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ELECTRONIC PROPERTIES OF A SEMICONDUCTOR TWO-BARRIER STRUCTURE

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ANNOTATION

The dependence of the transmission coefficient for an electron with energy E tunneling through a potential barrier of finite height and thickness in a two-barrier semiconductor structure is calculated, and it is shown that this dependence has an oscillatory character.

On the basis of the continuity equation, the energy dependence of the frequency of electron collisions with the walls of the size-quantized potential is analyzed.

KEY WORDS: ***transmission coefficient, two-barrier semiconductor structure, size quantization, energy spectrum, potential well.***

INTRODUCTION

In recent years, the scientific interest of researchers in superlattices consisting of layered structures of various semiconductors with characteristic layer sizes of 10–1000 Å has increased [1–6]. Therefore, layered structures consisting of nanostructures are used in electronics as completely new types of artificial materials with unusual physical properties. In turn, interest in nanostructures stimulates the development of modern technologies and surface structure at the atomic level.

The research of electron transport through multilayer semiconductor heterostructures of the type) [1–6] and cascade heterolasers [3–4] has attracted great interest. On the one hand, this is due to the possible use of such heterostructures for creating resonant tunneling devices. On the other hand, interference phenomena are possible in multilayer structures, leading to the appearance of structures with unique properties, for example, unusual transparency.

In the works investigated by us, the calculation was mainly carried out on a computer, where it is difficult to analyze intermediate calculations [6, 7], and analytical calculations were carried out [8–9], where changes in the effective masses of electrons during the transition from one layer to another are not taken into account.

Let us consider a periodic structure consisting of thin layers of semiconductors alternating in the same direction. They have special physical properties: a significant change in comparison with the original semiconductors of the energy spectrum of current carriers; the presence of a large number of energy bands, including size-quantized subbands; very strong anisotropy arising due to the reduction in the dimension of current carrier systems; suppression of a number of channels of electron-hole recombinations; the concentration of current carriers in the superlattice is a tunable quantity and is not determined by doping; wide possibilities of band structure rearrangement depending on the quantization size.

We note here that in the literature devoted to periodic structures, layered semiconductors are mainly considered, in which the period of the structure is much larger than the crystal lattice constant, but less than the mean free path of electrons. But the electronic states or optokinetic properties of asymmetric semiconductor structures, taking into account the Bastard condition [11–15], have not been studied so far, which is the subject of this work.

It is known [5] that when growing epitaxial layers of a narrow-gap semiconductor between two layers of a wide-gap material, a certain potential energy profile can be realized. In this case, the problem of determining the stationary electronic states is reduced to the quantum-mechanical problem of the behavior of a particle in a potential well. Therefore, below we consider the

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general issues of propagation of de Broglie waves of electrons in a structure consisting of alternating potential wells and barriers (layers). The theoretical approach to the problem of elastic scattering (or tunneling) of noninteracting spinless microparticles is based on solving the stationary Schrödinger equation.

THE MAIN RELATIONSHIPS

Modern technology makes it possible to obtain semiconductor layers with an arbitrary composition change profile (structure with a quantum well) to improve the characteristics of devices based on them. In this case, the problem of electronic states is reduced to the problem of particle behavior in rectangular potential wells, between two neighboring of which there is a potential well. Let the potential well have the form

$$U(x)=\begin{cases} U_j & at\ \ x\langle x_j, \\ U_{j+1} & at\ \ x_{j+1}\langle x\langle x_{j+2}, \\ U_{j+2} & at\ \ x_{j+2}\langle x\langle x_{j+3}, \\ U_{j+3} & at\ \ x_{j+3}\langle x\langle x_{j+4}, \\ U_{j+4} & at\ \ x\rangle x_{j+4}... \end{cases} \qquad (1)$$

Note that to create a new generation of resonant tunneling diodes, heterolasers with separated electronic and optical confinement, structures with rectangular size-quantized wells are used, in the center of which there is an additional energy dip. Such a structure is described by the potential (1.1), where we must assume that $U_j, U_{j+4}\rangle 0,\ U_{j+1}, U_{j+3}=0, U_{j+2}\langle 0$.

Nanostructures grown on the basis of a narrow-gap semiconductor between two layers of a wide-gap material are described as a structure with asymmetric rectangular potential barriers, i.e. with potential (1), where $U_j, U_{j+2}\rangle 0,\ U_{j+1}, U_{j+3}, U_{j+4}=0$.

