Extraction enhanced lateral IGBT (E²LIGBT) : 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 $t_{off}=300\text{ns}$, on-state voltage $V_{ON}=3.0\text{V}$ (120/A/cm²), and breakdown voltage $BV_{CES}=500\text{V}$ [2, 3]. Kaneko et al. developed junction-isolated hybrid IGBT with employing anode short and electron irradiation, resulting in turn-off time $t_{off}=50\text{ns}$, $V_{ON}=5.5\text{V}$ (68A/cm²), and $BV_{CES}=800\text{V}$ [1]. Sin et al. developed HSINFET, where the anode contains p-emitter and Schottky contact on n-drift, resulting in $t_{off}=50\text{ns}$, $R_{ON}=70\Omega$, and $BV_{CES}=130\text{V}$ [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 (E²LIGBT) performing a super-high speed ($t_{off}=34\text{ns}$) and a low forward voltage ($V_{ON}=3.7\text{V}$ at 84A/cm²) with a high breakdown voltage of 738V. For the first time, both the switching speed and on-resistance of the developed E²LIGBTs 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 (S₂) toward n-drift under the anode region, resulting in high conductivity modulation. The wide Schottky contact (S₁) extracts a large portion of electrons flowing along the Schottky contact. The conductivity modulation in the anode region can be controlled by the area ratio of the Schottky area over the p+-injector. It was found that the conductivity modulation in the anode region can be controlled by the area ratio of the Schottky area over the p+-injector. This means that both a low $V_{ON}$ and a short $t_{off}$ will be achieved by designing an adequate ratio, $S_1/S_2$. It is also expected that the electrical characteristics are highly independent from temperature because they are determined by the area ratio, $S_1/S_2$.

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 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 E²LIGBT 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) E²LIGBT and (b) conv. LIGBT under $V_G=7\text{V}$ and $I=200\text{mA}$ (84A/cm²). Hole density at point-A in E²LIGBT is $7.0\times10^{16} \text{cm}^{-3}$ 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
E²LIGBT was fabricated using SOI wafer of 15µm thick silicon and 5µm BOX. An interface n-diffusion-layer with the dose of $1.5\times10^{15} \text{cm}^{-2}$ 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 E²LIGBT. The cell pattern is truck shape and the collector is located at the center. The area ratio, $S_1/S_2$, 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 1.9mm², which is 7.9 times larger than that of E²LIGBT.

3-2. DC characteristics
High blocking voltages of 738V for E²LIGBT 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 E²LIGBT is 3.7V for $V_G=7\text{V}$, $I=200\text{mA}$, 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 E²LIGBT, the on-resistance of LDMOS is worse than that of E²LIGBT.

3-3 Turn-off characteristics
Turn-off time, $t_{off}$, of the fabricated devices were measured under an inductive load. Fig. 5 shows $S_1/S_2$ dependence of $t_{off}$ for E²LIGBT. The short $t_{off}$ of 34ns is obtained at $S_1/S_2=33$. It is clearly verified that $t_{off}$ of E²LIGBT is simply determined by $S_1/S_2$. Fig. 6 shows measured turn-off waveforms. The measured $t_{off}$ of 34ns of E²LIGBT is considerably shorter than 44ns of LDMOS.
The switching loss, \( E_{\text{OFF}} \), of E2LIGBT hardly depends on temperature. The switching loss, \( E_{\text{OFF}} \), of E2LIGBT is remarkably smaller than that of LDMOS, as seen in Fig. 7(b). Especially, the temperature dependence of \( V_{\text{ON}} \) of E2LIGBT 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 \( V_{\text{ON}} \) and fall time/turn-off time among all the reported high voltage lateral MOS power devices. It is clear that the trade-off of E2LIGBT is the most excellent compared with those of all the other lateral silicon power devices, so far reported. Especially, E2LIGBT with \( S_{E}/S_{I}=33 \) is better than LDMOS both in on-resistance and switching speed.

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**References**