ACOUSTICAL PROPERTIES OF RECTANGULAR GaN QUANTUM WIRES COVERED BY ELASTICALLY DISSIMILAR BARRIERS WITH CLAMPED OUTER SURFACES

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Abstract

We had theoretically studied the energy spectra and group velocities of the acoustic phonons in the rectangular GaN nanowire, covered with elastically dissimilar barriers. It was established that the number of quantum branches increases and spatial degeneracy by wave number \( q \) disappears in such wire. The elastic properties of acoustically mismatched barrier influence dramatically the phonon spectrum. The barriers with lower sound velocity (“acoustically slow” barriers) are “compressing” the phonon energy spectrum and strongly reducing the group velocities of the phonons. The barriers with higher sound velocity (“acoustically fast barriers”) demonstrated the opposite effect.

The reason for such anomalous, at first look, but strong influence of barrier had been established. In particular, it consists in the re-distribution of the elastic deformations in the heterowire. In the case of “acoustically slow” barriers the wave of elastic deformations in a wide interval of the wave vector retracts into barriers (phonon depletion of the core wire) and spreads there with the velocities corresponding to the acoustic properties of the barrier layers. The opposite situation takes place in the case of “acoustically fast” barriers.

It is concluded that these effects can be used in the phonon engineering.

1. Introduction

The last decade the great successes were achieved in the field of the manufacturing technology for the highly perfected nano-dimensional semiconductor heterostructures: quantum wells, quantum wires, and quantum dots. In this connection, the electronic and phonon properties of low-dimensional structures attract the rapt attention of researchers. The features of the energy spectrum of the acoustic phonons, stipulated by the dimensions and shape of the structures [1-11], manifest themselves in kinetic and optic phenomena when feature size \( d \) of the structure becomes smaller than the phonon mean free paths \( \lambda \). The controlling of the phonon and electron phenomena by means of the modification of the phonon spectra got name of the phonon engineering [12].

Complete description of the elastic vibrations in the freestanding slabs was given in Ref. [1]. Also, there were presented some particular solutions for the problem of elastic vibrations in cylindrical and rectangular nanowires. Theoretically, the folded acoustical phonons in a layered medium have been studied by Rytov [2]. Later, the folded phonons have been observed experimentally in quantum well superlattices [3]. The important properties of the acoustic phonons in the slabs, quantum wires and quantum dots were established in Refs. [4-7]. Acoustic properties of the spherical quantum dots, surrounded by the acoustically dissimilar medium were described in Ref. [8]. Dispersion of the phonons in quantum dot
superlattices was recently calculated with account of the elastic properties of both quantum dot and barrier material [9]. The phonon spectra in the rectangular nanowires with an aspect ratio of 2 or greater were considered in Ref. [10]. The complete solution of this problem with the description of all types of the acoustic phonon polarization was given in Ref. [11].

In a number of our articles [13-15] acoustic phonon spectra and electron-phonon phenomena in the planar three-layered heterostructures with free and clamped surfaces were investigated in detail. In the present work we consider the rectangular heterowires with clamped outer surfaces. Due to the lateral confinement in the quantum wires we can expect more pronounced manifestations of the quantum phonon effects than in the planar heterostructures. We have calculated phonon energy spectra, phonon group velocities and distributions of the elastic deformations in the rectangular quantum heterowire with GaN core wire and different cladding barriers.

The remainder of the paper is organized as follows. Section 2 contains the derivation of the equation of motion for the elastic vibrations in the inhomogeneous rectangular heterowire. The hexagonal symmetry of GaN core wire is accounted. There are formulated the boundary conditions for the heterowire with clamped outer surfaces. The method of numerical solution of the equations of motion for the rectangular heterowire with inhomogeneous distribution of the mass density and elastic constants in the cross-sectional plane is described.

The results of the calculation of phonon energy spectra and group velocities depending on phonon wavenumber and phonon frequency are presented in Section 3. The conclusions are given in Section 4.

2. Theoretical model

We consider the structure consisting of rectangular GaN wire (forming quantum well) confined in the rectangular barrier. A schematic view of the structure is presented in the insets to Fig. 1.

As an example of the well material, there was used GaN, possessing wide perspectives of application in quantum electronics and optics. It is important to note that calculating programs developed and used by us allow considering the any combinations of the wells and the barrier materials. It is assumed that GaN crystal lattice has wurtzite structure with reference axis $c$ along the nanowire axis. The axis $X_3$ of the Cartesian coordinate system is directed along axis $c$, but axes $X_1$ and $X_2$ are in the cross-sectional plane of the nanowire parallel to its sides (see insets to Fig.1). The origin of the coordinate system is in the center of the nanowire. Linear sizes of the rectangular core wire are designated $d_{1}^{(1)}$ and $d_{2}^{(1)}$ while the total lateral dimensions (nanowire thickness plus barrier thickness) are $d_1$ and $d_2$ correspondingly. The lateral dimensions of the nanowire $d_{1}^{(3)}$ and $d_{2}^{(3)}$ are chosen in the nanometer range, while the length of the wire is formally considered as infinite. For the description of the influence of the barrier material we have calculated also phonon energy spectra for the bare GaN wire (see Fig.1(a,b)).