Then we choose the solution of the stationary Schrödinger equation with potential (1) as

$$\psi_j(x)=A_j\exp(ik_jx)+B_j\exp(-ik_jx), \qquad (2)$$

where $k_j(x)=k_j=\sqrt{\frac{2m_j}{\hbar^2}\left(E-U_j\right)},\ \ j=1,2,3,...$ m_j is the effective mass of current carriers in the layer

.

In further calculations, we assume that the effective masses of electrons are different in different regions. Therefore, when solving the Schrödinger equation with potential (1), we take into account the Bastard conditions [11-15], i.e.

$$\psi_j(x=x_j)=\psi_{j+1}(x=x_j),\ \ \frac{1}{m_j}\frac{\partial\psi_j(x)}{\partial x}\bigg|_{x=x_j}=\frac{1}{m_{j+1}}\frac{\partial\psi_{j+1}(x)}{\partial x}\bigg|_{x=x_j} . \qquad (3)$$

Substituting (2) into (3), it is easy to obtain the following linear combination of the amplitudes of electron de Broglie waves

$$\begin{aligned} 2A_j&=\left(1+\frac{\tilde{k}_{j+1}}{\tilde{k}_j}\right)A_{j+1}\exp(i(k_{j+1}-k_j)x_j)+\left(1-\frac{\tilde{k}_{j+1}}{\tilde{k}_j}\right)B_{j+1}\exp(-i(k_{j+1}+k_j)x_j), \\ 2B_j&=\left(1-\frac{\tilde{k}_{j+1}}{\tilde{k}_j}\right)A_{j+1}\exp(i(k_{j+1}+k_j)x_j)+\left(1+\frac{\tilde{k}_{j+1}}{\tilde{k}_j}\right)B_{j+1}\exp(-i(k_{j+1}-k_j)x_j). \end{aligned} \qquad (4)$$

Here $\tilde{k}_j=k_j/m_j$.

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To simplify further calculations, we introduce a transfer matrix that satisfies the following equality

$$\begin{bmatrix} A_j \\ B_j \end{bmatrix} = \hat{T}^{(j,j')} \begin{bmatrix} A_{j'} \\ B_{j'} \end{bmatrix} \begin{bmatrix} T_{11}^{(j,j')} & T_{12}^{(j,j')} \\ T_{21}^{(j,j')} & T_{22}^{(j,j')} \end{bmatrix} \begin{bmatrix} A_{j'} \\ B_{j'} \end{bmatrix}, \qquad (5)$$

where are the matrix elements in the case $j' = j+1$

$$T_{11}^{(j,j+1)} = \frac{1}{2}\left(1+\frac{\tilde{k}_{j+1}}{\tilde{k}_j}\right)\exp(i(k_{j+1}-k_j)x_j), T_{12}^{(j,j+1)} = \frac{1}{2}\left(1-\frac{\tilde{k}_{j+1}}{\tilde{k}_j}\right)\exp(-i(k_{j+1}+k_j)x_j),$$
$$T_{21}^{(j,j+1)} = \frac{1}{2}\left(1-\frac{\tilde{k}_{j+1}}{\tilde{k}_j}\right)\exp(i(k_{j+1}+k_j)x_j), T_{22}^{(j,j+1)} = \frac{1}{2}\left(1+\frac{\tilde{k}_{j+1}}{\tilde{k}_j}\right)\exp(-i(k_{j+1}-k_j)x_j), \qquad (6)$$

Note that the matrix $\hat{T}^{(j,j+1)}$ satisfies the following relation

$$T_{11}^{(j,j+1)} = T_{22}^{(j,j+1)*},\ T_{12}^{(j,j+1)} = T_{21}^{(j,j+1)*}, T_{11}^{(j,j+1)}T_{22}^{(j,j+1)} - T_{21}^{(j,j+1)}T_{12}^{(j,j+1)} = \tilde{k}_{j+1}/\tilde{k}_j \qquad (7)$$

the matrix $\hat{T}^{(j,j+1)}$ becomes a unipolar matrix in the case $\tilde{k}_{j+1} = \tilde{k}_j$, i.e. for symmetric structures, when the height of potential barriers and effective masses of electrons are the same.

