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A New Insulated Gate Bipolar Transistor Structure employing an Embedded Over-current Protection Device

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1. Introduction

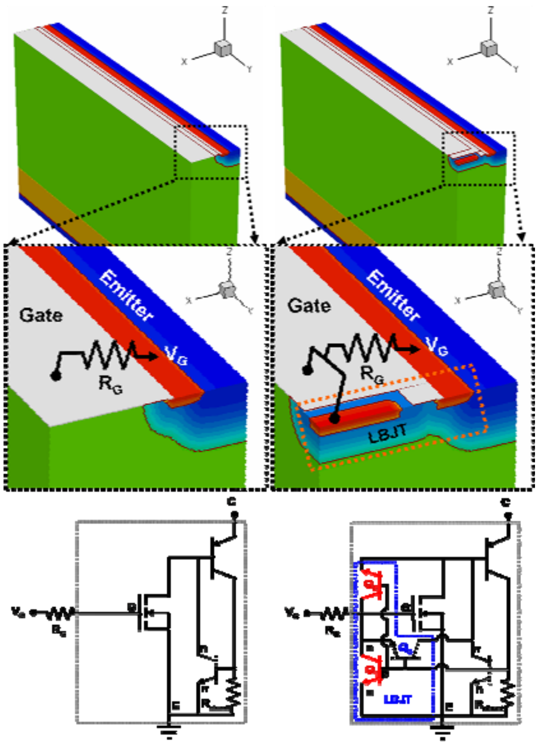
It is well known that Insulated Gate Bipolar Transistor (IGBT) requires the short-circuit protections.[1] In order to protect the IGBT from the thermal destruction of IGBT due to the high power dissipation during the short-circuit condition, the protection circuit should be operated within 10 us.[1] Various protection circuits of IGBT using current sensing scheme, de-saturation detection, V_{GE} detection and floating p-well voltage detection have been reported.[2] However, these protection circuits provide the main IGBT with the short-circuit protection by employing the sensing devices and pull-down circuits added externally or integrated wth the main IGBT.[3][4][5]

The purpose of our work is to propose and fabricate a new self-protected IGBT without any additional circuit such as pull-down circuit or sensing device by employing the embedded lateral bipolar junction transistor (LBJT), integrated in the main IGBT cell by using a three dimensional layout without any additional mask layer and process step, which senses the over-current caused by the short-circuit fault and simultaneously pulls down the gate voltage. The proposed IGBT has been verified by measuring the forward current-voltage characteristics and short-circuit behaviors and also analyzed by the 3-D numerical simulation using ISE-TCAD [6].

2. Device Structure and Operation Principle

Fig. 1 shows the conventional IGBT, the proposed self-protected IGBT and its equivalent circuit. The LBJT of the proposed IGBT was fabricated in the edge of gate area. The n+ collector of the LBJT and n+ emitter of the proposed IGBT were formed together by using the same mask layer and process step. As shown Fig 2 (b), the gate pulse (V_G) is applied to the gate of the IGBT and n+ collector of LBJT(node C_P) through R_G. The gate leakage current is not severely increased in the range of V_G from -10V to 10V, because the measured BV_{CEO} of the LBJT is approximately 14 V.

When the collector current of LBJT(I_B) flowing through the R_G is increased, the gate voltage of the IGBT is decreased by the voltage drop due to the product of the I_B and R_G. In the normal conduction state, the base current of the LBJT, which is a portion of the injected hole current from the p+ collector of the IGBT, is low enough to maintain the high voltage with the gate of the IGBT. When the collector current of the IGBT (I_C) is increased under the short-circuit fault condition, the increased hole current injection to the base of the LBJT initiates the electron injection from the n- emitter of the LBJT to the p- base of the LBJT which is collected by the reverse biased collector of LBJT so that the voltage of node C_P is decreased due to the bipolar operation of the LBJT. It should be noted that Q1, Q2 and Q3 are formed by the LBJT. The Q1 and Q2 are main LBJT, while Q3 is the parasitic bipolar component.



(a) (b)

Fig. 1 Device structure and equivalent circuit of the conventional IGBT (a) and the proposed self-protected IGBT (b)

3. Simulation and Experimental Results

Fig. 2 shows the measured and simulated forward I-V characteristics at the V_G of 10V. The device parameters used in fabrication and 3D numerical device simulation are summarized in the Table I. The forward voltage drop of the proposed IGBT is rather increased by 0.2V compared to that of conventional IGBT due to the decrease of the channel density. However, the forward voltage drop of the proposed IGBT can be minimized by optimizing the ratio of the proposed IGBT cells and the conventional IGBT cells. The R_G, which is not only the gate resistance but also the collector resistance of the LBJT, should be sufficiently large enough to reduce the voltage of node C_P by the I_B under the fault condition. When the IGBT is 600V 16A, the R_G should be above 50 ohms. It is clear that R_G can be also minimized by increasing the current rating of the IGBT.

