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A Novel Lateral IGBT Structure with Improving the Dynamic Latch-up Performances

Hitoshi Sumida and Atsuo Hirabayashi

Advanced Device Technology Laboratory, Fuji Electric R&D, Ltd.
4-18-1, Tsukama, Matsumoto, Nagano, 390, Japan

The lateral IGBTs(LIGBTs) have shown great promise for use in power ICs. However, the occurrence of the latch-up, which leads to loss of control of the collector current by the gate-bias, must be prevented, because the LIGBT structure contains an inherent thyristor element. It has been tried extensively to improve the latch-up characteristics for the LIGBT.[1-3]

The latch-up for the IGBT can be generally classified as the static and dynamic modes. The dynamic mode of the latch-up occurs in the switching. The current density at the latch-up occurs in the dynamic mode is lower than that in the static mode. Especially, the decrease of the latch-up current during the turn-off transient under an inductive load drops noticeably, because the constant turn-off current at the storage duration must be maintained by the minority carriers.

In this study, the modified LIGBT structure for improving the dynamic latch-up performances is presented with its numerical simulations and experimental results. The latch-up currents during the turn-off transient under the inductive load is estimated at R.T. and 125°C in comparison with those for the conventional LIGBT.

Figure 1 illustrates both structures of the conventional and modified LIGBTs. The modified LIGBT has no additional diffusion layers, as compared with the conventional LIGBT. The main difference between the conventional and modified LIGBTs is the place of the emitter region. In the modified LIGBT the p^+-emitter layer exists between the gate and collector regions in order to divert the holes in the drift region to the emitter contact, so as not to flow through the p-base layer. The current flow path in the drift region of the modified LIGBT and its equivalent circuit are shown in Fig.2. The R1 and R2 indicate the short resistance of the p-base and p^+-emitter layers, respectively. The resistance in the drift region after the conductivity modulation occurs are divided into two components, Rmod1 and Rmod2.

The electrons are injected through the MOS channel and the electron current flows along the path 'Ie', as indicated in Fig.2(a). The hole current has two paths, 'I_{1h}' and 'I_{2h}'. The holes attracted by the electrons flow along the I_{1h} path and are collected at the emitter contact through the R1. This component of the hole current induces the latch-up. The holes flowing along the I_{2h} path are collected at the emitter contact without flowing through the area underneath the n^+-source layer, so that they do not cause the latch-up. At the on-state, since the electrons are injected through the MOS channel, the hole current of the I_{1h} path is large. On the other hand, at the turn-off state the holes flowing along the I_{1h} path decrease because the electron injection is stopped. It is believed that the modified LIGBT structure is responsible for the improvement of the dynamic latch-up current during the turn-off transient.

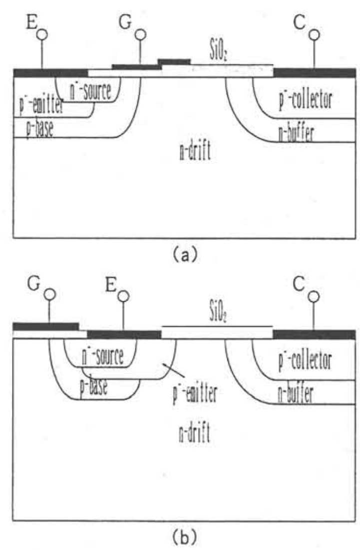

Fig.1 The schematic cross section of the (a) conventional and (b)modified LIGBTs

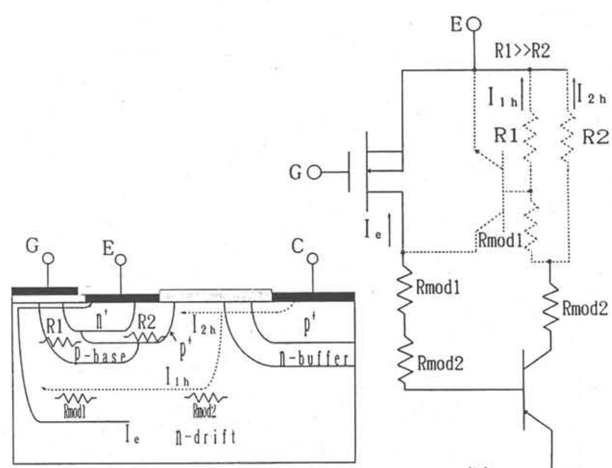

Fig. 2 (a) The current flow path and (b) equivalent circuit of the modified LIGBT

The characteristics of the on-state and the turn-off under the inductive load were simulated numerically by using a two dimensional device simulator. The analyzed structure shown in Fig.1 had the size of 0.015cm^2. The thickness and resistivity of the drift region were 30μm and 40Ω cm, respectively. The p-base layer had a surface concentration of 1.0x10^{17}cm^{-3} and the depth of 3.6μm. The channel length was 1.5μm. A life time of 0.1μs was used for the n-drift region. The device's lengths, including the drift length of 30μm, of the conventional and modified LIGBTs were 55μm and 65μm, respectively. The turn-off simulations were carried out at R.T.

