A Safe Operating Area Model for SOI Lateral IGBTs

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Abstract

This paper reports, for the first time, a mechanism, which limits the safe operating area (RBSOA). We numerically verifies that a RBSOA limiting mechanism is that the device breakdown voltage dynamically reduces when the net positive sheet charge in the SOI layer exceeds the optimum positive sheet charge determined by SOI-Resurf principle. It was found that forward SOA for steady conduction state is far larger than the reverse SOA for switching transients.

I. Introduction

High voltage SOI technology has been attracting interest, because high voltage devices can be integrated with control and protection circuits, and even with an MPU at reasonable cost.

Recently we have achieved large current capability and a large safe operating area (SOA) in trench gate lateral IGBTs [1,2] as well as multi-channel LIGBTs. On the other hand, SOA of LIGBTs has hardly been discussed. The present paper reports, for the first time, a mechanism, which limits the SOA for load short-circuit conditions as well as switching transients.

Figure 1 shows that drain current and gate voltage waveforms for repetitive short circuit SOA tests at the applied DC voltage of 300 V. The developed LIGBTs withstand the current voltage product of 1.5 x 10^5W/cm^2 for 5μsec. Actual current density and voltage product reaches 1.5 x 10^6 VA/cm^2. In order to find out the limiting mechanism of SOA, we carried out two dimensional numerical simulations of the same short circuit SOA test conditions (V_G=7V, V_D=300V) as that where the device failure has taken place.

In the present paper, we numerically verifies that an SOA limiting mechanism is that the device breakdown voltage dynamically reduces when the net positive sheet charge in the SOI layer exceeds the

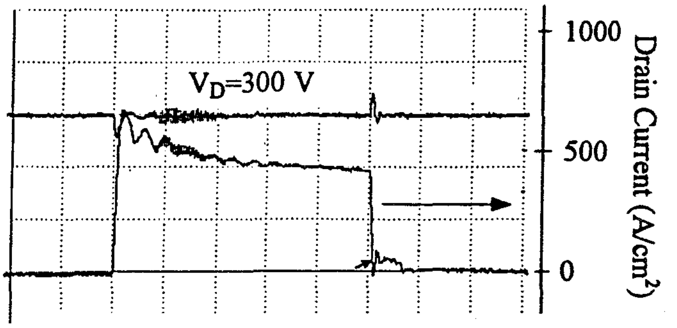

Fig.1 Drain current and voltage transients for short circuit SOA tests at the applied DC voltage of 300V and the gate voltage of 7V. (time: 1μs/div)

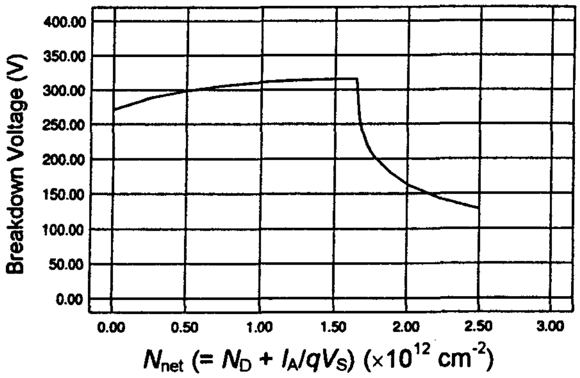

Fig.2 Calculated safe operating area for SOI devices. Here, I_A is the anode current for the 1cm device width and V_S is the saturation velocity.

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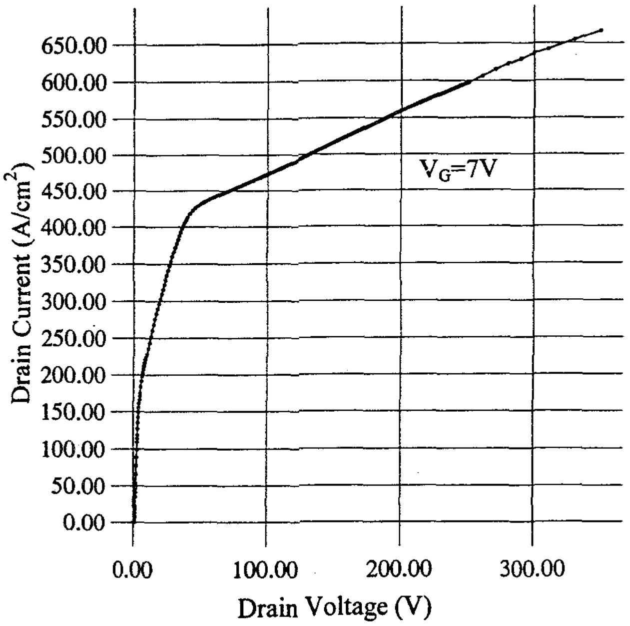

Fig.3 Calculated steady state current-voltage curve.

optimum positive sheet charge determined by SOI-Resurf principle, as shown in Fig.2 [3].

