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고전압 역도통 Gate Commutated Thyristor (RC-GCT) 소자의 공정 및 구조 설계

Process and Structure Design for High Power Reverse-Conducting Gate Commutated Thyristors (RC- GCTs)

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Abstract

The basic design structure of RC-GCTs (Reserve-Conducting Gate-Commutated Thyristors) is firstly given in this paper. The bulk of wafer is punch-through (PT) type with high resistivity and narrow N-base width. The photo-mask was designed upon the turn-off characteristics of GCT and solution of separation between GCT and diode part. The center part of Si wafer is free-wheeling diode (FWD) and outer is GCT part which has 240 fingers totally. The switching performance of GCT was investigated by Dessis of ISE. The basic manufacture process of 2500V-4500V RC-GCTs was given in this work. Additionally, the local carrier lifetime control by 5Mev proton irradiation was adopted so as to not only to have the softness of reverse recovering for FWD but for reduction of turn-off losses of GCT as well.

Key words: Gate-Commutated Thyristor(GCT), turn-off, diode, lifetime control

1. Introduction

Recently high power integrated gate commutated thyristor (IGCT) is mostly prospecting power device to compete with high voltage insulated gate bipolar transistors (IGBTs) in the power electronics application such as inverter and converter, SVC or even in traction drives. IGCT is easier in manufacturing and higher in production yield comparable to MOS-like fabrication of IGBTs. IGCT fabrication is compatible to bipolar device such as GTO and thyristor. In comparison with PNPN thyristor-mode turn-off of Gate Turn-off Thyristors (GTOs), IGCTs has a more reliable turn-off mechanism of PNP transistor-mode. Therefore, IGCT has a lower turn-off loss by shorter switching time, resulting in easy of snubberless operation and series connections for high voltage power application. On the other hand, IGCTs can easily be connected in parallel connections due to its hard-driven via unity of turn-off gain by smart designing Gate Driven

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Unit(GDU). However, the core technology of IGCT is GCT chip itself. The design and process technologies of GCT have not sufficiently been disclosed even though the many publications have been appeared elsewhere.

2. Basic Design of GCT

Central FWD and surrounding GCT parts for peak turn-off current rating of 1000A at snubberless (2000A at 3μF snubber capacitance) are designed on n-type Si wafer in diameter of 63.5mm. It is necessary to minimize the wafer thickness to obtain low on-state voltage drop and short turn-off time. We have designed, therefore, punch-through structures on NTD (Neutron Transmutation Doped) wafers of high resistivity with low radial distribution of 7%. The N-base thickness of wafer was determined in 220μm and 420μm for 2,500V and 4,500V , respectively. The 2,500V device has a resistivity of 430Ωcm and the 4,500V device has 550Ωcm. Fig.1 shows the bulk structure of wafer by simulator ISE

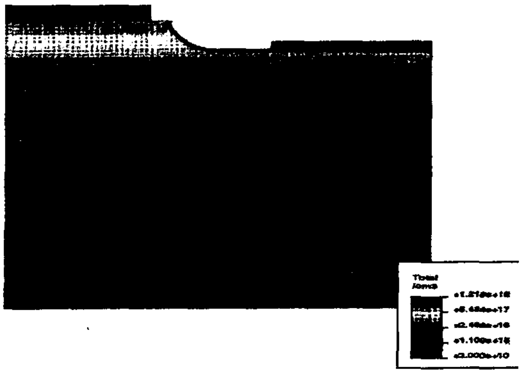

Fig. 1 simulated GCT bulk structure by simulator of ISE.

GCTs cathode finger of 280μm in width and 2.72mm in length is designed to turn off peak current of 5A for each finger. Total 240 fingers are arranged on 3 concentric rings to achieve maximum turn-off current of 1,000A in snubberless operation and 2,000A with snubber capacitor of 3μF.

An additional process for P^+ layer is adopted after grooving recessed gate so as to have very low P-base sheet resistance and finally to get the highest negative gate turn-off current to extract the excess carriers during turn-off transient. For the same purpose a shallow gate groove of 10μm depth is made by chemical etching. Separated contact Aluminum layers are formed by the E-beam evaporation for cathode and gate electrodes of 20μm and 10μm in thickness, respectively, which will guarantee the electrical isolation between gate and cathode. This is a key difference from ordinary GTOs technology.

The ring anode-shorts pattern with interdigitated N^+ on P^+ matrix instead of P^+ transparent emitter [1] is the better solution for easier mask process of anode side. The authors[2] have reported that the ring anode-short structure results in uniform turn-off characteristics in general GTOs of large diameter. Our further improvement in this work has given more effective extraction of stored carriers, comparable to P+ transparent emitter.

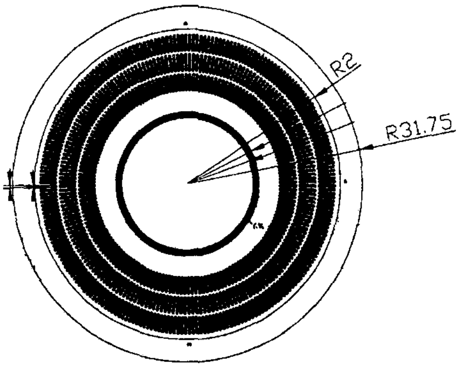

Fig. 2 Basic mask pattern for 63.5mm RC-GCTs (FWD is located in center of wafer).

