A New IGBT with Reverse Blocking Capability

A. Lindemann
IXYS Semiconductor GmbH
Edisonstraße 15, D – 68623 Lampertheim
www.IXYS.net

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Abstract

A new IGBT has been developed, providing reverse blocking capability. This feature is needed in various applications, such as in current source inverters, resonant circuits, bidirectional switches or matrix converters. This paper presents technology of the monolithic chip and its operational behaviour, measured with first samples in typical circuits.

1 Introduction: Applications

Typical circuits requiring controllable switches for unidirectional current flow with reverse blocking capability can be classified as:

- conventional current source inverters as shown in figure 1 [1] [2]
- resonant converters with a current source as exemplarily shown in figure 2 [3] [4] [5]
- auxiliary resonant circuits used for soft switching of the power semiconductors in the main current path [6]
- bidirectional switches, such as in matrix converters as shown in figure 3 [7] [8]

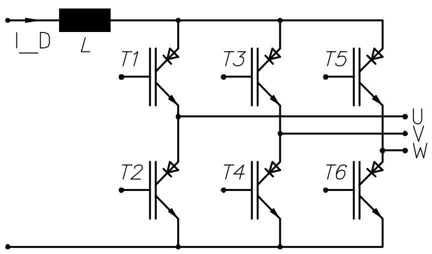

Figure 1: current source inverter

If IGBTs are applicable with respect to voltage, current and frequency, this kind of switches up to now has been composed of a standard IGBT without reverse blocking capability and a series

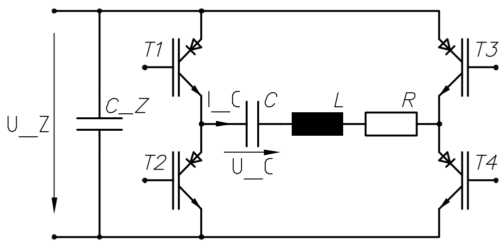

Figure 2: resonant circuit for induction heating

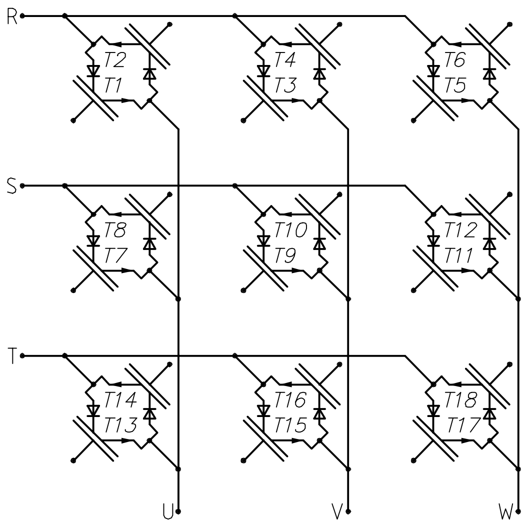

Figure 3: matrix converter with bidirectional switches

diode. Compared to that, a monolithic solution would offer benefits such as less conduction losses, lower space requirements and cost.
An IGBT with reverse blocking capability has now been developed: After a brief explanation of its chip technology in section 2, the operational behaviour is documented in section 3.

2 Chip Technology

Figure 4 (right) displays a schematic cross section of the reverse blocking IGBT chip. Cell structure as drawn will continue to the left, while the chip edge with the guard rings for junction termination is shown on the right. Geometry basically corresponds to NPT IGBTs' as depicted in figure 4 (left) [9] [10]. An NPT IGBT is not capable to block a significant negative collector-emitter voltage: The lower p^+-n^- junction would deplete within the chip, however break through at the edges without field stop. This constraint is overcome using the technique of isolation diffusion which is known from the production of thyristor chips: It permits to fold up the reverse blocking IGBTs' lower p^+ layer at the chip edge as shown in figure 4 (right). This way, the p^+-n^- junction remains within the chip, ending below the isolating top oxide layer. The junction — which is part of the IGBT anyway — is thus properly terminated and capable to block reverse voltages like a p-n diode. This measure does not change the structure within the active volume of the chip; it thus can be expected that — besides the fact that it is capable to block reverse voltages — the reverse blocking IGBT will exhibit an operational behaviour like a normal NPT IGBT.
The symbol in the right of figure 4 is proposed to represent the reverse blocking IGBT; it shows the diode on collector side in the chip structure. Measurements for characterization as described in the following have been taken with the TO247 packaged type IXRH50N120, being designed

