New 1600V BIMOSFET™ Transistors Open Up New Applications

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Introduction

There are many applications today using high voltage MOSFETs and IGBTs, which would benefit from a higher voltage part. Examples are sweep circuits, radar pulse modulators, capacitor discharge circuits, solid state relays, auxiliary power supplies on traction equipment and other high voltage switch mode power supplies. MOSFETs are connected in series-parallel strings to overcome their voltage and high $R_{DS(on)}$ limitations. High voltage IGBTs are too slow for some applications. A new family of high voltage BIMOSFET™ transistors is fulfilling these needs.

The conventional construction for both MOSFETs and IGBTs is commonly referred to as DMOS (double-diffused-metal-oxide-silicon), which consists of a layer of epitaxial silicon grown on top of a thick, low resistivity silicon substrate, as shown in Fig. 1b. However, at voltages in excess of 1200V, the thickness of the N- silicon layer required to support these blocking voltages makes it more attractive and less costly to use a non-epitaxial construction as illustrated in Fig. 1a. This type of construction is also known as "homogeneous base" or "non-punch through" (NPT).

Referring to Figure 1a, the typical pnpn-structure for the IGBT has been maintained, but note that an N+ collector-short pattern has been introduced in order to reduce the current gain of the PNP transistor and consequently its turn-off switching behavior. However, now there is a "free" intrinsic diode from emitter to collector , not unlike that found in a MOSFET, which led us to coin the acronym 'BIMOSFET™ transistor.' The turn-off behavior of the BIMOSFET™ transistor is controlled by the amount of collector shorting. In order for the diode to be usable and not cause commutating dV/dt problems, the lifetime of the minority carriers must be reduced by irradiation. The end result is a device, which can be optimized for either high frequency or low frequency switching by tailoring its collector short pattern along with suitable amounts of ir-

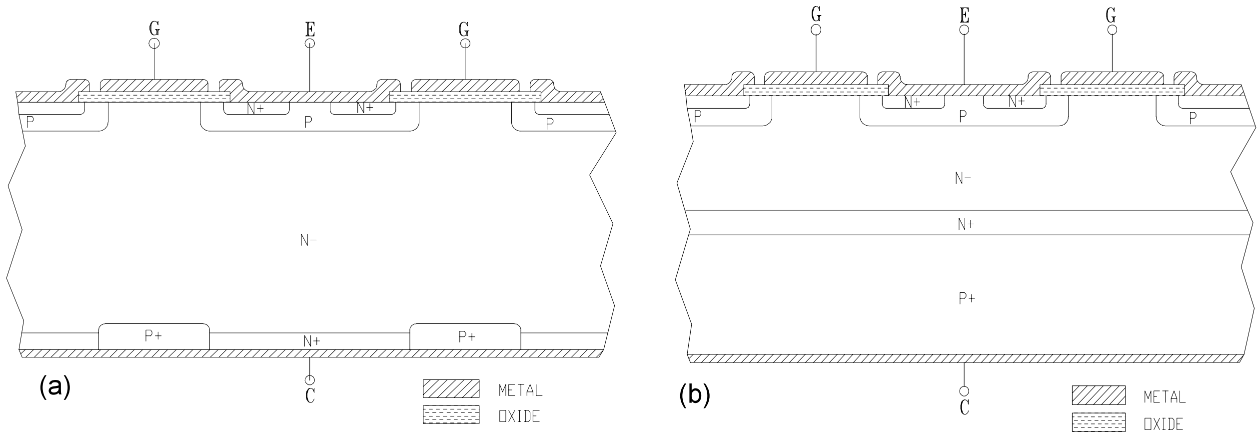

Figure 1. Comparison of the BIMOSFETTM IXBH40N160 cross-section (a) to an IGBT with epitaxial construction (b).

Table 1: Comparative Electrical Performance

Parameter	IXBH40N160	IXLH45N160
DC Parameters (Tj = 25C)		
BVces	1600V	1600V
Vge(th)	5-9V	5-9V
Vce(sat) @ Ic = 25A	7V	2.5V
Qg(on)	121nC	108nC
Ic(on) @ Vge = 15V	110A	100A
Switching (Tj = 125C)		
Turn-on (Note 1)		
td(on)	50ns	50ns
tri	195ns	168ns
E(on)	0.78mJ	0.66mJ
Turn-off (Note 2)		
trv	195ns	335ns
tfi	240ns	1980ns
E(off)	3.0mJ	29mJ

Notes:
1. Turn-on test conditions: V_C = 960V; I_C = 30A; R_G = 2.7Ω; Resistive load
2. Turn-off test conditions: V_C = 1440V; I_C = 25A; R_G = 22Ω; Inductive load

radiation.

