IXBH40N160 BiMOSFET™ Developed for High Voltage, High Frequency Applications

by

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ABSTRACT

In the IXBH40N160, IXYS has developed an extremely fast, homogeneous base IGBT by the introduction of collector shorts. Since this modification made the device behave like a very low $R_{DS(on)}$ MOSFET, IXYS coined the acronym BiMOSFET™ to distinguish this new class of switches. Rated at 1600V, its $R_{DS(on)}$ is less than 10% of an equivalent voltage rated MOSFET yet it has a switching time of less than 200ns. Consequently it will supplant conventional IGBTs and MOSFETs in high voltage applications running at frequencies from 10kHz to 75kHz and higher using soft-switching techniques.

1. INTRODUCTION

Applications abound today for high voltage MOSFETs but which would also benefit from a better part. Examples are sweep circuits, radar pulse modulators, capacitor discharge circuits and high voltage switch-mode power supplies. MOSFETs are connected in series-parallel strings to overcome their voltage and high $R_{DS(on)}$ limitations. Conventional, high voltage IGBTs are just too slow. IXYS has developed a new 40A, 1600V, homogeneous base IGBT to fulfill this need for a faster and higher voltage switch.

The conventional construction for both MOSFETs and IGBTs is commonly referred to as DMOS, double-diffused-metal-oxide-silicon, which consists of a thick layer of epitaxial silicon grown on top of a large, low resistivity silicon substrate. However, at voltages in excess of 1200V, the thickness of the N-silicon layer required to support those blocking voltages makes it attractive to construct a homogeneous-base IGBT. A cross-sectional view of this type of construction is shown in Figure 1.

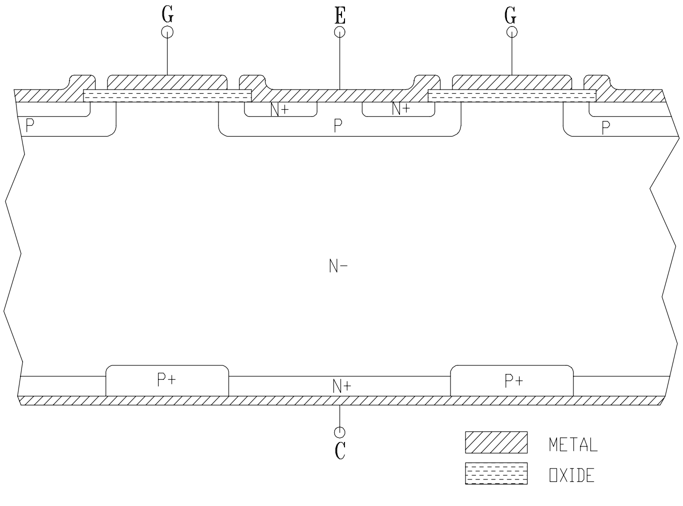

Figure 1. BiMOSFET™ cross-sectional view.

Referring to this figure, 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, not unlike that found in a MOSFET. The turn-off behavior of the BiMOSFET™ is controlled by the amount of collector shorting. However, 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 will be 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 irradiation.

Table 1: Electrical Performance Table

PARAMETER	IXBH 40N160 BiMOSFET™	IXSH 35N120A IGBT	IXFH 12N100 MOSFET
DC Parameters			
BV_{DSS} @ 3mA	1600V	1200V	1000V
$V_{GE(th)}$ @ 4mA	5-9V	4-8V	2-4.5V
$V_{CE(sat)}$ @ I (125ºC)	7V @ 25A	4V @ 35A	13.9V @ 6A
g_{FS} @ I	20S	26S	10S
C_{ISS} (25V) C_{OES} (25V) C_{RES} (25V)	3275pF 210pF 28pF	3750pF 235pF 60pF	4000pF 310pF 70pF
$Q_{g(on)}$	121nC	150nC	122nC
$I_{c(on)}$	110A	170A	48A
Switching (T_J = 125ºC)			
$t_{d(on)}$ (R_g = 5Ω)	50ns	80ns	21ns
t_{ri}	195ns	150ns	33ns
t_{fi} (R_g = 22Ω)	240ns	1100ns	32ns
E_{off}/A (960V)	0.12mJ/A	0.26mJ/A	0.04mJ/A