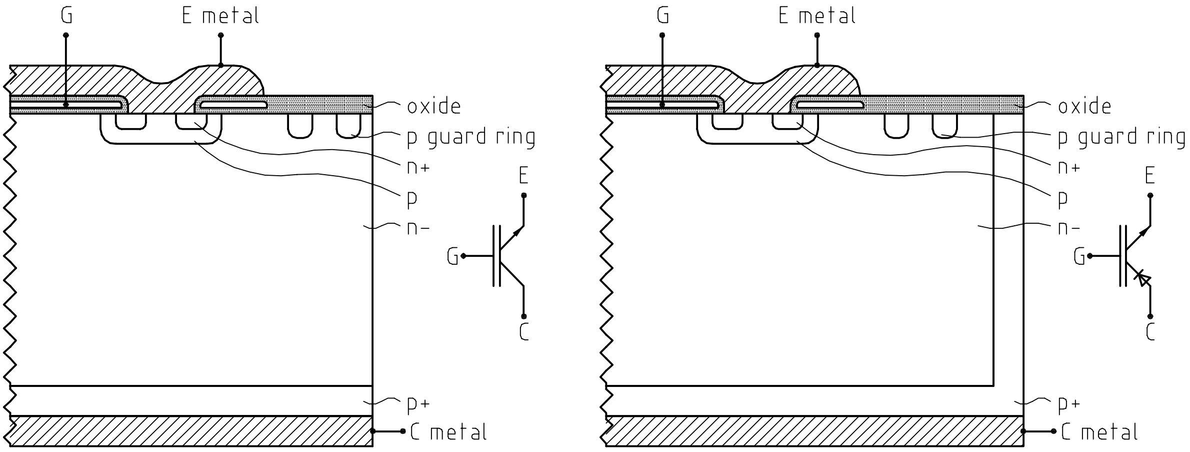

Figure 4: chip structure of and symbol used for NPT IGBT (left) and reverse blocking IGBT (right)

for 1200V bidirectional blocking voltage.

3 Electrical Characteristics

3.1 Forward Characteristics

The measurements performed confirm the physical expectation that the characteristics of the reverse blocking IGBT and of standard NPT IGBTs correspond to each other with respect to conduction of a collector current $I_C \gg 0$, to blocking a collector-emitter voltage $U_{CE} \gg 0$ and to the transitions between these states:
Figure 5 shows the forward characteristics — collector current I_C versus saturation voltage U_{CEsat} at various gate-emitter voltages U_{GE} and two temperatures. Please note that the saturation voltage is lower than could be achieved with a comparable series connection of a 1200V-IGBT and diode. As desirable for parallel connection, the temperature coefficient of saturation voltage is positive. The corresponding transfer characteristics — collector current I_C versus gate-emitter voltage U_{GE} — is depicted in figure 6.

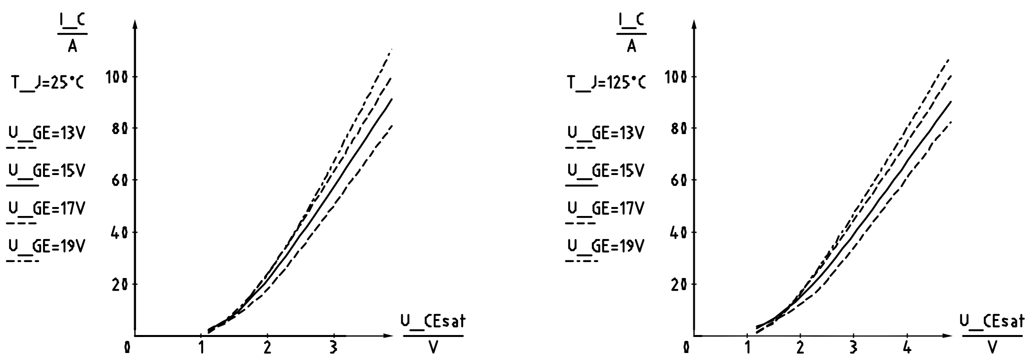

Figure 5: typical collector current versus saturation voltage at room temperature (left) and elevated temperature (right)

