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Effect of Spatially Correlated Disorder on Electronic Transport Properties of Aperiodic Superlattices ($GaAs/Al_xGa_{1-x}As$)

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***Abstract*—**We examine the electronic transport properties in $Al_xGa_{1-x}As/GaAs$ superlattices. Using the transfer-matrix technique and the exact Airy function formalism, we investigate theoretically the effect of structural parameters on the electronic energy spectra of trimer thickness barrier (TTB). Our numerical calculations showed that the localization length of the states becomes more extended when the disorder is correlated (trimer case). We have also found that the resonant tunneling time (RTT) is of the order of several femtoseconds.

***Keywords*—**Electronic transport properties, structural parameters, superlattice, transfer-matrix technique.

I. Introduction

RESEARCH activities on multibarrier resonant tunneling has gained momentum on both theoretical and experimental front since the pioneering works of Esaki and Tsu [1] and Chang et al. [2].

The rapid progress achieved with the crystal grow technologies like molecular beam epitaxy allows one to fabricate semiconductor superlattice with the desired electronic properties [3]. This motivation may be attributed to the potential and extensive applications of the resonant tunneling phenomenon in high speed electronic devices that encompasse lasers, modulators, photodetectors, and signal processing devices [4], [5]. GaAs/AlGaAs superlattice systems are considered ideal candidates to carry out basic experiments to allow for a clear-cut validation of theoretical results, like delocalization by correlated disorder [6]. Resonant tunneling through a quantum well has generated considerable experimental and theoretical interest, not only because of its possible application to ultrahigh speed electronic devices, but also due to the characteristic time scales involving the key process that governs the ultimate speed of resonant tunneling in quantum-well devices. Taking this into account, we will study the effect of structural parameters on the electronic transport properties in aperiodic profile superlattice ($GaAs/Al_xGa_{1-x}As$). Specifically, determination of the RTT is vital to estimate the frequency limit of high speed tunneling devices.

In this article, we examine the effect of the structural parameters on the electronic transport properties in aperiodic profile superlattice. The disorder is introduced by triplet.

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II. Formalism

The one-dimensional time-independent Schrödinger wave equation for an electron in a semiconductor heterostructure, with V(z) potential, under the envelope function and effective mass approximations is given by:

$$\frac{1}{m^*(z)}\frac{d^2}{dz^2}\psi(z)+\frac{2}{\hbar^2}[\mathrm{E}-V_{SL}(z)]\psi(z)=0 \qquad (1)$$

where z is the growing axis, E is the incoming electron energy, $\psi(z)$ is the wave function in the growing direction, and m^* is the electron effective mass in each monolayer. The transmission coefficient is then given by:

$$T=\frac{\left(4\frac{\mathrm{K}'}{\mathrm{K}}\right)}{\left(\mathrm{A}+\frac{\mathrm{K}'}{\mathrm{K}}\mathrm{D}\right)^2+\left(\frac{\mathrm{K}'\mathrm{B}}{\mathrm{m_a}}-\frac{\mathrm{Cm_a}}{\mathrm{K}}\right)^2} \qquad (2)$$

where $K=\sqrt{\frac{2m_aE}{\hbar^2}}, K'=\sqrt{\frac{2m_a(E+eV_a)}{\hbar^2}}$ are the wave vectors, and A, B, C and D are the elements of the diffusion matrix S (0, L).

III. Results and Discussions

The physical parameters values, N = 499 regions, thickness barriers d_{b1} = 20 Å, d_{b2}= 24 Å and the width well d_w=14 Å are chosen to have permitted minibands under barriers. A disordered superlattice model constituted of two different structures randomly distributed along the growth direction, with the additional constraint such that thickness barriers d_{b2} appears only by triply (trimer unit cell), hereafter called trimer thickness barrier (TTB), as shown in Fig. 1.

