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# Electronic transmission and dwell time on a double barrier system with an accelerating quantum well

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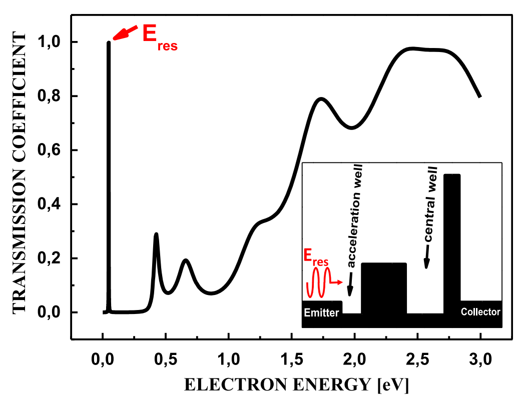
## HIGHLIGHTS

- A resonant tunneling device has been described.
- Variational resonant energy has been considered.
- Geometrical effects have been exhibited.

## GRAPHICAL ABSTRACT

The transmission and the dwell time of the tunneling structure are determined by the properties of the accelerating well and the central well.

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## ABSTRACT

Resonant tunneling quantum structures consist of asymmetric wells and barriers have been investigated to find their optimized geometrical parameters and potential profile by the numerical calculations. The results show that the widths and the depths of the asymmetric wells have a significant effect on the transmission coefficient and the dwell time. The properties exhibited in this work may establish guidance to the device applications.

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## 1. Introduction

Resonant tunneling effects in specific quantum structures have been investigated due to their importance in nanotechnological applications and in design of new-age electronic devices. The triple barrier diodes [1,2] and the hot electron transistors [3,4] are the examples of these structures with which the tunneling phenomena is studied to explore the potential applications. The transition coefficients in symmetrical and asymmetrical rectangular barrier systems have been calculated, and the dependence of the resonant tunneling on the geometrical parameters and the barrier heights is extensively viewed from the various aspects

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[5–11]. Also, different semiconductors are considered to analyze crystallographic effects on the tunneling properties [12–13].

The inclusion of the quantum wells in the barrier systems establishes new properties for the resonant tunneling. It has been reported that the resonance energies take same values with the energy states of the structure if a quantum well is sandwiched between the two barriers [14,15]. In a similar structure, the resonance conditions are found to be formed by the energy levels in the well [16]. In an asymmetric rectangular triple barrier structure, the tunneling occurs simultaneously at two independent energy levels [6,7].

The electron transmission time is a crucial parameter as it determines the operation speed of a tunneling device. It can also be called dwell time which is defined as the residing time of an electron in a specific region of the structure. The electron transition time for the resonant conditions has been calculated by using a simple analytical formula [17]. It has been characterized in terms of the structural parameters such as the widths of the wells or barriers and the mole fractions [18,19]. The control of the dwell time by the resonance voltage is also described as the resonant energy is constant [20,21].

In a structure consist of a couple of asymmetric rectangular double barrier separated by a center quantum well, the dwell time can be considerably reduced if a quantum well is set at the start of the structure [22]. This well has been named as “the accelerating well”, and the dwell time for the resonance was analytically calculated on assumption that the resonance energy is a constant together with other fixed parameters such as the barrier widths and the center well width.

We here consider the identical structure given in Ref. [22] to exhibit the geometric and the mole fraction effects in more detail on the expense of the analytical calculations. The numerical calculations are described in theory section. The results and discussion section involves the effects of the width and depth of the accelerating well together with the barrier widths on the transmission coefficient, the dwell time and the resonance energy in comparison with that of earlier studies.

## 2. Theory

We show a double barrier structure which cannot be expressed by linear functions in Fig. 1. To obtain transmission coefficient, $T$, of an electron in this structure, the system is divided to $N$ parts along the growth direction. The Schrödinger equation is solved for each part, and the coefficient matrix is then obtained using the standard boundary conditions. This process can be formulated as follows:

The wave function $\psi_j$ in the $j$th region is given by

$$\psi_j(x) = A_j \exp\left(k_j x\right) + B_j \exp\left(-k_j x\right), \tag{1}$$

where $k_j$ is the wave number expressed as

$$k_j = \begin{cases} i\sqrt{\left[2m_j^*\left(E - V_j\right)\right]/\hbar^2}\, E > V_j \\ \sqrt{\left[2m_j^*\left(V_j - E\right)\right]/\hbar^2}\, E < V_j \end{cases} \tag{2}$$

The potential barrier $V_j$ and the effective mass $m_j^*$, in the $j$th region in Eq. (2) are defined by the multistep function model

$$V_j = V\left[(X_j - dX/2)\right] \tag{3a}$$

$$m_j^* = m^*\left[(X_j - dX/2)\right] \tag{3b}$$

for $j = 1, 2, \ldots N-1, N$. From the continuity conditions of the wave function, the following equations hold as the boundary conditions

$$\psi_j(x)\Big|_{x=x_j} = \psi_{j+1}(x)\Big|_{x=x_j} \tag{4a}$$

$$\frac{1}{m_j^*}\frac{\partial\psi_j(x)}{\partial x}\bigg|_{x=x_j} = \frac{1}{m_{j+1}^*}\frac{\partial\psi_{j+1}(x)}{\partial x}\bigg|_{x=x_j} \tag{4b}$$

for $j = 1, 2, \ldots N-2, N-1$. Assuming $A_1=1$ and $B_N=0$, 2 N-2 equations are derived by using the boundary conditions given by Eqs. (4a) and (4b). The system of the equations is then solved by the transfer-matrix method [23] to obtain the transmission coefficient $T = |A_N|^2$ and the total reflection coefficient $R = |B_1|^2$.

The dwell time, $\tau$, of an electron in the region of $[x_0, x_N]$ is given by the equation

$$\tau = \frac{m_1^*}{\hbar k_1}\int_{x_0}^{x_N} |\Psi(x)|^2 dx \tag{5}$$

where $\hbar k_1/m_1^*$ is the probability density flow [22].

## 3. Results and discussion

The asymmetric rectangular double barrier system as a resonance tunneling device is shown in Fig. 2 together with their structural parameters.

If the structure in Fig. 2 is considered with the fixed parameters $E_{res}=50$ meV, $L_{aw}=2$ nm and $L_{lb}=4$ nm, the right-hand side

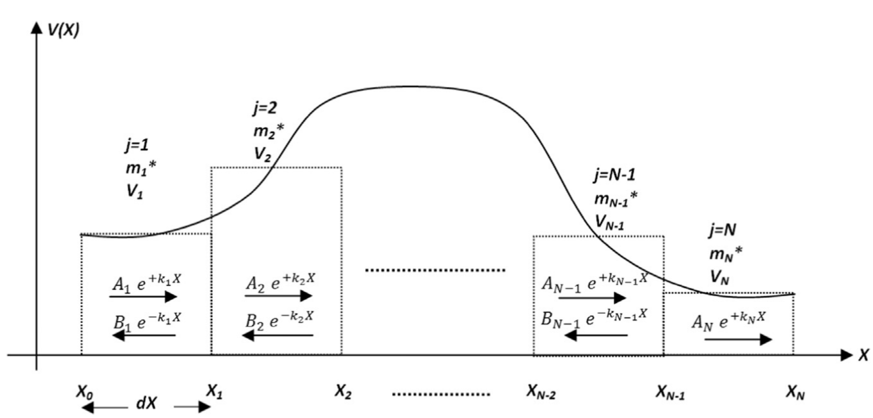


**Fig.1.** An arbitrary potential barrier separated to N part with the wavefunction in each region.

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