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Characteristics of AlGaAs/GaAs heterostructure RT-SCR model

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ABSTRACT

Electrical properties of a resonant-tunneling-semiconductor-controlled rectifier (RT-SCR) model have been presented. The current, temperature, gain, doping concentration, and layer size versus voltage relationships have been numerically obtained. The RT-SCR device requires smaller turn-on voltage than a comparable traditional device for the same gate current. This indicates that, in comparison with the traditional thyristor, a smaller control current may be used to turn on the device at a particular voltage. Characteristics of the device are affected by p1, n1, and p2 regions. It is showed that higher doping concentrations cause lower turn-on voltages and an increase in the region width results in higher turn-on voltages for p1 and p2 regions. Changing the doping concentration and width in n1 region affects the characteristics of the structure differently from that of the p1 and p2 regions.

1. Introduction

The pnpn thyristor structure has been around and used as a semiconductor switch to handle large amounts of currents. Traditionally, the pnpn thyristor structure is modeled with two transistors: a pnp transistor and an npn transistor—the base of each transistor is connected to the collector of the other transistor.

For a resonant-tunneling-semiconductor-controlled rectifier (RT-SCR) device, the npn transistor is replaced with a resonant-tunneling transistor (RTT) with an anticipation of reducing the turn-on current. The simulation results indicate that the RT-SCR is turned on at a lower voltage than the turn-on voltage of the traditional SCR for the same gate current [1]. Because tunneling is inherently a very fast phenomenon, the structure has a high potential to be used as a fast turn-on switch. Although resonant tunneling has some major problems, it has many advantages for high-speed devices [2,3]. The RTD is considered among the fastest devices ever made [4]. Like RTD, RTTs have many advantages such as faster switching time for high-speed operation devices; the RT-SCR is expected to have a fast switching response [1].

In this work, the tunneling characteristics of a RT-SCR device are outlined, and electrical properties of the RT-SCR model are presented.

2. Resonant-tunneling-semiconductor-controlled rectifier

A pnpnpn AlGaAs/GaAs heterostructure has been used in the simulation of the RT-SCR device. The circuit given in Fig. 1 is used to model the RT-SCR structure. It is the modified two-transistor model, which has T_1 as a traditional pnp bipolar transistor and T_2 as an RTT [5].

2.1. The current–voltage equations

The anode current of RT-SCR can be expressed as follows:

$$I_{A_{RT}} = \frac{\alpha_{2RTT} I_g + I_{CORTT} + I_{CO1}}{1 - (\alpha_1 + \alpha_{2RTT})} \tag{1}$$

The common-base current gain α_{2RTT} for the resonant-tunneling structure will be as follows:

$$\alpha_{2RTT} = \frac{I_{CRTT}}{I_{ERTT}} \tag{2}$$

The voltage distribution in the model for the RT-SCR is shown in Fig. 1. The anode–cathode voltage is as follows:

$$V_{AK} = V_{BE1} + V_{BC} + V_{BE_{RTT}} \tag{3}$$

2.2. The physical structure

For the model, a physical RTT structure reported by Wu et al. [6] is adopted. The structure for the RT-SCR is shown by splitting the structure and adding necessary regions as shown in Fig. 2.

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In the model, the tunneling takes place between the gate and the cathode.

The physical properties of p1, p2, n1, and n2 regions are given in Table 1.

3. Simulation results

MATLAB has been used to obtain electrical properties of the device. The results are presented in a graphical form in Figs. 3–13.

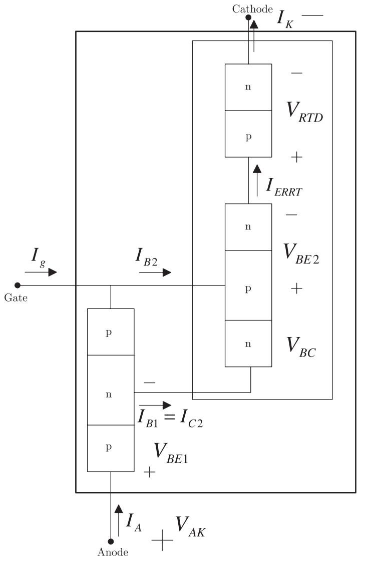

Fig. 1. Currents and voltage distributions in a two-transistor model for the RT-SCR.

