

# Nano Scale Simulation of GaAs based Resonant Tunneling Diode

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**Abstract:** All kinds of tunneling diodes make use of the quantum mechanical tunneling. A resonant-tunneling diode (RTD) is a diode with a resonant-tunneling structure in which electrons can tunnel through some resonant states at certain energy levels. In this research article, analytic model of resonant tunnelling diode (RTD) is simulated for two different structures, i.e. single barrier (1B) RTD and double barrier (2B) RTD. Different parameters such as conduction band, VI characteristics, resonant energy and transmission coefficients are studied to evaluate the performance of these structures. Double barrier RTD shows improved results in comparison to the single barrier RTD by keeping other parameters constants in absence of electric field

**Keywords:** RTD, transmission coefficient, resonance, conduction band.

## 1. Introduction

The performance of semiconductor devices depends on their physical properties, chemical composition as well as on the arrangements of atoms in the crystal [1]. In spite of these properties, the semiconductor nanostructures possess the features of a highly ordered structure within extremely confined geometries [2] [3]. Nano-scale diodes exhibit a wide variety of applications in electronic and communication systems, such as in sensors, low power and other optical applications [4]. Besides the synthesis of these devices, the study of electrical transport properties is another important parameter for characterizing nano-devices for potential applications in the area of electronics. Moreover, the electrical properties of the diodes can be controlled by selective doping [5]. The realization of p-n junctions is specifically important as these junctions form the basis for devices including p-n junction diode, resonant tunnelling diode, schottky diode, light emitting diodes (LED), bipolar transistors, lasers, detectors, and sensors [6-9]. The most efficient design of nano p-n junction is a core-shell structure, where the injection occurs uniformly over the entire cross section of the device. I-V characterization of nano-electronic devices requires low level current measurements in the range of nano-ampres to femto-ampres [10-12]. Thus, high sensitive instruments are required, and appropriate measurement and connection techniques must be employed to avoid errors.

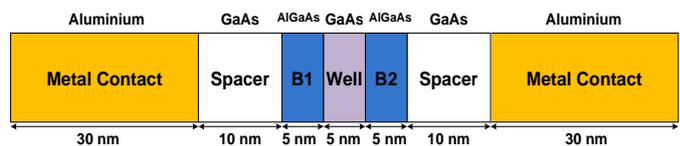
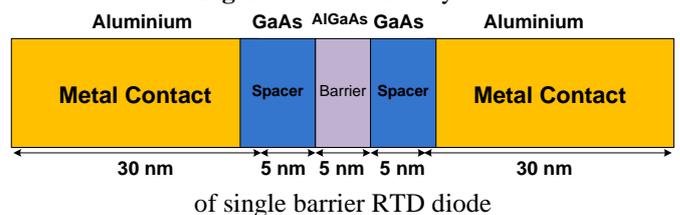
In recent times, resonant tunnelling diode is considered as an element of a future low power, high density integrated circuit because of a possible ultra low power operation with a few electrons [13-15]. For the practical application, it is necessary for RTD to be operated at room temperature [16]. For this purpose the dimensions of the device must be as small as

possible. In this paper, 1B and 2B RTD are designed to evaluate their performances.

## 2. Experiment

A model for single and double barrier Resonant tunneling diode has been simulated at room temperature conditions. The selected material for simulation is GaAs with AlGaAs as barriers. The metal contacts used are Aluminium. The layout for single and double barrier resonant tunneling diodes is shown in fig.1 and fig. 2 respectively.