The equations of motion for elastic vibrations in an anisotropic medium can be written as

$$\rho \frac{\partial^2 U_m}{\partial t^2} = \frac{\partial \sigma_{mi}}{\partial x_i}, \quad m = 1, 2, 3; \quad i = 1, 2, 3,$$

(1)

where $\vec{U} = (U_x, U_y, U_z)$ is the displacement vector, $\rho$ is the mass density of the material, $\sigma_{mi}$ is the elastic stress tensor given by $\sigma_{mi} = c_{ijk} U_{jk}$, and $U_{ij} = (1/2)((\partial U_i / \partial x_j) + (\partial U_j / \partial x_i))$ is the
strain tensor. Some normal acoustical modes in an isotropic rectangular quantum wire without shell \( (c_{\text{dm}} = \text{const}) \) have been studied in Ref. [1] and for cubic quantum wire in Ref. [11]. At the differentiation performing in Eq. (1) it is necessary to take into account that investigated structure is inhomogeneous in the cross-sectional plane of the wire \((X_1, X_2)\), therefore elastic modules \( c_{\text{mod}}(x_1, x_2) \) and material mass density \( \rho(x_1, x_2) \) are the piece-wise functions of \( x_1, x_2 \).

At the performing of numerical calculations we replaced the piece-wise functions with the functions smoothly varying from the value in the nanowire material to the value in the barrier material. A posteriori check has shown that the selection of the smoothing function very weakly (of the order of calculation error) influences the calculated phonon energy spectrum and distributions of the displacements \( u_i(x_1, x_2) \) if the thickness of the transition layer is taken equal to or less than lattice constant and the smoothing function is selected without sharp changes of the derivatives. We have used the standard system of the two-index notations accepted in Ref. [13]. In the wurtzite crystal of the hexagonal symmetry (hexagonal space group \( C_{\text{6v}} \)) there are five different elastic modules: \( c_{11}, c_{33}, c_{12}, c_{13}, c_{44} \), where

\[
c_{11} = c_{2222}, \quad c_{33} = c_{3333}, \quad c_{12} = c_{1212}, \quad c_{13} = c_{1133} = c_{3311} = c_{2323} = c_{3222}, \quad c_{44} = c_{1313} = c_{3131}, \quad c_{55} = c_{44}, \quad c_{66} = c_{1212} = c_{2121} = (c_{11} - c_{22})/2.
\]

The axis \( X_3 \) is assumed to be along with the direction of the acoustical wave propagation. Since considered structure is homogeneous in the direction of \( X_3 \), and inhomogeneous in \((X_1, X_2)\) plane we look for the solution of Eq. (1) in the following form

\[
U_i(x_1, x_2, x_3, t) = u_i(x_1, x_2)e^{i(\omega t - q x_3)}
\]

Substituting Eq. (2) in Eq. (1) we take three equations for components of the displacement vector:

\[
(-\omega^2 \rho + c_{44}q^2)u_1 = c_{11}\frac{\partial^2 u_1}{\partial x_1^2} + c_{12}\frac{\partial^2 u_1}{\partial x_2^2} + c_{13}\frac{\partial u_1}{\partial x_1}\frac{\partial u_3}{\partial x_3} + c_{44}\left[\frac{\partial^2 u_1}{\partial x_1^2} + \frac{\partial^2 u_1}{\partial x_2^2}\right]
\]

\[

+ c_{44}\frac{\partial u_1}{\partial x_1} + \frac{\partial c_{11}}{\partial x_1} \frac{\partial u_1}{\partial x_1} + \frac{\partial c_{12}}{\partial x_2} \frac{\partial u_1}{\partial x_2} + \frac{\partial c_{13}}{\partial x_1} \frac{\partial u_3}{\partial x_3} + \frac{\partial c_{44}}{\partial x_1} \frac{\partial u_1}{\partial x_1} + \frac{\partial u_1}{\partial x_1}
\]

\[
(-\omega^2 \rho + c_{44}q^2)u_2 = c_{11}\frac{\partial^2 u_2}{\partial x_1^2} + c_{12}\frac{\partial^2 u_2}{\partial x_2^2} + c_{13}\frac{\partial u_2}{\partial x_1}\frac{\partial u_3}{\partial x_3} + c_{44}\left[\frac{\partial^2 u_2}{\partial x_1^2} + \frac{\partial^2 u_2}{\partial x_2^2}\right]
\]