Table 1
Physical properties of the four layers in the RT-SCR structure

Region	Material	Doping (cm^{-3})	Thickness (μm)
p1	GaAs	5×10^{16}	0.3
n1	GaAs	5×10^{16}	0.3
p2	GaAs	5×10^{16}	0.3
n2	AlGaAs	8×10^{17}	0.15

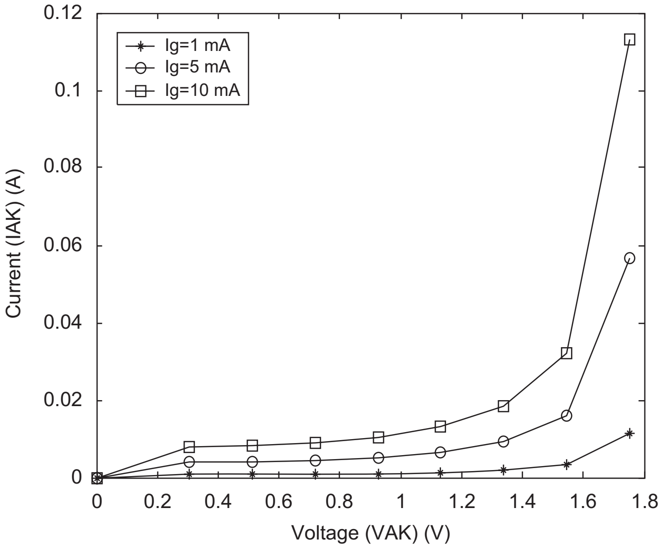

Fig. 3. Current–voltage characteristic of RT-SCR for different gate currents at 300 K.

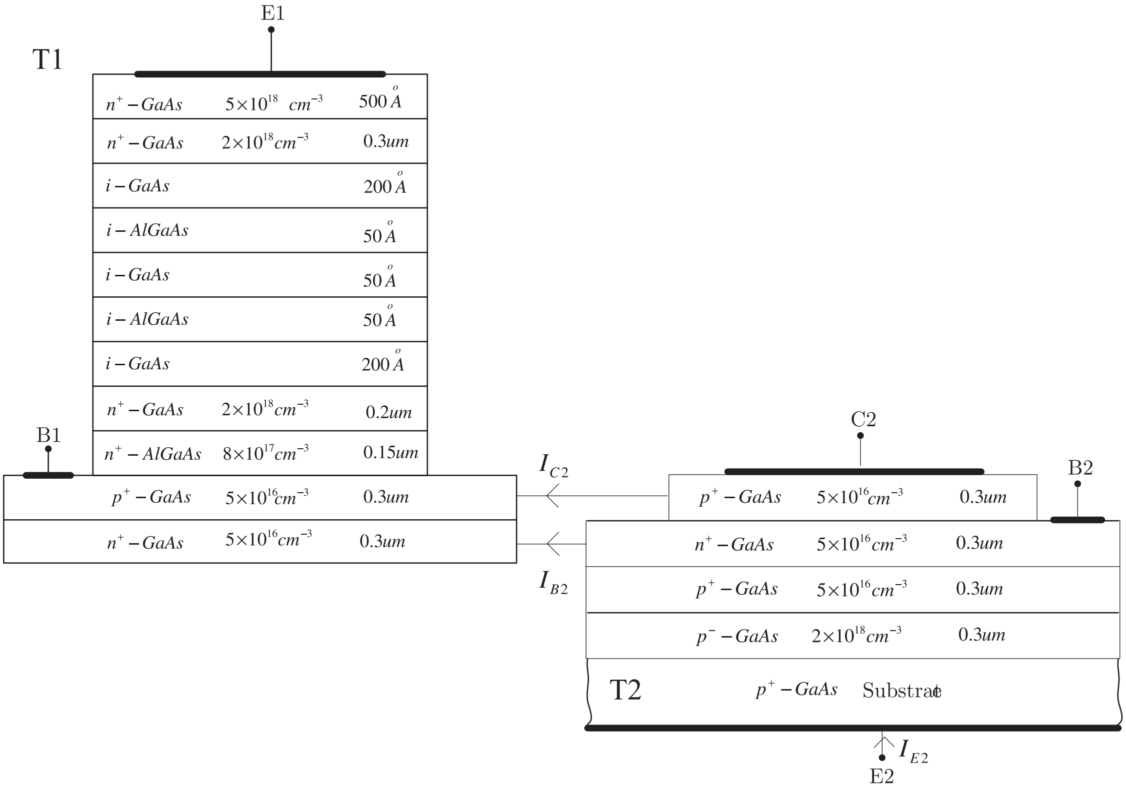

Fig. 2. Cross-sectional drawing of the two-transistor RT-SCR model.