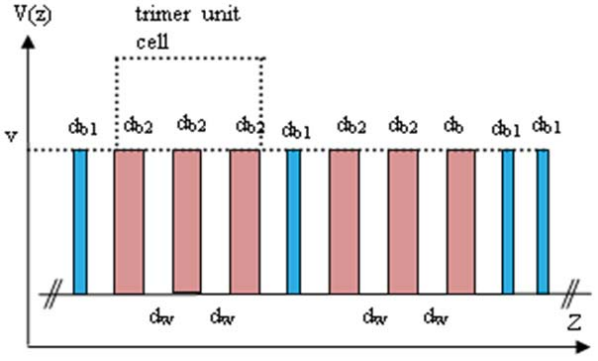

Fig. 1 Schematic diagram of SL containing TTB

In Fig. 2, the transmission coefficient is shown as a function of the electron energy in TTB. We observe the apparition of two sub-minibands located at the resonant energies E_{r1} = 0.183eV and E_{r2} = 0.274eV. The two peaks are due to the trimer because they present the same resonance energies as the basic cell (system with three barriers, red line).

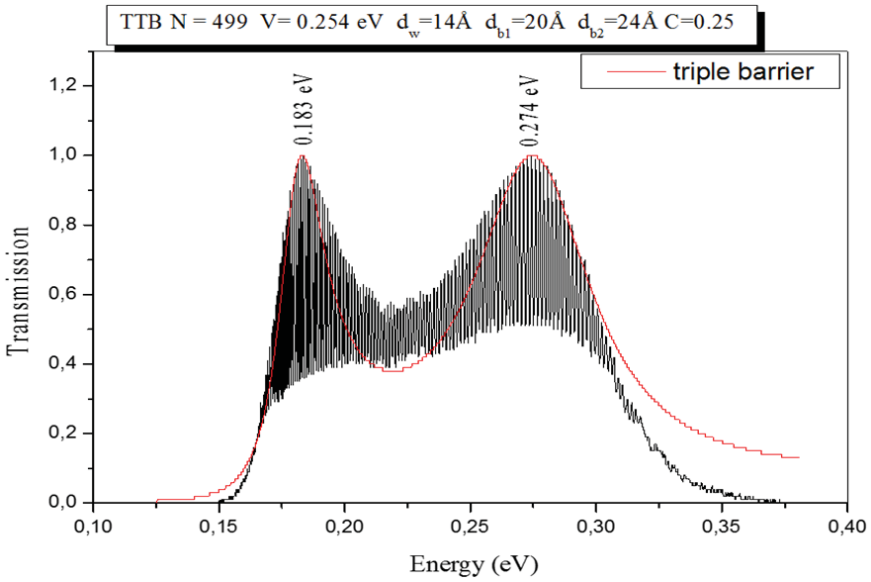

Fig. 2 Transmission versus electron energy of TTB

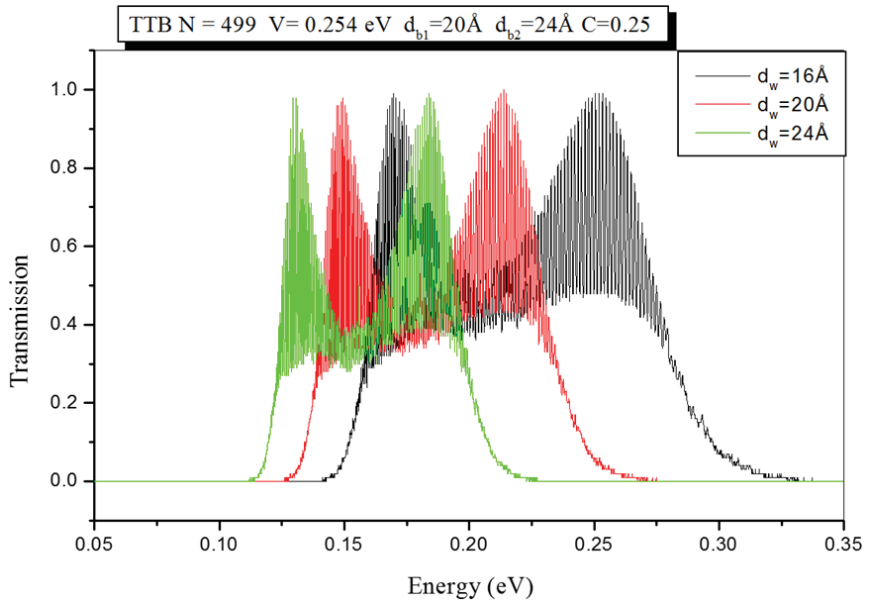

Fig. 3 Transmission versus electron energy for different well width

In Fig. 3, with the increase of the well width dw, the electronic states become confined inside the quantum wells This is due to the electron energy containment within the quantum wells.