Since there are many applications in which the electrical characteristics of the intrinsic diode are not optimum for the application, e.g. high on-voltage or reverse recovery current or too high power dissipation, a modified fabrication process has been developed to block the intrinsic diode without impacting the effectiveness of the collector shorts. The first member of the family with the diode blocked is the 1600V rated IXLH45N160 BIMOSFET™ transistor intended for high current applications with low repetition rates. This part has a much lower saturation voltage (3.5V at I_c = 30A) because it is not irradiated. Its switching speed is controlled by the amount of collector shorting; more shorting results in higher saturation voltages due to loss of conducting area but faster switching performance.

DC Electrical Performance

It is foreseen that the BIMOSFET™ transistor family will span the range of high voltage applications, from a simple high voltage switch to increasing the upper frequency performance of high voltage IGBTs. Table 1 offers a comparison of their electrical performances.

In examining this table and some of the figures below, we can note the following:

1. The typical threshold voltage of the BIMOSFET™ transistor family is higher than normal IGBTs but its $Q_{g(on)}$ is comparable. This

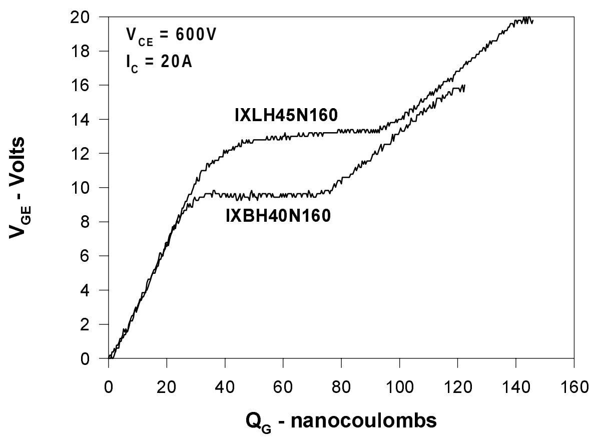

Figure 2a: Gate charge

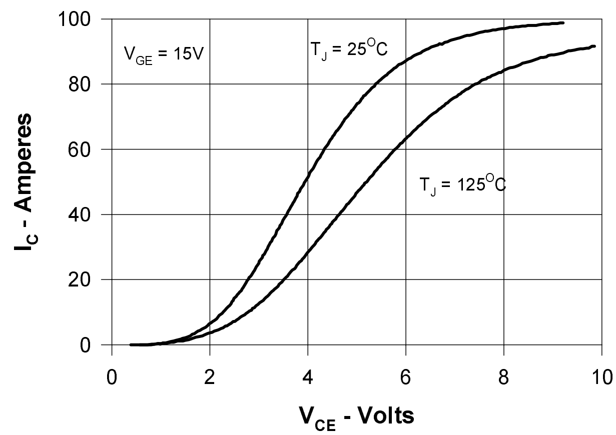

Figure 3a: $V_{CE(sat)}$ of the IXLH45N160 showing the effect of increasing T_J.