**Figure 1:** Structural layout



**Figure 2:** Structural layout of double barrier RTD diode

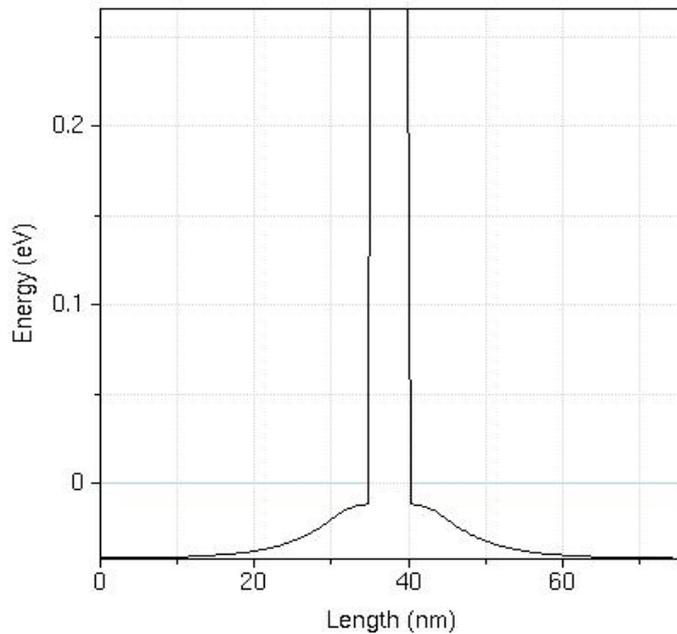
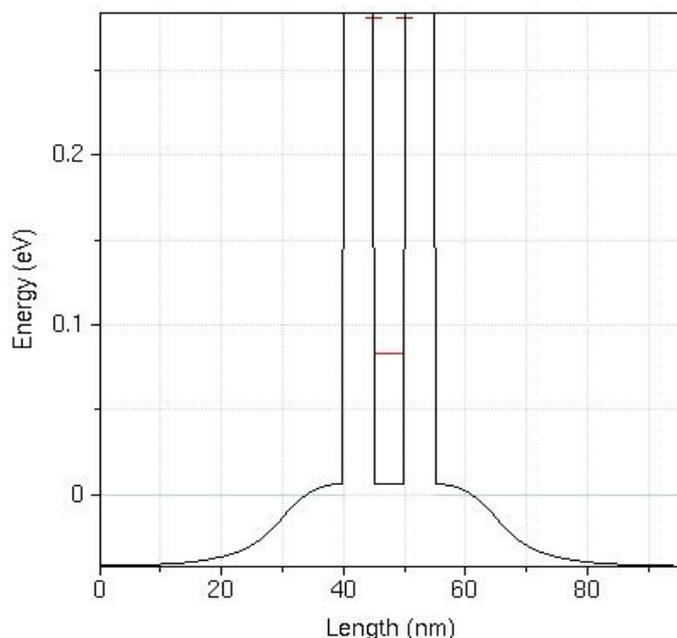
From fig. 1 and fig. 2, it is clear that the total length of the single barrier device is 75 nm while for double barrier RTD diode, the total length is 95 nm. The applied biasing voltage is set at 0.5 volts. Different doping concentrations are selected in different zones of the device. The doping profile for both the devices is same and is shown in table 1.

