudo-square and can hold 2 (Figure 1), 4 or 6 (Figure 2) submodules. Our BiMOS line is designed for high manufacturability and as a result of recent factory expansion, high volume manufacturing is possible.

Each submodule has 12 chip positions and the layout of the IGBT connections to the gate pad allows for at least four different IGBT/diode ratios in the submodule. The ratio can be 1:1, 2:1, 3:1 or even 5:1. The fifth possible configuration with only IGBT chips is currently not possible due to package restraints relating to the maximum current

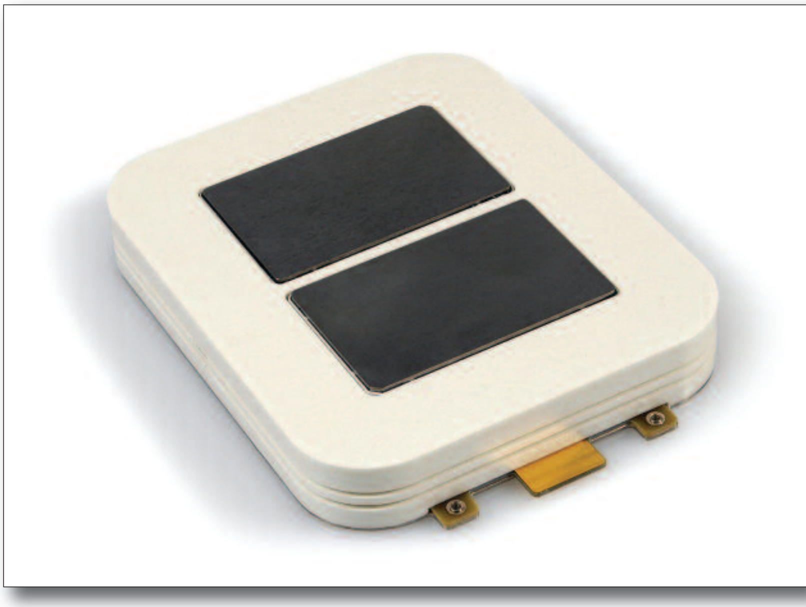


Figure 1: StakPak™ (4.5 kV) in a pseudo-square frame package with two submodules

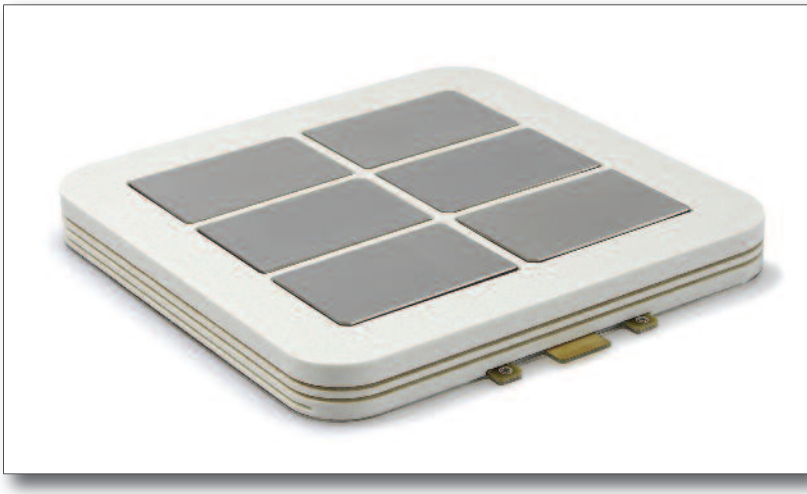


Figure 2: StakPak™ (4.5 kV) in a pseudo-square frame package with six submodules

flow through the package. The maximum current flow at present is 2600 A in a 2:1 configuration between IGBT and diodes. The 2600 A maximum rating for the complete switch means that one phase leg of the medium voltage drive can be built from one stack only without special considerations concerning the diode and special design rules with respect to the cooling system and the elimination of parasitics. The fact that only one StakPak compact stack is needed per phase leg is highly beneficial in terms of footprint of the drive and manufacturability of the complete drive. Figure 3 shows the soldering of a StakPak.