2. DC Electrical Performance

We foresee that the BiMOSFET™ should find applications both as a high voltage switch as well as to increase the upper frequency performance of high voltage IGBTs. Table 1 offers a comparison of its electrical performance to that of an 1000V MOSFET (IXFH12N100) and a 1200V DMOS constructed, SCSOA rated IGBT (IXSH35N120A), all three parts being constructed using the same silicon chip size (7.11mm x 8.64mm). The comparison is conservative because both competing parts are lower-voltage rated.

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

1. The threshold voltage of the BiMOSFET™ is the highest of all but its $Q_{g(on)}$ is comparable. This is due to its relatively low Miller gate capacitance resulting in low Miller gate charge as can be seen

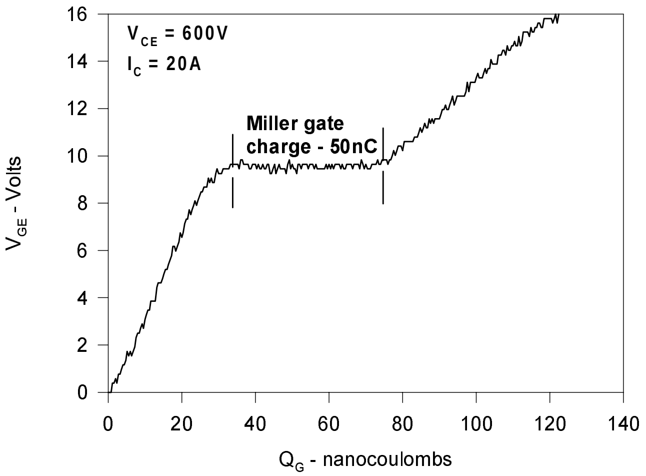

Figure 2: Gate charge

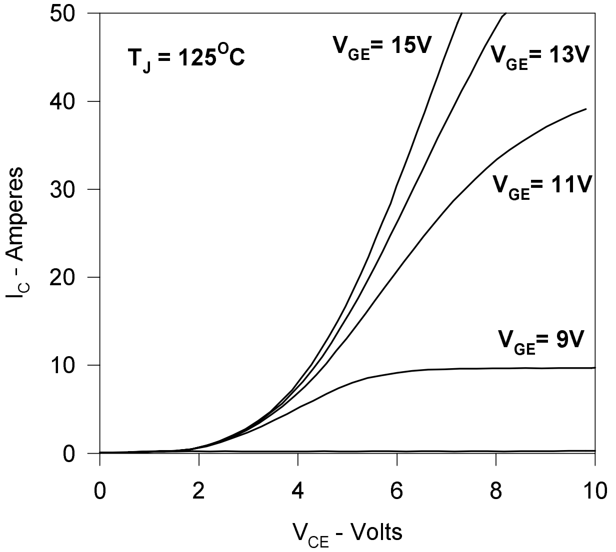

Figure 3a. Output characteristics at 125°C.

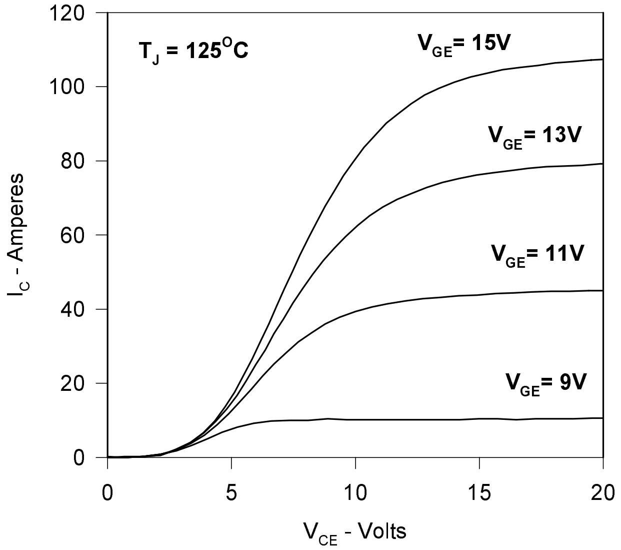

Figure 3b. Extended output characteristics.

in Figure 2. In one sense, a high threshold voltage can be considered as an advantage in electrically noisy environments.