In Fig. 4, we observe a narrowing of the minibands towards the area with the increase of d_{b2}. The scope of the wave decreases while increasing the thickness of the barrier. On the other hand, the influence of the barrier height shows a translation of the resonance peaks to the highest energy. This can be explained by the variation of the band gap of $Al_xGa_{1-x}As$ with the concentration x relative to the potential V (Fig. 5).

In order to investigate the effect of structural parameters on the response of TTB, we calculate the RTT. Several methods are cited in the literature to calculate this important physical factor such as the Hamiltonian technique, the complex eigenvalues method [7]-[10], and the Lorentzian method.

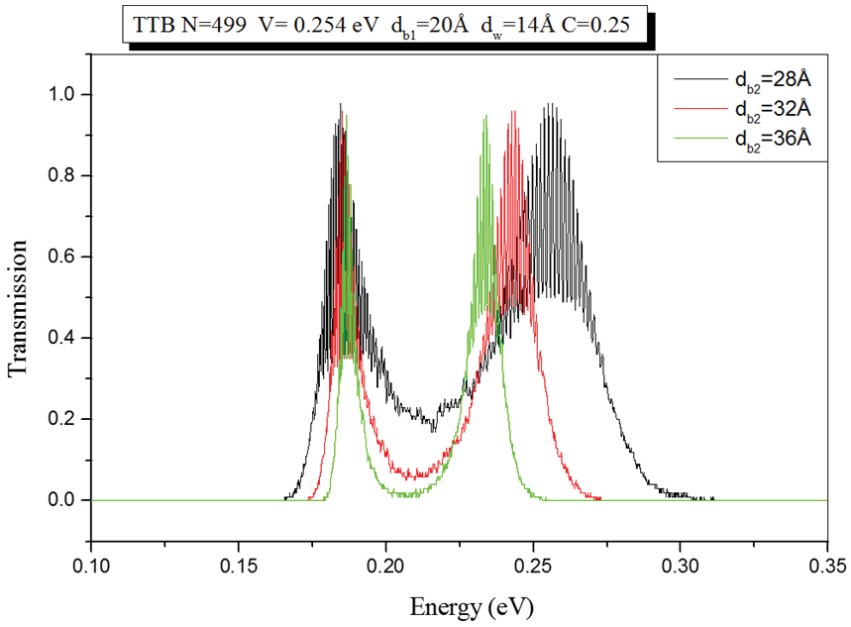

Fig. 4 Transmission versus electron energy for different barrier thickness

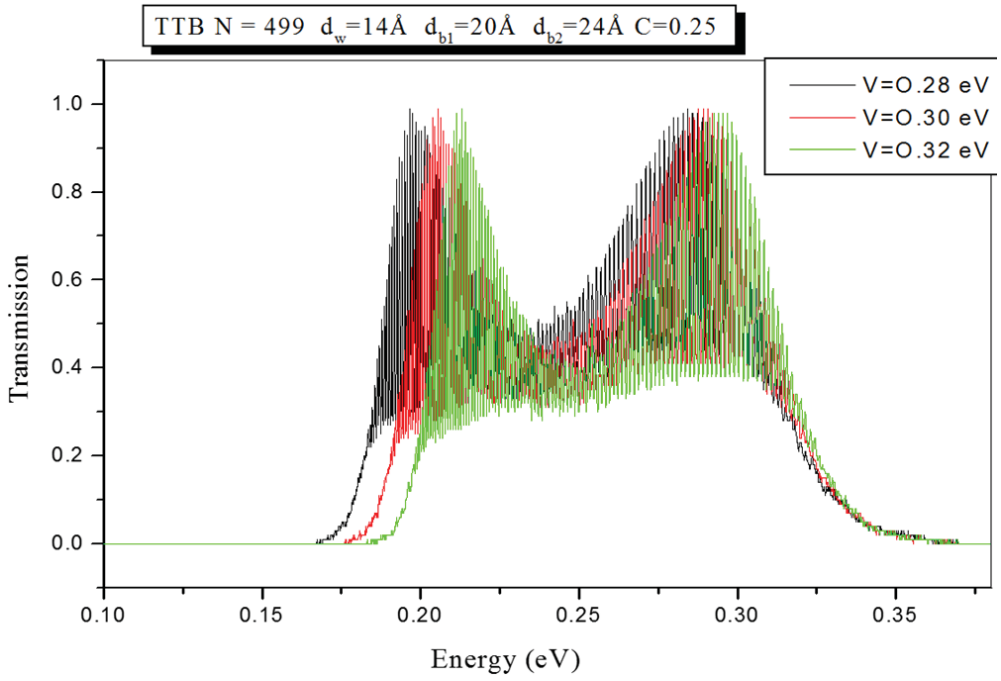

Fig. 5 Transmission versus electron energy for different barrier height

The electron RTT is calculated by the Lorentz formula:

$$t = \frac{\hbar}{\Delta E} \tag{3}$$

where ΔE is the half-height width of the resonance transmission peak [11].

In Fig. 6, we plotted the RTT as a function of the well width with and without an applied bias voltage (Va = 10 mV). The increase of well width d_w leads to increase to RTT. The time is expressed in femtosecond. This can be explained by the bed interference between electron wave functions, which allows for a thinner resonance peaks. It is also observed that the RTT is longer than the one obtained by Va = 0 mV. This is due to the Stark effect which confines the electronic states under the electric field action [12]. The same phenomenon is observed

in Figs. 7 and 8. This is explained by the fact that d_{b2} is greater than the wavelength λ of the electron. In this situation, the wells are decoupled, and the electronic states become bounded in the wells (Fig. 7). On the other hand, in Fig. 8, increasing the aluminum concentration provides the decrease of the miniband width and slows the response of this systems.