Now let's consider specific cases: let a three-layer structure have one potential barrier in the middle. Then the reflection coefficients $\left(r_{j,j+2}\right)$ of the potential barrier and the passage through the potential barrier $\left(t_{j,j+2}\right)$, introduced as the ratio of the probability flux density in the reflected and transmitted de Broglie waves of electrons in the incident wave, in the transfer matrix formalism, have view

$$t_{j,j+2} = \frac{k_{j+2}}{k_j}\frac{\left|A_{j+2}\right|^2}{\left|A_j\right|^2} = \frac{k_{j+2}}{k_j}\frac{|1|^2}{\left|T_{11}^{j,j+2}\right|^2} =$$

$$= \frac{4\dfrac{k_{j+2}}{k_j}\dfrac{m_j}{m_{j+2}}}{\left(1+\dfrac{k_{j+2}}{k_j}\dfrac{m_j}{m_{j+2}}\right)^2 - \left[1+\left(\dfrac{k_{j+1}}{k_j}\dfrac{m_j}{m_{j+1}}\right)^2\right]\cdot\left[1+\left(\dfrac{k_{j+2}}{k_{j+1}}\dfrac{m_{j+1}}{m_{j+2}}\right)^2\right]\sin^2\left[k_{j+1}\left(x_{j+1}-x_j\right)\right]}, \qquad (8)$$

where it was believed that the transfer occurs according to the scheme $j \to j+1 \to j+2$.

RESULTS AND CONCLUSIONS

Considering below, the two-barrier size-quantized structure is not isolated, since the barrier in it is tunnelable. Hence it follows that an electron can escape from it, passing through the barriers by tunneling [11–20], i.e. the state of an electron in a size-quantized well (QW) is not stationary and its energy is an indeterminate quantity. This means that in the SQW of the structure, the total energy of electrons along the quantization takes discrete values, and the allowed energy bands correspond to the levels corresponding to them. The width of these bands is determined by the electron lifetime τ with a given energy. If the lifetime due to

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tunneling from the well is known - the natural lifetime and the momentum relaxation time τ_p, then the value of τ can be calculated using the well-known formula [3]

$$\tau^{-1} = \tau_b^{-1} + \tau_p^{-1}. \quad (9)$$

The intrinsic lifetime of an electron in the SQW of the considered two-barrier structure with the energy En is determined in terms of the transmission coefficients of each of the barriers T1n и T2n and T2n by the formula

$$\tau_{bn} = \tau_{on} / \frac{1}{2}\left(T_{1n} + T_{2n}\right), \quad (10)$$

where4 $\tau_{0n} = a / v_n$ is the time of flight of an electron in the SQW with a speed $v_n = \sqrt{2m^* E_n} / \hbar$, m^* is the effective mass of the electron in the SQW. From (8) The transmission coefficient for an electron with energy E tunneling through a potential barrier with height V and thickness b depends on the energy according to the formula

$$T = \left\{1 + \frac{\sin^2(b\kappa)}{4(E/U_0)(E/U_0 - 1)}\right\}^{-1}, \quad (11)$$

where $\kappa = \sqrt{2m^*(E - U_0)} / \hbar$ is the wave vector of an electron passing over the barrier. For resonant energy values E_n, at which the transmission coefficient T=1, from the condition we obtain

$$E_n = V_b\left(n^2 + U_0 / U_b\right), \quad (12)$$

where $n = 1, 2, \ldots.; U_b = \pi^2\hbar^2 / 2m^* b^2$. Note that for the sub-barrier passage of electrons, where E<V in (11), it is necessary to carry out a transformation of the type:

$$T = \left\{1 + \frac{sh^2(bk_1)}{4(E/U_0)(1 - E/U_0)}\right\}^{-1}. \quad (13)$$

In the case of thick barriers, as well as for $U_0 \rangle E$, i.e. $bk_1 = b\sqrt{2m^*(U_0 - E)} / \hbar >> 1$, if , then we have that

$$T = 16\frac{E}{U_0}\left(1 - \frac{E}{U_0}\right)\exp\left(-2b\sqrt{2m^*(U_0 - E)} / \hbar\right), \quad (14)$$

according to which the transm

4 The continuity equation for calculating the probability of finding an electron in the SQW with energy E has the form $\frac{d}{dt}\rho(t) = -\frac{T_1 + T_2}{2\tau_0}\rho(t)$, where $\rho(t) = \int_{-a/2}^{+a/2} |\Psi(x,t)|^2 dx$, Ox is dimensional quantization axis, $\tau_0 = \frac{\hbar a}{\sqrt{2m^* E}}$ is the time of electron collisions with the SQW walls, factor 2 is related to the equal probability for the electron to move to the right or to the left. According to this equation, the probability decreases exponentially with time $\rho(t) = \rho(0)\exp(-t/\tau)$, whence formula (9) follows.

