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Study of 4.5 kV MOS-Power Device with Injection Enhanced Trench Gate Structure

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We propose two new MOS power device structures, which realize further lower on-state voltage than previously proposed IEGTs. One is an improved IEGT (or IEGN), and the other is MOS controlled diode (or IEGD). By using 2-D numerical simulations, it has been confirmed that the IEGN and the IEGD realize lower on-state voltage drop than the conventional IEGT, retaining an easy MOS gate drivability. The 4.5 kV IEGN and IEGD can operate in the same circuit condition as a 4.5kV GTO-thyristor.

1. Introduction

Injection enhanced gate transistors (IEGTs) were proposed as promising future high voltage power devices[1-3]. In this device, the most important principle is to increase electron injection efficiency by reducing an amount of direct hole current flow into the cathode electrode by the novel trench gate structure. IEGTs achieve a thyristor-like carrier distribution and resultantly realize a low on-state voltage even for 4.5kV devices.

The trench gate structure is a key concept for future power devices[4]. In this paper, we propose two new trench gate MOS power device structures[5]. One is an improved IEGT(or IEGN, see Fig.1a), we shows that a further improvement is obtained by introducing a barrier layer in the trench channel for hole current flow. The other is MOS controlled diode (or IEGD, see Fig.1b), where the trench gate concept again plays an essential role to improve current turn-off capability as well as low on-state voltage.

2. IEGN

The improved IEGT (IEGN: injection enhanced gate transistor with n-type barrier layer) is characterized by an n-diffusion layer beneath the p-base, which works as an electrical barrier for direct hole current flow into the source electrode and further enhances electron injection efficiency.

The cross sectional view of IEGN with electron carrier density distribution during on-state in the middle of two trench gates are shown in the Fig.1a.

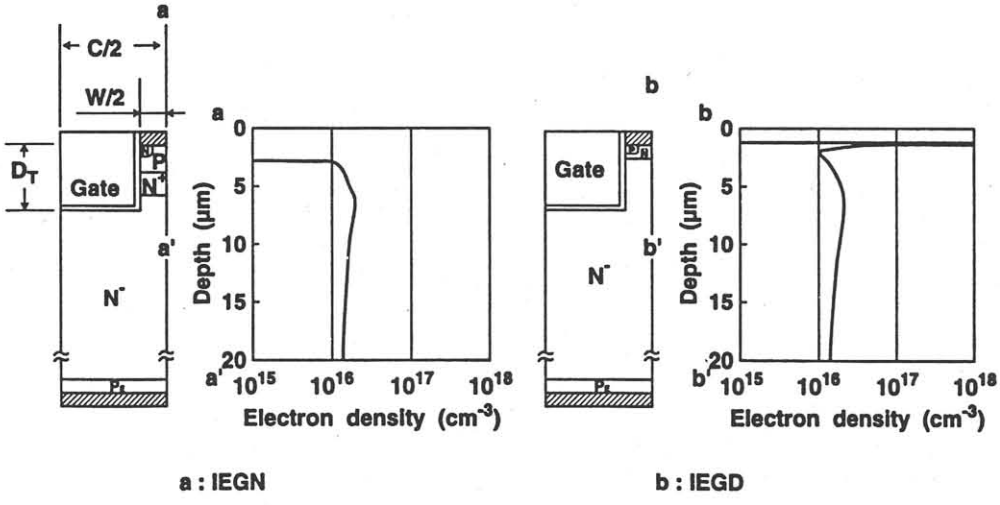

Fig.1 Cross sectional view of IEGN and IEGD with electron carrier density in the middle of two trench gates

Figure 2 shows the calculated current-voltage curves of 4.5 kV IEGN with the impurity concentration of the n-diffusion layer inside the trench channel beneath the p-base as a parameter. The depth of the trenched gate is 5 μ m. It is clearly seen that the n-diffusion layer of $5x10^{16}cm^{-3}$ improves the on-state voltage. The impurity concentration of the n-diffused layer is smaller than that of conventional n-emitter layer. The current-voltage curve of the IEGN with the n-diffusion layer of $5x10^{14}cm^{-3}$ is almost same as that of the IEGT.