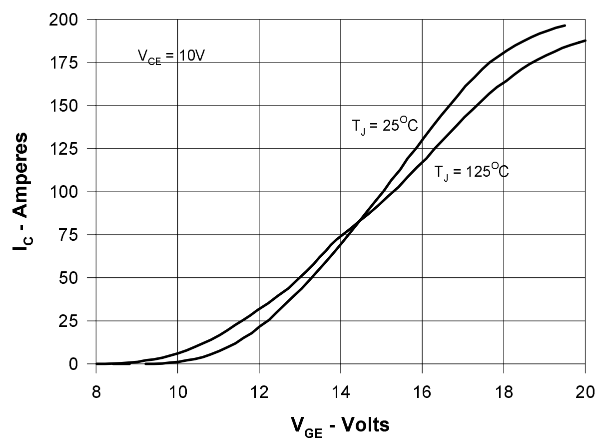

Figure 2b: IXLH45N160 output current vs. gate-emitter voltage

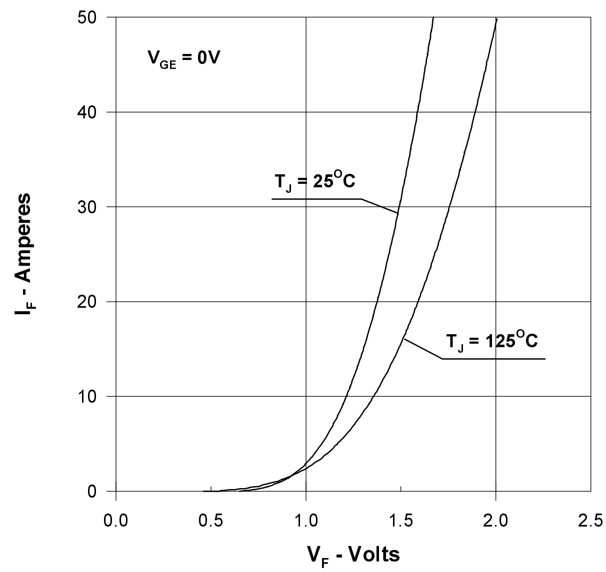

Figure 3b. Forward voltage drop of the IXBH40N160 intrinsic diode.

is due to its relatively low Miller gate capacitance resulting in low Miller gate charge as can be seen in Figure 2a. In one sense, a high threshold voltage can be considered as an advantage in electrically noisy environments. The low $V_{CE(sat)}$ version also has a 2V higher $V_{GE(on)}$. Figure 2b plots its transconductance at room and elevated temperatures and shows that the output current vs. V_{GE} is relatively independent of temperature.

2. The $V_{CE(sat)}$ of the IXLH45N160 is almost one-third of the IXBH40N160, 2.5V and 7.0V respectively at I_C = 25A. The saturation voltage of both parts has a strong, positive temperature coefficient as evidenced in Fig. 3a, depicting the $V_{CE(sat)}$ curves for the IXLH45N160. Fig. 3b plots the diode voltage drop of the IXBH40N160 and shows that it too has a positive tempco. Consequently it is easier to operate BIMOSFET™ transistors in parallel than either DMOS IGBTs or MOSFETs.

3. In order to survive short circuit testing (SCSOA) at higher voltages, low transconductance, yielding low short circuit current $I_{CE(on)}$ is required. So with $I_{CE(on)}$ values in the order of 100A, the BIMOSFET™ transistors can be used in applications where survivability to this type of fault is a must.

4. However in many pulse applications, the capability to conduct high peak currents is more

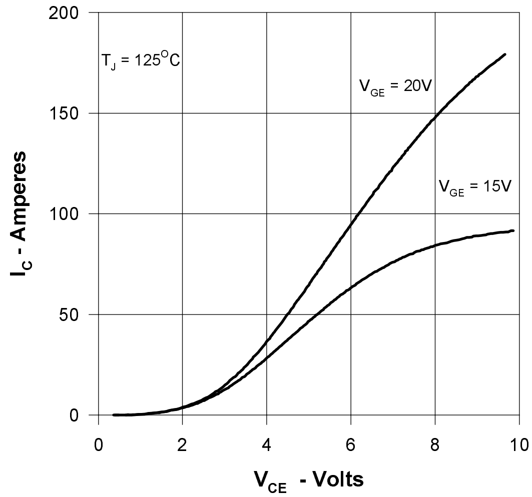

Figure 4. Saturation voltage curve for the IXBH45N160. Note increased output current capability and lower $V_{CE(sat)}$ voltage with 20V gate drive.

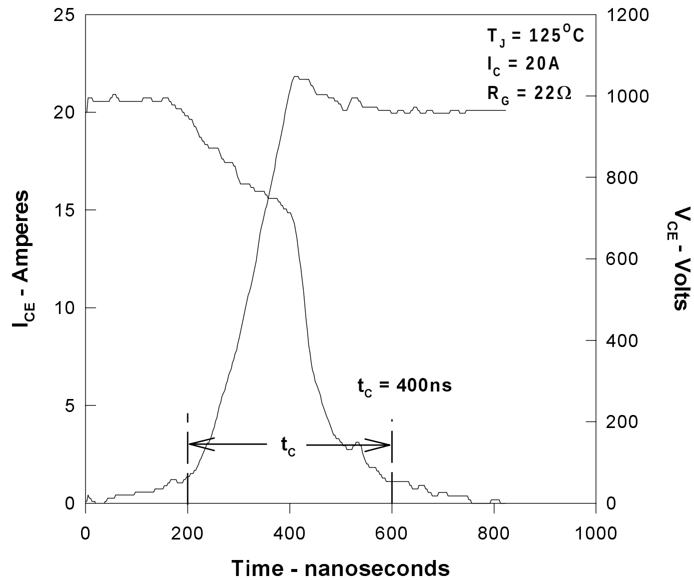

Figure 5. Turn-off current and voltage waveforms of the IXBH40N160.

