Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 7 (3): 417-420, 2007
ISSN 1812-5654

Electronic States Nature of Trimer Height Barrier Disorder Superlattices

R. Djelti, S. Bentata and Z. Aziz
Département de Physique, Faculté des Sciences, Université Abdelhamid Ibn Badis,
B.P. 227 Mostaganem, Algérie

Abstract: The transmissions coefficient and localization length are numerically investigated in trimer semiconductor superlattices by means of the transfer matrix model. We are interested in the GaAs/Al_xGa_{1-x} As layers, having different thickness, where the Aluminium concentration x takes at random, two different values, with the constraint that one of them appears only in triply, i.e., the Random Trimer Barrier (RTB). The electronic states of the SL have been studied by numerical calculation of the miniband structure. We observed that delocalization processes take place when the disorder is correlated, confirming theoretical expectations.

Key words: Superlattices, random trimer barrier, delocalized state, transmission coefficient

INTRODUCTION

Discussion of electron transport in semiconductor superlattices (SLs) can be traced back more than quarter a century to the pioneering work by Esaki and Tsu (1970).

The case of disorder superlattices is more challenging because in this system there is no translational symmetry and the Bloch theorem is not applicable. Since the original paper of Anderson (1981), the problem of localization of a particle in any amount of disorder, is still of continuous interest for physicists. Mott and Twose (1961) proved rigorously that all states are exponentially localized in one-dimensional full randomness parameters.

The simplest model that exhibits the suppression of localization in disordered systems is the so-called continuous random dimer model (Flores, 1989): impurities are placed randomly with the main restriction to be generated with pair, without any aggregates.

In this context, surprisingly recent developments on the subject have pointed out the possible suppression of localization in one-dimensional disordered systems induced by nonlinearity (Kivshar *et al*., 1990), correlation in disorder (Dunlap *et al*., 1990) or long-range interactions (Rodriguez, 2000).

Experimental studies of electronic properties of GaAs/Al_xGa_{1-x}As SL with intentional short correlated disorder by means of photoluminescence and vertical dc resistance have already supported the existence of delocalized states in random dimer SL (Bellani, 1999).

Weakly coupled semiconductor superlattices (SLs) represent a nonlinear system due to sequential resonant tunnelling between subbands in adjacent wells. Therefore, even in the presence of disorder, a regime of weak localization can occur (Bergmann, 1982).

Such results have been predicted by Dominguez-Adame, in the last decade, (Berman *et al*., 1997) introducing the correlated structural disorder by means of the so-called random dimer quantum wells superlattices (RDQWSL).

In such a case, the resonant tunnelling appears as the principal physical mechanism, breaking down the destructive interference introduced by disorder.

To the best of our knowledge very little has been done in the case of cellular disorder, namely the case of Trimer for which randomness is assumed in the height of the barriers.

Therefore, this situation has motivated us to examine numerically the effect of Random Trimer Barriers (RTB) on the nature of the eigenstates of one-dimensional disordered superlattices (RTBSL).

FORMALISM

Here, we study the electronic properties of the RTBSL in the stationary case.

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

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

Corresponding Author: R. Djelti, Département de Physique, Faculté des Sciences, Université Abdelhamid Ibn Badis, B.P. 227 Mostaganem, Algérie

Where z is the growing axis, E the incoming electron energy, $\Psi(z)$ the wave function in the growing direction and m* the effective mass of each monolayer.

We solve Eq. (1) by using the transfer matrix formalism (Walker and Gathright, 1994). In this case the incoming and outgoing amplitudes are related by a 2×2 complex matrix.

Using the Bastard continuity conditions (Bastard, 1981), for an incident electron coming from the left one has the relation between the reflected and transmitted amplitude r and τ, respectively:

$$\begin{pmatrix} 1 \\ r \end{pmatrix} = M(0,L)\begin{pmatrix} \tau \\ 0 \end{pmatrix} \tag{2}$$

A simple algebra yields the transfer matrix M(0,L) as:

$$M(0,L) = -\frac{m_w^*}{2ik}\begin{pmatrix} -\frac{ik}{m_w^*} & -1 \\ -\frac{ik}{m_w^*} & 1 \end{pmatrix} S(0,L)\begin{pmatrix} 1 & 1 \\ \frac{ik}{m_w^*} & -\frac{ik}{m_w^*} \end{pmatrix} \tag{3}$$

Here the diffusion matrix S (0, L) can be formulated in terms of the elementary diffusion matrices G_j (l) associated to each region j of the potential having a width l as the product:

$$S(0,L) = G_j(l) = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}. \tag{4}$$

The transmission coefficient is then given by

$$T = \frac{4}{(S_{11}+S_{22})^2 + \left(\frac{k}{m_w}S_{12} - \frac{m_w}{k}S_{21}\right)^2} \tag{5}$$

This expression measures the electron interaction with the structure through the elements of the diffusion matrix S (0, L) and the wave vector defined by $k^2 = \frac{2m_w E}{\hbar^2}$

For definiteness, we consider SL constituted by two semiconductor materials the well width d_w is different than the barrier thickness d_b in the whole sample which in turns preserves the periodicity of the lattice along the growing axis. $d = d_w + d_b$ is the period of the unit supercell.