II. Results and Discussions

A. Steady State

Figure 2 shows the calculated static breakdown voltage vs. total impurity dose for the SOI LIGBT with 50μm n-drift region fabricated in 10μm thick SOI layer with 2μm buried oxide.

Figure 3 shows the calculated steady state current-voltage curve for the applied gate voltage of 7 V. It was found that the device breakdown voltage did not decrease in steady conduction state or it rather clearly increased. No impact ionization was observed even if the applied voltage exceeded the static breakdown voltage of 320V. The reason is that the hole accumulation layer was formed on the buried oxide. The positive charges in the induced hole accumulation layer were redistributed in such a way that the electric field inside the device was reduced and that the highest and optimized device breakdown voltage was achieved according to Resurf principle. The sheet positive charge in the SOI layer is kept under the optimum value from

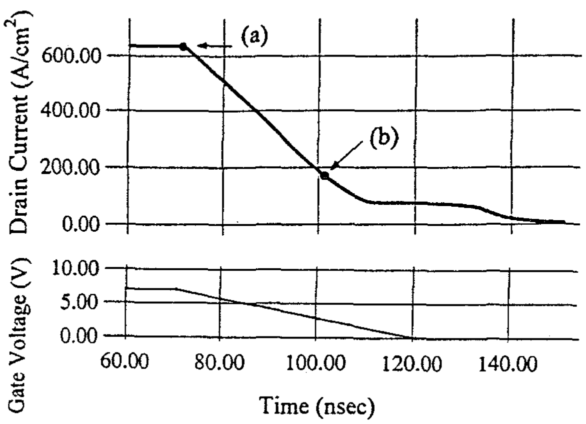

Fig.4 Calculated turn-off transient. Drain current was safety turned-off.

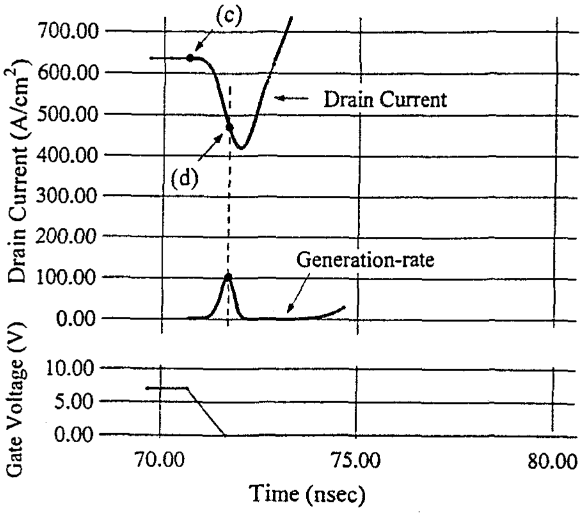

Fig.5 Calculated turn-off transient waveforms for a failure case. The drain current initially decreased. However, it increased again, resulting in turn-off failure because of large impact ionization. The calculated impact ionization rate is shown in the figure in terms of dimension of current density (q*G[A/cm2]).

Resurf principle. It should be noted that the executed simulation did not consider temperature effects, because we wanted to simplify the phenomena.

B. Transient state

Figure 4 shows a calculated turn-off transient from the short circuit condition. The device was directly connected to a 300V constant voltage source, and the gate voltage was reduced from 5V to zero in 50 nsec. It was found that the drain current could safely turned-off for this case. The distributed positive sheet charge was always kept under the optimum value determined from Resurf principle, as seen in curves (a) and (b) in Fig.6. Note that the curve (a) shows the sheet charge distribution for a steady state.