2. Its transconductance and peak on-state current are lower than the IGBT, making the latter the preferred switch for low frequency applications. In order to survive short circuit testing at higher voltages, low transconductance is required so that the BiMOSFET™ can be used in applications where survivability to this type of fault is a must.

3. Figures 3a and 3b show the typical output characteristic of the BiMOSFET™ at 125°C. Its $V_{CE(sat)}$ is also higher than the IGBT but its on-state voltage drop at 20A is only 15% of an 1000V MOSFET of equal silicon area. In actuality, the $V_{CE(sat)}$ of a 1500V rated MOSFET would go up by another factor of 2.4.

4. Figure 4 plots the temperature dependence of $BV_{CES,}$ $V_{GE(th),}$ and $V_{CE(sat)}$ normalized to their 25°C values. Figure 5 plots the forward voltage drop of the intrinsic diode at room and elevated temperatures. The behavior of $BV_{CES\ and}$ $V_{GE(th)}$ with temperature is the same as an IGBT. However, note that since both $V_{CE(sat)}$ and V_F have a positive tem-

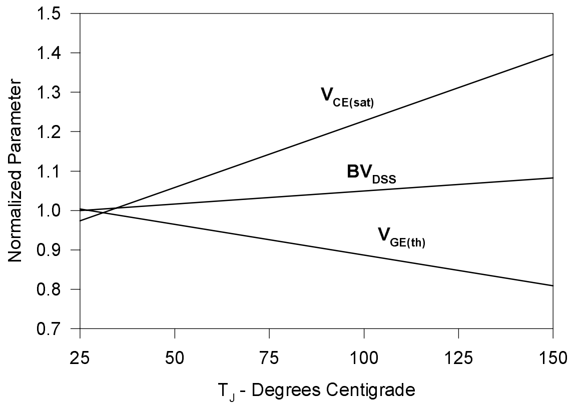

Figure 4. Temperature dependence of breakdown, threshold and saturation voltages. Values normalized to room temperature.

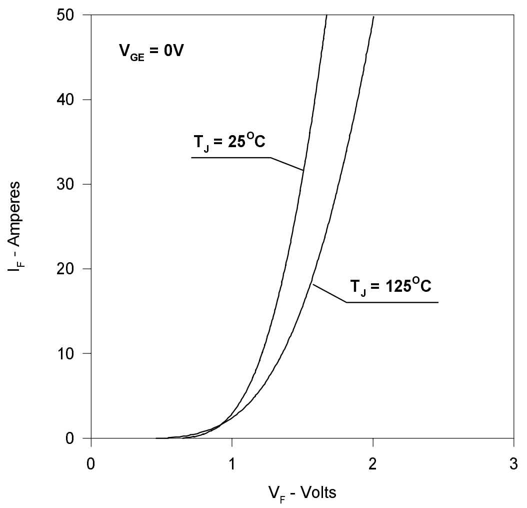

Figure 5. Forward voltage drop of the intrinsic diode.