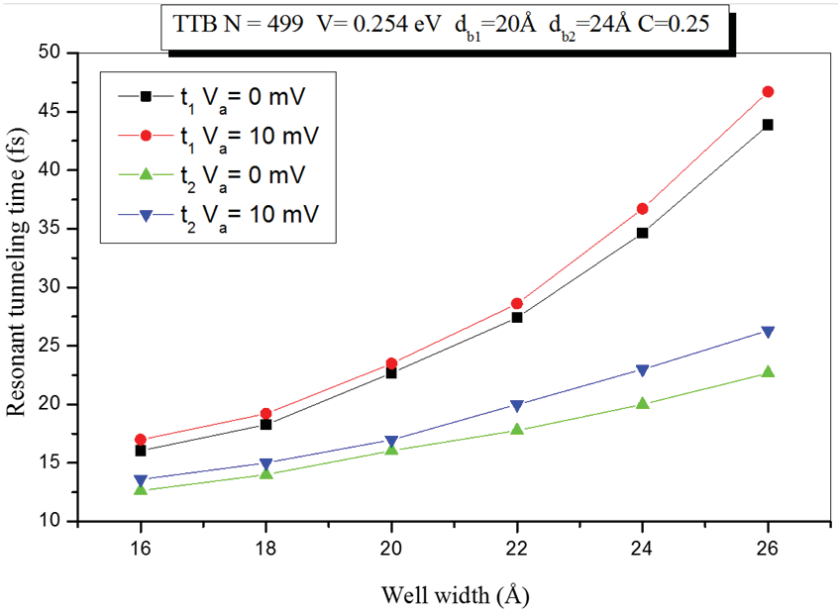

Fig. 6 RTT versus well width

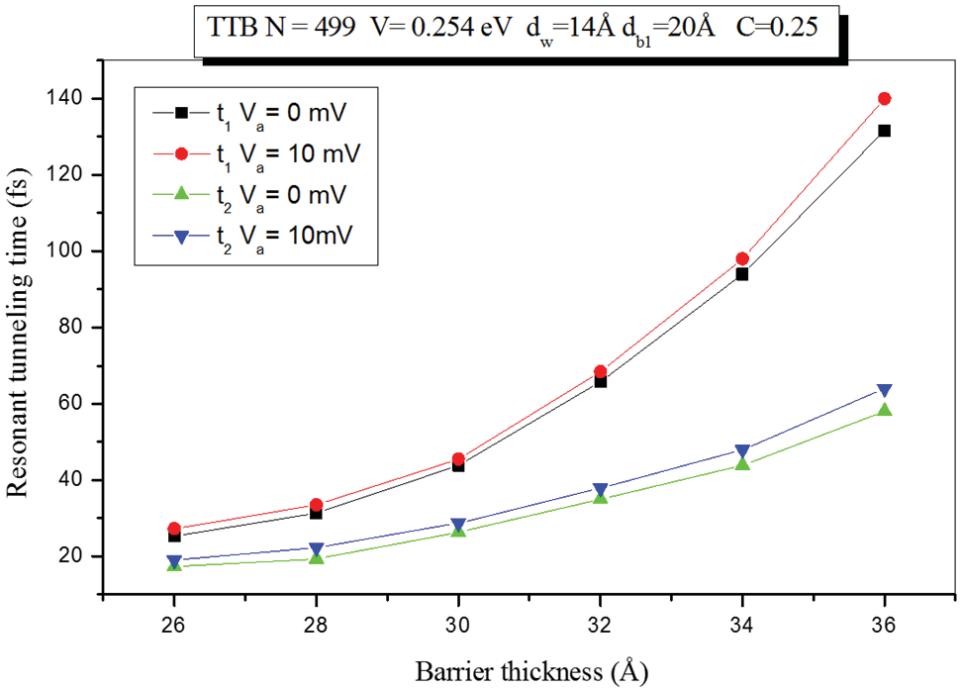

Fig. 7 RTT versus barrier thickness

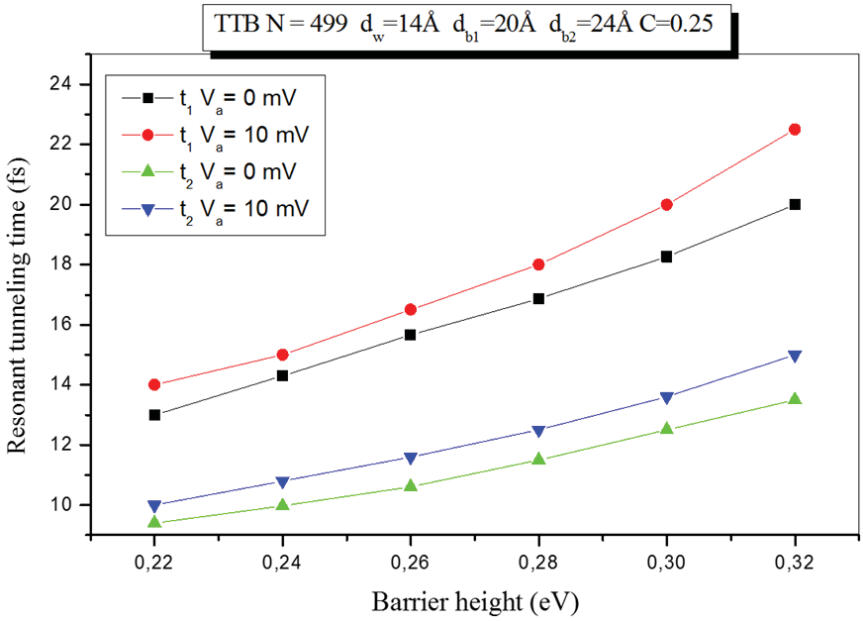

Fig. 8 RTT versus barrier height

IV. Conclusion

We have studied the impact of structural parameters on the electronic transport properties in aperiodic profile of superlattice, using the exact Airy function formalism and transfer-matrix technique. Our results showed that increasing the width of superlattice's well d_w allows the confinement of minibands inside the quantum wells. The barrier thickness d_{b2} and the barrier height V control the interaction force between neighboring eigenstates and the structural disorder degree. It was also noted that the variation of the structural parameters, principally the barrier height, changes the gap. The RTT obtained for this structure is in the range between 10 and 140 fs.

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