**Table 1:** Doping profile of the simulated RTD diode

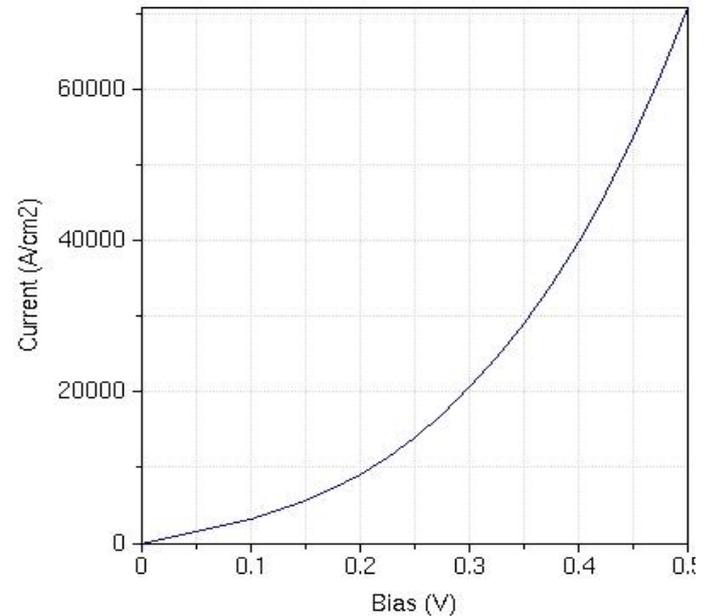
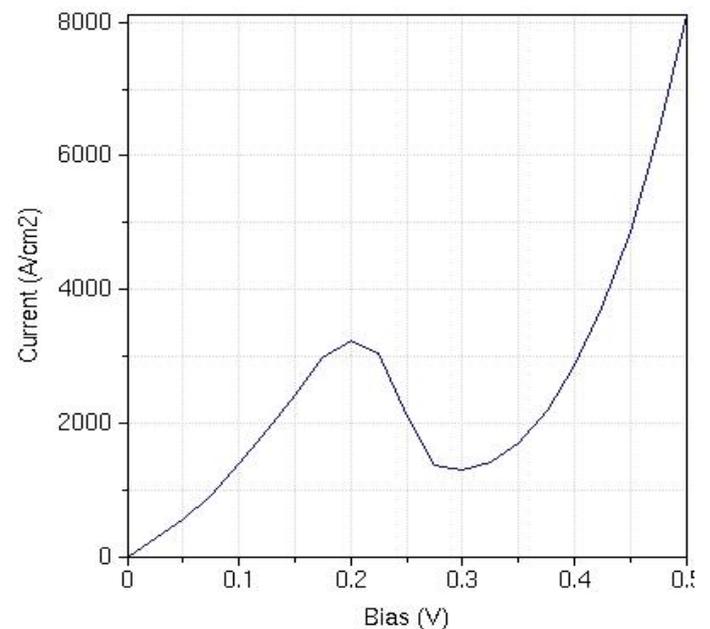
Parameters	Doping Concentration (per $cm^3$ )
Contacts	$1 \times 10^{18}$
Barrier 1	$31 \times 10^{15}$
Barrier 2	$31 \times 10^{15}$
Well	$1 \times 10^{15}$
Spacer	$1 \times 10^{15}$

### 3. Results and Discussions

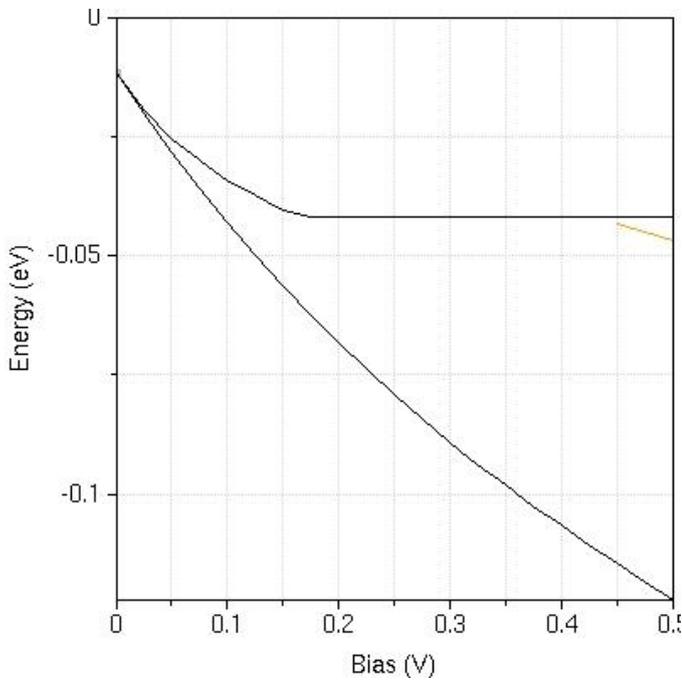
The simulated results for the single barrier and the double barrier resonant tunneling diodes are taken using effective mass model. Fig. 3 shows the conduction band for single barrier resonant tunneling diode where as fig. 4 shows the conduction band for double barrier resonant tunneling diode.