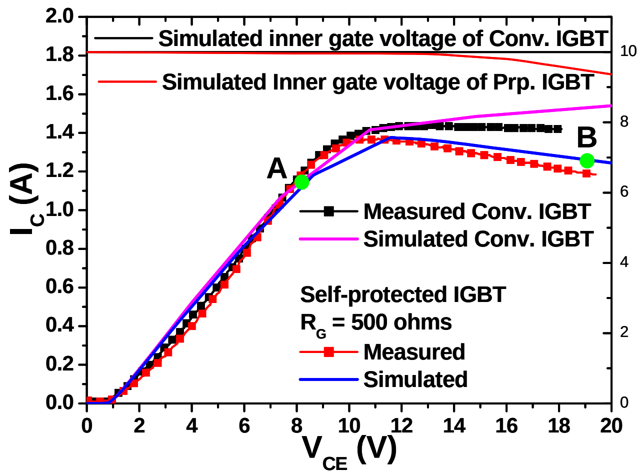


Fig. 2 The measured forward-IV characteristics of the conventional IGBT and proposed IGBT (Point A and B according to V_{CE})

Fig. 3 shows the electron and hole current distribution according to various V_{CE} shown in Fig. 2. As shown in Fig. 3, before the turn-on of Q2 (Point "A"), the electron current flows laterally (x-direction) from the n+ emitter to the n+collector of LBJT due to the turn-on of Q1, after the activation of Q2 (Point "B"), the electron current is injected from the n-drift region beneath the gate oxide to the n+collector of LBJT(-y-direction). The total collector current of LBJT is significantly increased by the activation of Q2. This results in enhancing the pull-down operation of gate voltage of IGBT and the decrease of collector current of IGBT.

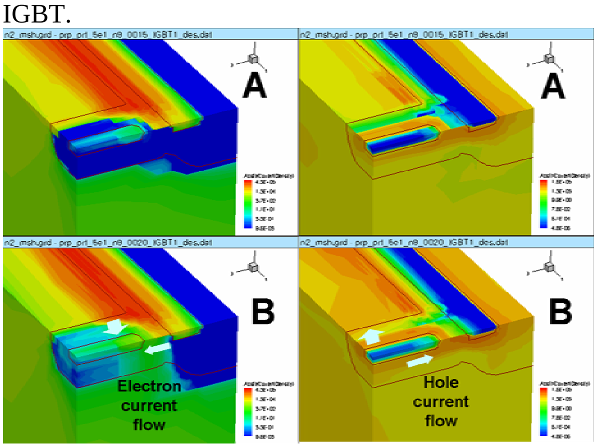


Fig. 3 Electron and hole current distribution in the LBJT according to various V_{CE} shown in Fig. 2

Fig. 4 shows the measured short-circuit behavior under the hard switching fault condition. The short-circuit fault current of conventional IGBT was increased up to 10A and caused device failure due to thermal stress because conventional IGBT before the pull-down operation of the LBJT. After the activation of pull-down operation by the increase of the I_B due to the regenerative action of LBJT, the I_C is decreased to be sufficiently low enough to withstand the fault condition. The measured inductive load switching characteristics shows that the gate charging time is rather increased due to the junction capacitance between n+ collector of LBJT and p-base. The false detection of fault during the turn-on is not observed because the I_B does not increase under the normal switching condition.

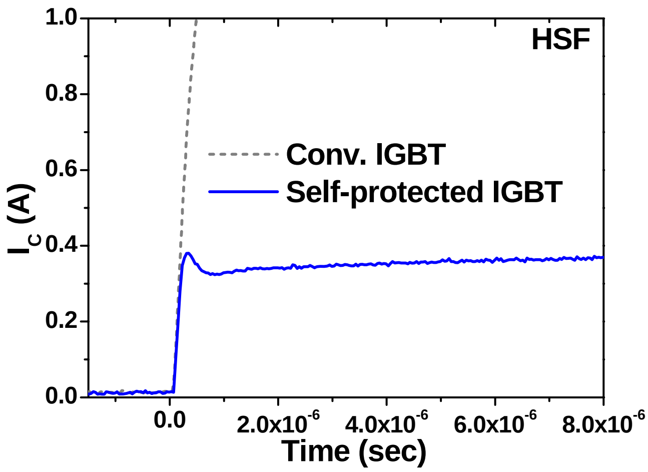


Fig. 4 The measured short-circuit behavior under the hard switching fault condition

4. Conclusion

A new IGBT structure having a self-protecting function without any additional protection circuit is successfully proposed and fabricated by employing 3D numerical simulation and 6 masks planar IGBT process. Although the forward voltage drop of proposed device is negligibly increased due to the decreased effective channel width by internal lateral bipolar transistor, short-circuit withstanding capability of proposed IGBT is considerably improved due to the current limiting of the IGBT by self-protecting function under the short-circuit fault condition, while the conventional IGBT is failed as soon as the short-circuit fault is applied. Switching characteristics shows that the internal lateral bipolar transistor does not affect on switching performance without any additional delay time and switching failure due to the parasitic thyristor.

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