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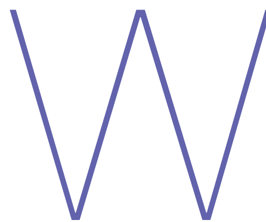
1200 V/100 A Si IGBT/SiC Diode Copack Cuts Switching Losses

A recently launched 1200 V IGBT integrates Optimal Punch Through (OPT) Si IGBTs with best-in-class SiC Schottky diodes. These copacks deliver superior switching performance by reducing the overall switching losses by about 28% when compared with the current state-of-the-art Si IGBT modules.



ith the increasing demand for improving system efficiencies, the development of the low loss, high current, high voltage, rugged power modules for high frequency power electronic applications is of critical importance. The relatively high conduction losses of MOSFET accentuate IGBT as a better choice for most of the applications requiring blocking voltages >1000 V and switching frequencies >5 kHz. IGBT modules are the industry standard power semiconductor modules for various applications between the kW and MW power range [1]. In IGBT power modules, IGBTs are integrated with Free Wheeling Diodes (FWD) to protect them from inductive switching. The losses associated with the FWDs in these modules have a significant impact on the circuit efficiencies. SiC Schottky diodes as FWDs in the IGBT modules provide zero reverse recovery losses, low reverse leakage currents, exceptional thermal properties, thereby improving the overall circuit efficiencies.

GeneSiC offers two Si IGBT/SiC diode copack products that serve as near-ideal candidates for the replacement of industry's conventional Si IGBT power modules/copacks. These two products, GA100XCP12-227 and GA35XCP12-247 (*Fig. 1*) are designed by connecting GeneSiC SiC JBS diodes in anti-parallel direction with the low loss Si IGBTs in industry-standard (SOT-227 and TO-247) packages to deliver superior switching performance by reducing the IGBT and FWD losses by about 47% and 88% respectively when compared with a commercial Si IGBT power module. They are targeted towards the solar inverter, aerospace actuator, server power supply, induction heating and electronic welding applications.

Fig. 1. Si IGBT/SiC diode Copacks come in standard (SOT-227 and TO-247) packages.

For high frequency applications, replacing the Si IGBT in these copacks with a SiC power switch will further reduce the overall switching losses due to the exceptional material properties offered by SiC. GeneSiC's best in class, SiC based power switch, Super Junction Transistor (SJT), is designed to offer superior switching characteristics than the state-of-the-art Si power MOSFETs with its conduction losses comparable to the conventional Si IGBTs.

NPT and FS are the most commonly employed technologies when designing IGBTs for 1200 V and above blocking voltages [2]. FS is more advanced and rugged technology that combines the advantages offered by PT and NPT technologies. GA100XCP12-227 is a 1200 V/100 A Si IGBT/ SiC diode copack that uses OPT technology for its IGBT design. The OPT IGBT is designed to exhibit positive temperature coefficient of saturation voltage, low gate charge requirement and high Short Circuit (SC) current capability with reduced conduction and switching losses. The other benefits of this OPT technology include an almost square RBSOA characteristic. The positive temperature coefficient of saturation voltage indicates that the copacks

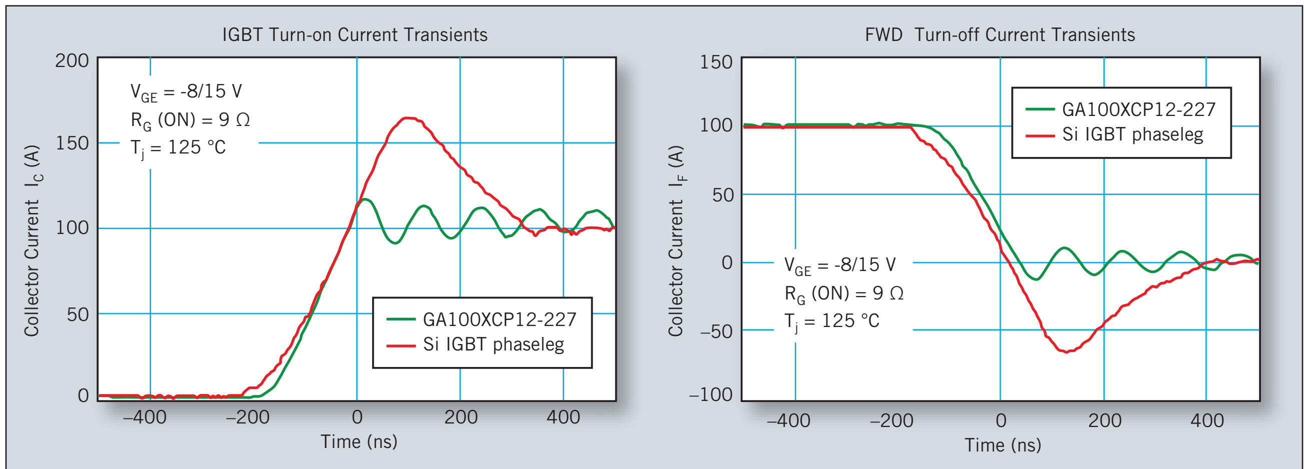


Fig. 2: Comparison of IGBT turn on, FWD turn off current switching transients.

