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Electronic features of Gaussian quantum well as depending on the parameters

Hülya BOYRAZ , ***Emine ÖZTÜRK****

[1]*Sivas Cumhuriyet University, Department of Physics, 58140, Sivas/TURKEY*

Abstract

In this study, the electronic characteristics of Gaussian quantum well have been examined as dependent on the parameters such as the concentration ratio, the even power parameter and Gaussian potential range. The energy levels and the wave functions in Gaussian quantum well (GQW) under effective mass approach were concluded by Schrödinger equation solution. According to our results, all parameters have a great impact on the electronic characteristics of GQW. These characteristics have practical interest in the design of adjustable semiconductor devices using such structures.

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1. Introduction

The electronic characteristics of the low-dimensional structures (LDSs) are extremely reliant on the shape of the potential profile of a semiconductor quantum well (QW). Superior interest has been motivated on GaAs/$Al_xGa_{1-x}As$ heterostructures due to their direct band gap for Al concentration **x**-factor below (0.40–0.45). The studies on quantum heterostructures open a new field in fundamental physics, and also offer a wide range of potential applications for optoelectronic devices [1-2]. GaAlAs / GaAs QW systems are applied in modern photo-electronics and high-speed electronic devices, the electrical and optical properties of the related systems have been widely investigated under both the pressure and external fields [3-9]. There is no direct experimental method for defining the confinement potential. The confinement potentials are frequently modeled by rectangular potential well or the parabolic potential [10]. It was noted that, the conventional rectangular QW has basic, but unrealistic form owing to the non-parabolic shape at the center of the QW. On the other hand, the parabolic potential is inappropriate to describe the experimental results due to its infinite depth and range [10]. Based on the experimental results, Xie [11] has pointed that the real confinement potential is not parabolic but Gaussian quantum well (GQW) potential which possesses the finite depth and range. Based on GQW potential, a lot of studies have been conducted investigated the electronic and optical properties of heterostructures [12-13].

This study focused on the theoretical research of the electronic qualities of $Ga_{1-x}Al_xAs$/GaAs GQW depending on the x-concentration (where **x** represents the contribution rate of Al in GQW) and the structure parameters. The paper is organized as follows: In Section 2, the theoretical material and method is outlined. In Section 3, we discuss the results of our calculations. In particular, we compare the potential shape and the energy levels according to structure parameters. Section 4 is allocated to a brief conclusion of the study.

2. Material and Method

With the effective-mass approach, the wave functions and the energy levels for electrons in GQW could be accomplished by solving the one-dimensional Schrödinger equation.

$$\left(-\frac{\hbar^2}{2m^*}\frac{d^2}{dz^2}+V(z)\right)\Psi(z)=E\,\Psi(z) \qquad (1)$$

*Corresponding author. *Email address: eozturk@cumhuriyet.edu.tr*

where V(z) is the confined potential, m^* is the effective mass of electron, and **E** and Ψ(z) are the eigen-energy and eigen-function of the Eq. (1) solution.

The confinement potential of GQW for the electron z-direction is given by

$$V(z) = V_0 \left\{ -\mathrm{Exp}\left[-\left(\frac{2z}{\beta}\right)^{p} \right] + 1 \right\} \qquad (2)$$

The discontinuity in the conduction band edge of $Ga_{1-x}Al_xAs/GaAs$ [9, 13, 15]

$$V_0 = 0.6\,(1.155\,x + 0.37\,x^2) \qquad (3)$$

Where **x** denotes the concentration of Al in the structure, **p** is the even power parameter [13], **β** is the Gaussian potential range (in nm unit).

3. Results and Discussion

It has been notionally examined the electronic features of $Ga_{1-x}Al_xAs/GaAs$ GQW structure as depending on the changeable parameters. In this study, the well width is $L = 10$ nm and $m^* = 0.067\ m_0$ (m_0 is the free electron mass).

For different two **p**-values, Fig. 1 and Fig. 2 demonstrate the variation of the confinement potential related to **x**-concentration for $\beta = 0.5$ and $\beta = 1$ value, respectively. As understood from these figures, when the **x**-concentration increases, the height of the confined potential increases. For $\beta = 0.5$, all enclosed potentials at $p = 2$ value yield the Gaussian potential profile, while at $p = 6$ rate these profiles approach towards square well potential profiles (see Fig. 1). For $\beta = 1$, while at $p = 2$ the quantum well potentials both with less depth and behave more like parabolic quantum wells appear, whereas for $p = 6$ value shows almost square quantum well profiles (Fig. 2). It can be understood from here that by changing the Gaussian potential parameters, quantum well shapes similar to parabolic and square well potential profiles can be obtained from the Gaussian potential profile. Such different profiles describe the diffusion process [16] which is used in order to realize a desired configuration of the energy levels (for example, a group of equidistant levels). A change in the **p**-parameter leads to an adjustment of the confinement potential shape from the Gaussian well for $p = 2$ to the parabolic or square quantum well for $p > 2$. Thus, the elasticity of the present approach in treating the confined carriers in a QW is guaranteed [17].

