Vol. 31, No. 6 Journal of Semiconductors June 2010

Conductivity modulation enhanced lateral IGBT with SiO_2 shielded layer anode by SIMOX technology on SOI substrate*

Chen Wensuo(陈文锁)†, Zhang Bo(张波), Li Zhaoji(李肇基), Fang Jian(方健), and Guan Xu(关旭)

(State Key Laboratory of Electronic Thin Films and Integrated Devices, University of Electronic science and Technology of China, Chengdu 610054, China)

Abstract: A new lateral insulated-gate bipolar transistor (LIGBT) with a SiO_2 shielded layer anode on SOI substrate is proposed and discussed. Compared to the conventional LIGBT, the proposed device offers an enhanced conductivity modulation effect due to the SiO_2 shielded layer anode structure which can be formed by SIMOX technology. Simulation results show that, for the proposed LIGBT, during the conducting state, the electron–hole plasma concentrations in the n-drift region are several times larger than those of the conventional LIGBT; the conducting current is up to 37% larger than that of the conventional one. The enhanced conductivity modulation effect by SiO_2 shielded layer anode does not sacrifice other characteristics of the device, such as breakdown and switching, but is compatible with other optimized technologies.

Key words: enhanced conductivity modulation effect; shielded anode; SIMOX technology
DOI: 10.1088/1674-4926/31/6/064004 **EEACC:** 2560

1. Introduction

The lateral insulated-gate bipolar transistor (LIGBT) insulated-gate bipolar transistor (LIGBT) is a promising power device for power ICs due to its combination of the high input impedance of the MOS gate and the conductivity modulation effect of the bipolar transistor. Conductivity modulation permits the LIGBT to have a low forward drop, but the conventional devices have an insufficient conductivity modulation effect. Recently, various approaches have been reported in the literature to make a tradeoff between on-state voltage drop and turn-off time for the LIGBT[1−4]. These technologies achieve fast switching speed but almost all sacrifice the forward drops. In low frequency applications, the conducting loss is the main part of total power losses[5]. Enhancing the conductivity modulation of the n-drift region is an effective approach to reduce LIGBT forward drop and power loss.

In this paper, a novel enhanced conductivity modulation effect with SiO_2 shielded layer anode by SIMOX technology[6, 7] lateral IGBT on silicon-on-insulator (SOI) substrate is proposed and discussed. Numerical simulations are carried out to help with the analysis of the characteristics for the proposed LIGBT. A thin silicon n-drift layer on the insulator[8] make this device be feasibly isolated from low-voltage devices for power IC application. SOI substrates overcome the deep plasma injection into the substrate for junction-isolation substrates[9, 10].

2. Device structure and parameters

A schematic cross section of the proposed LIGBT on SOI substrate is illustrated in Fig. 1. Distinguishing from the conventional LIGBT anode structure, the proposed anode has a special SiO_2 shielded layer under the anode P^+ region. The anode SiO_2 shielded layer, which can be formed by SIMOX technology, is a key concept for the new device to enhance the conductivity modulation effect and reduce conducting loss. The n-drift region doping concentration was optimized to fulfil the RESURF condition[11]. Table 1 shows the device parameters used in the numerical simulation.

3. Operation and discussion

For the proposed LIGBT, when a voltage above the threshold is applied to the gate, the device turns on. At forward bias, electrons will flow through the cathode N^+ region, n-channel and n-drift region, and while holes are compelled to inject to n-drift to meet the neutral character, electron–hole plasma is finally presented in the n-drift region and conductivity modulation is achieved. Due to the anode SiO_2 shielded layer, the electrons diffusing toward the part covered with oxide in the proposed LIGBT cannot be collected by the anode P^+ directly and accumulate at this area, leading to the increase of electron concentration in the n-buffer and n-drift regions. The electrons, providing the base drive for the pnp transistor inherent in the LIGBT, in turn enhance the hole injection from the anode P^+ to maintain electrical neutrality in the n-buffer and n-drift re-

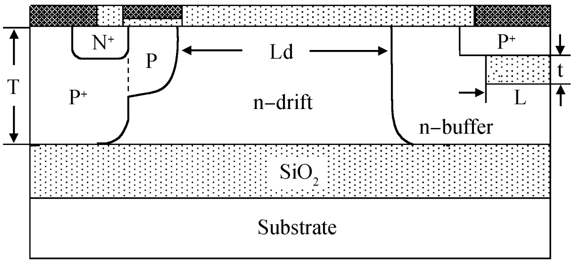

Fig. 1. Schematic cross-sectional view of the proposed LIGBT.

