Integrated Thyristor Switch Structures for Capacitor Discharge Application

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Abstract

A thyristor switch circuit for capacitor discharge application, of which the equivalent circuit includes a resistor between cathode and gate of a reverse-conducting thyristor and an avalanche diode anti-parallel between its anode and gate to set thyristor turn-on voltage, is monolithically integrated by planar process with Al/B double-implantation method.

To ensure a lower breakdown voltage of the avalanche diode for thyristor turn-on than the break-over voltage of the thyristor, p^+ wells on thyristor p base layer are made by boron implantation/drive-in for a steeper doping profile with higher concentrations while rest p layers of thyristor and free-wheeling diode parts are formed with Al implantation/drive-in for a doping profile of lower steepness. The free-wheeling diode part is isolated from the thyristor part by formation of separated p-well emitter for suppressing commutation between them, which is achieved during the formation of thyristor p-base layer.

Key Wards(중요용어) : Thyristor, Diode, Switch, Integration,

1. Introduction

Pulse current generation circuits based on thyristor are widely used for electric ignition systems for gas grills and boilers. Fig. 1 shows a simple circuit having a resister between thyristor cathode and gate, and a Zener diode anti-parallel between its anode and gate to trigger thyristor with a free wheeling diode (FWD). The thyristor is turned on by voltage drops higher than 0.7V at the parallel resistor between gate and cathode of thyristor developed by currents through the Zener diode when the reverse bias voltage developed in the diode by capacitor-charging voltage reaches its breakdown voltage.

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When the thyristor switch is turned on, the capacitor discharges to give a pulse current to the coil developing a high voltage. After capacitor discharging, as the thyristor anode current becomes lower than its holding current it turns automatically off and charging voltage on the capacitor becomes developing again, which makes a repetitive pulse wave from the circuit.

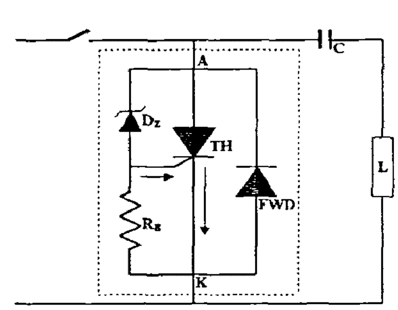


Fig. 1. A thyristor switch circuit with a Zener diode for capacitor discharge application.

Series of these thyristor switches monolithically integrated by planar process have been commercialized [1] but device structures and processes for them have not been announced.

Theoretically the Zener process, quantum mechanical tunneling of electron through a reverse bias pn junction, becomes predominant when its depletion width is small enough, I. e. d<100Å. Ideal Si Zener diodes with impurity concentrations larger than $10^{17}cm^{-3}$ in both sides have reverse breakdown characteristics with V_{BR} (reverse breakdown voltage) lower than 4.5V and its negative temperature coefficient [2]. The circuit will, therefore, show a positive temperature coefficient of pulse wave frequency with lower charging voltages at higher temperatures. It may be recommendable to design an avalanche diode with a positive temperature coefficient of V_{BR} to improve the frequency - temperature property of the circuit of Fig. 1.

Since V_{BR} of the Zener diode in the circuit limits capacitor charging voltage, there is need to increase its V_{BR}. It is, however, not easy to make a real Zener diode of high V_{BR} monolithically integrated with reverse-conducting thyristor (RCT) structure. In this work we suggest two different structures with avalanche-type diode (D_A) instead of Zener diode to increase V_{BR}.

2. Structure and Operation

Fig. 2 shows a proposed structure with triggering p^+n diodes instead of p^+n^+ Zener diodes.

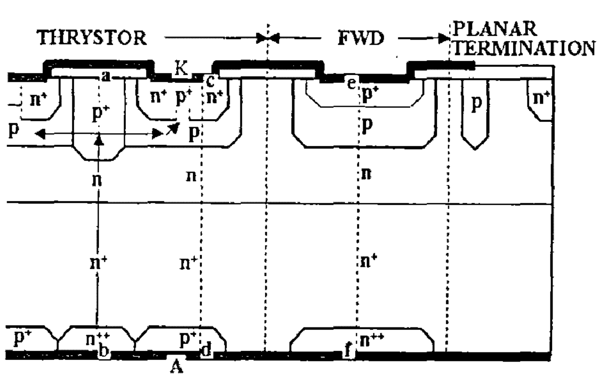


Fig. 2. Integrated RCT switch with deep p^+-wells to trigger it (structure 1).

The structure is very similar to an anode-shorted IGBT (Insulated Gate Bipolar Transistor) with deep p^+ wells for improving the latch-up characteristic.

When a forward bias voltage is applied to the thyristor part, a reverse bias voltage is induced at the p^+n junctions on the current paths (arrow) through $n^{++}/n^+/n/p^+/p/p^+$. J_2 junctions of the $n^+pnn^+p^+$ thyristor structure and the pn junction of p^+pnn^+ FWD are also reversely biased. The highest electric field at the p^+n junctions is, however, developed because of a steeper doping profile with high concentrations at p^+-side in comparison with the pn junctions.