important than SCSOA. One way to overcome low transconductance is to increase gate voltage. Figure 4 shows that $I_{C(on)}$ almost doubles from 100A to over 200A as V_{GE} is increased from 15V to 20V, while gate charge only increases by 20nC. This is easily done using either discrete MOSFETs or bipolar transistors in the gating circuit or by using commercially available IC drivers, such as the Telcom TC4431 or TC4432 MOSFET drivers.

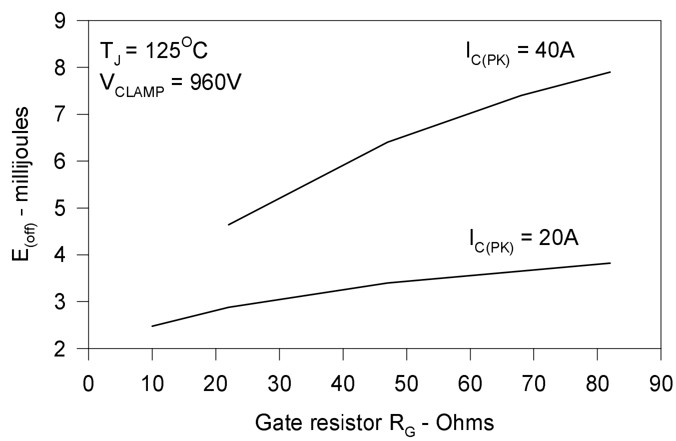

Figure 6. Turn-off energy versus gate resistor R_G for the IXBH40N160.

Switching Performance Comparison

Both BIMOSFET™ transistors switch exceptionally fast for 1600V rated parts. The resistive turn-on time of the IXLH45N160 with a 2.7Ω gate resistor is typically 168ns, which edges out the IXBH40N160 (t_{ri} = 195ns) because the latter is irradiated. But Figure 5, illustrating the IXBH40N160 turning off a 20A inductive load into a 1000V clamp at the elevated temperature of 125°C, shows where it shines. There is relatively little tail current so that the $E_{(off)}$ is 2.4mJ, which is 50% less than a comparable IGBT. Figure 6 plots its turn-off energy as a function of the series gate resistor R_G. This resistor primarily determines the rate-of-rise of collec-

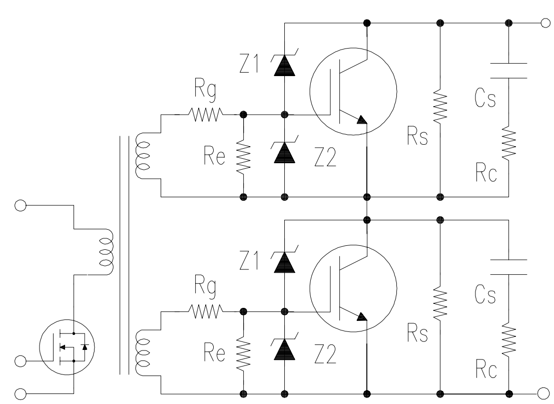

Figure 7. Series connection

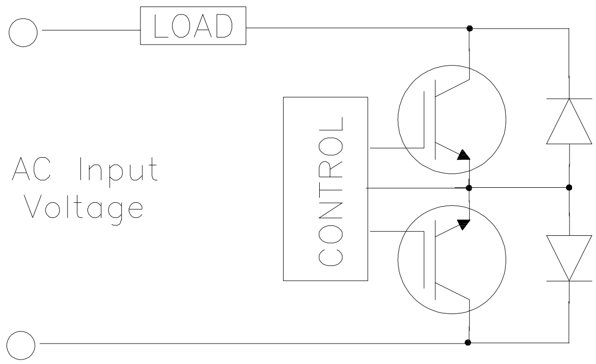

Figure 8a: Bi-directional AC switch.

