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Numerical analysis on quantum dots-in-a-well structures by finite difference method

Gong Liang [a,*], Shu Yong-chun [a], Xu Jing-jun [a], Zhu Qin-sheng [b], Wang Zhan-guo [b]

[a] Key Laboratory of Advanced Technique and Fabrication for Weak-Light Nonlinear Photonics Materials, Ministry of Education, NanKai University, Tianjin 300457, China
[b] Key Laboratory of Semiconductor Materials Science, Institute of Semiconductors, Chinese Academy of Sciences, P.O. Box 912, Beijing 100083, China

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ABSTRACT

A finite difference technology is applied to the InAs/InGaAs/GaAs quantum dots-in-a-well (DWELL) structures in order to determine their electronic properties. Conventional quantum dots (QDs) sample has a simple structure, i.e., the QDs are imbedded in a GaAs bulk medium. In stead of the conventional structure, we prefer the weak confinement DWELL structure because it can efficiently lower the intersubband transition energy. Thus the DWELL detector is expected to make the longer wavelength detection possible. Present method used in this study is demonstrated to be efficient and flexible for determining the electronic state of the DWELL system. However, to our knowledge there has been no literature reporting so far on the electronic structure of DWELL characterized by the finite difference method.

1. Introduction

Quantum dot infrared photodetectors (QDIPs) based on their intersubband transitions have a wide application in mid-wave infrared and long-wave infrared detections [1], but the conventional QDIPs lack the control of the size and shape of the quantum dots which are spontaneous growth. As a result, they are difficult in adjusting the operations of wavelengths. However, recently a quantum dots-in-a-well (DWELL) structure which mainly relies on the mature technology of the forming quantum wells

* Corresponding author. Tel./fax: +86 022 66229609.
E-mail address: gongliang@mail.nankai.edu.cn (L. Gong).

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has been designed for overcoming the problems. By varying the thickness of the quantum well which inserted between the layers of dots and barriers, it is able for the DWELL structure to modulate the wavelengths to meet the requirements of detections, thus DWELL photodetectors have become the focus of research in the future [2].

In contrast to theory and simulation of the quantum well and/or quantum dot electronic structure [3–5], theoretical modeling to gain insight into the nature of the electronic states in the DWELL detectors is left behind. The main challenge lies in the complex potential profile, which involves a two-dimensional quantum well and a zero dimensional quantum dot simultaneously. Most of methods presented for the theoretical calculations tend to solve one or two dimensional symmetric problems and only refer to small eigenvalue solutions, such as the wave function expanded using a Bessel function [6], the effective mass envelope-function theory [7] and so on [8–10]. Besides, very few results can be applied by current computational methods for the real three dimensional structure. Because of the difficulties in solving complicated quantum system, a numeric method becomes more and more important due to its feasibility, accuracy and simplicity. Among all of the numeric methods, the finite difference technology is demonstrated to be more powerful one to solve the complicated quantum structures, such as the present DWELL structure. In this study, we make use of a finite difference technology to calculate the eigenstate of the DWELL structure in the conduction band in rather detail. Inspired by the paper [11], we also realize that the finite difference scheme incorporates the jump condition automatically without enforcing them explicitly to simulate the DWELL structure.

2. Theoretical model

Generally a quantum dot is similar to the pyramidal shape as the standard product of modern semiconductor manufacturing [12]. Our simulating model of the DWELL structure is shown in Fig. 1, a pyramid-shaped quantum dot (QD) with a height H and base-width a is formed in the center

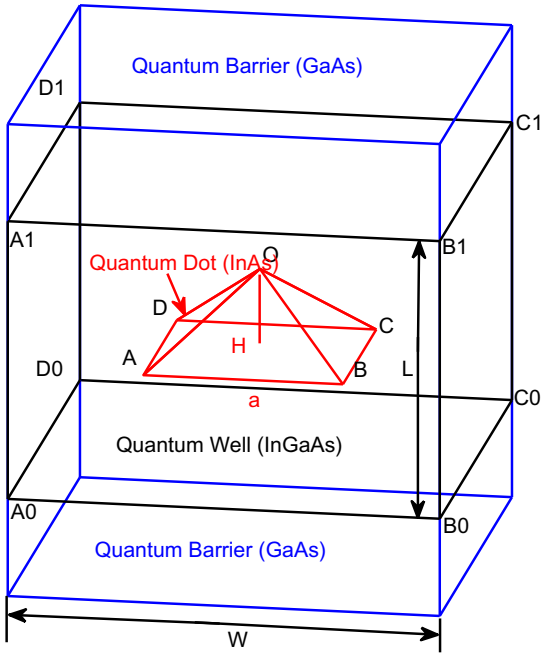

Fig. 1. A schematic illustration of a quantum dots-in-a-well (DWELL) structure. A pyramid-shaped quantum dot (QD) domain around by the lines O–$ABCD$ is shown. The rectangular volume around by the line A_0–B_0–C_0–D_0–A_1–B_1–C_1–D_1 denotes quantum well (QW) domain, and other parts left denote quantum barrier (QB) domain, respectively.