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Extraction enhanced lateral IGBT (E^2 LIGBT) : A super high speed LIGBT superior to LDMOS

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1. Introduction

Lateral IGBTs (LIGBT) have been frequently integrated into power ICs such as DCDC converters [1] or micro-inverters [2]. In order to miniaturize the system, high speed and high frequency operation of LIGBT has been strongly demanded. Nakagawa et al. developed SOI-LIGBT with a lightly doped p-layer collector, resulting in fall-time t_F=300ns, on-state voltage V_{ON}=3.0V (120A/cm^2), and breakdown voltage BV_{CES}=500V [2, 3]. Kaneko et al. developed junction-isolated hybrid IGBT with employing anode short and electron irradiation, resulting in turn-off time t_{OFF}=110ns, V_{ON}=5.5V (68A/cm^2), and BV_{CES}=800V [1]. Sin et al. developed HSINFET, where the anode consists of p^+ emitter and Schottky contact on the n-drift, resulting in t_{OFF}=50ns, R_{ON}=7ohm, and BV_{CES}=130V [4]. However, all the devices, thus far reported, were still slower in switching speed than lateral DMOS (LDMOS), although their on-resistances were lower than that of LDMOS.

We have successfully developed novel Extraction Enhanced LIGBT (E^2LIGBT) performing a super-high speed (t_{OFF}=34ns) and a low forward voltage (V_{ON}=3.7V at 84A/cm^2) with a high breakdown voltage of 738V. For the first time, both the switching speed and on-resistance of the developed E^2LIGBTs are simultaneously superior to those of lateral DMOS.

2. Device concept

2-1. Electron Extraction by Schottky contact on p-layer

We propose a new anode structure, a combination of a narrow p^+-injector and a wide Schottky contact on lightly doped p-layer with an n-buffer, as shown in Fig. 1. Electrons flow from the channel toward the anode, forward biasing the n-buffer/p^+-injector junction. Holes are injected from the narrow p^+-injector (S_I) toward n^--drift under the anode region, resulting in high conductivity modulation. The wide Schottky contact (S_E) extracts a large portion of electrons flowing along the Schottky contact. As the Schottky area increases, a greater part of the electrons are extracted from the Schottky contact, and only the remaining smaller fraction of electron current flows into the p^+-injector.

It was found that the conductivity modulation in the anode region can be controlled by the area ratio of the Shottky area over the injector area, S_E/S_I. This means that both a low V_{ON} and a short t_{OFF} will be achieved by designing an adequate ratio, S_E/S_I. It is also expected that the electrical characteristics are highly independent from temperature because they are determined by the area ratio, S_E/S_I.

We report, for the first time, that **the Schottky contact on the lightly doped p-layer** is far better than the Schottky contact directly on the n^--drift or the n-buffer. The Schottky contact directly on the n^--drift or the n-buffer too much suppresses the hole injection from the p^+-injector, and forces a high forward voltage as seen in HSINFET [4]. The conductivity modulation can be precisely tuned by the area ratio only if the Schottky contact is placed on the lightly doped p-layer.

2-2. Evaluation of the effect of Schottky contact on p-layer

Device simulation of E^2LIGBT is carried out in order to evaluate the effect of the Schottky contact on the p-layer. The detailed device parameters of the simulated and fabricated devices are given in **Section 3-1** below. Conventional LIGBT without the Schottky contact is also calculated and compared. Fig. 2 shows the simulated hole density distributions at the anode region for (a) E^2LIGBT and (b) conv. LIGBT under V_G=7V and I_C=200mA (84A/cm^2). Hole density at point-A in E^2LIGBT is 7.0×10^{16} cm^{-3} which is significantly lower than that of conv. LIGBT. Thus, the conductivity modulation at anode region is effectively suppressed by the Schottky contact on the p-layer.