The system consists of N rectangular barriers (N = 200). In this model of disordered SL, we consider that the height of the barriers takes at random only two values, namely V and $\overline{V}$.

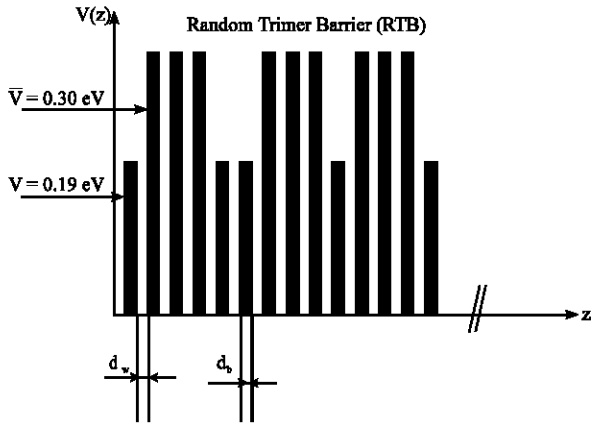

Fig. 1: Potential profile of the studied structure

These two potentials height are proportional to the two possible values of the Al fraction x in the $Al_xGa_{1-x}As$ barriers.

The sequence of potential is short-range correlated since the $\overline{V}$ appears forming triply randomly placed in the structure i.e.,

$V\overline{VVV}\,VV\overline{VVV}V\overline{VVV}V$.....

The potential used in this study is schematically shown in Fig. 1.

RESULTS AND DISCUSSION

The results concerns the statistical description of the electronic transport process in the RTBSL devices, by means of numerical calculations of its transmission coefficient.

Physical parameter values, such as d_w = 20Å, d_b = 26Å, V = 0.19 eV and $\overline{V}$ = 0.30 eV, are chosen, to obtain allowed minibands lying below the barriers.

The corresponding effective masses are taken to be $m_w = 0.067m_0$, $m_b = 0.0877m_0$ and $\overline{m_b} = 0.1002m_0$ for, respectively the quantum well, host barrier and trimer barrier layers, where m_0 is the free electron mass.

For convenience, the bottom of GaAs wells has been chosen as the energy reference.

For the above parameters, transmission coefficient versus electron incident energy T(E) is plotted in Fig. 2 by averaging over 1000 samples of N = 200 barriers.

Figure 2 shows the position of the lower and upper band edges of the minibands corresponding to the two ordered superlattices with the two barrier heights V and $\overline{V}$.

We can observe the existence of one miniband under the well, ranging from 99 up to 242 meV for V and from 151 up to 251 meV for $\overline{V}$. We can explain the process of the

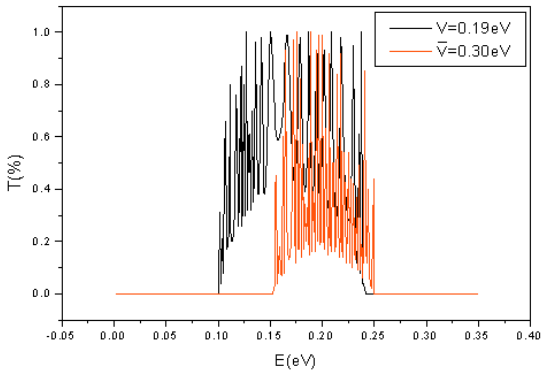

Fig. 2: Transmission coefficient as a function of incident electron energy E of ordered SL for two different high barriers N = 200, d_w = 20Å, d_b = 26Å

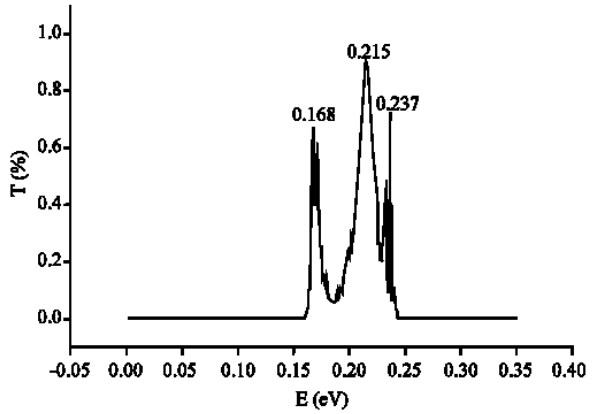

Fig. 3: Transmission coefficient versus electron energy for a RTBSL N = 200, d_w = 20Å, d_b = 26Å, V = 0.19 eV, $\overline{V}$ = 0.30 eV, C = 0.20

minibande structure formation inside the well by the existence of N-1 states allowed in N-1 well ranging between the barriers.