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* Project supported by the National Natural Science Foundation of China (Nos. 60876053, 60806025, 60976060).

† Corresponding author. Email: wensuochen@uestc.edu.cn

Received 17 December 2009, revised manuscript received 28 January 2010

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Table 1. Device parameters used in the simulation.

Device parameter	Value
N-drift region length, L_d	20 μm
N-drift region doping concentration, N_d	2.5×10^{15}cm^{-3}
N-drift region thickness, T	3 μm
SiO$_2$ insulator thickness	2 μm
Anode SiO$_2$ shielded layer length, L	1–4 μm
Anode SiO$_2$ shielded layer thickness, t	0.375 μm
Anode P$^+$ junction; cathode N$^+$ junction	0.2 μm
Anode P$^+$ length	3 μm
Threshold voltage, V_th	5.6 V
Gate voltage, V_g	10–20 V
Cathode voltage	0 V
Substrate voltage	0 V

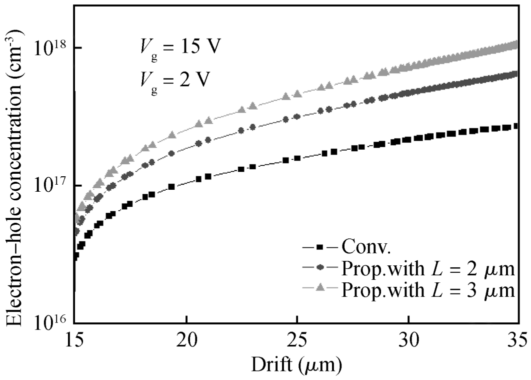

Fig. 2. Electron–hole concentrations along the n-drift region of the conventional LIGBT and proposed LIGBT with L = 2 μm, L = 3 μm; gate voltage V_g = 1.5 V, anode voltage V_a = 2 V; carrier lifetimes t = 1 μs; temperature Temp = 300 K.

gions. Thus, the anode P$^+$ injection efficiency is enhanced, which results in an enhanced conductivity modulation effect. It should be noted that, according to the enhanced conductivity modulation effect due to the anode SiO$_2$ shielded layer, the electron–hole plasma concentration is high compared to that of the conventional one.

Figure 2 shows n-drift region electron–hole plasma concentrations of the conventional LIGBT and proposed LIGBT. In numerical simulation with the Medici simulator[12], the conventional and proposed LIGBTs have the same structure except for the anode SiO$_2$ shielded layer. The anode SiO$_2$ shielded layer thickness is 0.375 μm which is according to the SIMOX technology parameter, and the lengths are L = 2 μm, L = 3 μm; gate voltage V_g = 15 V, anode voltage V_a = 2 V; carrier lifetimes t = 1 μs; temperature Temp = 300 K. It can be seen that the electron–hole plasma concentrations of the proposed LIGBT are several times larger than those of the conventional one along the n-drift region; for L = 3 μm, the increment is from 3 to 4 times, and for L = 2 μm, the increment is from 2 to 3 times.

Equation (1) shows the conducting state characteristics for the proposed LIGBT:

$$\begin{cases} V_\mathrm{a} = I(R_\mathrm{channel} + R_\text{n-drift} + R_\mathrm{others}), \\ R_\text{n-drift} = \dfrac{L_\mathrm{d}}{q\mu N_\mathrm{d} T w}, \end{cases} \tag{1}$$

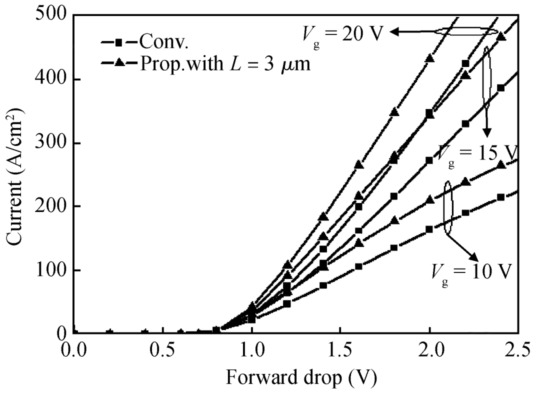

Fig. 3. I–V characteristics of the conventional LIGBT and proposed LIGBT with L = 3 μm; gate voltage V_g = 10, 15, 20 V; carrier lifetime t = 1 μs; temperature Temp = 300 K.