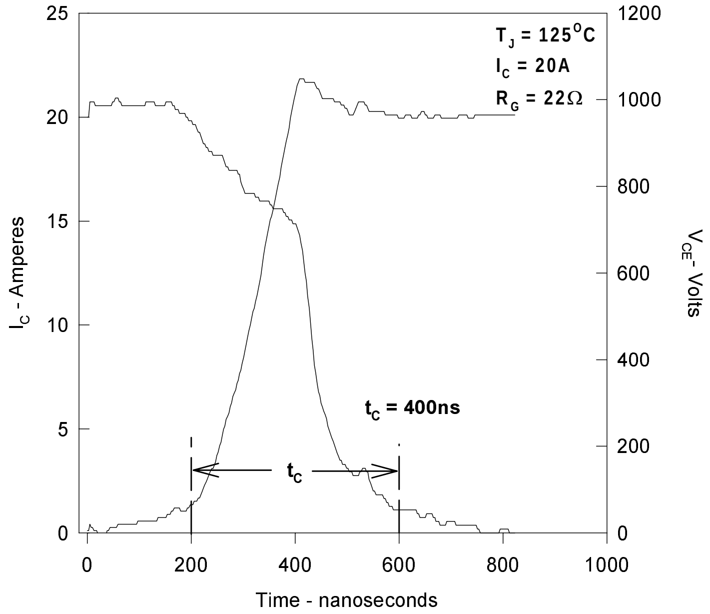

Figure 6. Turn-off current and voltage waveforms.

perature coefficient, these devices will be much easier to parallel than IGBTs, which require very close matching to ensure equal current sharing when used in parallel.

3. Switching Performance

The IXBH40N160 BiMOSFET™ does switch exceptionally fast for a 1600V rated part. Its total resistive turn-on time with a 5Ω gate resistor is typically 245ns. Figure 6 illustrates the part turning off a 20A inductive load into a 1000V clamp at the elevated temperature of 125°C. There is relatively little tail current so that the $E_{(off)}$ is 2.4mJ, which is be less than 50% of the comparative IGBT in Table 1. Figure 7 plots turn-off energy as a function of the series gate resistor R_G. This resistor primarily determines the rate-of-rise of collector voltage, which increases as R_G decreases and correspondingly $E_{(off)}$.

Presently the one shortcoming of the BiMOSFET™ is that it is not completely latch-free at elevated temperatures. At T_J =125°C, the maximum dV/dt should be kept less than 10V/ns by either the R_G selection or a simple snubber. To turn-off safely peak currents above 40A without a snubber, the minimum recommended R_G resistor is 47Ω. However, it should also be remembered that the IXBH40N160 is only the first member of the BiMOSFET™ family and it is expected that further development will result in its being just as rugged as the short circuit rated IGBTs.

4. Conclusions

In addition to high voltage, low frequency switching, the graphs in Figure 8 show the frequency bandwidth in which the BiMOSFET™ enjoys an advantage over the IGBT and MOSFET. Up to 8kHz, the IGBT can carry more current. Above that frequency, the BiMOSFET™ becomes the switch of choice until its switching losses force it to hand the baton to MOSFETs at around 50kHz. However, research continues in all aspects of power MOS switches so that continued improvements will be made in all these parts. The homogeneous-base IGBT does have inherent advantages, which will be exploited to optimize it for high voltage and high frequency switching.