For the ordered structure, we notice that for low barrier height (V = 0.19 eV) the wide of the mini band is significant ($\Delta E \approx 0.143$ eV).

The transmission versus electron energy for trimer concentrations c = 0.20 (Fig. 3). This fraction is defined as the ratio between the number of barriers high $\overline{V}$ and the total number of barriers in the lattice.

We observe apparition of three sub-minibands located at the resonant energies Er_1 = 168 meV, Er_2 = 215 meV and Er_3 = 237 meV, the origin of these regions is directly related to the loss of long-range quantum coherence of the electron (Bentata *et al*., 2001), due to the introduction of the disorder trimer cell.

It is noted that the two first peaks are due to the trimer because they present the same resonance energies as the basic cell system with three barriers presented in

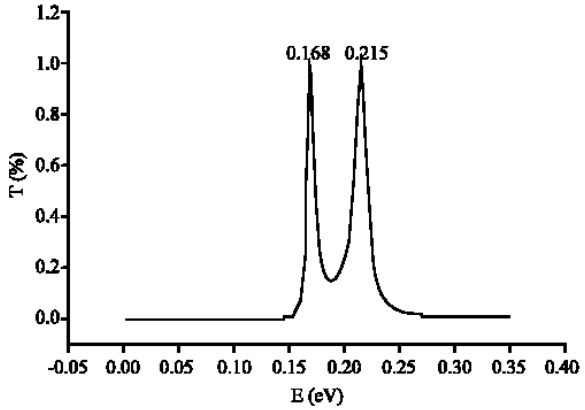

Fig. 4: Transmission coefficient versus electron energy for triple barrier system ordered structure N = 3, d_w = 20Å, d_b = 26Å, V = 0.30 eV

Fig. 4, whereas the third peak is due to the commutation i.e., the overlap of the two systems to potential V and $\overline{V}$ one in the other.

This last peak must appear in the intersection region of the two miniband structures of ordered system shown in Fig. 2.

This result is in perfect accord with that obtained by Bentata (2005) in the case of RDBSL.

Other theoretical methods already used, Kronig Penney (Sanchez and Dominguez, 1994), strong bond (Balagurov *et al*., 2004; Dominguez-Adame and Malyshev, 2004), airy function (Mington *et al*., 1990) and the green functions (Kawamura *et al*., 1994) proved the existence of delocalized state in one-dimensional disordered systems, where disorder presents some correlation, these results are into perfect agreement with those found by the transfer matrix method used in this study.

The position of the resonant energies does not depend on the degree of disorder, they are identical for each concentration (Fig. 5).

Furthermore, the intensity of the peak is sensitive to the degree of disorder and decreases with increasing the degree of disorder.

We can conclude that these energies depend only on the structure of the SL, i.e., the widths of the wells, the thickness of barriers and the height of potential.

In order to measure the degree of localization we calculate the Lyapunov exponent (Kirkman and Pendry, 1984), witch is in one-dimensional systems the inverse of the localization length.

$$\gamma = -\frac{1}{2N}\ln T$$

The Lyapunov exponent versus the energy for the TRBSL with disorder concentration C = 0.20 (Fig. 6).

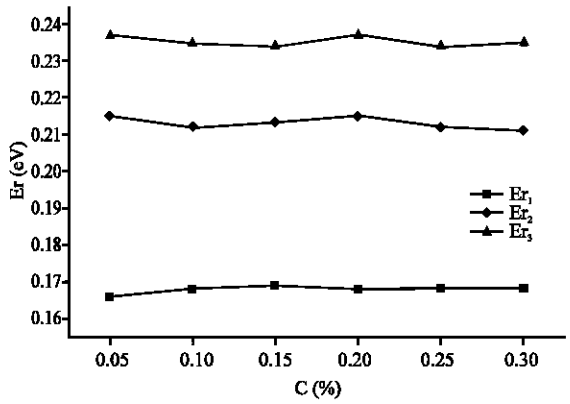

Fig. 5: Resonance energy versus the concentration of disorder C, N = 200, d_w= 20Å d_b = 26Å, V = 0.19 eV $\overline{V}$ = 0.30 eV