3. Results and discussion

3-1. Device fabrication

E^2LIGBT was fabricated using SOI wafer of 15µm thick silicon and 5µm Box. An interface n-diffusion-layer with the dose of 1.5×10^{12}/cm^2 was introduced on the Box [5], as shown in Fig. 1, in order to increase the breakdown voltage by 150V. If the interface n-diffusion-layer is not used, a thick Box of 8µm is required to realize the same breakdown voltage. Fig. 3(a) shows the photo of E^2LIGBT. The cell pattern is truck shape and the collector is located at the center. The area ratio, S_E/S_I, were chosen to be 33, if not specified. Fig. 3(b) shows the LDMOS consisting of 36 cells. LDMOS has the total device area of 1.9mm^2, which is 7.9 times larger than that of E^2LIGBT.

3-2. DC characteristics

High blocking voltages of 738V for E^2LIGBT and 731V for LDMOS were achieved as seen in Fig. 4(a). The I-V characteristics are shown in Fig. 4(b). The on-state voltage, V_{ON}, of E^2LIGBT is 3.7V for V_G=7V, I=200mA, whereas V_{ON} of LDMOS is 6.3V for the same condition. Although the device area of LDMOS is 7.9 times greater than that of E^2LIGBT, the on-resistance of LDMOS is worse than that of E^2LIGBT.

3-3 Turn-off characteristics

Turn-off time, t_{OFF}, of the fabricated devices were measured under an inductive load. Fig. 5 shows S_E/S_I dependence of t_{OFF} for E^2LIGBT. The short t_{OFF} of 34ns is obtained at S_E/S_I=33. It is clearly verified that t_{OFF} of E^2LIGBT is simply determined by S_E/S_I. Fig. 6 shows measured turn-off waveforms. The measured t_{OFF} of 34ns of E^2LIGBT is considerably shorter than 44ns of LDMOS.

Fig. 7 compares temperature dependence of E^2LIGBT and LDMOS regarding (a) turn-off time, t_{OFF}, (b) turn-off energy loss, E_{OFF}, and (c) on-state voltage, V_{ON}. The t_{OFF} of E^2LIGBT hardly depends on temperature. The switching loss, E_{OFF}, of E^2LIGBT is remarkably smaller than that of LDMOS, as seen in Fig. 7(b). Especially, the temperature dependence of V_{ON} of E^2LIGBT is far better than that of LDMOS, as seen in Fig. 7(c).

Fig. 8 compares trade-off relation between current density at 3V of V_{ON} and fall time/turn-off time among all the reported high voltage lateral MOS power devices. It is clear that the trade-off of E^2LIGBT is the most excellent compared with those of all the other lateral silicon power devices, so far reported. Especially, **E^2LIGBT with S_E/S_I=33 is better than LDMOS both in on-resistance and switching speed**.

Acknowledgements

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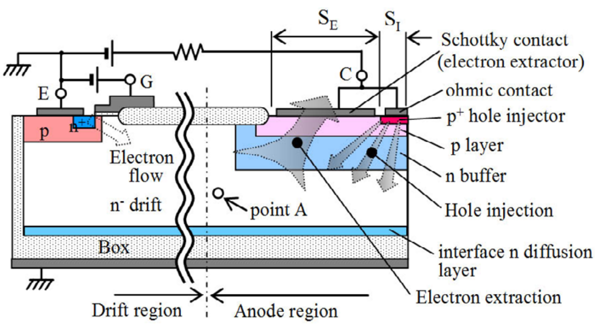
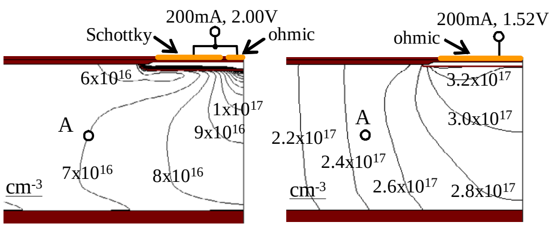
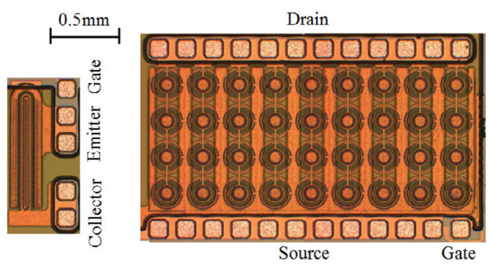


Fig. 1 Conceptual device structure with operation principle of SOI E^2LIGBT.