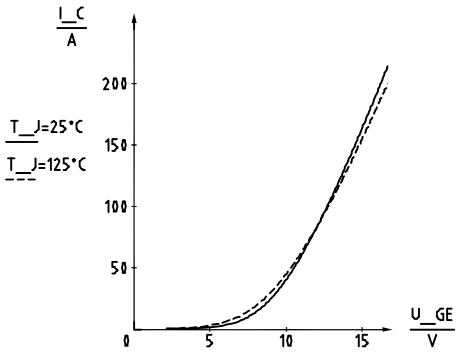

Figure 6: typical transfer characteristics at room temperature and elevated temperature

The topology for the evaluation of switching behaviour with inductive load is shown on the left in figure 7, a measured turn off waveform on the right. The characteristic values determined in this experimental setup are summed up in table 1.

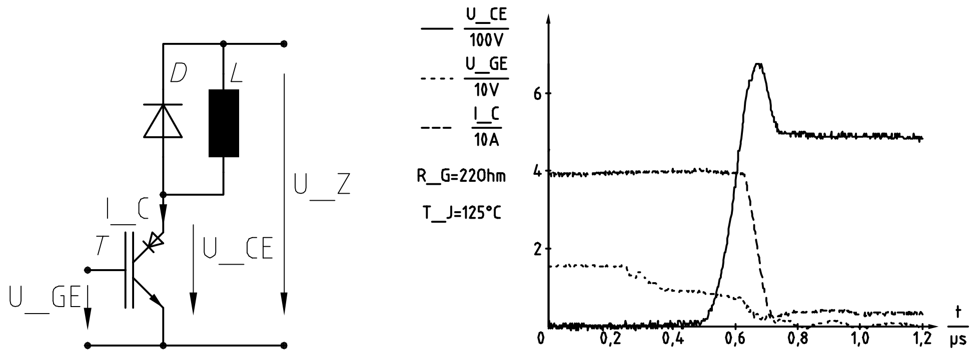

Figure 7: switching behaviour — turn off in hard switched chopper circuit

Table 1: typical switching behaviour with inductive load at $U_{CE} = 500V$, $I_C = 40A$, $U_{GE} = 15V \leftrightarrow 0V$, $R_G = 22\Omega$, $T_J = 125°C$

$t_{d,on}$	=	$80ns$	$t_{d,off}$	=	$380ns$
t_r	=	$100ns$	t_f	=	$75ns$
E_{on}	=	$3,6mJ$	E_{off}	=	$2,1mJ$

3.2 Reverse Characteristics

Measurements in two experimental setups have been taken, being representative for the circuits requiring reverse blocking capability mentioned in section 1: The functionality as "controlled diode" of T_1 in figure 8 is comparable to operation in hard switched current source inverters or matrix converters, while the controlled oscillator in figure 9 contains a bidirectional switch and may represent the group of resonant circuits.
The reverse recovery of the IGBT's intrinsic series diode is shown in figure 8: T_1, being forward biased with a gate voltage $U_{GE} = 15V$, initially is conducting a free wheeling current $I_C > 0$, driven by the inductor L, while T_2 is in the off state. When T_2 is turned on again, the

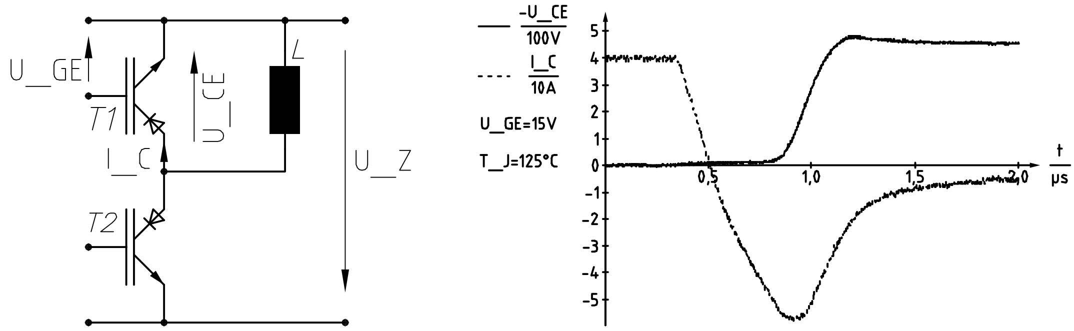

Figure 8: switching behaviour — turn off of the reverse blocking IGBT used as "controlled diode" in a chopper circuit