The press-pin that contacts the emitter side of the IGBT chip has been designed with two additional goals in mind besides conducting the current when the switch is on. The first of these goals is to make the pin assembly consisting of 12 pins on a carrier independent of each other and the second goal is to bring a failing IGBT chip into short circuit failure rather than open circuit failure as is the case for insulated IGBT modules. The underlying principle in order to achieve the first goal is the independent suspension principle. This principle originates in the automotive industry and is considered to offer the highest quality and load characteristics for the individual pins as well as for the pin assembly. The individual pins are designed for lowest possible unsprung weight and each individual pin spring contacts the carrier without affecting the other pin spring contacts in the submodule (Figure 4).

IGBT and diode technology

The IGBT chips inside the StakPak are manufactured using the Soft-Punch-Through (SPT™) technology platform that is considered among the best high voltage (HV) chip and which performs excellent in both hard switching and soft switching applications. The HV IGBT SPT+ chips use the same rugged planar cell design as the former SPT chips, but the SPT+ chips have a much lower on-state voltage drop. The lower on-state voltage drop has been achieved by introducing an enhancement layer within the IGBT cell that increases the carrier concentration on the emitter side during turn-on of the device. The SPT+ chips, besides having a much lower on-state voltage in comparison with SPT chips, also show an improved turn-off SOA as a result of the advanced design.

The diode chips inside the StakPak need to have a fast recovery when they go from the conductive state to the blocking state, so that the diode does not become a limiting factor with respect to the overall losses of the switch. In principle, the diode is a simple pin type structure

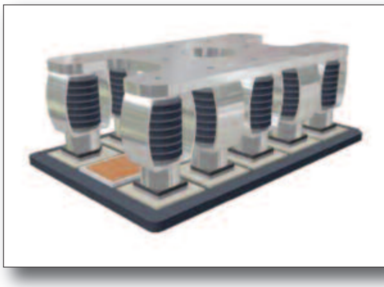
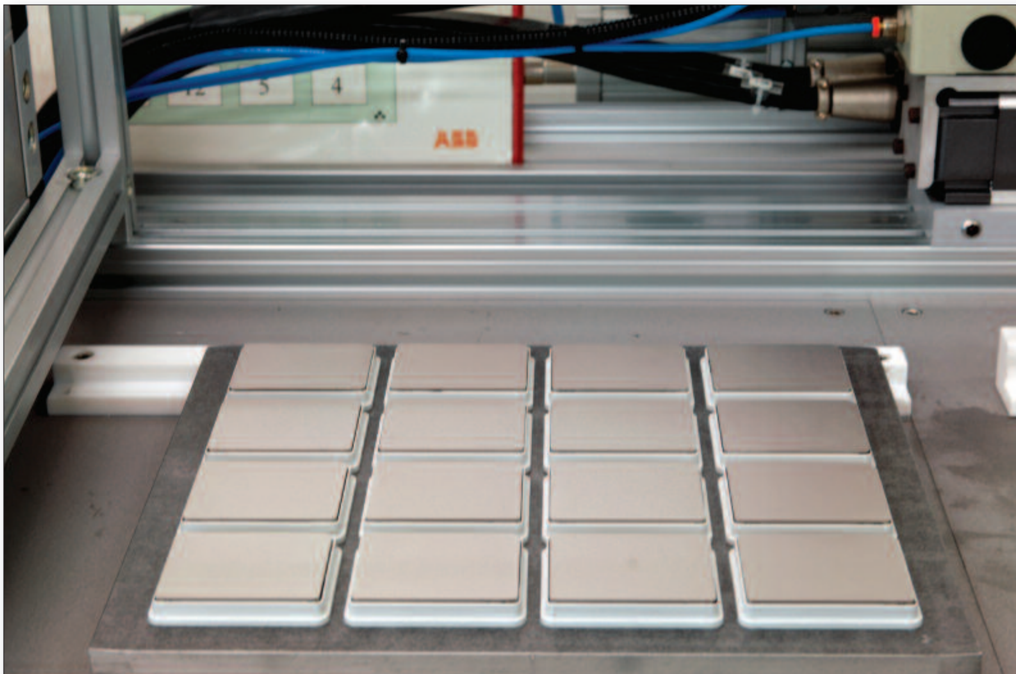


Figure 4: Press-pins contact the emitter side of the IGBT chip

manufactured using the same technology as is used for the SPT+ IGBT chips. In order to match the performance of the IGBT chips, there is a trade-off needed in the on-state voltage versus the switch-off losses. This trade-off curve increases the on-state voltage by placing specially

Figure 3: Soldering of a StakPak



designed carrier lifetime control layers in the bulk and close to the pn-junction of the diode, but in turn makes the recovery fast and significantly lowers the diode switching losses. The localized carrier lifetime control technique gives a much better diode performance in comparison with conventional carrier lifetime control techniques, where the carrier lifetime in the whole bulk is lowered by i.e., electron irradiation. With localized carrier lifetime controlling, the minority carrier lifetime is kept high in the bulk, which in turn lowers the leakage current in the device. When switched off, the localized layers act as a carrier recombination drain for fast recovery, and it shapes the tail of the reverse recovery current for optimum softness.

