POWER GTO WITH COMPENSATED RING ANODE-SHORT

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ABSTRACT-This paper gives the novel design of compensated ring anode-short for power GTO thyristor. By means of this design the power GTO of Φ63.5mm 2500A/4500V reaches more uniform turn-off compared with conventional ring shorts GTO, resulting in higher turn-off ability and low tail current/tail time.

1. INTRODUCTION

In many power electronics applications, GTO is still dominating power semiconductor device due to its high controllable on-state current, high blocking voltage, low on-state voltage drop and ease fabrication compared to power IGBTs. Although the Integrated Gate Commutated Thyristor (IGCT) is the newly emerged power semiconductor device , and it will replace GTO thyristor and IGBT as a power semiconductor devices in the near future , however, the basic structure of IGCT is almost as same as that of power GTOs[6]. Therefore to realize best characteristics of power GTO is still mostly interesting subject for power semiconductor researcher. There are two aspects to be solved for big GTO: one is high tail current[7], i.e., high turn-off loss E_{off}, in accordance with high rating of GTO; the other is to increase turn-off uniformity of big GTO. This paper focuses on these aspects so as to have higher turn-off ability.

2. DESIGN CONSIDERATION

Most of high power GTO thyristor have employed anode shorts emitter in order to achieve a reduction in the turn-off tail current and to have a low α_{pnp} [1,2]. The newly anode shorts structure i.e. ring anode shorts has the advantage of ease manufacture and adjustable tail current based upon different ring shorts pattern[3,4]. We have applied this new structure to power GTO in China[5], improving the turn-off performance for high voltage 1000A-2500A/3-4.5KV GTOs. In the case of ring anode shorts structure, the significant improvement of turn-off characteristics in terms of maximum turn-off current I_{TGQM} for big diameter GTO is needed.

In order to have clear image of turn-off characteristics of power GTO thyristor, we have simulated the turn-off performance of 250A/1200V reverse-blocking GTO by commercial simulator TMA-MEDICI. Fig.1 shows its results of 250A GTO. From this figure we know that the tail current/tail time is higher for reverse-blocking GTO, therefore it is necessary to reduce tail current/tail time by novel ring anode shorts design for big current GTO thyristor.

Fig.2 shows cathode design pattern for 2500A/4500V ring anode shorts GTO. There are totally 953 cathode fingers arranged in 6 concentric rings on Φ63.5mm wafer. Each finger has width of 240μm and length of

2.4mm. In order to improve turn-off uniformity the ring gate metallization is designed between 3rd and 4th concentric cathode fingers.

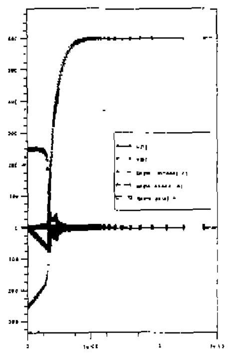

Fig.1, The simulated turn-off results of 250A/1200V GTO Thyristor

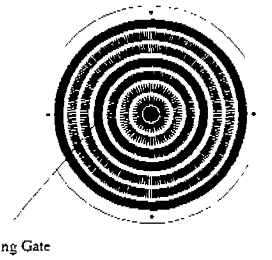

Fig.2, Cathode pattern of Φ63.5mm GTO

For big diameter GTO wafer to handle high turn-off current, there are some non-uniform parameters across the whole wafer (for example the non-uniformity of carrier lifetime τ_p and concentration N_s across the wafer) during device fabrication process. In particular for large area Φ63.5mm GTOs, the ring gate metallization was specially designed to improve the turn off uniformity of total GTOs. Even though in this case there are still some of fingers slowly turn off, therefore, the further improvement on turn off uniformity by using ring anode shorts structure is needed.

Fig. 3 shows the simulation results of the gate voltage drop distributions and cathode current distributions in each cathode concentric rings across the whole GTO wafer. It is worthwhile noting that the gate voltage drop and cathode current in each ring are much difference among gate metallization and out-most concentric finger due to the effect of both P-base lateral resistance and gate-cathode junction (J_3) re- biased during the reverse gate current to turn-off GTO. It means that the gate reverse turn off current beneath out-most finger at the edge of wafer would become weaker than that of beneath inner finger in the center of wafer, resulting in non-uniform turn off for all fingers and device failure during long-term operation.

