A new IGBT has been developed, providing reverse blocking capability. This feature is needed in various circuits, such as current source inverters, resonant bridges for induction heating or bidirectional switches in matrix converters. This paper presents technology of the monolithic chip and characterises component behaviour under typical operational conditions.

Introduction

Circuits requiring controllable switches for unidirectional current flow - thus with the ability to turn on and off a current in one direction, while always blocking current flow in reverse direction - typically belong to one of the following groups:

- conventional current source inverters [1]
- resonant converters [2]
- bidirectional switches, such as in matrix converters [3]

If IGBTs are applicable with respect to voltage, current and frequency, the required switches up to now have been composed of a standard IGBT without reverse blocking capability and a series diode. Compared to that, a monolithic solution would offer benefits such as less conduction losses, lower space requirements and cost. This kind of IGBT with reverse blocking capability has now been developed.

Chip Technology

Figure 1 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 and thus mode of IGBT operation basically correspond to NPT IGBTs [4]. However, in addition to the NPT structure, the p+ collector is folded up by isolation diffusion from the bottom to the top at the chip edge. This enables the lower p+ - n- junction to block a reverse voltage - the collector being negative. Without this measure, the junction would break through at the chip edge due to lack of field stop, which is the reason why standard IGBTs must not be connected to significant reverse voltage.

The symbol proposed in the right of figure 1 shows the integrated diode on collector side; it will be used in the following to represent the reverse blocking IGBT.

IGBT Characteristics

The device characterised in the following is of IXRH50N100 type. It is TO-247 packaged, rated for a blocking voltage of $U_{Ces} = 1000\text{V}$ and a collector current capability of $I_{ces} = 40\text{A}$ at a case temperature of $T_c = 90\ ^\circ\text{C}$.

Saturation voltage versus collector current is plotted in figure 2. A positive temperature coefficient of saturation voltage at nominal current can be observed, which is advantageous for parallel connection. Anyway, please note that saturation voltage of the reverse blocking IGBT is lower than could be achieved with a series connection of corresponding standard IGBT and diode as mentioned before.

Turn off waveforms of the device together with the hard switching chopper circuit they have been measured in are shown in figure 3; the corresponding characteristic values - switching times and energies - are summarized in table 1.

It can be concluded that the behaviour of the reverse blocking IGBT indeed corresponds to an NPT's as far as conduction and blocking of a positive collector-to-emitter voltage are concerned, as could be expected from semiconductor physics.
Reverse Characteristics

Reverse characteristics under two different operational conditions shall be considered; they are representative for the aforementioned circuits requiring reverse blocking capability:

Figure 4 depicts a similar chopper circuit as figure 3 before; however the free wheeling diode has been replaced by a reverse blocking IGBT \( T_1 \): When turned on by a positive gate voltage \( U_{GE} = 15\) \( V \), it will conduct a positive collector current \( I_C > 0 \) with collector-to-emitter voltage being positive \( U_{CE} > 0 \); this happens, when inductor \( L \) carries current and transistor \( T_2 \) is turned off. When \( T_2 \) is on however, \( T_1 \) will block the applied reverse voltage \( U_{CE} = -U_Z < 0 \). The reverse blocking IGBT \( T_1 \) is thus operated as some kind of “controllable diode” in this circuit. Reverse recovery of this diode - intrinsically integrated in chip structure as explained above - is shown in figure 4: Turn off is very soft, leading to smooth waveforms with almost no voltage overshoot. Switching speed is some higher than of a mains rectifier diode but far lower than of fast recovery types.

Further, diode behaviour under resonant switching conditions shall be considered, as can be evaluated using the circuit shown in figure 5: Current flow in an L-C oscillator is controlled by a bidirectional switch, consisting of an anti parallel connection of two reverse blocking IGBTs. Initially, the capacitor \( C \) is charged with a positive voltage \( U_C > 0 \), inductor current is zero \( I_L = 0 \) and transistor \( T_1 \) turned off by a gate voltage \( U_{GE} = 0 \). As displayed in the waveforms, \( T_1 \) is turned on around \( t = 100\) \( \mu\)s: This triggers a halfwave of sinusoidal current, changing polarity of capacitor voltage with an approximately cosinusoidal shape of waveform, however with some reduction of amplitude caused by losses in the circuit. A reverse voltage \( U = U_C > 0 \) is then applied to \( T_1 \), preventing any current flow, until \( T_2 \) is turned off and \( T_2 \) turned on around \( t = 380\) \( \mu\)s, which triggers the reverse oscillation. It is noticeable that the diodes exhibit virtually no reverse recovery current peak under those resonant switching conditions.

Applications

The basic ratings and characteristics of the reverse blocking IGBT IXRH50N100 as derived previously are summed up in table 1. The following properties are particularly significant with respect to the aforementioned typical applications:

- Switching frequency of conventional current source inverters and matrix converters should be matched in a way that takes into account contradictory requirements: A high frequency permits to choose small components for the necessary filters. However, operational mode of the semiconductor switches includes hard turn off in reverse direction by application of a negative collector-to-emitter voltage; the correspondent reverse recovery current peak leads to power losses, which can and in most cases should be limited applying a moderate switching frequency.

- This limitation is overcome by resonant reverse turn off, which is the reason that the devices are well suitable for resonant switching with higher frequency. Thus they are particularly interesting for applications such as induction heating.

![Table 1: basic ratings and characteristics of IXRH50N100](image-url)

| \( U_{CE} \) | 1000V | max. |
| \( I_{GO} \) | 40A | max. at \( T_C = 90\) °C |
| \( U_{CEsat} \) | 2,5V | typ. at \( I_C = 40A; U_{GE} = 15V; T_J = 25\) °C |
| \( U_{CEsat} \) | 3,0V | typ. at \( I_C = 40A; U_{GE} = 15V; T_J = 125\) °C |
| \( t_{on} \) | 80ns | typ. at \( U_{CE} = 500V; I_C = 40A; U_{GE} = 0V/15V; R_G = 22Ohm \) |
| \( t_{off} \) | 100ns | \( T_J = 125\) °C |
| \( E_{on} \) | 3,6mJ | |
| \( E_{off} \) | 380ns | |
| \( t_{f} \) | 75ns | |
| \( E_{f} \) | 2,1mJ | |
| \( I_{RM} \) | 58A | typ. at \( U_{GE} = 500V; I_C = 40A; di_{CE} = -400A/\mu s; U_{GE} = 15V \) |
| \( t_{f} \) | 840ns | \( T_J = 125\) °C |
In all applications making use of the feature of reverse blocking capability, conduction losses are reduced because the new devices' saturation voltage is lower than the sum of saturation voltage of a conventional IGBT plus forward voltage of a separate, series connected diode.

Conclusion

An IGBT with a modified chip structure has been developed. It basically behaves like a standard NPT device, but additionally is capable to block negative collector-to-emitter voltages independent from applied gate voltage. This monolithic device thus can replace a series connection of a conventional IGBT and a separate diode, this way increasing power density and reducing conduction losses. The new component is in particular interesting for use in new designs of resonant converters, current source inverters, matrix converters and other topologies requiring bidirectional switches.

References