(a) E^2LIGBT (S_E/S_I =16) (b) conventional LIGBT

Fig. 2 Comparison of hole density distribution between E^2 LIGBT and conv. LIGBT. The Schottky contact on p-layer greatly reduces the stored carriers and enhances the switching speed.



(a) SOI E^2LIGBT (0.24mm^2) (b)SOI LDMOS (1.9mm^2)

Fig. 3 Micrographs of the fabricated devices.

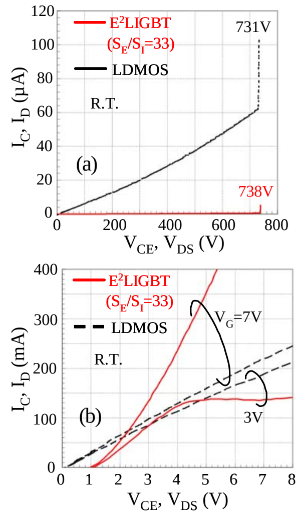


Fig. 4 Measured (a) breakdown and (b) I-V characteristics.

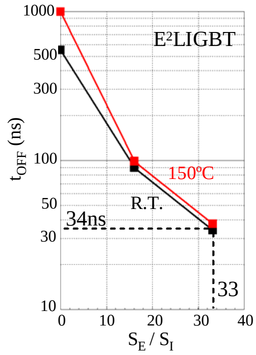
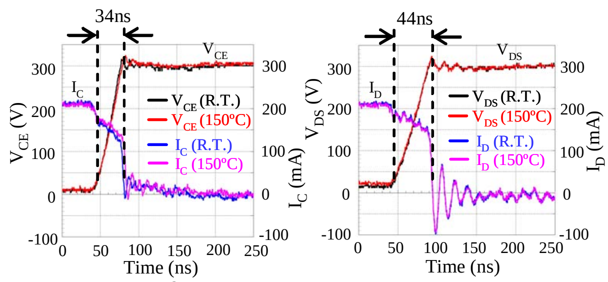


Fig. 5 Measured t_{OFF} of E^2LIGBT as a fuction of S_E/S_I.



(a) SOI E^2LIGBT (b) SOI LDMOS

Fig. 6 Measured turn off waveforms under inductive load.

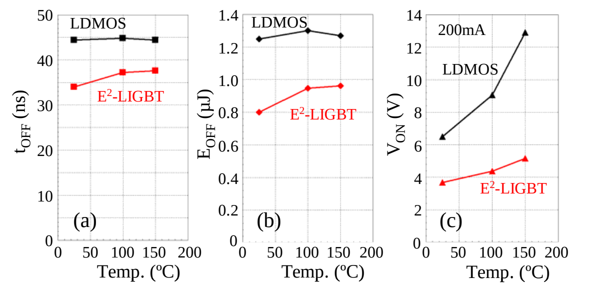


Fig. 7 Measured temperature dependence of t_{OFF}, E_{OFF}, and V_{ON}. E^2LIGBT is always better than LDMOS in (a), (b), and (c).

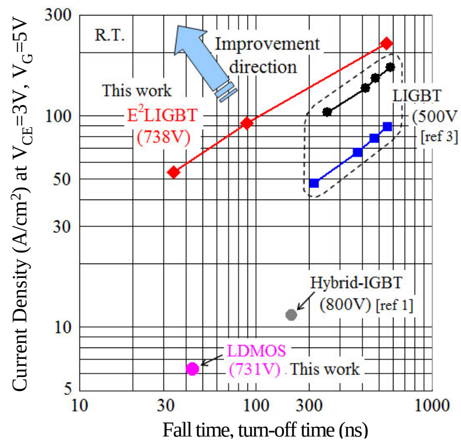


Fig. 8 Trade-off relation between current density and fall time/turn-off time. E^2LIGBT is the best among the all the reported devices.