As the applied voltage increases the reverse bias p^+n junctions become first broken down and resulted currents are injected into thyristor p-base and flow through cathode shorting holes. When the currents induce forward voltage drops at n^+p emitter (J_1) junctions, i.e. higher than 0.7V, the junctions emit electrons finally to turn on the thyristor. P^+-wells are homogeneously distributed on the thyristor cathode surface and they are isolated from cathode metal by oxide. Its density is controlled from the tradeoff properties of di/dt $-V_F$ and di/dt-trigger current. If the reverse breakdown currents are too large, then they can put the junctions under the dangerous second breakdown condition. Usually they can be safely maintained because the currents are automatically reduced by the thyristor turn-on.

Cathode topology can have large variations by having separated round p^+ wells or honeycomb structure of p^+ well. The cathode shorting improves dV/dt as well known, while the anode shorting provides the triggering current paths as well as improves thyristor turn-off characteristics. The area ratio of n^+/p^+ on thyristor anode should be determined from tradeoff between turn-off time and V_F. The pn junction of FWD surrounding thyristor is isolated from the thyristor p-base, shown in Fig. 2. This structure helps to suppress commutation between thyristor and FWD. The reverse recovery charges of the diode penetrating into thyristor part can trigger the thyristor [3].

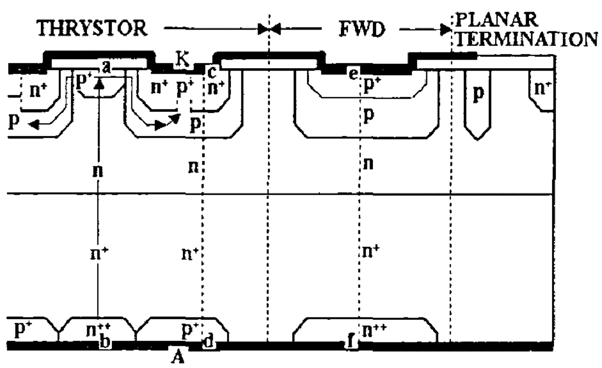


Fig. 3. Structure 2 switch with shallow p⁺n junctions to increase difference between V_{BR} of triggering p⁺n junctions and V_{BO} (break-over voltage) of thyristor.

Another structure is illustrated in Fig. 3, basically similar to the first structure but followed by a much different manufacturing process. In order to decrease the temperature coefficient of V_{BR} of the triggering-diode junctions, higher doping concentrations in p^+ wells are recommended, which also results in a large difference between their V_{BR} and thyristor break-over voltage (V_{BO}). If the difference is so small at room temperature, thyristor may first break over at higher temperatures because V_{BR} of avalanche-type triggering diodes has a positive temperature coefficient while V_{BO} has a negative temperature coefficient. To solve the problem, we suggest the structure 2 with shallow p^+ wells of a steeper doping profile with higher concentrations.

3. Fabrication and Property

The structure 1 can be fabricated with a planar process similar to IGBT process [4]. First, deep p^+ wells are made by B diffusion with a high surface concentration on an n/n^+ epi-wafer. Since it is necessary to make V_{BO} as well as V_{BR} of FWD higher than V_{BR} of D_A to trigger thyristor, they should have p layers of more diffused doping profile with lower concentrations. They, with field limiting rings, are simultaneously made by implantation/drive-in of Al with very high diffusivity.

The p^+ anode and the n^+ cathode can be made by diffusion of B and P, respectively. For ohmic contact of anode shorting holes and FWD cathode, n^{++} is driven-in. The structure needs an additional process to form p^+ deep wells in comparison with reverse-conducting Gate Turn-Off thyristor. Fig. 4 shows doping profile for each part of an example device simulated with a specified thermal history by the designed process sequence.

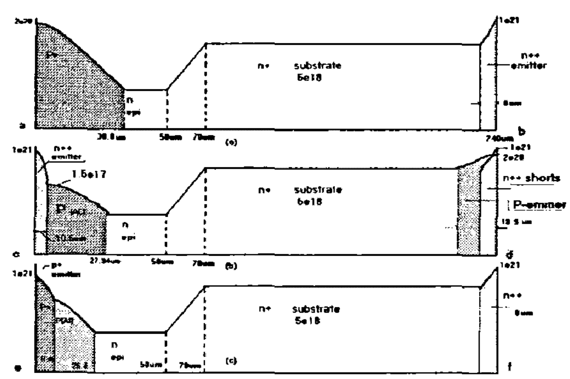
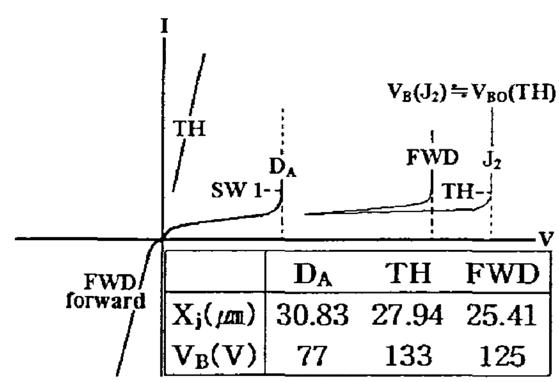


Fig. 4. Vertical doping profile for each segment of an example device of the structure 1.

