POWER DEVICES.

STATIC INDUCTION THYRISTOR

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Résumé. — On présente des résultats expérimentaux récents sur le thyristor à induction statique (SIT thyristor), dans lequel l'injection de porteurs est contrôlée par le champ électrostatique autour de la porte. Ces résultats sont comparés avec les estimations théoriques. Le SIT thyristor peut couper le courant continu avec une très grande vitesse et une efficacité relativement bonne. La constante de temps de coupure et la chute de tension peuvent être aussi faibles que 50 ns et 1,5 V, respectivement.

Abstract. — Recent experimental results of Static Induction thyristor, in which the injection of the carrier is controlled by the electro-static field around the gate, are reported comparing with the theoretical estimations. SIT thyristor can switch even d.c. power with very high speed and with relatively high efficiency. Fall time and forward voltage drop have been able to be as small as 50 ns and 1.5 V, respectively.

1. Introduction. — Static induction transistor (SIT), which is analogous to the vacuum tube triode proposed in 1950 by Y. Watanabe and J. Nishizawa [1], shows non-saturating I - V character and high-frequency and high-efficiency characteristics [2] as the result of the reduction of the series channel resistance. SIT has a caged type gate electrode similar to the grid in vacuum tube triode and the electro-static potential around the gate electrode control the flow of majority carriers. The SIT has composed a new family in semiconductor devices, such as a high-power transistor over kW, a high-frequency and high-power microwave transistor, a very high-speed and low-power logical integrated circuit (SITL), a high-packing density and low-energy transistor memory (SITM) and so on. And a static induction thyristor (SIT-thyristor) is also in the family and operates with the same principle with SIT [2]. The SIT-thyristor has been shown to have many advantages [3] comparing to a conventional p-n-p-n thyristor, such as very high speed and very low energy for switching very high power even d.c. power switching. These excellent switching properties are based on the very sensitive control of the carrier distribution by static field around the gate electrode, which has not been so easy for minority carrier because of the existence of the large amount of majority carrier in base layer in conventional thyristor.

2. Experimental results. — One of the structures of the SIT-thyristor shown in figure 1 is fabricated by epitaxial techniques after selective conventional diffusion for the structure having embedded gate stripes.

The device has a similar I - V characteristic to the conventional thyristor except the point that the SIT thyristor can be prepared to be normally-off or normally-on, and in this case, the thyristor is switched-off with backward bias for gate electrode as shown in figure 2. The minimum forward voltage drop is from

FIG. 1. — Cross-sectional view of SIT-thyristor (Embedded-gate type).

FIG. 2. — I - V characteristic of SIT thyristor.

1.5 to 3 V, and the maximum blocking voltage is in the same order with the conventional one.

An example of the switching waveform is shown in figure 3, where a main d.c. voltage is kept applying between the anode and the cathode, and a step gate bias is applied to the gate for quenching the main current. The fall-time t_f in the turn-off operation is very fast as shown in figure 4, the minimum data of t_f is about 50 ns in this device, and also the rise-time in turn-on operation is very fast as 200 ns, which depends on thickness of the n^- layer between the gate and the anode. In the same time, the SIT-thyristor is shown to be controllable by very low energy. The peak value of the gate current during turn-off I_{Gp} ; one of the control

characteristics, is shown in figure 5. In the figure, the I_{Gp} and the applied gate voltage for turn-off V_G is normalized by the anode current I_A and the voltage applied to the anode V_{AA} respectively, the current ratio is about 1/3 even at the peak current, and in other devices it is less than 1/5 and the voltage gain is more than 10. Another control characteristic is shown in figure 6, that is the total charge flowing out from the gate during turn-off of the d.c. quenching action. The flow-out charge from the gate corresponds to the hatched area of the waveform in the figure, which is shown as solid curves as the function of the gate

FIG. 3. — D.C. quenching operation by SIT thyristor.

FIG. 5. — Gate voltage and peak gate current.

FIG. 4. — Fall-time characteristic.

FIG. 6. — Flow-out charge from the gate.

voltage V_G . After correction about charging an input capacitance of the gate, the flow-out charge is shown as dotted curves, those decrease gently as increases the gate voltage, and is an order of a millicoulomb per square centimeter. The cross-hatched area Q_A of the waveform of the anode current I_A relates with the stored charge in the channel, and is from twice to three times larger than the gate charge Q_G in this device.

The input-output characteristic of the SIT-thyristor is shown in figure 7, which has the hysteresis and there are two stable states in some range of gate bias voltage. And in figure 8, there are shown the dependences of the gate voltages to turn on (V_{Gon}) and to turn off (V_{Goff}) to an external resistance between the gate and the cathode (R_G). V_{Gon} is not so affected by the change of R_G , while V_{Goff} is linearly varied by the change of R_G whose coefficient of the line is about 1/10 of the anode current in this device.

FIG. 7. — Input-output characteristic of SIT-thyristor.

FIG. 8. — R_G dependences of turn-on/turn-off voltage.

3. Discussion. — The structure of this SIT-thyristor is considered as shown in figure 9, corresponding to that of the conventional thyristor [4]. It contains an n-channel SIT, a p-n-p bipolar transistor (BJT) and the connecting circuit between them. The I - V characteristic of this simulating circuit is shown in figure 10, which contains three portions, that is, low resistive *on* state, high resistive *off* state having exponential character and transient traces between them with negative resistance. This characteristic coincides with

FIG. 9. — Simulating circuit of SIT-thyristor.

FIG. 10. — I - V characteristic of the simulation.

the test device and shows that in low anode current region the SIT-thyristor operates almost similar to the SIT, and the increase the anode current increase the hole injection from the anode, which occurs the transient trace to the *on* state as a diode. On the analogy of the conventional thyristor, two equations about the circuit are obtained, that is,

$$-I_G = \frac{\beta}{1 + \beta} I_A + I_{CBO} \quad (1)$$

$$-I_G = \frac{I_A}{1 + g_m R_G} \quad (2)$$

where β is the current gain and I_{CBO} is the leakage current of the BJT, and g_m is the mutual conductance of the SIT. Eq. (2) is because that almost all of the collector current of BJT flows through the resistance R_G . And from eqs. 1 and 2,

$$I_A = \frac{(1 + g_m R_G) I_{CBO}}{1 + \frac{\beta}{1 + \beta} (1 + g_m R_G)} \quad (3)$$

The turning point from the exponential to the transient regions appears under the condition that the denominator of the eq. (3) is equal to zero, which is,

$$\beta \cdot g_m = \frac{1}{R_G}$$

and this agrees well in the simulating circuit.

The very fast switching of the SIT-thyristor comes from the very small input time constant of the gate, because of its structure and the impurity concentration, and also the sweeping out action of the excess stored carriers by the gate. Simultaneously, this makes

possible to realize a large scale device, and the d.c. quenching operation.

The bistable region in figure 4 can be moved in any gate bias even in positive voltage by the design of the dimension and the impurity concentration of the gate and the channel. And the SIT-thyristor can be also realized with the gate which is contacted at the surface of the device, as shown in figure 11. This is also, of course, the similar mechanism and the operation to the device of figure 1.

FIG. 11. — Cross-sectional view of SIT-thyristor (Surface-contacted-gate type).

Also two caged type gate structure was prepared and it gives much faster switching properties compared with the one caged type gate structure described in this paper.

4. Conclusion. — The SIT-thyristor was measured in some advantageous characters, that is, high-speed, high-efficiency and wide-applicable operation in its static, switching and input-output characteristics. And it is expected to be applied in the field such as d.c. power transmission and high power source till 10 MHz.

References

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