Low-loss IGBTs Improve Switching In Sub-2.5 kW Inverter Applications

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Traditionally, IGBTs have addressed applications requiring high-voltage and -current ratings and relatively slow switching frequencies. When the switching frequency is low, the inherently low conduction losses resulting from the device’s low $V_{CE(on)}$ (collector-to-emitter saturation voltage), which derive from the IGBT’s minority carrier operation, outweigh the poor switching performance, enabling high overall operating efficiency. This article will discuss a new depletion-stop trench IGBT technology that combines low switching losses with the traditional IGBT advantage of low conduction loss for sub-2.5 kW inverter applications.

IGBT Loss Mechanisms

The latest-generation IGBTs, which benefit from depletion-stop trench technology, address the requirement for low conduction and switching losses, and carry up to 60 percent more rms current than previous devices. This results in smaller discrete IGBTs and IGBT modules, and enables designers to reduce heat sink size significantly.

Switching losses in IGBTs result from the slow dispersal of holes in the drift region after the gate-emitter voltage falls below the threshold voltage to turn the device off. Either the holes recombine or a voltage gradient sweeps them out. Until this process completes, the IGBT exhibits a tail current, which slows the switching speed and increases switching losses. The PT (punch through) IGBT introduced a buffer layer adjacent to the drift region to quickly absorb remaining holes during turn off and, thereby, eliminate the excessive tail current. However, this enhanced switching performance is at the expense of higher $V_{CE(on)}$. In addition, PT IGBTs do not display the short-circuit-withstand capability most motor-control applications require.

Depletion-stop Trench IGBTs

This lost conduction performance can be regained by adopting a trench structure to increase channel density compared to the traditional planar IGBT structure. Other factors that enhance $V_{CE(on)}$ performance include enhanced accumulation-layer injection and elimination of the parasitic JFET resistance inherent in the planar IGBT structure. Introducing a low-dose field-stop layer to the trench IGBT enhances the trade-off between $V_{CE(on)}$ and switching loss still further, due to a reduction in the n-base thickness.

The new depletion-stop layer allows further thinning of the n-base as well as a higher transistor gain and switching speed. In addition, the optimized device displays highly efficient anode properties, enabling enhanced control over minority carrier injection and a lower tail current at turn-off, delivering a further reduction in turn-off losses. This new thin wafer, depletion-stop trench IGBT technology offers improved efficiency while maintaining the smooth turn-off characteristics and robust SOA (safe operating area) that hard-switching applications demand. $V_{CE(on)}$ and ETS (total switching energy) are both considerably lower than for planar PT and NPT type IGBTs. This combination of low saturation voltage and low total switching energy reduces power dissipation and improves current handling in applications operating at switching frequencies up to 30 kHz. These devices also provide higher power density and reduce heat sink dimensions, or eliminate it entirely.

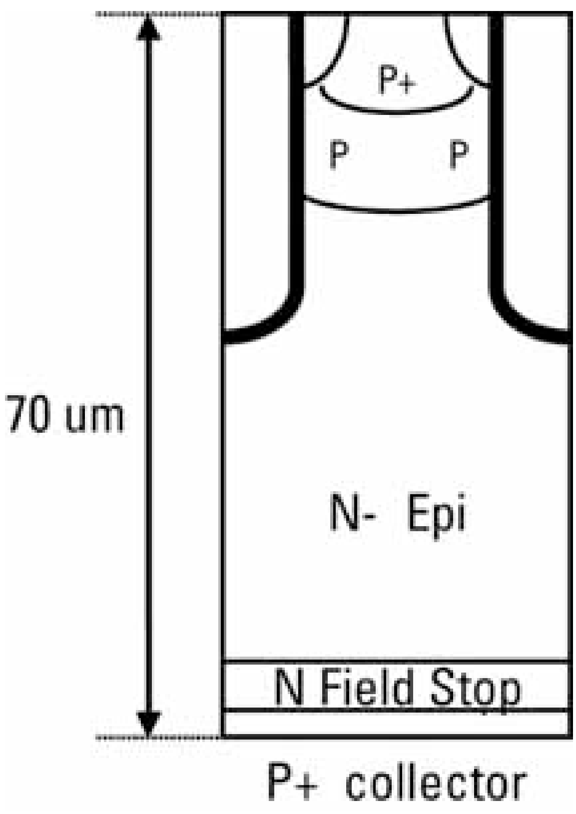

Figure 1. A schematic cross-section of the depletion-stop trench IGBT.

