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6000V Gate Turn-Off Thyristor (GTO) with N-Buffer and New Anode Short Structure

Tsuneo Ogura, Mitsuhiko Kitagawa*, Hiromichi Ohashi and Akio Nakagawa
Research and Development Center and Tamagawa Works*, Toshiba Corp.
1 Komukai Toshiba-cho, Saiwai-ku, Kawasaki 210, Japan

A 6000V gate turn-off thyristor (GTO) has been developed for application to inverters, choppers and other high voltage transformers. In order to obtain a high blocking voltage as well as a low turn-off switching power dissipation, a combination of an n-buffer layer and a cylindrical anode short structure was implemented. In this new structure, it is easy to reduce anode shorting resistance merely by using a small shorting area, so that the tail current can be easily decreased without an increase in the on-state voltage. This paper shows the design concept for this 6000V GTO structure.

Introduction

High power gate turn-off thyristors (GTO) have received much attention as a key switching device for high power inverters and choppers. For these applications, a 4500V GTO has already been developed [1],[2]. However, it is desirable to develop higher voltage and higher current GTOs to make these power systems still smaller. The main problem in developing higher power GTOs is a significant increase in the on-state voltage and a large switching power dissipation caused by the increase in the n-base width. For example, for reverse blocking structure, an approximately 1100μm n-base width is required to realize 6000V forward blocking voltage. In order to overcome these problems, various device structures, such as the anode short [3], n-buffer [4], amplifying gate [5] and P^+P^- anode emitter [6] structures, have already been proposed. In the present paper, a new structure, consisting of the n-buffer and cylindrical anode short (CAS) structure, is proposed. The n-buffer structure can realize 6000V forward blocking voltage with an approximately 550μm n-base width. The CAS structure is effective in sweeping away excess carriers during the turn-off transient without increasing the on-state voltage. In this paper, fundamental characteristics for a 6000V GTO with this new structure are described. The device was fabricated on a 33mm diameter silicon wafer by using conventional diffusion and PEP techniques.

N-buffer structure

Generally, there are three GTO structure categories, reverse blocking, anode short, and n-buffer structures. The anode short and n-buffer structures do not have the reverse blocking capability. For ordinary applications, only the forward blocking capability is required. The impurity doping profile and the electric field profile, when forward anode voltage is applied to these three structures, are shown in Fig.1. For the reverse blocking structure shown by (a) in Fig.1, as the applied voltage increases,

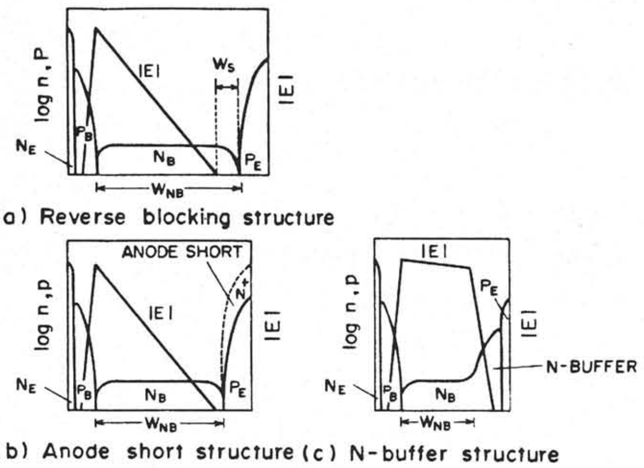

Fig.1 Impurity concentration and electric field (|E|) profile for three GTO structures.

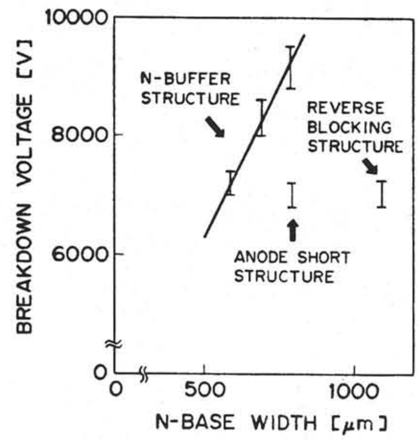

Fig.2 Relation between n-base width and forward blocking voltage for three GTO structures.