where V_a is forward drop, R_channel is n-channel resistance, $R_\text{n-drift}$ is n-drift region resistance, R_others includes other resistances, I is current flow in the n-drift region, L_d is n-drift region length, N_d is n-drift region electron–hole plasma concentration, q is basic charge, μ is electron–hole effective mobility, T is n-drift region thickness T = 3 μm, and w is the third dimension device length and in our two-dimension simulation w = 1 μm.

For a high voltage LIGBT, $R_\text{n-drift}$ is a main part of the total resistance. Figure 3 shows the I–V characteristics of the conventional LIGBT and proposed LIGBT with L = 3 μm at different gate voltages V_g = 10 V, V_g = 15 V, V_g = 20 V. According to Eq. (1), it is seen that the currents of the proposed LIGBT are much higher than those of the conventional one at different gate voltages because of the higher n-drift region electron–hole plasma concentrations.

To quantitatively explain, we define the current increment ratio as follows:

$$\text{Current increment ratio} = \frac{I - I_0}{I_0} \times 100\%, \tag{2}$$

where I, I_0 are the conducting currents for the proposed and conventional LIGBTs, respectively.

At gate voltage V_g = 15 V, Figure 4 illustrates the current increment ratio of the proposed LIGBT with different SiO$_2$ shielded layer anode lengths (from 1 to 4 μm). As seen, at lengths (from L = 2.8 μm to L = 3.0 μm) about the same as that of the anode P$^+$ region (L_0 = 3 μm), the current increment ratio achieves the largest value and the conducting current density of the proposed LIGBT is up to 37% larger than that of the conventional one. This may be explained as follows: when $L < L_0$, the enhancement of hole injection from the anode P$^+$ increases as L_0 increases and the conductivity modulation effect in the n-drift region is enhanced; when $L > L_0$, at the left side of the anode P$^+$ region, there is a highly resistive, very thin n-buffer region above the SiO$_2$ shielded layer current path, which means that the effective hole injection from the anode P$^+$ is quickly reduced and the conductivity modulation effect in the n-drift region weakens.

Additionally, the enhanced SiO$_2$ shielded layer anode conductivity modulation effect does not sacrifice other characteristics of the device, such as breakdown and switching, but is

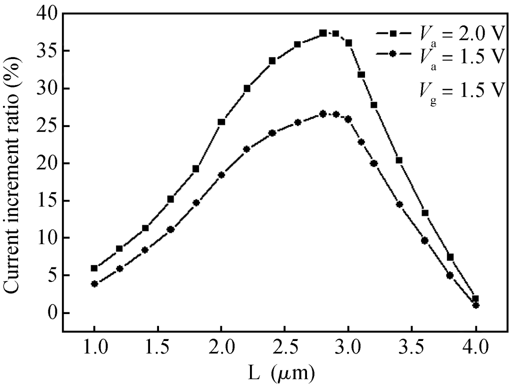

Fig. 4. Current increment ratio with different anode SiO_2 layer lengths L for the proposed LIGBT; gate voltage V_g = 15 V; forward drop V_a = 2.0, 1.5 V; carrier lifetime t = 1 μs; temperature Temp = 300 K.

compatible with other optimized technologies. The breakdown voltage of the proposed LIGBT is about 220 V, the same as that of the conventional one.

4. Conclusion

In this paper, a novel shielded anode LIGBT on SOI substrate has been proposed and discussed. The influences of the key parameter, anode SiO_2 shielded layer length, have been numerically simulated by the Medici simulator and discussed. The shielded anode concept, which can be formed by SIMOX technology, offers an enhanced conductivity modulation effect during the conductive state. Numerical simulation results show that the electron–hole plasma concentrations in the n-drift region are several times larger than those of the conventional LIGBT; the current density is up to 37% larger than that of the conventional one. Additionally, the enhanced shielded anode conductivity modulation effect does not sacrifice other characteristics of the device, such as breakdown and switching, but is compatible with other optimized technologies.

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