However, the effect of n-diffusion layer becomes less as the trench gate depth increases. Almost no manifest improvement in the on-state voltage for deeper trench gate IEGNs has been obtained as seen in Fig.3.

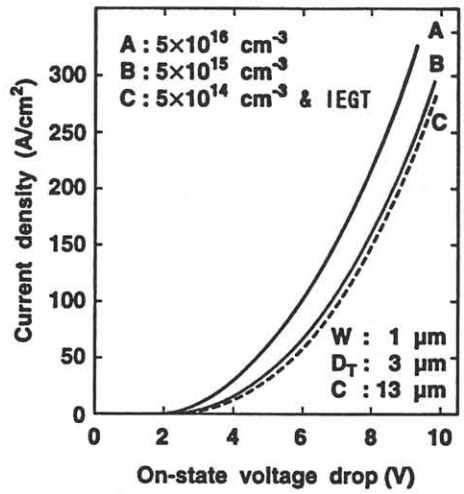

Fig.2 Current-voltage curve for IEGN as a parameter of impurity concentration in the n^+ diffused layer

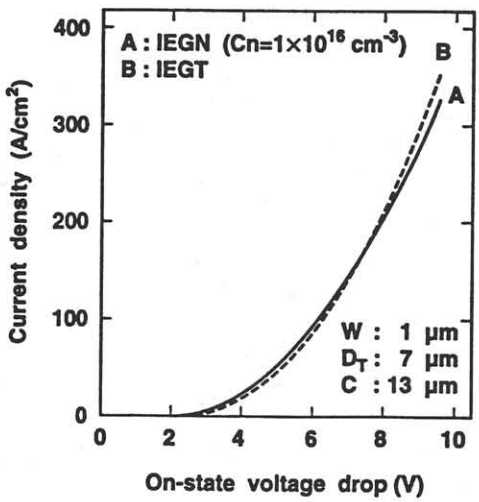

Fig.3 Current-voltage curve for IEGN and IEGT

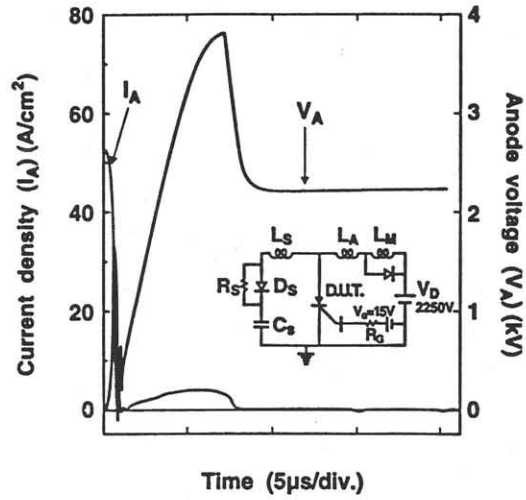

Fig.4 Calculated turn-off waveform for IEGN

where the current-voltage curves of IEGT and IEGN with 7 μ m deep trench gates are compared.

It was numerically shown that the proposed 4.5kV IEGN was successfully turned off even under a large inductive load. Figure 4 shows the simulated turn-off waveforms of the IEGN and the used external circuit.

3. IEGD

MOS controlled diode (or IEGD: injection enhanced gate diode) is based on the p-i-n diode structure, and it is characterized by a n-emitter layer with p-drain layer and narrow current channel surrounded by two trench gates.

The cross sectional view of IEGD with electron carrier density distribution during on-state in the middle of two trench gates are shown in the Fig.1b. An p-drain layer is formed in the n-emitter. The essential point is that the trench channel width W is designed to be sufficiently small so that if the gate electrode is positively biased, the whole trench channel become accumulated. The accumulated n-layer works as an n-emitter layer and the device reduces to a p-i-n diode. On the other hand, if the gate electrode is negatively biased, the whole trench channel is inverted and form an inverted p-layer. The IEGD effectively reduces to a p-n-p transistor and achieves device turn-off.