At the on-state current density of 100A/cm^2 with the gate bias of 15V, the forward voltage for the conventional and modified LIGBTs are 1.7V and 2.8V, respectively. The forward voltage for the modified LIGBT is about 1.0V larger than that for the conventional LIGBT. This is due to the additional resistance, Rmod1, and to the larger device size than the conventional LIGBT.

Figure 3 shows the simulated turn-off waveforms at the controllable current for the conventional and modified LIGBTs. The results on the dynamic latch-up current during the turn-off transient are 130A/cm^2 for the conventional LIGBT and over 335A/cm^2 for the modified LIGBT. The turn-off simulations exhibit the about 2.6 times improvement in the latch-up current.

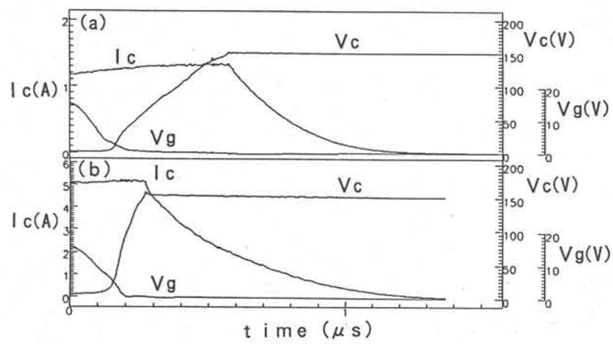

Fig.3 The simulated turn-off waveforms at the controllable current for the (a) conventional and (b) modified LIGBTs

The conventional and modified LIGBTs were fabricated on the 30μm thick SOI layer with the about 4μm thick buried n$^+$ diffusion layer on the 2μm thick bottom oxide, using the same wafer process for each. The resistivity of the SOI layer was 40Ω cm. Both IGBTs had the drift length of 30μm, the channel length of about 2μm and the device size of 0.015cm^2. The cell pitches of the conventional and modified LIGBTs were 110μm and 130μm, respectively. No life time killer was used. The threshold voltage and breakdown voltage for both IGBTs were about 6V and 300V, respectively.

At the current density of 100A/cm^2 with the gate bias of 15V, the forward voltage for the modified LIGBT was 3.2V, which is 0.8V larger than that for the conventional LIGBT. As predicted before, this is due to the additional resistance and the larger cell size.

The dynamic latch-up current during the turn-off transient under the inductive load was measured at R.T. and 125°C with the gate resistance of 150Ω and the inductive load of 200μH. The clamp voltage and the gate bias were 150V and 20V, respectively. The results of both LIGBTs are shown in Fig.4. The current at which the latch-up occurs for the modified LIGBT is 350A/cm^2 at R.T. and 290A/cm^2 at 125°C. These results indicate the improvement of about 3.5 times at R.T. and about 5.5 times at 125°C compared with those for the conventional LIGBT. The distinct improvement of the dynamic latch-up performance is accomplished, especially at 125°C. Experimental results are identical to the simulations.

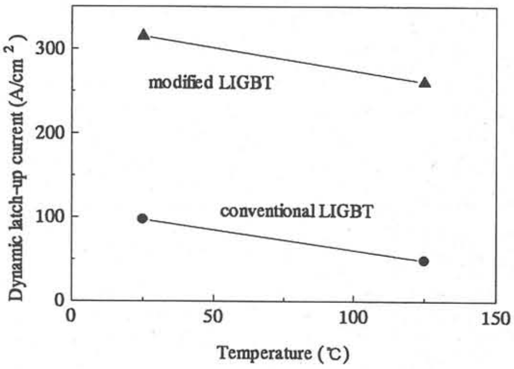

Fig.4 Experimental results on the dynamic latch-up current

The turn-off current at the storage duration must be maintained by the holes in the depletion layer. Therefore, it is generally observed that the latch-up current during the turn-off transient becomes smaller than that at the on-state. However, the dynamic latch-up current during the turn-off transient for the modified LIGBT is nearly equal to the latch-up current at the on-state, because the hole current of the I_{1h} path, which induces the latch-up, reduces with the reduction of the electron injection. This is an unique feature of the modified LIGBT.

In summary, we modified the LIGBT structure for improving the dynamic latch-up characteristics and demonstrated its performances. The dynamic latch-up current during the turn-off transient under the inductive load for the modified LIGBT exhibits the improvement of about 3.5 times at R.T. and about 5.5 times at 125°C in comparison with that for the conventional LIGBT. This improved latch-up performance can be obtained at the expense of an increase of 0.8V in the forward voltage drop.

References

1) H. Sumida et al., submitted to IEEE TED.
2)D.R.Disney et al., Proc. ISPSD, pp.405-410, 1994.
3)T. Paul Chow et al., Proc. ISPSD, pp.57-61, 1994.