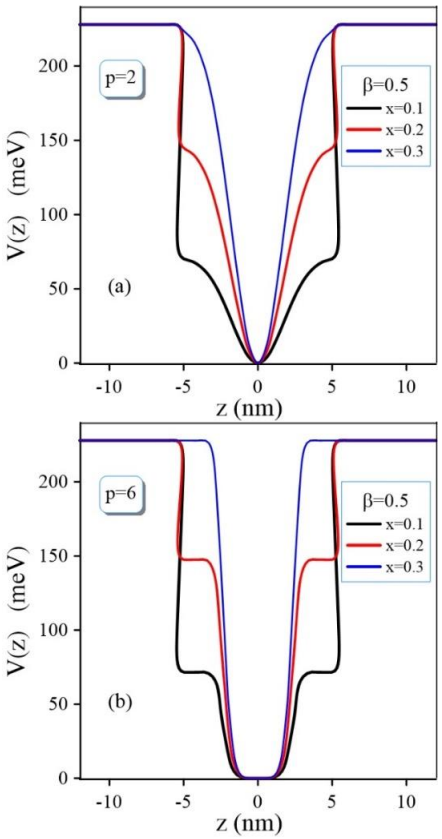

Figure 1. For $\beta = 0.5$, the change of confined potential of GQW related to the x-concentration for a) $p = 2$, b) $p = 6$.

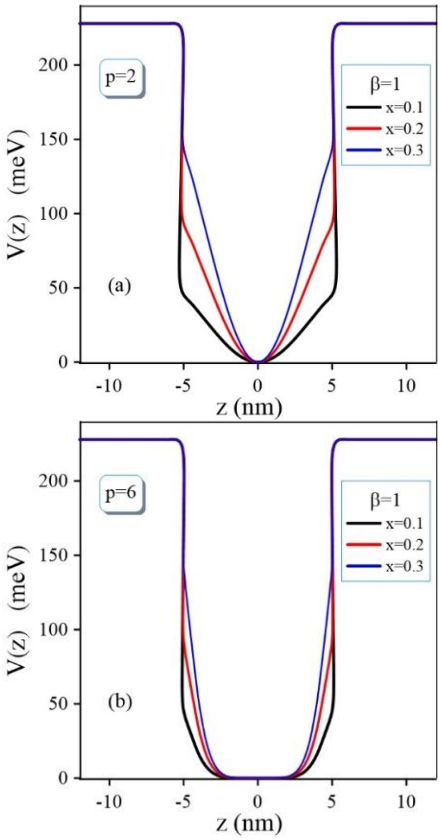

Figure 2. For $\beta = 1$, the change of confined potential of GQW related to the x-concentration for a) $p = 2$, b) $p = 6$.

For three different x-values, Fig. 3 exhibits the confinement potential, the bound energy levels and squared wave functions referred to these energy levels for $\beta = 0.5$ and $p = 2$. The major difference for these values is the depth and width of the Gaussian potential. As estimated, for $x = 0.1$ the energy levels with lower Gaussian potential height is continuously lower than the energy levels of $x = 0.1$ and 0.3 values. As can be seen from these figures, there are two, two and single energy states in GQW structure for $x = 0.1, x = 0.2$ and $x = 0.3$, respectively. Although the depth of the Gaussian potential is large for $x = 0.3$ value, there is only one energy level due to its narrower width. As the height and width of the Gaussian potential profile changes depending on the concentration ratio, both the bound state energy levels and the probability densities of electrons at these energy levels change.

For (both $p = 2$ and $p = 6$ number) $\beta = 0.5$ and $\beta = 1$ value, the resulting bounded state energy levels corresponding to the change in the concentration ratio between $x = (0.10 - 0.3)$ are given in Fig. 4a and Fig. 4b, serially. As the x-value increases, the ground and second energy levels increase. As the β-value shrinks, the Gaussian potential profile narrows and energy levels rise. For $\beta = 0.5$, the change of E_1 and E_2 level versus x-number is faster than $\beta = 1$. So, for $\beta = 0.5$, the E_2 level for $x > 0.28$ values is outside the Gaussian potential well, whereas for both $p = 2$ and $p = 6$, these energies are almost at the same level for $x \leq 0.28$. As the number p increases, its potential profile gradually resembles a square well. As a result, for $p = 6$, both energies and these energy changes depending on the x-parameter are smaller compared to $p = 2$. This seems to be more obvious than the graphs drawn for $\beta = 1$.