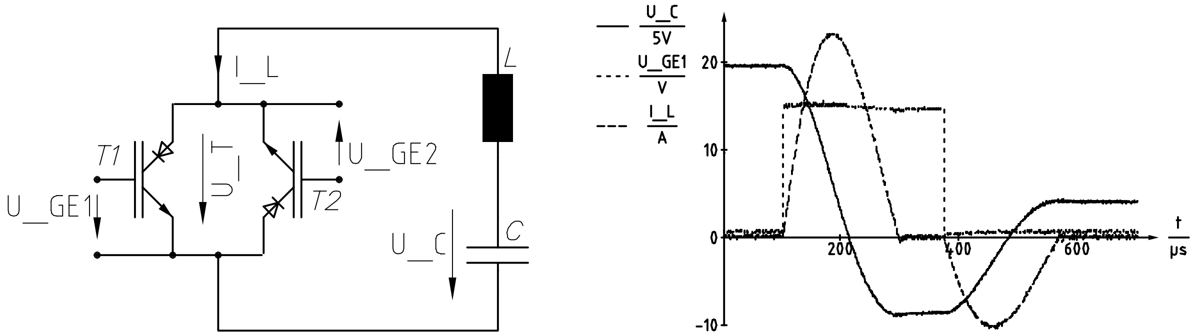

Figure 9: waveforms in a resonant circuit controlled by a bidirectional switch consisting of two reverse blocking IGBTs

inductor current commutates to T_2 and T_1 blocks the voltage of DC link in reverse direction $U_{CE} \approx -U_Z < 0$. The positive gate voltage U_{GE} being still applied in the channel region of T_1 does not prevent the p-n junction on collector side to deplete, as can be expected based on the chip structure explained in section 2. The turn off behaviour of the reverse blocking IGBT against negative voltage obviously corresponds to the reverse recovery of a normal p-n diode. Turn off is very soft, leading to smooth waveforms with a minor voltage overshoot. Switching speed is higher than of mains rectifier diodes, which is sufficient for many of the aforementioned typical applications. It however may be subject of further optimization in the course of chip development.
The operational behaviour of the oscillator in figure 9 can be calculated to be

$$i_L(t) = U_{C0} \cdot \sqrt{\frac{C}{L}} \cdot \sin \frac{t - t_0}{\sqrt{L \cdot C}} \tag{1}$$

$$u_C(t) = U_{C0} \cdot \cos \frac{t - t_0}{\sqrt{L \cdot C}} \tag{2}$$

for $t \geq t_0$ with the boundary conditions

$$u_C(t_0) = U_{C0} \text{ and } i_L(t_0) = 0 \tag{3}$$

neclecting all losses and provided that the respective transistor in the current path is turned on: A positive current flow $i_L > 0$ is possible when T_1 is turned on, and a negative $i_L < 0$ with

T_2 being turned on. With the components used $L = 180\mu H$, $C = 20\mu F$ and the initial value $U_{C0} = 100V$, the current amplitude according to equation 1 will be

$$\hat{I}_L = U_{C0} \cdot \sqrt{\frac{C}{L}} \approx 33A \tag{4}$$

and the duration of a halfvave of voltage and current according to equations 1 and 2

$$\frac{T}{2} = \pi \cdot \sqrt{L \cdot C} \approx 190\mu s \tag{5}$$

which is in good accordance with the measured wafeforms in figure 9: T_1 has been turned on for $270\mu s > \frac{T}{2}$. This first makes the capacitor voltage change polarity, however with some voltage drop due to losses during damped sinusoidal current flow for $\frac{T}{2}$; afterwards capacitor voltage remains constant and inductor current zero, because T_1 blocks reverse voltage and T_2 is still off. With T_1 being turned off and T_2 on, the inverse halfwave of the oscillation is triggered. Thus the bidirectional switch consisting of antiparallel reverse blocking IGBTs controls the oscillator in the expected way. In this application the IGBT is zero current soft switched; reverse blocking capability is required, but no reverse recovery occurs.

4 Conclusion

A new NPT IGBT has been developed: Besides the typical characteristics of an IGBT, it provides reverse blocking capability due to a modified chip structure. Measurement results document its operational behaviour under standard conditions and making use of the feature of reverse blocking capability. The new component is expected to contribute to progress in the development of current source inverters, bidirectional power electronic switches, matrix and resonant converters.

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