the anode current in forward blocking mode increases with the corresponding increase in α_{pnp}, which is a small-signal current gain for the pnp transistor portion of a GTO. Therefore, the n-base width must be greater than the depletion layer width by W_S, in the case for Fig.1 (a). As for the anode short structure, shown by (b), the n-base width can be reduced to almost the same as the depletion layer width, since α_{pnp} is essentially zero. In contrast to these two structures, the n-buffer structure, shown by (c), can realize an almost flat electric field distribution, because the n-buffer layer stops the depletion layer. Therefore, the same forward blocking capability can be theoretically obtained by the n-buffer structure with a half of the n-base width, compared with the anode short structure. From these facts, it is concluded that the n-buffer structure is the most suitable for high blocking voltage GTOs. Figure 2 shows the experimental results of the n-base width vs forward blocking voltage for the three structures. As is evident from this figure, the n-base width for the n-buffer structure is reduced to almost 55% of that for the reverse blocking structure, and almost 75% of that for the anode short structure.

Cylindrical anode short structure

A new anode short structure has been combined with the n-buffer structure to reduce turn-off switching power loss in GTOs. The structure of the unit GTO element, with the new anode short, called cylindrical anode short (CAS), is shown in Fig.3. Since the n-buffer layer resistance is very small, a large amount of gate current is required to trigger the GTO on, if the anode short area is as large as that of a conventional unit. Therefore, small and cylindrical anode short structures, shown in Fig.3, are made at anode side positions, where n-emitter elements are located on the opposite side. The number of these anode shorts can be changed to control the anode shorting resistance. The area for one CAS portion is less than 1% of the total area for the

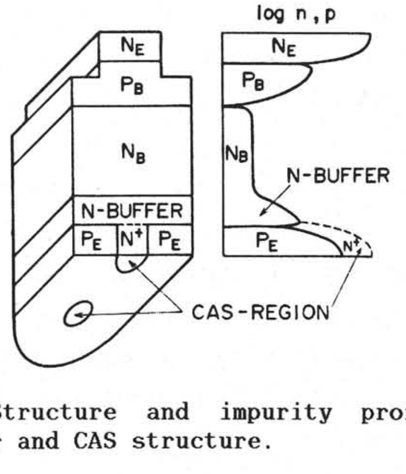

Fig.3 Structure and impurity profile for n-buffer and CAS structure.

p-emitter for the unit element. Figure 4 shows the relation between the number of CAS (N_{CAS}) and the gate triggering current (I_{GT}). As is evident from this figure, I_{GT} rapidly increases with the increase in N_{CAS}. I_{GT} can be characterized by

$$I_{GT}=\frac{Vj}{Rsg} \qquad (1)$$

where Vj is a critical forward voltage for the diode, consisting of the p-emitter and the n-buffer, and Rsg is the shorting resistance for I_{GT}. When N_{CAS} is one, Rsg is estimated to be 3 ohms, from Fig.4, by assuming Vj=0.6V. Similarly, Rsg is approximately 0.6 ohm for the case when N_{CAS}=4. In the CAS structure, Rsg can be easily controlled by changing N_{CAS}. As the CAS portion area is very small, the decrease in Rsg has no effect on the on-state voltage. This means that the CAS structure is superior to the conventional structure in designing the shorting resistance.

In the next paragraph, the CAS structure turn-off characteristics are discussed in detail. Anode short structure dose not exhibit a longer tail period than the reverse blocking structure, due to the effect of sweeping away excess carriers during the turn-off tansient. However, for the conventional anode short structure, the reduction in the shorting resistance

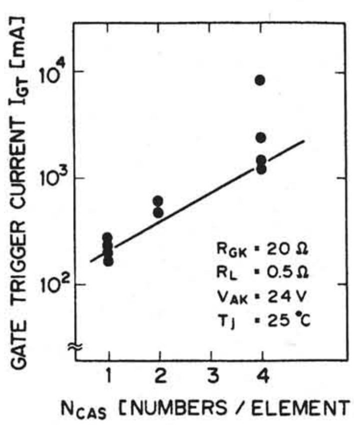

Fig.4 CAS number dependence on the gate triggering current.

accompanies the decrease in the p-emitter area. This not only causes the tail current to reduce, but also causes the on-state voltage to increase. As mentioned before, in the CAS structure, it is easy to reduce shorting resistance merely using a small shorting area, so that the tail current can be easily decreased without an increase in the on-state voltage.

