Featured Products Technology

1.0 Introduction

Powerex's new F-Series IGBTs represent a significant advance over previous IGBT generations in terms of total power losses. The device remains fundamentally the same as a conventional IGBT, and the advice given in the application notes "General Considerations for IGBT and Intelligent Power Modules" and "Using IGBT Modules" should be observed. However the use of a trench-gate structure, and an integrated short circuit current control circuit, mean that there are sufficient differences in characteristics and behavior to warrant further explanation.

2.0 Trench Gate IGBT Structure

Since the IGBT's introduction, successive generations of IGBT technology have featured steady improvements in on-state voltage and switching losses. However, improving the performance of existing IGBT technology has become increasingly difficult due to the constraints of the planar IGBT structure. The limitations of the planar IGBT arise partly from the resistance of the JFET region between adjacent cells in the MOSFET portion of the device, and partly from the forward voltage V_F of the diode structure in the bipolar portion of the device.

F-Series IGBTs overcome the first constraint by utilizing a trench gate structure, in which the gate oxide and conductive polysilicon gate electrode are formed in a deep narrow trench below the chip surface. The second limitation is addressed by using a new proton irradiation process.

Figure 1 shows a comparison of the structures of a conventional planar IGBT cell and a trench gate IGBT cell. This figure shows the components making up the on-state voltage drop, $V_{CE(sat)}$. Performance improvements realized in each of these components in the new structure are described below.

2.1 Reduction of Channel Resistance

When voltage is applied to the gate, the MOSFET channel forms along the vertical wall of the trench perpendicular to the surface of the chip. This is in contrast to the planar structure where the channel forms parallel to the chip surface. The vertical channel requires less chip area, permitting a substantial increase in cell density. The consequent increase in channel width per unit area results in a reduction in the R channel portion of the IGBT's on-state voltage drop.

2.2 Elimination of JFET Region

The "JFET" resistance (R_{JFET}) in a planar IGBT exists due to the constriction of current flow in the region between adjacent cells. The trench gate structure effectively eliminates this region as shown in Figure 1. Furthermore, the non-uniform current density in the JFET region of planar IGBTs can lead to inconsistencies in the device SOA at high current densities. The trench structure achieves more uniform current flow which, combined with greater cell density, increases the rated current density compared with 1200V third generation planar.

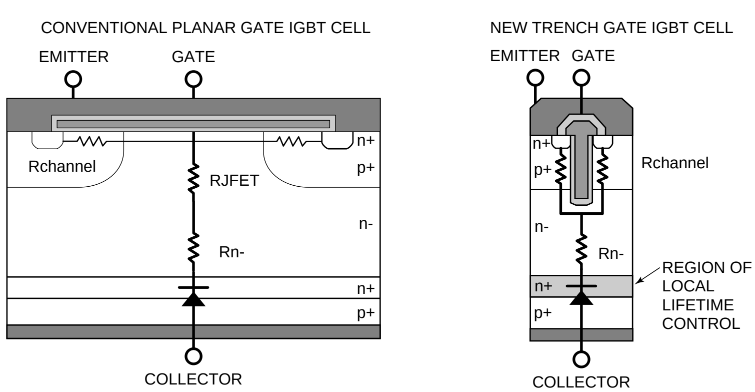
2.3 V_F Reduction in Bipolar Region

The new IGBT is a punch through (PT) device, using a newly developed local lifetime control process. This proton irradiation technique allows carrier lifetime to be reduced in the n+ buffer layer onlyas shown in Figure 1. Hence the turn-off losses can be reduced whilst maintaining a higher carrier lifetime in the n- drift region than was possible with the uniform lifetime control used in third generation planar IGBTs. This results in a greater carrier concentration in the drift region during conduction which reduces the Rn- component of $V_{CE(sat)}$.