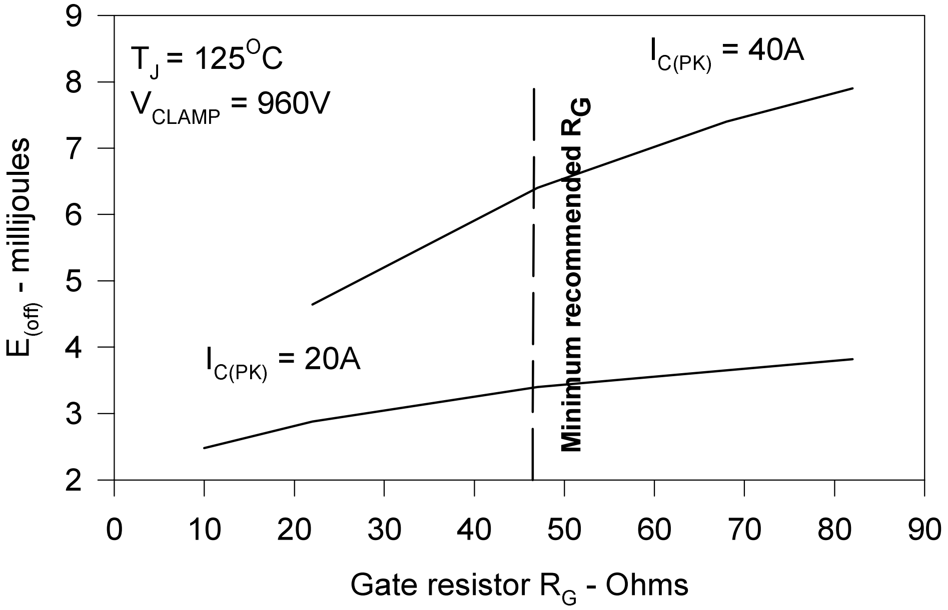

Figure 7. Turn-off energy versus gate resistor R_G.

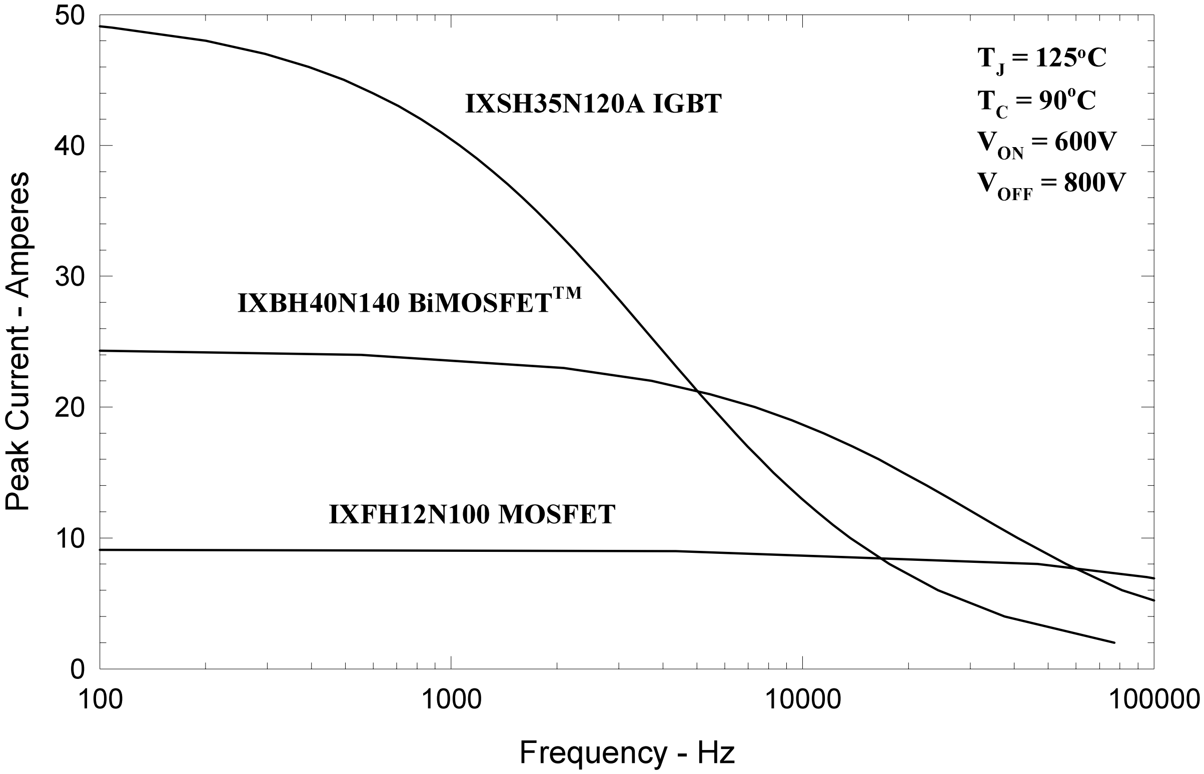

Figure 8. Comparison of the current carrying capability of the BiMOSFET™ to that of a 1200V IGBT and 1000V MOSFET.