Fig. 2 shows the basic photo-mask for cathode pattern in our work. Total 11 layers of photo-masks are needed including a boron implantation mask for anode-shorts. Fig. 3 gives turn-on and turn-off waveform obtained from mixed-mode simulation by DESSIS of ISE. It is clearly that GCTs has a fast turn-on(Fig.3a) and turn-off during switching transient at snubberless. At turn-off 170A of I_{TGQM}, negative dI_G/dt has already reached up to 850A/s and storage time ts is only 0.2 second. The total turn-off time is about 0.6 second and no obviously tail current is observed in this case.

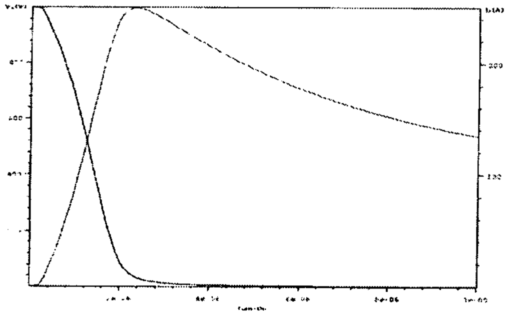

Fig. 3(a) The simulated turn-on waveform:V_A =1000V and I_A=250A.

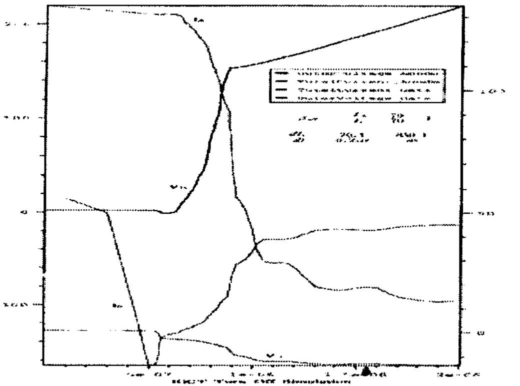

Fig. 3(b) The simulated turn-off waveform I_A=170A;V_A=220V; I_G=-170A; V_G=-16V; C_s=0F and R_S=10.

3. Integration GCT and FWD

There are two issues to be solved for monolithic integration of GCT and FWD: One is to protect rushing currents from FWD into P-base of GCT part during GCTs off-state phase, which possibly results in fault triggering. Another is to achieve softer reverse recovery characteristics of FWD. Otherwise, its hard reverse recovery will cause the tremendous turn-on over-shoot of GCTs, which may result in permanent destroy of GCT itself.

We propose a novel technology for separation between GCT and FWD parts, as seen in Fig.4. At the first step, separated P+ layers of low resistance are diffused into P base of GCT and P emitter of diode. Secondly a deep separation groove is etched down to P^+/P interface depth.

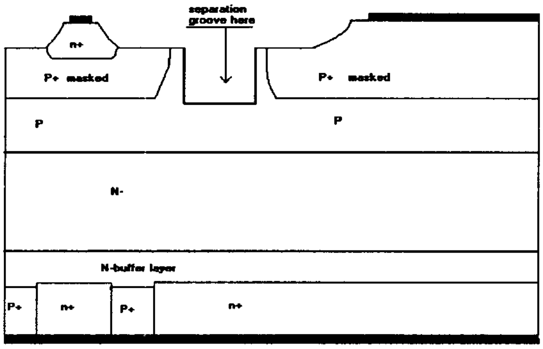

Fig. 4 A novel separation technology proposed for RC-GCTs.

In order to realize soft reverse recovery of FWD, local carrier lifetime control by proton irradiation is introduced to RC-GCT. Previously work indicated that local carrier lifetime control by 5.0MeV proton irradiation in depth of 220㎛ can have softness of recovery characteristics for 1000A punch-through diode[3]. It has been demonstrated that proton irradiation can considerably reduce the turn-off losses E_{off} for power GCT.

4. Basic fabrication

The important process for GCT is to form the P-base by implantation of Aluminum and Boron. The deep Aluminum drive-in forms a deep P-base and shallow concentration in front of P-N junction so as to sustain the high forward blocking voltage. The Boron implantation was firstly done by 120keV with dosage of $4.5\times 10^{15}/cm^3$ then drive-in at 1200℃ of 8 hours. By means of chemical etching off the separation area of GCT and diode, the separated P+ layer was formed. The following process is implantation of Aluminum by 80keV and driven-in. All oxidation is oxidized with TCE (trichloroethylene) in order to have long carrier lifetime before irradiation.

Acknowledgement

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References

[1] F. Bauer, W. Fichtner et all, A Comparison of Emitter Concepts for High Voltage IGBTs, Proceedings of ISPSD, PP.230-235, 1995.

[2] Changli. Zhang, N. Xu, Z. Chen, Power GTO with Compensated Ring Anode short, Proc. IEEE 30th annual power electronics specialist conference (PESC99), USA, PP. 381-384, 1999.

[3] Changli. Zhang, Juerg Waldmeyer, Peter Roggwiller, Z. Chen, Soft Recovery Characteristics of Punch-Through Power Diode by Proton Irradiation, Proc. IPEMC 2000, Beijing, China, PP. 229-234, 2000.