are easy for paralleling and are best suitable for high current configurations. The tail current during the turn off decreases with increase in the collector-emitter voltages. The gradient of the turn off losses as a function of temperature is considerably low due to the low injection of minority carriers into the base region, still the device yields a low saturation voltage.

BEST IN-CLASS PERFORMANCE

A current family of SiC JBS diodes have current ratings ranging from 1A to 20A for 1200 V and 1A for 2000 V voltage ratings. The implementation of superior design and robust processing techniques allow these diodes to deliver best-in-class performance with positive temperature coefficient of avalanche breakdown voltage, ultra low zero bias capacitance, high surge current capability, high temperature operation (≤ 225 °C) and low switching losses. These majority carrier diodes show a positive temperature coefficient of resistance due to the decrease in the drift electron mobilities with the increase in temperature. This positive temperature coefficient of resistance makes it possible to parallel the devices for high current applications. The reverse leakage current of these devices manifests the smallest increase, when the temperature is increased from 25 °C to 225 °C, thereby indicating a much better leakage current stability with temperature.. The typical leakage current is only about 80 µA for a 20 A JBS diode at 1200 V at 175 °C. Unlike Si FREDs, the reverse recovery charge in SiC JBS diodes is purely capacitive and independent of applied di/dt, turn-off current level, and more importantly, temperature. The excellent thermal properties of SiC material demands relatively small heat sinks for these devices. They are paralleled up in the two Copack products to obtain the desired current rating.

The real benefits of the Si IGBT/SiC Diode Copack over the commercial Si IGBT power modules can intuitively be realized from their switching characteristics. The industry's best-in-performance, 1200 V/100 A Si IGBT phase-leg module is used for comparing the switching performance with GA100XCP12-227. Two of GA100XCP12-227 copacks are arranged in a phase leg configuration for the switching test setup. An inductively loaded clamped circuit is used for investigating the switching characteristics of the two power modules [3]. It is to be noted that the reverse recovery characteristics of FWD reflect on the IGBT turn on characteristics. The IGBT turn on and FWD turn off switching transients of GA100XCP12-227 compared with Si IGBT module at 125 °C operating temperature are shown in *Fig. 2*.

The ringing associated with the SiC FWD turn off characteristics depicts the diode's capacitive nature of reverse recovery charge. The FWD in the Si IGBT phase-leg module is a minority carrier device that displays a positive temperature coefficient of reverse recovery charge. Unlike GeneSiC's GA100XCP12-227, the reverse recovery characteristics of FWD in the Si IGBT phaseleg module are dependent on applied di/dt, turn off current level and temperature. *Fig. 3* shows the individual contributions of the components

