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Calculation of current density for triangular multi-barrier structure in a constant electric field

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ABSTRACT

In this paper, the current density expression for one-dimensional triangular multi-barrier structure in the presence of a constant electric field has been derived. For a selected range of parameters of semiconductor materials, the characteristics of the current density versus the applied voltage have been calculated in numerical methods, and the influence of temperature, the width of the barrier and the height of the barrier on the curves of current density–voltage have been also analyzed.

1. Introduction

In the 70 s, in a finite superlattice, Tsu and Esaki [1] have studied transmission coefficient and the characteristics of the relationship between current density and voltage by using numerical calculation methods, which has attracted a great deal of researches over the past decades years on the resonant tunnelling heterostructures [2–14]. For the resonant tunnelling heterostructures, calculating and investigating the transmission coefficient are one of the most useful means and methods to understand the resonant tunnelling properties and phenomenon. Through the resonant tunnelling theory and the quantum effects, many new functional devices have been fabricated by the multi-barrier structures, such as quantum cascade lasers (QCL), the quantum well infrared photodetector [15] (QWIP) based on transition theory among intersubband of the quantum well, intersubband and continuous state, the photomodulator [16] based on the quantum-confined stark effect, optical bistable device [17], the resonant tunnelling diodes (RTD) based on the resonant tunnelling theory and resonant tunnelling transistors (RTT).

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In order to investigate the resonance transmission, the transmission coefficient and current density are usually used in the rectangular multi-barrier structure [18–25]. For designing and optimizing a new device, people need to understand the resonant tunnelling features of multi-barrier quantum well structure with the different shape of the potential energy. For example, Schulz and Goncalves Da Silva [26] and Papp et al. [27] have calculated transmission coefficient and current density of the step potential barrier structure. Ohmukai [28,29] studied the quantum well structure with slope of double barrier and the relationship between transmission coefficient and structure parameters of a triangle double barrier structure. Chang, et al. [30] investigated the transmission coefficient and current density for the trapezoid structure.

In this paper, firstly, the current density has been calculated by the transmission coefficient of a multi-barrier structure with the incident electrons under a certain energy and wave vector. Secondly, the relationship between the resonance transmission coefficient and the bias voltage have been analyzed. Thirdly, on the basis of the characteristic curve of the current density–voltage, the influences of the different temperature, barrier width and height on it has been investigated. In the paper, the transfer matrix method [31–33] has been used to calculation the transmission coefficient.

2. Models and theories

This article use the model as shown in Fig. 1, in which, N and v_0 are the number and the height of potential barrier, a and b are the width of the potential well and barrier respectively. The effective mass of the electrons in the potential well and barrier are m_w^* and m_b^*, and v_B is the applied external voltage for barrier structure.

Now we consider a simplified potential barrier structure consisting of the $GaAs/Ga_{1-x}Al_xAs$ conduction band, where $GaAs$ and $Ga_{1-x}Al_xAs$ form the potential well and the barrier, respectively, and assume that the potential barrier and well do not contain impurities. As shown in Fig. 1(a). If a positive voltage v_B exerts on the potential barrier structure from right to left, the potential barrier structure is tilted as shown in Fig. 1(b). If the electrons is incident from left to right, the transmission current can be formed in the multi-barrier structure.

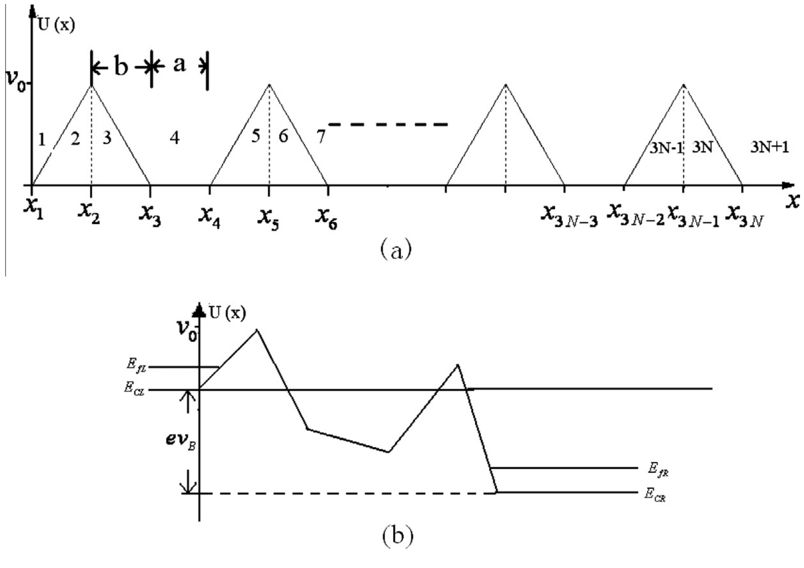

Fig. 1. (a) One dimensional triangular multi-barrier structure; (b) one dimensional triangular barrier structure in an external electric field. E_{CL}, E_{CR} are the bottom of the conduction band on the left side and on the right side, E_{fL}, E_{fR} are the Fermi energy on the left side and on the right side.