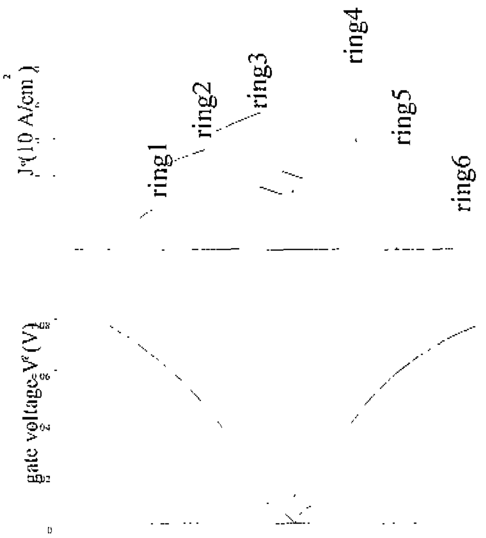

Fig.3, Gate voltage drop and cathode current density distribution across wafer

From above results the special design consideration for ring anode shorts GTO is given in this paper. Fig.5(a) and Fig.5(b) gives the old design(uniform ring shorts) and new design(non-uniform ring shorts) anode mask, respectively. The new design shown in Fig.5(b) which is called compensated ring anode-shorts is realized in the fabrication of Φ63.5mm GTO since it can compensate the above side-effect from non-uniform of gate reverse turn-off current flows across the whole wafer ,i.e., the n^+ width of ring anode-short in the center of wafer (aligning to 1st, 2nd and 3rd concentric ring of cathode side) is narrow and the n^+ width of ring anode-shorts at the edge of wafer is much wider, resulting in much carrier extraction in the center of wafer via the n^+ layer of anode shorts during tail current period.

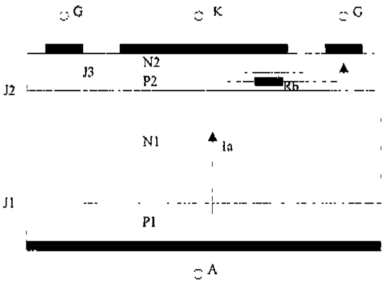

Fig.4, Gate re-biased during turn-off

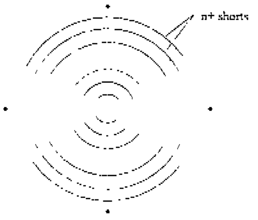

Fig.5(a), Old ring anode-short design mask

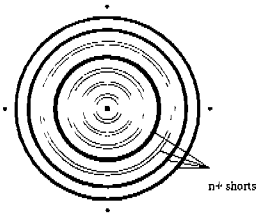

Fig.5(b), Compensated ring anode-short design mask

Therefore the carrier fast sweep out from the n^+ shorts region can compensate the carrier slow extraction by the lower negative gate- cathode voltage at the edge of wafer. This gives considerably improvements in the turn off performance compared with the previously old design without compensated ring anode shorts.

3. DEVICE FABRICATION

GTO thyristor mentioned above adopts non punch-through(NPT) type design since the thick N-base W_{NB} is preferable to have high turn-off current I_{TGQM}[1]. The wafer thickness is around 800μm and raw NTD silicon resistivity is around 225Ω•cm. Following is the main fabrication process for this GTO:

(1)P-type Gallium diffusion performed by Ga-Ge source in sealed tube at 1250°C to form PNP.

(2)Lapping one side P-type diffusion layer to have PN layer and polish P-side as cathode side.

(3)Oxidation with trichlorethylene(TCE) at 1180°C and then lithographic photo-mask on N-side to open the anode-shorts window.

(4)37μm depth of N^+ anode short is performed by phosphorus deposition and drive-in.

(5)32 μm depth of p^+ region at anode is formed by B_2O_3 coating source in the open tube diffusion.

(6)Oxidation and etching to form n^+ window at the cathode-side.

The other processes including gate grooving etc. are as same as conventional GTOs. Nevertheless the 5Mev proton irradiation of local lifetime control technique from front-side of wafer was applied to the ring shorts power GTO since local lifetime control can reach lowest tail current[7] and have best trade-off between E_{off} and V_{TM}.

4. EXPERIMENT RESULTS

Fig.6 shows the tail current wave-form for old anode-mask design and new anode-mask design of 2500A GTO, the testing current is 1000A at T_j=125°C, C_s=4μF. It is evident that the tail current decay after turn-off is very fast and peak tail current value $I_{pk(tail)}$ is low for the compensated ring anode shorts design shown in Fig.5(b), resulting in low turn-off loss E_{off} compared with old ring anode shorts design. Actually the experiments result indicates that decay of tail current after its peak value can be simply represented in the following form:

$I = I_{pk(tail)}\, e^{-(t/T)}$ (1)

$I_{pk(tail)}$ is peak value of tail current, in case of Fig6(a) $I_{pk(tail)}$=57.6 and Fig.6(b) $I_{pk(tail)}$=48.8A;

T is tail current decay rate. For a reverse-blocking GTO, T= τ_p = N-base minority carrier lifetime. In the case of an anode shorts GTO, $1/T=1/\tau_p + 1/\tau_s$ (2)

τ_s is anode shorts lifetime and τ_s is mainly dependent on the anode shorts geometry used in different design. By means of accurate measurements of tail current in Fig.6(a)T=9.96 and Fig.6(b) T=9.68.