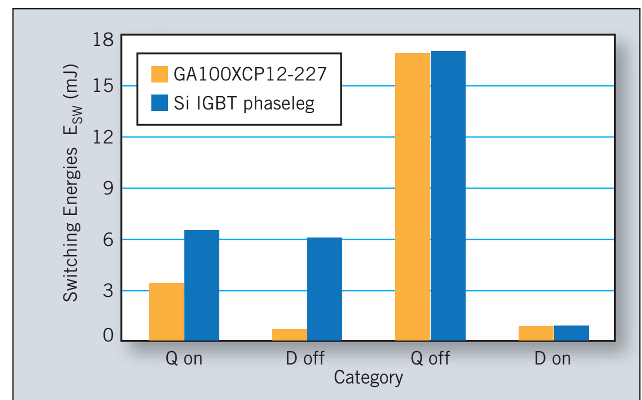


Fig. 3. Comparison of IGBT and FWD switching energies at 125 °C

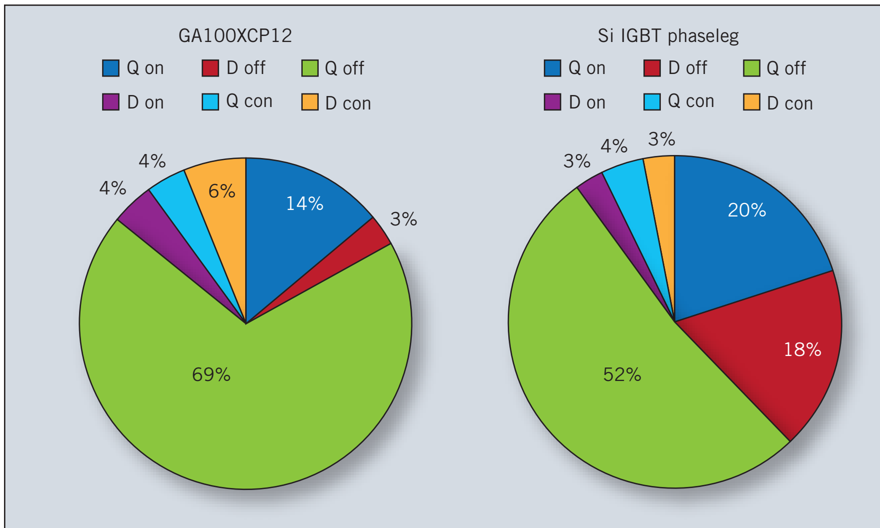


Fig. 4. Overall loss comparison at f_{SW} = 100 kHz, D = 0.5 and T_J = 125 °C.

As it can be seen, the contribution of IGBT losses to the overall losses is very significant in both modules. For high frequency applications, GeneSiC SJT module will be an ideal replacement to the Si IGBT/SiC diode module that can even drastically reduce the overall losses. *Fig. 5* shows the switching losses of the two modules at switching frequencies from 5 kHz to 200 kHz at 125 °C.

The GeneSiC IGBT copack designed by the integration of Si OPT IGBT with SiC JBS diode enjoys huge benefits as compared to the commercially available Si IGBT modules. These benefits include high switching speed withstand capability, low switching losses, high temperature operation, low EMI, better thermal properties, industry's best SOA capabilities and excellent product stability. These features and benefits make it an efficient product that can replace state-of-the-art Si IGBT power modules in high frequency power electronic applications.

towards switching performance of the two modules. With GA100XCP12-227, a reduction of 88% and 47% is realized in the IGBT turn on and FWD turn off energies respectively at 125 °C operating temperature. This results in an overall switching loss reduction of about 28% as compared to its silicon counterpart. The GA100XCP12-227 shows moderate increase in the switching losses with increase in temperature. This moderate increase is only due to positive temperature coefficient of IGBT turn off losses.

LOWER SWITCHING LOSSES

Deeper insight into the overall losses and their individual contributions can be obtained from *Fig. 4.* A switching frequency of 100 kHz and a modest duty cycle value of 0.5 is assumed for all the calculations. High percentage reductions in the IGBT turn on and FWD turn off losses of GA100XCP12-227 can be attributted to the phenomenol switching performance of GeneSiC JBS diodes.

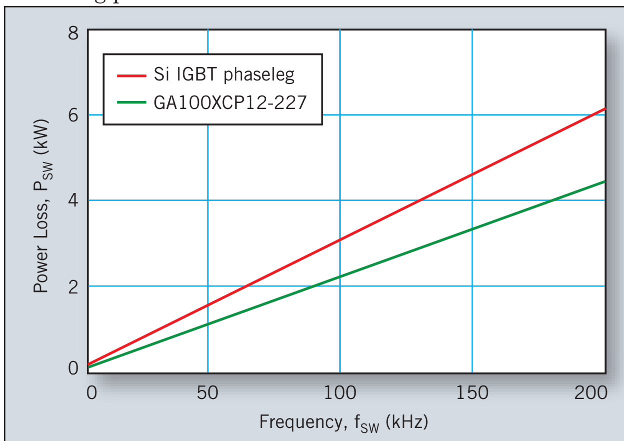


Fig. 5. The switching losses of the two modules at switching frequencies from 5 kHz to 200 kHz at 125 °C.

SUPER JUNCTION TRANSISTOR

Looking to the future, GeneSIC Semiconductor is leveraging the technology to develop an innovative power device called the Super Junction Transistor. The transistor will be developed in voltages ranging from 1200 V to 10 kV. A gate – oxide free, normally – off, current driven, quasi – majority device, SJT is a "Super – High" current gain SiC based BJT that exhibits a square reverse biased safe operating area (RBSOA), high temperature operation (>225°C) capability, superior blocking performance with low VDS(on) and extremely fast switching capability (10's of MHz) than any other competitor SiC switch.

The Super Junction Transistor devices display a positive temperature coefficient of resistance, making them suited for device paralleling for high current solutions. The conversion efficiencies can be improved tremendously by incorporating these devices, which will allow a reduction in the size/weight/volume of power electronics.

REFERENCES

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