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Comparative Simulation of GaAs and GaN based Double Barriers-Resonant tunneling Diode

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Abstract

In this work, we propose GaN based Double Barrier-Resonant Tunneling Diode (DBRTD) model and it is compare with GaAs based Quantum DBRTDs at room temperature. This comparison can be utilized to improve the performance of the RTD at higher frequencies. This paper also demonstrates the potential impact of doping concentration on current density of the device. Quantum tunneling mechanism results, based on non-equilibrium Green's function formalization within ballistic limits, shows high peak current with GaN RTD and achieves high peak to valley ratio as compared to GaAs RTD. Furthermore, comparison helps in analyzing the better device between both models. Simulation of the device has been performed with the use of Atlas Silvaco and Nextnano3 tool which confirms the various results presented in this research.

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Keywords: Quantum tunneling; RTD, Double Barriers; III-V group semiconductors; GaN based Quantum Structures.

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1. Introduction

Resonant tunneling devices are the key factor to enhance the performance of any circuit which requires high switching speed along with negative differential resistance. Currently, GaN based resonant tunneling diodes give bistable and enhanced characteristics for ultrafast nonvolatile memories [1]. Investigation of Resonant tunneling effect for designing of ultramodern electronic devices is significant for application in nanotechnology [2]. DBRTs have the vibrant feature to propose novel circuits that utilize its properties of bistability, multi-valued logic with positive feedback, such as compact modeling of oscillators [3-4]. Among all the features related to resonant tunneling, Negative differential resistance (NDR), nonlinearity and device operation at Terahertz frequencies are more important, includes peak or steps in the current-voltage (I-V) curves [5].

The simplest RTD can be modeled with quantum well (GaAs or GaN) sandwiched in between two undoped tunnel barriers (AlGaAs or AlGaN) [6-7]. But fabrication of this device is quite complex, we have to use different approaches to fabricate the DBRTs. In late 1960's, Molecular beam epitaxial technique has invented to realize these nanostructures along with large mean free path. But, in today's era, the semiconductor industries grow a lot and fabricate these devices with Silicon on insulator (SOI), Metal –Insulator-Metal (MIM) nanostructures [8]. In recent years, RTDs have widely deliberate because they can achieve ultra-high speed operation and high functionality with reduced circuit complexity and low power consumption owing to their negative differential resistance (NDR) features [9-10].

Fermi Energy with band gap is an important factor of a material used to simulate these nano-dimension heterostructure. Here, we simulate the GaAs/AlGaAs and GaN/AlGaN heterostructure under the consideration of NEGF boundary conditions. Also compare these two structures in context with their Band gap edges, doping concentration and Current density- voltage (J-V) characteristics. These devices are used in many Terahertz applications and provide more accurate results in optical devices due to fewer losses [11]. Moreover, Film-Diode Technology which is extremely compact with low cost use these RTDs for the fabrication of both integrated circuits and discrete diodes for millimeter wave applications [12]. Some Biomedical applications also use these terahertz devices for imaging systems and radiations [13].

This paper compared two proposed models of RTDs and concludes drawn characteristics by varying device parameter. Remainder of this paper is organized as follows. The next section includes the basic concepts or theories of proposed model. In section 3, we discuss the device structure along with layer dimensions. Simulation results are discussed in section 4. Finally, concludes the paper in last section.

2. Theoretical Model and Basics

As we know, Quantum devices like RTDs work on the Quantum resonant tunneling concept within ballistic limits. When the size of the conductor becomes lesser to their mean free path, conductor approaches to its limiting values. When these limits reach beyond phase relaxation length, then quantum comes into play an important role in the heterostructure [14]. Schrodinger wave equation plays an important role in resonant tunneling; the probability of tunneling of an electron through quantum well has been calculated through the Green Function and Schrodinger wave equation.

2.1. Double Barrier Quantum Structure

The basic quantum structure of the device is shown in the Fig. 1, which includes the quantum well sandwiched between two barriers. Double barrier means number of undoped barrier are two, which are grown on undoped quantum well along with two heavily doped contact and for providing metal contact we use the gold (Au). Some offsets are required for proper working of the device so we give 0.2 eV offset in case of GaAs based RTD. As electron transport is required for carry the functionality of electron tunneling under the bias voltage. Because the electron wavelength are comparable with characteristic dimensions of the DBQW structure, the wave nature of electrons leads to quantum phenomena such as tunneling, interference, energy quantization, etc. As a result, resonant tunneling phenomena occur in DBQW structures and form the basis for RTD operation [15].