**Figure 3:** Conduction band for single barrier RTD**Figure 4:** Conduction band for double barrier RTD

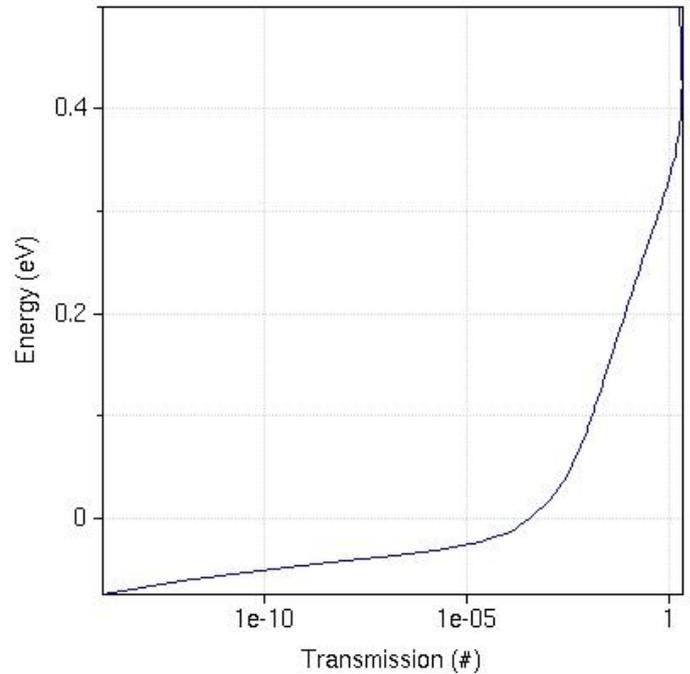
The conduction peak of these RTD occurs when a localized state in the emitter notch region is aligned with the well state. Similarly, Fig. 5 shows the current vs voltage characteristics for single barrier resonant tunneling diode while fig. 6 for double barrier resonant tunneling diode.

**Figure 5:** VI characteristics for single barrier RTD**Figure 6:** VI characteristics for double barrier RTD

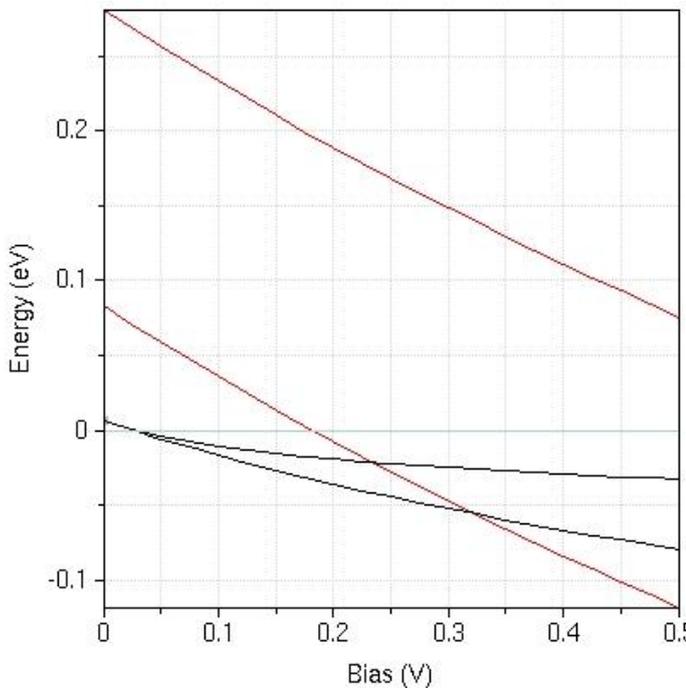
Both the VI characteristics differ due to difference in structural design used. For single barrier RTD, the forward VI characteristics are almost same as that of simple pn junction diode. However, for double barrier RTD, the current increases with respect to voltage upto the peak point. After peak point, the device shows negative resistance region upto the valley point. For a specific voltage range, the current is a decreasing function of voltage. This property is very important in the circuit implementation because it can provide for the different voltage-controlled logic states corresponding to the peak and valley currents. Fig. 7 and fig. 8 shows the resonant energies for single and double barrier RTD respectively.