3.0 Module Packaging

The F-Series utilizes Powerex's innovative low inductance packaging technology, which was first introduced in the U-Series

Figure 1 Comparison of Trench and Planar IGBT Structures

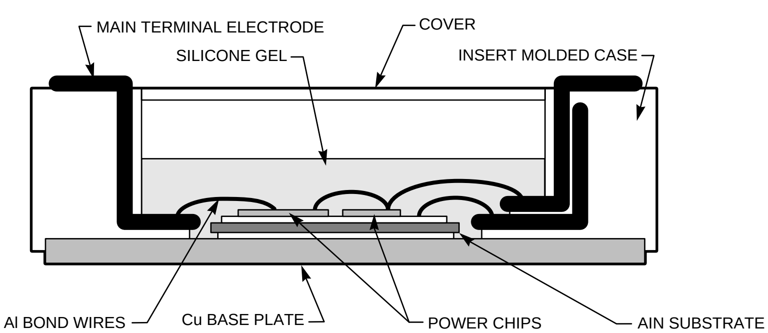


range of planar IGBT modules. A cross-section of a typical module is shown in Figure 2.
The main power terminals are realized as a laminar busbar structure molded into the side of the case. This gives much lower inductance than soldered electrodes, which are inserted into conventional modules after the case is moulded. In the new module, the terminals are wire bonded directly to the chips. The strain relieving S-bends needed in soldered electrodes are eliminated, further reducing the module inductance. This construction results in the new module having about one-third the internal inductance of conventional modules.

Since no substrate area is required for soldering the electrodes, the total ceramic substrate area is reduced when compared with a conventional module. Thus aluminium nitride (AlN) ceramic, with lower thermal resistivity than aluminium oxide (Al_2O_3), can be economically used. Additionally, the parasitic capacitance of the module is reduced, increasing the impedance to high frequency noise between chip and heat sink.

In the manufacture of a conventional module a high temperature soldering process is used for chip-to-substrate and substrate-to-base plate soldering. After case assembly, a second soldering process attaches the electrodes to the substrate. In the F-Series module, this second step is not required. This in turn means that the first soldering step can be performed at lower temperature, reducing thermal stress during production.

Figure 2 New Package Cross Section



4.0 RTC Description and Behavior

F-Series IGBTs include an integrated real-time current control (RTC) circuit for protection against short circuits, which was originally developed for intelligent power modules (IPMs). The RTC is a separate chip wire-bonded directly to the IGBT die and mounted adjacent to it. During normal operation of the device, the RTC is effectively “transparent” to the gate driver. Its power supply is drawn from the main collector-emitter path of the IGBT, so it imposes no additional drain on the gate driver.

The RTC is connected to a current mirror emitter on the trench IGBT chip. A simplified diagram of this is shown in Figure 3. When the IGBT operates in a short circuit, the RTC detects the excessive current in the IGBT and reduces the gate-emitter voltage to limit the short-circuit current. The gate-emitter voltage is reduced to less than 12V, compared with the normal recommended value of 15V. The effect of gate-emitter voltage on short-circuit current is shown by Figure 4.

It is important to note that the RTC acts only to limit short-circuit current; it does not switch off the IGBT. Therefore the gate driver circuit should be designed to ensure that the IGBT is turned off within 10µs of a short circuit occurring.

The RTC limits the short circuit collector current to 2-4 times rated current, depending on the junction temperature of the IGBT and the short circuit di/dt. The minimum trip threshold for the RTC is 2 times the rated current of the device and occurs at high T_j and high di/dt. Therefore operation of the IGBT within its normal switching SOA is unaffected by the presence of the RTC.

Figure 3 Simplified Diagram of RTC and IGBT Connection

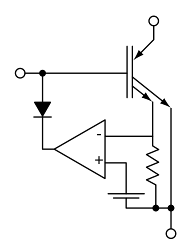


Figure 4 Effect of V_{ge} on Short Circuit Saturation Current of 150A, 120V IGBT (Without RTC)