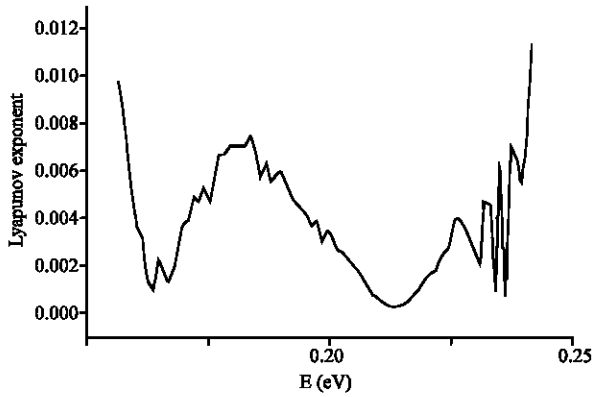

Fig. 6: Lyapunov exponent as a function of incident electron energy for N = 200, d_w = 20Å, d_b = 26Å, V = 0.19 eV, $\overline{V}$ = 0.30 eV, C = 0.20

We observe the existence of different types of eigenstates those having a very low lyapunov exponent close to the resonant energy and those with high slope in other region.

The particular behaviour of lyapunov exponent suggests the existence of a cross-over between separating the two phases: strongly localized states in the band tails from weakly or extended localized near to the resonant energy.

We noted that the delocalized states due to commutation are not clean only with the dimer but also for the trimer.

Our work is fundamental and original because it treats a disorder in trimer case, we invite the experimenters to prove the existence of the third peak.

CONCLUSION

In summary we have presented a numerical approach study of electronic states in correlated disordered layered microstructures.

The fluctuations of the transmission due to disorder in these SL have a different strength in different regions of the spectrum and characterize the tunnelling transport properties in these regions. It is then interesting to study the statistics of the transport in these systems.

There exists a different type of electronic states that remain unscattered (or almost unscattered) by trimer defects.

We have found three resonant regions in RTBSL, two of them are due to the trimer tunnelling state originated for the basic cells of three singular barriers.

Unexpectedly, the TRBSL support another type of resonance its origin being completely different, this one is due to the commutation of the two potential V and $\overline{V}$.

In this case all the blocks of each type can be moved to one of the two sides. We can represent this process of commutation as follows:.

$$V\overline{V}V\overline{V}V\overline{V}V\overline{V}V\overline{V} \rightarrow VVVVVV\overline{V}\overline{V}\overline{V}\overline{V}\overline{V}$$

REFERENCES

Anderson, P.W., 1981. Phys. Rev., B 23: 4828.

Balagurov, D.B., V.A. Malyshev and F. Dominguez-Adame, 2004. Phys. Rev., B69: 104-204.

Bellani, V., E. Diez, R. Hey, L. Toni, L. Tarricone, G.B. Parravicini *et al.*, 1999. Phys. Rev. Lett., 82: 2159.

Bentata, S., S.B. Ait and H. Sediki, 2001. Superlattices and Microstructure 30: 300.

Bentata, S., 2005. Superlattices and Microstructures, 37: 297.

Bergmann, G., 1982. Phys. Rev. Lett., 49: 162.

Berman, G.P., F. Dominguez-Adame and A. Shanchez, 1997. Physica. D., 107: 166.

Bastard, G., 1981. Phys. Rev., B24: 5693.

Dominguez-Adame, F. and V.A. Malyshev, 2004. Am. J. Phys., 72: 227.

Dunlap, D., H.L. Wu and P. Phillips, 1990. Phys. Rev. Lett., 65: 88.

Esaki, L. and R. Tsu, 1970. IBM. J. Res. Dev., 14: 61.

Flores, J.C., 1989. J. Phys. Condens. Matter, 1: 8471.

Kawamura, T., H.A. Fertig and J.P. Leburton, 1994. Phys. Rev., B 49: 5105.

Kirkman, P.D. and J.D. Pendry, 1984 J. Phys. C., 17.

Kivshar, Y.S., S.A. Gredeskul, A. Sanchez and L. Vazquez, 1990. Phys. Rev. Lett., 64: 1693.

Mington, C., J. Xu and S. Zukolynski, 1990. J. Applied Phys., 67: 3011.

Mott, N.F. and W.D. Twose, 1961. Adv. Phys., 10: 107.

Rodriguez, A., V.A. Malyshev and F. Dominguez-Adame, 2000. J. Phys. A. Math. Gen., 33 L: 161.

Sanchez, A. and F. Dominguez-Adame, 1994. J. Phys. A: Math. Gen, 27: 3225.

Walker, J.S. and Gathright, 1994. J. Am. J. Phys., 62: 408.