The transistor charge control model was adopted to estimate the relation between the shorting resistance and the tail current, assuming that only the pnp transistor portion is in the active state. The excess charge (Q_b) in the n-base is given by

$$\frac{dQ_b}{dt}=-\frac{Q_b}{\tau_b}-I_s \qquad (2)$$

where τ_b is the hole lifetime in the n-base, and I_s is the current through the shorting resistance. I_s is related to shorting resistance Rst in the tail period by the following equation.

$$I_s=\frac{Vj}{Rst} \qquad (3)$$

And the following equations is valid [7].

$$I_{tl}=\frac{Q_b}{\tau_c} \qquad (4)$$

$$\frac{\tau_b}{\tau_c}=\frac{\alpha_{pnp}}{1-\alpha_{pnp}} \qquad (5)$$

where I_{tl} is tail current and τ_c is minority carrier transit time for the n-base. Combining Eqs. (2), (3) and (4), the tail current is given as

$$I_{tl}=\frac{1}{\tau_c}\{(\tau_c I_{tl0}+\tau_b\frac{Vj}{Rst})e^{-\frac{t}{\tau_b}}-\tau_b\frac{Vj}{Rst}\} \quad (6)$$

where I_{tl0} means the initial tail current value. Figure 5 shows a comparison between experimental results and calculated results in two N_{CAS} cases. This figure shows that experimental results can be explained well

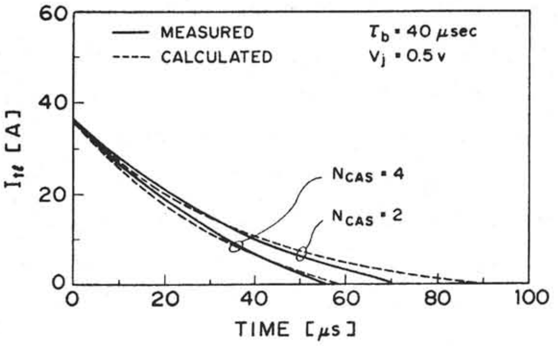

Fig.5 Change in tail current with time.

by this charge control model. As is obvious from this figure, the tail current can be reduced by increasing N_{CAS}. The relation between N_{CAS} and the turn-off power dissipation (E_{OFF}) and the on-state voltage (V_T) is shown in Fig.6. A strong relation was observed between N_{CAS} and E_{OFF}. In contrast to this, N_{CAS} has no effect on V_T, since the CAS area is relatively small, compared to the p-emitter area, as already

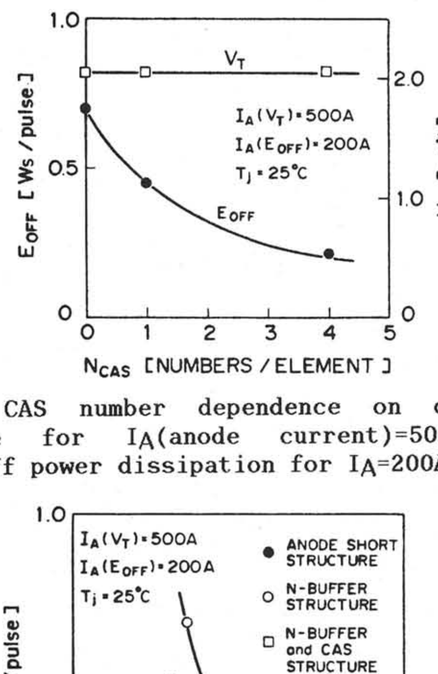

Fig.6 CAS number dependence on on-state voltage for I_A(anode current)=500A and turn-off power dissipation for I_A=200A.

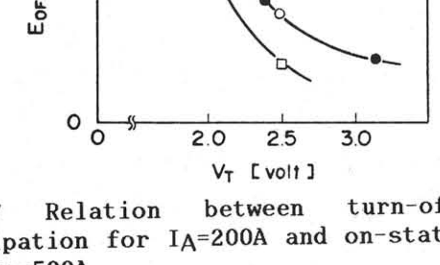

Fig.7 Relation between turn-off power dissipation for I_A=200A and on-state voltage for I_A=500A.

mentioned before. Figure 7 shows the trade-off relation between E_{OFF} and V_T for the CAS structure and the other two structures. The I_{GT} for the CAS and the anode short structure were set to be almost the same for fair comparison. Figure 7 was obtained by varying the n-base lifetime. As is shown in this figure, the CAS structure has the best trade-off relation among these three structures.

Conclusion

The new anode short structure, consisting of the n-buffer and the cylindrical anode short, was developed to realize low on-state voltage and small turn-off power dissipation. Based on this structure, the 6000V GTO was successfully realized.

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