For GQW, we give in Fig. 5 and 6 the first two energy levels as a function of the x and p-parameter for $\beta = 0.5$ and $\beta = 1$ rate, respectively. Considering the E_1 and E_2 variations plotted against the increasing x and p parameters at the same rates, it was seen that the energy levels were smaller for $\beta = 1$. As seen from Fig. 5b, for $\beta = 0.5$, the E_2 level at $x > 0.28$ is not within the Gaussian potential. For $\beta = 0.5$ the sensitivity of the energy levels to the x-concentration ratio appears to be higher than $\beta = 1$. Thus, we suggest that the potential shape affects the confinement and localization. These figures are different from Fig. 4 since both x and p-factors change together in Fig. 5 and Fig. 6.

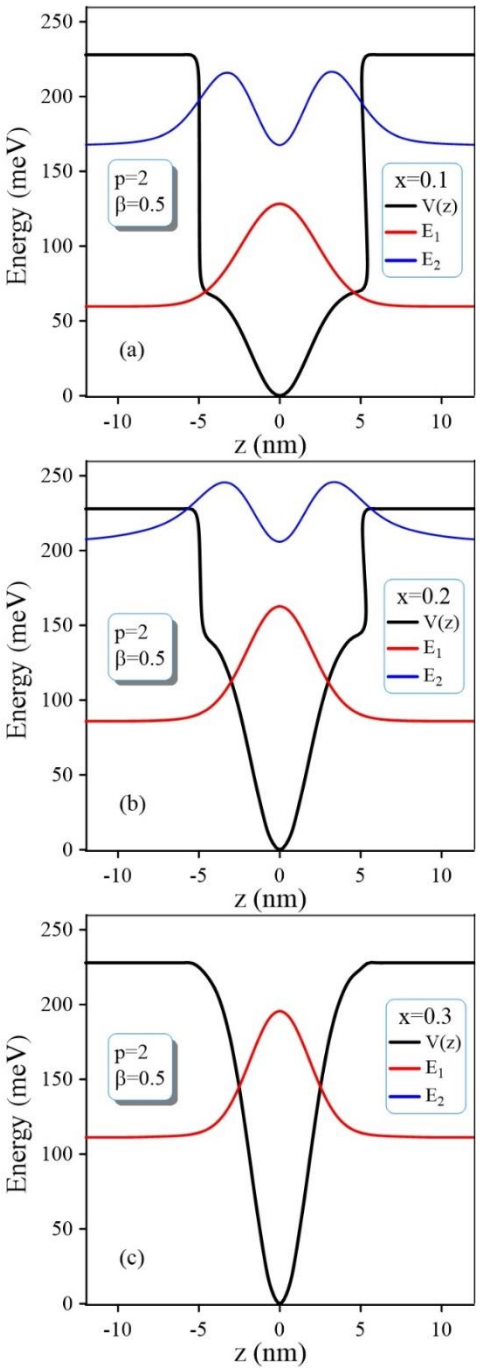

Figure 3. For $\beta = 0.5$ and $p = 2$, the confined potential and the bound energy levels with their squared wave functions for a) $x = 0.1$, b) $x = 0.2$, c) $x = 0.3$.

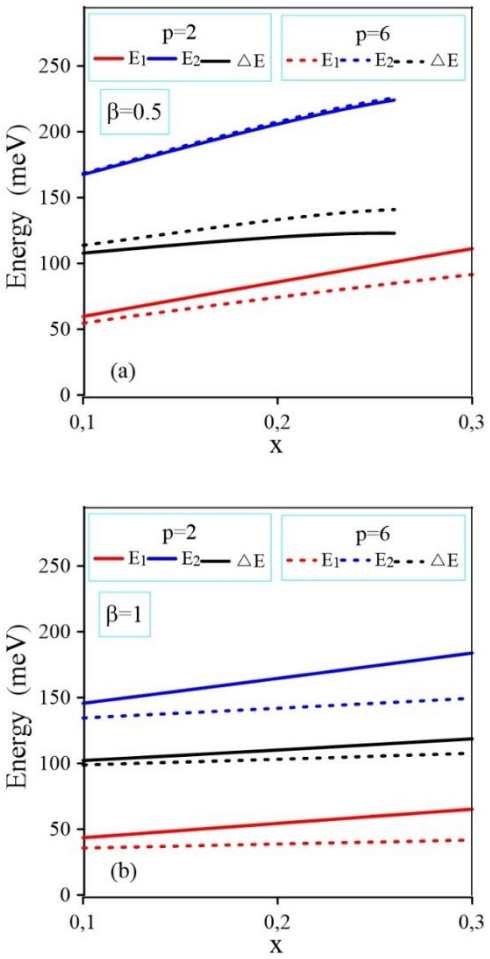

Figure 4. For p = 2 and p = 6 number, the variation of the bound energy levels and the energy difference versus the x-concentration ratio values for a) β = 0.5, b) β = 1.