Application benefits

There are several other functional advantages of the StakPak PPI over standard PPIs and insulated IGBT modules. The benefits are all functionalities that make the design of medium voltage drives more straightforward or help to reduce the need for power semiconductor protective circuits in the drive.

Probably the most important parameter that will greatly benefit the designer of medium voltage drives is the unsurpassed thermal properties of the StakPak. Besides the possibility of cooling both the emitter and the collector side, the IGBT and diode thermal resistance (junction to case) is as low as 4 K/kW, but since only ~20% of the heat flows to the emitter side when double side cooling is employed, it is crucial that the main emphasis is on collector side cooling. Cooling only from emitter side must be avoided.

When taking care in the design of the heatsink (mostly the surface roughness), it is possible to achieve a thermal resistance from case to heatsink for both the IGBT and Diode of only 1 K/kW. The thermal resistance from junction to heatsink is up to 50% lower compared to standard PPIs and insulated IGBT modules. The excellent thermal properties are obtained by having the chips soldered directly onto the molybdenum submodule disc. With the chip-to-case alloyed design, the short-time thermal overload capacity, which is another important parameter for the designer of the medium voltage drives, is also much improved in comparison with other types of IGBT module design.

In case of an event outside the safe operating area (SOA) for the switch or a chip in the switch, the press pin alloy to the IGBT chip because of the local temperature increase at the failing point. If the alloyed pin/IGBT is not conductive, the switch fails into open circuit, which is a disaster for series connected devices. The design thus has to be so that the pin/IGBT alloy is conductive in the event of a failure. The current path is thus short circuited by creating a low current path between the collector and emitter. The built-in pin short circuit failure mode (SCFM) is a key feature of the switch.

The trend in medium voltage drives is to move away from bulky protective circuit elements in the design; i.e. reduce the number of passive elements. This basically put the protective control scheme on the semiconductor switch itself or alternatively on the on/off gate control unit. Another important protection feature of the StakPak is the surge current capability, which is up to 27 kA (w/o reapplied voltage) dependant on the diode content in the switch.

Yet another element of built-in protection, which is very difficult to test, but is an important parameter for designing medium voltage drives, is case non-rupture rating. The case non-rupture rating is the highest current in reverse direction that a damaged module can tolerate without emitting plasma that can damage other elements of the drive. The case non-rupture rating is often referred to as an explosion rating for the semiconductor element. For the StakPak there are no high current carrying wire bonds in the module and the module is not a tight capsule type of module. Both of these facts will be beneficial in case reverse voltage is applied to a damaged element. With the StakPak, it is difficult to define a worst case for damage to the module that will cause an explosion. In the event of a damaged module, we do not expect any emission of plasma to occur, because the module is not sealed and therefore a huge pressure build-up inside the module is unlikely.

BiMOS and Bipolar outlook - solutions for industrial drives

With the introduction of the StakPak press-pack IGBT to the industrial market, ABB not only offers the largest variety of high power semiconductor switches in Bipolar and BiMOS, but also the highest power levels available in single switch configurations. ABB manufactures IGCT devices with 4.5, 5.5 and 6.5 kV blocking voltage capabilities with switch-off capability of more than 5 kA of current. For BiMOS switches, ABB has a production line in operation since 2010 capable of producing more than 150'000 modules. ABB Semiconductors offers products in the blocking voltage range from 1.7 kV to 6.5 kV for standard insulated IGBT modules. Because of the built-in isolation, these modules are ideally suited for medium voltage drives, in which the modules are paralleled to achieve high power levels. The StakPak addition to the industrial product platform offers manufacturers of medium voltage drives an opportunity to use the latest IGBT technology in packages suitable for series connection. The midterm roadmap is to achieve higher current ratings in the same package. This is a challenging task, because each press pin must conduct higher current in a potentially more challenging working environment.