By the ATLAS 1D simulator [5], breakdown voltages of FWD (e-f doping profile), J_2 in the thyristor (c-d), and D_A (a-b) from Fig. 4 are about 125V, 133V, and 77V, respectively. Fig. 5 shows I-V characteristics of an integrated 2D structure with doping profiles of Fig 4, having a turn-on voltage of 42V approximately the same as V_{BR} of D_A by 2D simulation and compared with those of separated segments.



	D_A	TH	FWD
$X_j(\mu m)$	30.83	27.94	25.41
$V_B(V)$	77	133	125

Fig. 5. I-V characteristics of the structure 1 simulated from doping profile data of Fig. 4.

In the first quadrant, the characteristics before thyristor turn-on at lower currents are mainly ruled by the current paths of the arrows through D_A while by thyristor part after its turn-on at higher currents. The I-V curve of the third quadrant is determined by FWD.

For the structure 2, Al implantation/drive-in for p wells of thyristor p-base and FWD emitter is first conducted and phosphorous diffusion is followed for n^+ emitter. Then p^+ wells for p^+n junctions to set thyristor turn-on voltage are formed by B implantation/drive-in, accompanied with p^+ layers for ohmic contacts of thyristor cathode shorting holes as well as the p side of FWD. Shallower p^+n junctions with a steeper p^+ doping profile with higher concentrations, as shown in Fig. 6, can be obtained by shorter drive-in time.

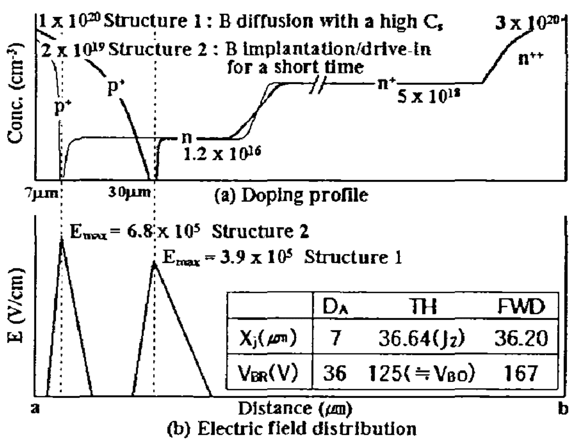


Fig. 6. Comparison of (a) impurity doping profile in the triggering diode segment, on the a-b line, and (b) electric field distribution at the same reverse bias condition for the structures 1 and 2.

Fig. 6(b) clarifies the structure 2 has a higher electrical field in D_A in comparison with the structure 1. Therefore the structure is characterized by easy controllability of V_{BR} of D_A. It is recommended to form the p^+ wells after formation of thyristor n^+ emitter in contrast to the structure 1. Furthermore we can reduce a mask layer in comparison with the structure 1, because an additional mask for p^+ wells is not necessary.

4. Conclusion

We suggest an integrated thyristor switch for capacitor discharge application having avalanche-type p^+n junctions with a positive temperature coefficient of V_{BR} instead of Zener diode in the known circuit. One can fabricate the integrated switch device based on a reverse-conducting thyristor. Thyristor gate is unconnected and isolated from cathode metal. J_2 junction of this part has the p^+ layer of a steeper doping profile with higher concentrations to ensure a lower V_{BR} of the triggering diodes than V_{BO} of thyristor. For this structure, Al/B double-implantation method is proposed.

We suggest two different structures; one has deep p^+ wells and the other has shallow p^+ wells. They have steeper doping profiles with higher concentrations in comparison with the p base of thyristor and the p emitter of FWD for both structures. The later structure is characterized by shorter drive-in time for p^+ wells as well as no additional mask for them. It has large difference between V_{BO} of thyristor part and V_{BR} of D_A.

Acknowledgements

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References

[1]. Internet homepage, http://us.st.com./stonline/products/selectros/235.htm

[2]. G. W. Neudeck, *The PN Junction Diode*, Modular Series on Solid State Devices Vol. II, Editors R. F. Pierret and G. W. Neudeck, p. 79, Addison-Wesley, Massachusetts, 1989.

[3]. P. Streit, "High Power Reverse Conducting GTO," *Power Semiconductor Devices and Circuits*, Editor A. A. Jaecklin, p. 63, Plenum Press, New York, 1992.

[4] J-H. Park, "Insulated gate bipolar transistors having built-in freewheeling diodes," U. S. Patent 6,051,850, April 18, 2000.

[5] ATLAS user manual, Silvaco Co., USA.