4. Conclusions

In present work, the electronic qualities of Gaussian quantum well have been examined as dependent on the parameters such as the concentration ratio (x), the even power parameter (p) and Gaussian potential range (β). We analyzed the potential height and the bound energy levels in GQW. In particular, we have considered the potential shape, the eigen-energies and the eigen-functions for these parameters. It is found that depending on the x-concentration value of the electronic features of GQW varies for both β and p-factors. Thus, if it is desired to obtain narrower Gaussian potential depending on x-concentration value, small β and p-values should be preferred. These features could be crucial in the improvement of continual wave operation of GQW semiconductor devices. So, we think that these consequences will supply a development in the electro-optical semiconductor devices applications, for proper selection of the structural parameters.

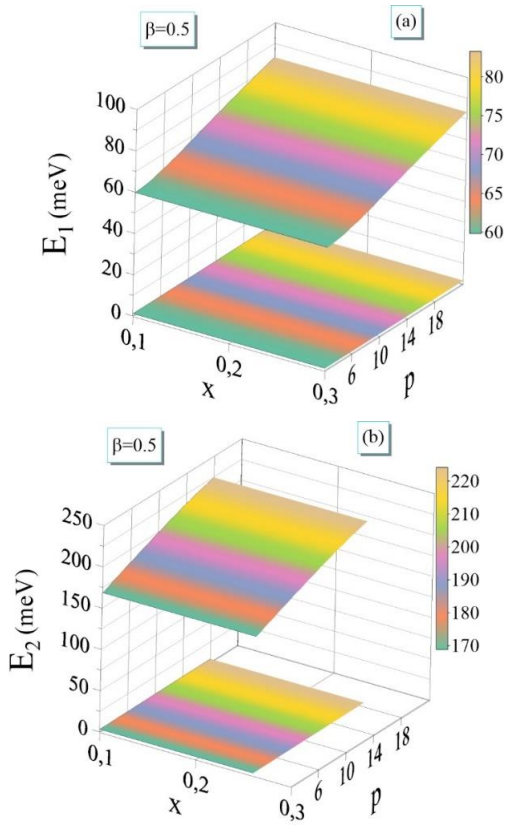

Figure 5. For β = 0.5 a) the ground state energy levels, b) the second state energy levels versus x-factor in X-axis and p-factor in Y-axis.

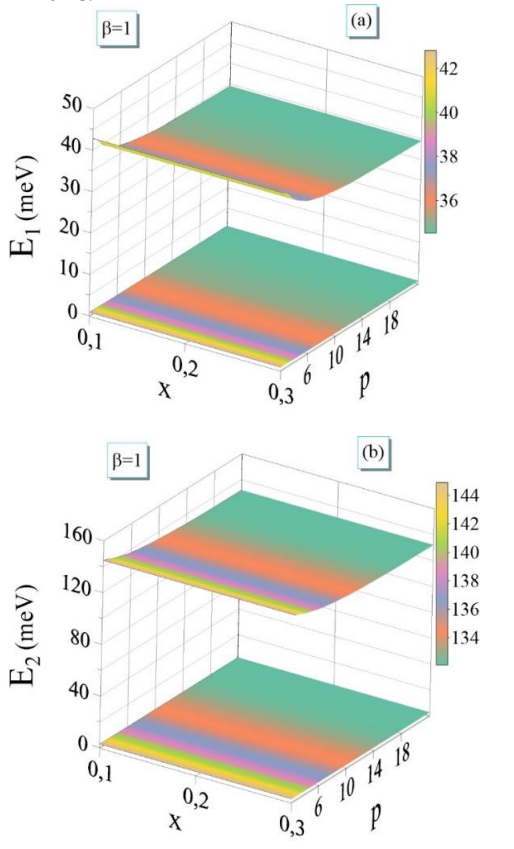

Figure 6. For β = 1 a) the ground state energy levels, b) the second state energy levels versus x-factor in X-axis and p-factor in Y-axis.

Conflicts of interest

There is no conflict of interest.

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