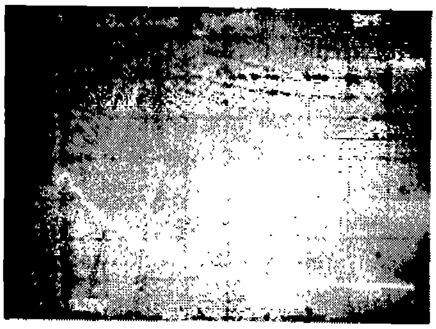

Fig.6(a) Tail current decay wave-form of old design. I_{tail}: 20A/div, t: 5μs/div

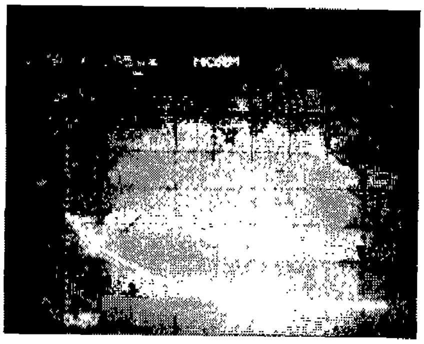

Fig.6(b) Tail current decay wave-form of new design. I_{tail}: 20A/div, t: 5μs/div

In table 1, we compare the turn-off performance of test results of compensated ring anode-shorts compared with the results of the old design (the uniform ring shorts). As is well known, ΔV_{DSP} is the measuring value for determining the turn-off ability I_{TGQM} for GTOs. If the value of ΔV_{DSP} is high, it means that the turn-off ability of device I_{TGQM} is high.

From table 1, it is very clear that the compensated ring anode-shorts design not only have higher value of ΔV_{DSP}, but also lower value of I_{tail}/t_{tail}(therefore lower E_{off}). Fig.8 shows the test turn-off waveform by this new ring anode-shorts design for 2500A/4500V GTO, in which the maximum controllable on-state current I_{TGQM} can reach up to 3000A with a snubber of C_s = 4μF, R_s=7Ω at T_j =125°C. However the I_{TGQM} with old mask anode shorts design is below 2000A shown in Fig.7(T_j=25°C) with the same snubber condition. This result indicates that the new design indeed improves the turn-off uniform of big GTO and achieves high turn-off capability. The on-state voltage V_{TM} is low just typically 2.5V at 2500A and I_{GT} is around 1200mA. Fig.9 shows the chip samples of this GTO thyristor.

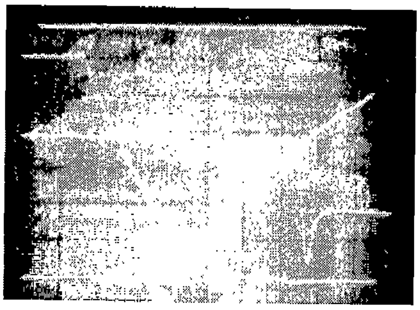

Fig.7 Turn-off wave-form of old shorts design at T_j 25°C I_A:500A/div, V_A:500V/div, t: 5μs/div

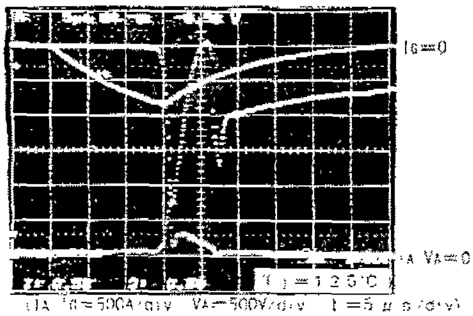

Fig.8, The test turn-off waveform of new shorts design for 2500A/4500V GTO

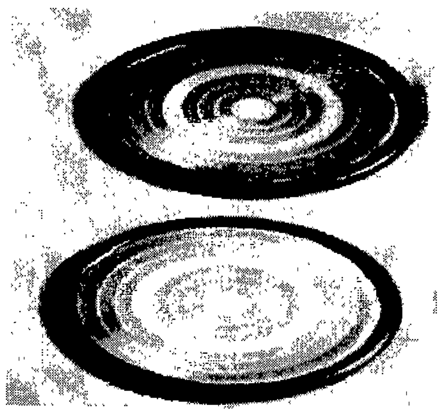

Fig.9, The developed sample of Φ63.5mm GTO

5. CONCLUSION

By the novel design of compensated ring anode-shorts, the power GTO thyristor can achieve the high turn -off ability due to the improvement on uniformity of lateral parameters across wafer. Also, this GTO has the low tail current/tail time compared with previously old ring anode shorts.

6. REFERENCES

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Table 1, The measuring values of GTO device with different ring anode-shorts mask

Short scheme	I_{TGQM}(A)	I_{GQM}(A)	V_{DSP}(V)	ΔV_{DSP}(V)	I_{tail}/t_{ail}(A/μs)	V_{TM}(V)
old design	1800(125°C)	600	506	166	400/24	2.30
new design	3000(125°C)	1000	600	300	246/8	2.50