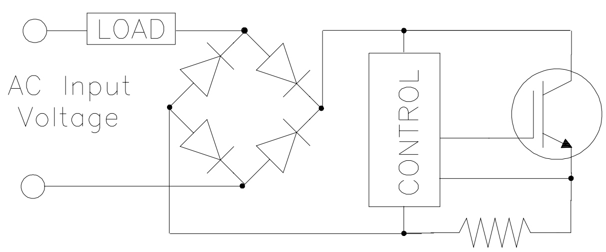

Figure 8b: AC current control using diode bridge.

tor voltage, which increases as R_G decreases and correspondingly $E_{(off)}$ decreases. The low $V_{CE(sat)}$ IXLH45N160 has a much longer tail current, which is only marginally affected by R_G. Consequently its operating frequency range is less than 5kHz.

Applications

Some of the many applications have already been mentioned but let us a review a few to see the advantages of the availability of high voltage switches.

One fast growing type of application is capacitor discharge circuits, such as found in laser power supplies, defibrillators, spot welders and similar circuits. The use of high voltage is an advantage because energy stored in a capacitor is proportional to voltage squared and fast current rise times are easier to achieve. Figure 7 shows a typical circuit using two IGBTs in a series string. Note the necessity of the following duplicate components:

1. Static voltage sharing resistors R_S due to unequal leakage currents of the two switches;
2. Dynamic voltage sharing capacitors C_S to compensate for differences in turn-on and turn-off times;
3. Resitor R_C may also be required to dampen voltage ringing or to limit capacitor in-rush current at turn-on;
4. Zener diodes Z1 to protect the IGBTs against overvoltage transients;
5. Duplicate gating circuit components R_G, Z2 and R_E.

Eight of these components can be eliminated when using only one high voltage switch! In addition, the pulse transformer is easier to wind since now there is only one secondary winding.

When one switch does not have the current handling capability, semiconductor switches are used in parallel. While both MOSFETs and IGBTs are used in parallel, both require matching to achieve satisfactory operation. The

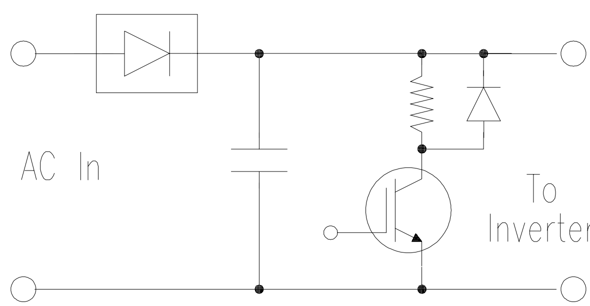

Figure 9a: Dynamic break configuration.

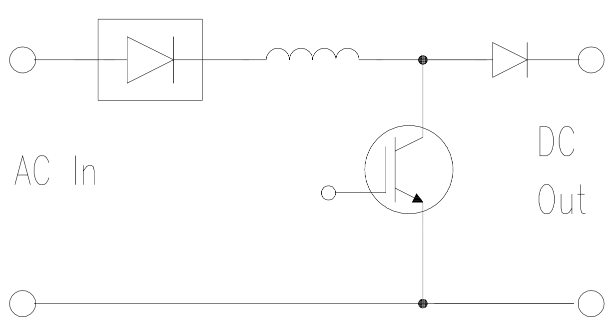

Figure 9b: Boost configuration.

BIMOSFET™ transistor family facilitates paralleling due to its positive voltage temperature coefficient of both its saturation voltage and forward voltage drop of the intrinsic diode as shown in Figure 3b..

A traditional usage of thyristors is in AC solid state switches. Two possible circuits are shown in Figures 8a and 8b. Figure 8a shows the connection diagram for two IXLH45N160 BIMOSFET™ transistors and two high voltage diodes while Figure 8b circuit uses one BIMOSFET™ transistor inside a full-wave bridge. Both circuits can be used on AC mains up to 600V(RMS) and both also provide the additional functions of precise current control and overcurrent protection. The circuit in Figure 8a can carry more current because the current is shared by the two BIMOSFET™ transistors and will be more efficient because current only flows through one diode. The circuit in Figure 8b will cost less because there is only one BIMOSFET™ transistor.

Finally Figures 9a and 9b show the usage of the BIMOSFET™ transistors in two rapidly growing applications, namely AC motor control featuring dynamic braking and boost inverters. Again due to the high voltage and fast switching capability of the IXBH40N160, one can now design these circuits to operate up to 600V(RMS) or produce output DC voltages up to 1200V.

Just as it is anticipated that the applications for BIMOSFET™ transistors will proliferate, IXYS will continue to grow the BIMOSFET™ transistor family by the additions of both higher and lower current devices with a range of switching speeds to meet the requirements of the power conversion market.

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