The simulated 4.5kV IEGD with 7 μ m deep and 13 μ m wide trench gate attains an on-state voltage drop of 4.5V at 100 A/cm^2 current density with a lifetime of 4 μ s for the 600 μ m thick n-base. This small on-state voltage drop is superior to that of the conventional IEGT with the same n-base width. Figure. 5 compares the current-voltage curves of the IEGD and a reference diode with the same fine drain/emitter pattern as the IEGD.

The simulated 4.5 kV IEGD was successfully turned off under a large inductive load. The turn-off mechanism

of the IEGD was already proposed as that of IGPT[6]. Figure 6 shows the hole density concentration in the center of trenched gates in the turn-off period. It was confirmed that the electron current stop when the region, surrounded by the trenched gates, is negatively biased.

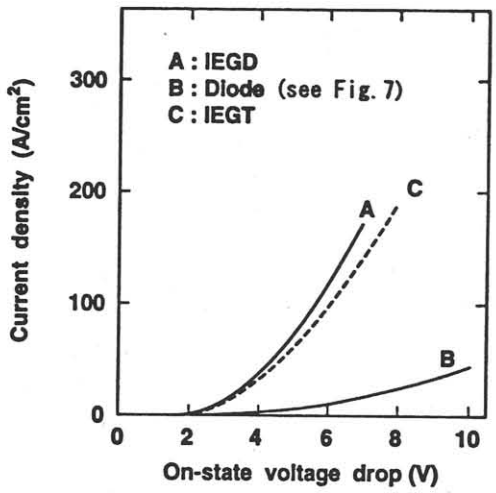

Fig.5 Current-voltage curve for IEGD and diode with the same drain/ emitter structure

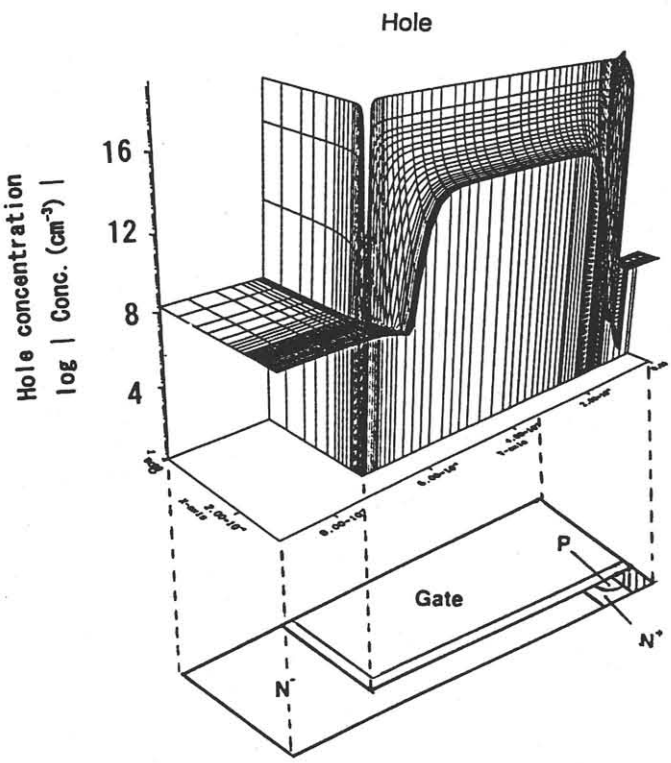

Fig. 6 Hole strage between the trenched gates during blocking state and cross-sectional view of IEGD at cathode side.

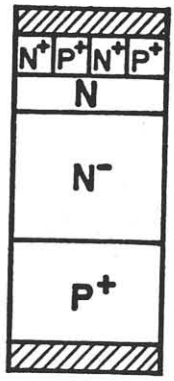

Fig. 7 Cross sectional view of the reference diode with the same drain/emitter structure as the IEGD

4. Conclusions

By using 2-D numerical simulations, it has been confirmed that the IEGN and IEGD realize lower on-state voltage drop than the conventional IEGT, retaining an easy MOS gate drivability.

It was verified that the IEGD has a large turn off ability because of the existence of hole storage between the two trench gates at the blocking state.

It was also confirmed that the 4.5 kV IEGN and IEGD can operate in the same circuit condition as a 4.5kV GTO-thyristor.

Acknowledgments

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