On the other hand, figure 5 shows a failure case, where the gate voltage was reduced more rapidly as compared with the case of Fig.4. In this case, the positive sheet charge in the SOI layer increases considerably, as seen in the curve (d) in Fig.6. This is because a large negative gate current have to be supplied by the hole current and increases the total hole current flow from the anode. The positive sheet charge especially in the drift region near the p-well (p-base) increased to the value of above 3 x 10^{12}/cm^2, and far exceeded the optimum value of 1.7 x 10^{12}/cm^2 determined from Resurf principle. This dynamically reduced the breakdown voltage and induced large impact ionization, resulting in the turn-off failure as illustrated in Fig,5.

Figure 7 shows the current flow lines for the time step (d) in Fig.5. Since the channel has disappeared, the most of the current flowing in the drift region near the source layer is carried by holes. It is seen that the hole current uniformly flows in the drift region near the gate electrode from Fig.7. This means that the large positive sheet charge shown by the curve (d) in Fig.6 is almost uniformly distributed in the silicon layer.

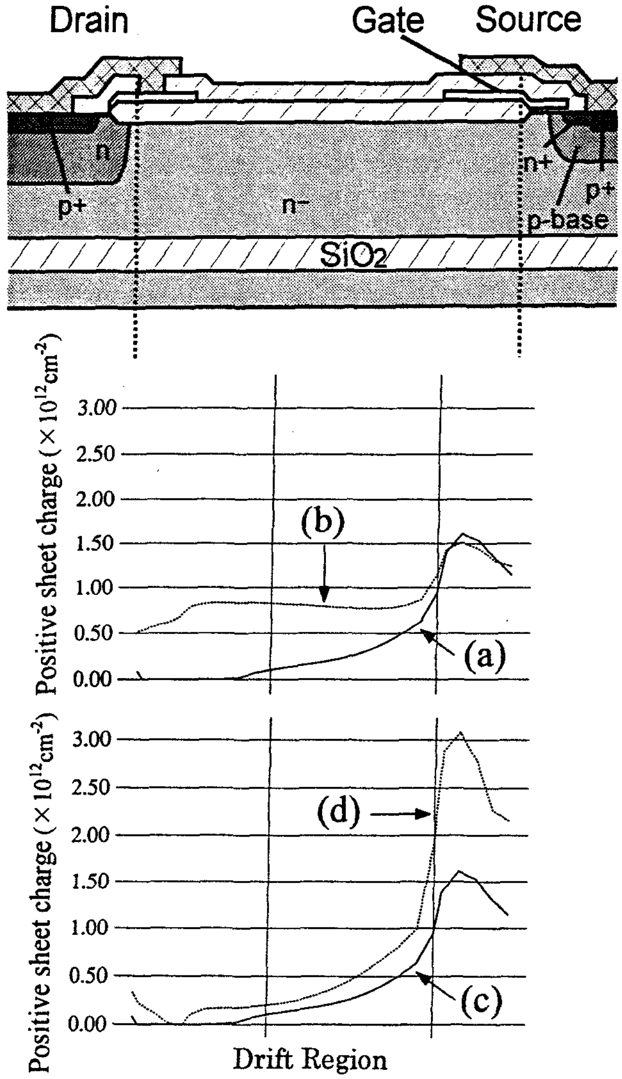

Fig.6 Positive sheet charge distributions in SOI layer: Curves (a) and (b) show positive sheet charge distributions of time steps (a) and (b) in Fig.4 and curves (c) and (d) show positive sheet charge distributions of time steps (c) and (d) in Fig.5.

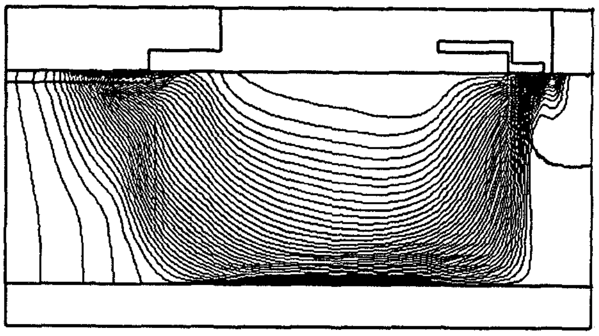

Fig.7 Current flow lines at the time step (d) in Fig.5.

III. Conclusion

We numerically verified that limiting mechanism for the reverse SOA (for switching transients as well as load short-circuit condition) is that the device breakdown voltage dynamically reduces when the net positive sheet charge in the SOI layer exceeds the optimum positive sheet charge determined by SOI-Resurf principle. It was also found that forward SOA for steady conduction state is far larger than reverse SOA for switching transients.

Acknowledgment

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