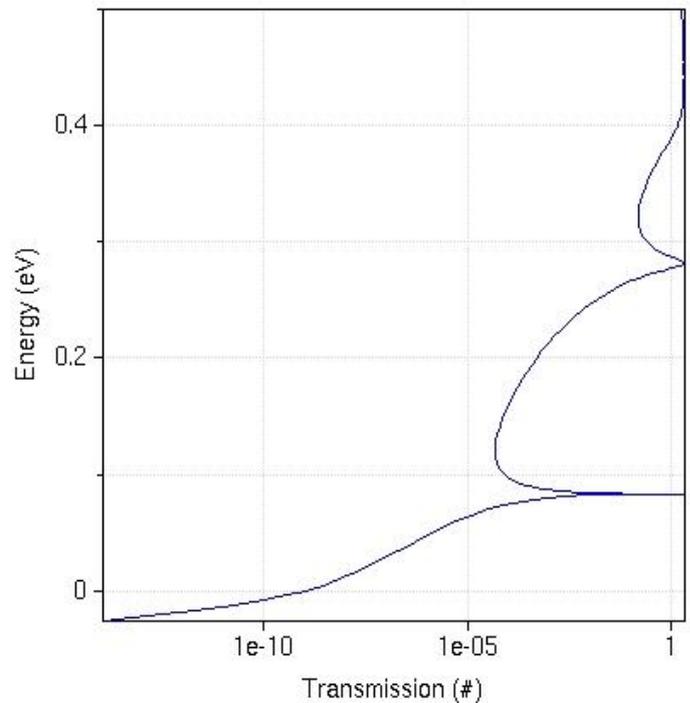
**Figure 7:** Resonant energy for single barrier RTD



**Figure 9:** Transmission coefficient for 1B RTD



**Figure 8:** Resonant energy for double barrier RTD



**Figure 10:** Transmission coefficient for 2B RTD

Resonances occur when the electron wavelength is a half integer multiple of the well width. The resonance locations are given by the energies corresponding to these wavelengths on the energy dispersion relationship. Band non-parabolicity reduces the dispersion for a given value of  $k$ . Therefore, the single band model, which is roughly parabolic, significantly overpredicts the excited state resonance energy. For the double barrier RTD, the region between the two barriers acts as a quantum well with discrete energy states. Resonant tunneling through the double-barrier structure occurs when the energy of the electrons flowing from the source coincides with one of the discrete energy levels in the well. The position of the bounded states within the well can be modulated with a gate bias. Fig. 9 shows the transmission coefficient for single barrier resonant tunneling diode while fig. 10 for double barrier resonant tunneling diode.

Tunneling of electrons depends on the barrier width. For both the RTD's the transmission coefficients become nearly equal to unity due to lower quantized energy level. The value of transmission coefficients depends on the barrier width and applied electric field. Since for both the simulated RTD's, electric field and the barrier widths are same, hence the transmission coefficients for both are almost same.

#### 4. Conclusion

In this work, analytic model of single and double barrier RTD's are simulated. It can be concluded that the double barrier RTD shows better performance than the single barrier RTD. For both the structures, the value of transmission coefficients reaches unity when resonance occurs. It can also be concluded that

resonance peaks are split into number of small peaks and the number of small peaks is generally equal to the number of barriers. Also, the absence of applied field is preferred to achieve maximum transmission coefficient.

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