Figure 1 shows emitter N+ regions adjacent to the trench. The fabrication process

grows an oxide layer on the trench walls and then deposits polysilicon, filling the trench volume. The base contact and channel form through a P-base diffusion and a heavy P+ implant, respectively. The deep trench extends below the P-base junction to form a gate-bias-induced channel between N+ emitter and N- drift region. The P+ region in the backside of the wafer enhances anode efficiency. The combination of this device construction and the trench structure's high channel density produces a high carrier density in the drift region and a low forward voltage drop.
New depletion-stop trench technology has been developed to maximize IGBT switching performance for appliance- and industrial-drive applications. The device optimizes carrier lifetime in the drift region, as well as carrier lifetime and doping concentration in the depletion-stop region near the anode. Leakage current and device breakdown voltage both increase with decreasing lifetime in the drift region. In addition, a 70µ-thick wafer is used, which permits lightly doping the anode to help reduce the total stored charge, thereby improving the device's switching performance, especially at higher temperatures.

Optimizing the construction, geometry, and doping in this way leads to lower $V_{CE(on)}$ and lower switching losses than previous PT and NPT IGBT devices. In practical applications, depletion-stop trench IGBTs reduce losses and deliver up to 60 percent more rms current than previous generation devices. For a given current, these devices require roughly 50 percent smaller heat sinks. The technology is suitable both for discrete IGBTs and for emerging families of smart power modules that combine driver circuitry with 600V IGBTs to simplify appliance-motor-control design, enabling a typical size reduction of 25 percent for such integrated modules.

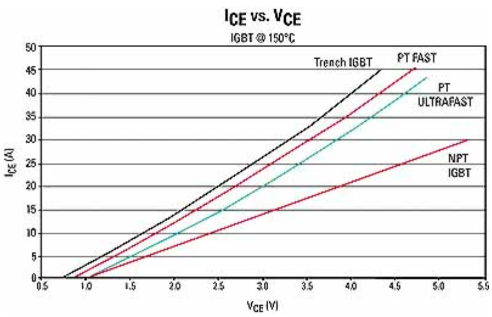

Figure 2. The forward voltage characteristics of various IGBT technologies.

Performance Comparison
The new 600V trench IGBT offers lower $V_{CE(on)}$ than previous generation PT and NPT devices, resulting in lower conduction losses (Figure 2). Designers need not change their gate-drive circuits because the threshold and maximum gate voltages for these devices are in the same range as for PT and NPT devices. The trench IGBT also has lower total gate charge, shorter propagation delays, and shorter turn-on and turn-off transition times. Thus no modification is needed to the controller's dead-time or minimum-pulse-width settings.

Faster switching brings the risk of spurious turn on of an inverter's low-side device, which fast dV/dt transients can cause. Spurious turn on can result in shoot-through currents that may impair inverter reliability and lead to early failure. However, depletion-stop trench IGBTs display a high ratio of gate-to-emitter capacitance (CGE) to reverse transfer capacitance (CRES), which provides immunity to high dV/dt induced spurious turn-on. This ensures robust performance even at high dV/dt switching conditions.

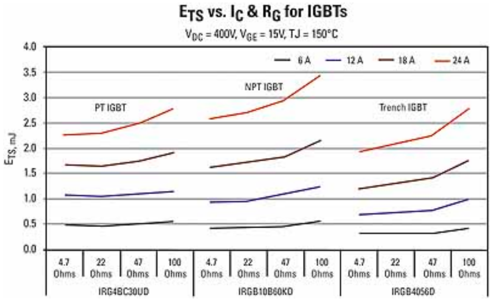

Figure 3. Switching energy characteristics of various IGBT technologies.

In terms of forward voltage, switching energy, and rms current versus frequency characteristics, trench IGBT devices offer improved performance compared to planar IGBTs. The depletion-stop trench IGBT devices clearly show lower conduction and switching-energy losses, leading to greater efficiency in inverter applications operating at high switching frequencies.

Reduced Stress for Enhanced Reliability

Further benefits of the depletion-stop trench IGBT include a number of features that provide more-robust performance in motion-control applications. One example is the IGBT's smooth turn-off characteristics under short-circuit conditions, which reduce voltage spikes and stress on the IGBT.

Another benefit is the absence of gate overcharging during short-circuits. This can occur in older IGBT structures, leading to an over-current spike that stresses the device and impairs the reliability of the inverter. The trench IGBT's square RBSOA characteristic also allows safe switching under severe overload. This, along with high peak turn-OFF capability and good short-circuit rating will allow more robust and reliable inverters suitable for a wide variety of applications.

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