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ission coefficient grows exponentially with increasing electron energy and vice versa. If the structure is symmetrical, i.e. $U_1 = U_2 = U_0$, $b_1 = b_2 = b$, then taking into account (14) gives that it is easy to obtain that

$$\tau_b = \frac{\tau_o}{T} \cong \frac{aU_0^{\,2}}{16vE(U_0 - E)} \exp\left(2b\sqrt{2m^*(U_0 - E)}/\hbar\right). \qquad (15)$$

It can be seen from the latter that the proper lifetime has a power singularity and at $E \to U_0$, we have $\tau_b \to \infty$.

REFERENCES

1. *Ivchenko, E. L., & Pikus, G. (2012). Superlattices and other heterostructures: symmetry and optical phenomena (Vol. 110). Springer Science & Business Media.*
2. *Ivchenko, E. L. (2005). Optical spectroscopy of semiconductor nanostructures. Alpha Science Int'l Ltd..*
3. *Ivchenko, E. L., & Rasulov, R. Y. (1989). Symmetry and real band structure of semiconductors.-Tashkent. Fan.*
4. *Shik, A. Y., Bakueva, L. G., Musikhin, S. F., & Rykov, S. A. (2001). Physics of low-dimensional systems.*
5. *Timofeev, V. B. (2004). Electron correlation phenomena in semiconductor low-dimension structures and nanostructures. Physics-Uspekhi, 47(10), 1037-1044.*
6. *Elesin, V. F., & Kateev, I. Y. (2008). High-frequency properties of double-well nanostructures. Semiconductors, 42(5), 571-575.*
7. *Dyakonov, M. I., & Khaetskii, A. V. (1982). Size quantization of holes in a semiconductor with complicated valence band and of carriers in a gapless semiconductor. Zh. Eksp. Teor. Fiz, 82, 1584.*
8. *Merkulov, N. A., Perel, V. I., & Portnoi, M. E. (1991). Momentum alignment and spin orientation of photoexcited electrons in quantum wells.*
9. *Albuquerque, E. L., & Cottam, M. G. (2003). Theory of elementary excitations in quasiperiodic structures. Physics reports, 376(4-5), 225-337.*
10. *Landau, L. D., & Lifshitz, E. M. (2013). Quantum mechanics: non-relativistic theory (Vol. 3). Elsevier.*
11. *Golub, L. E., Ivchenko, E. L., & Rasulov, R. Y. (1995). Intersubband absorption of light in a semiconductor quantum well with a complex band structure. Semiconductors, 29(6), 566-569.*
12. *Rasulov, R. Y., Rasulov, V. R., & Éshboltaev, I. (2018). To the Theory of the Polarized Radiation Absorption in a Semiconductor (001) Quantum Well. Russian Physics Journal, 61(3), 463-468.*
13. *Rasulov, V. (2017). To the Theory of Electron Passage in a Semiconductor Structure Consisting of Alternating Asymmetric Rectangular Potential Wells and Barriers. Russian Physics Journal, 59(10).*
14. *Rasulov, V. (2017). To the Theory of Electron Passage in a Semiconductor Structure Consisting of Alternating Asymmetric Rectangular Potential Wells and Barriers. Russian Physics Journal, 59(10).*
15. *Rasulov, V. R. (2019). Ballistic and surface photovoltaic effects and two-dimensional electronic states in semiconductors. Monograph. Under the total. ed. G. Yu. Gulyaev. Penza: ICSN" Science and Enlightenment.*
16. *Rasulov, R. Y., Salenko, Y. E., & Kambarov, D. (2002). Linear photovoltaic effect in gyrotropic crystals. Semiconductors, 36(2), 141-147.*
17. *Andrianov, A. V., Ivchenko, E. L., Pikus, G. E., Rasulov, R. Y., & Yaroshetski, I. D. (1982). Linear photogalvanic effect in p-type a3b5 crystals. Ferroelectrics, 43(1), 177-180.*
18. *Henneberger, F., Averkiev, N. S., & Rasulov, R. J. (1982). On a new photogalvanic effect due to free-carrier absorption. Physica Status Solidi. B, Basic Research, 109(1), 343-351.*
19. *Rasulov, V. R., & Rasulov, R. Y. (2018). DIMENSIONAL QUANTIZATION IN GAP. Scientific-technical journal, 22(3), 15-20.*
20. *Rasulov, R. Y. (1993). Photovoltaic Effects in Semiconductors at Linear and Nonlinear Absorption of Light (Doctoral dissertation, Thesis for Doctor of Phys.-Math. Sci. Degree, Leningrad).*