\[

+ c_{44}\frac{\partial u_2}{\partial x_2} + \frac{\partial c_{11}}{\partial x_1} \frac{\partial u_2}{\partial x_1} + \frac{\partial c_{12}}{\partial x_2} \frac{\partial u_2}{\partial x_2} + \frac{\partial c_{13}}{\partial x_1} \frac{\partial u_3}{\partial x_3} + \frac{\partial c_{44}}{\partial x_2} \frac{\partial u_2}{\partial x_2} + \frac{\partial u_2}{\partial x_2}
\]

\[
(-\omega^2 \rho + c_{44}q^2 - c_{44}(\frac{\partial^2}{\partial x_1^2} + \frac{\partial^2}{\partial x_2^2}))u_3 - \left(\frac{\partial c_{44}}{\partial x_1} \frac{\partial u_3}{\partial x_1} + \frac{\partial c_{44}}{\partial x_2} \frac{\partial u_3}{\partial x_2}\right) = -q(c_{11} + c_{44})(\frac{\partial u_1}{\partial x_1} + \frac{\partial u_2}{\partial x_2}) - q\frac{c_{44}}{\partial x_1} \frac{\partial u_3}{\partial x_1} + \frac{\partial c_{44}}{\partial x_2} \frac{\partial u_3}{\partial x_2}
\]

In deriving these equations, we first made substitution \( u_3 = -iu_4 \) and then renamed the variable again as \( u_3 \equiv u_4 \).

From the invariance of the system of Eqs. (3-5) regarding reflection operations in these planes four possible types of solution follow [11]:

1. Dilatational (D): \( u_1^{AS}(x_1, x_2); u_2^{AS}(x_1, x_2); u_3^{SS}(x_1, x_2) \rightarrow u_4^{D} \);
2. Flexural1 (Flex1): \( u_1^{AS}(x_1, x_2); u_2^{SS}(x_1, x_2); u_3^{SA}(x_1, x_2) \rightarrow u_4^{F} \);
3. Flexural2 (Flex2): \( u_1^{SS}(x_1, x_2); u_2^{AS}(x_1, x_2); u_3^{SA}(x_1, x_2) \rightarrow u_4^{F} \); and
(4) Shear (Sh): \( u_{1}^{SA} (x_1, x_2); u_{2}^{SA} (x_1, x_2); u_{1}^{AA} (x_1, x_2) \rightarrow u_{1}^{SH} \), where \( S \) (A) means evenness (oddness) of the function in respect of the operation of sign conversion of the corresponding variable:
\[
 f(x_1, x_2) = f(-x_1, x_2) = f(x_1, -x_2) \rightarrow f^{SH} (x_1, x_2); \quad f(x_1, x_2) = -f(-x_1, x_2) = -f(x_1, -x_2) \rightarrow f^{AA} (x_1, x_2)
\]
and so on.

In the rectangular wire \( (d_1 = d_2) \) the degeneracy takes place and Flexural\(_1\) and Flexural\(_2\) polarizations become indistinguishable.

The displacement vector of the heterowire has the form:
\[
 \vec{U}(x_1, x_2, x_3) = \frac{1}{L_n} \sum_{\alpha, n, q} A_{n}^{(\alpha)} (q, \tau) \vec{w}_{n}(x_1, x_2, q)e^{-iqx}, \quad (6)
\]
where \( A_{n}^{(\alpha)} (q, \tau) \) are the amplitudes of the normal mode with polarization \( \alpha \) \( (\alpha = D, \text{Flex}1, \text{Flex}2, \text{Sh}) \) from the branch \( n \) with wavenumber \( q \). Vectors \( \vec{w} \) are satisfied to the normalized conditions:
\[
 \int \rho(x_1, x_2) \vec{w}_{n}^{(\alpha)} (x_1, x_2, q) \vec{w}_{n}^{(\alpha^*)} (x_1, x_2, q) dx_1 dx_2 = \rho_{n}^{(\alpha)} (q) \delta_{nn}^{\alpha} \delta_{\alpha\alpha}, \quad (7)
\]
\[
 \int \vec{w}_{n}^{(\alpha)} (x_1, x_2, q) \vec{w}_{n}^{(\alpha^*)} (x_1, x_2, q) dx_1 dx_2 = \delta_{nn}^{\alpha} \delta_{\alpha\alpha}, \quad (8)
\]
where integrals in Eqs. (7) and (8) are taken over the surface of heterowire cross-sectional plane.

In the case of the clamped boundaries the displacement vector components are zero on the outer surfaces of the wire:
\[
 w_1 = w_2 = w_3 = 0, \quad (9)
\]

3. Results and discussion

The solutions of Eqs. (3-5) have been found numerically using the finite difference method. The calculations were carried out for the nanowires with the cross-section \( 2 \text{ nm x 3 nm} \) embedded into “acoustically slow” plastic barrier and “acoustically fast” AlN barrier. The complete cross-sections of heterowires were \( 4 \text{ nm x 6 nm} \) and \( 6 \text{ nm x 9 nm} \).

For the investigation of the influence of the barriers the wires without barriers were also considered with cross-section equal to (i) cross-section of the heterowires core \( (2 \text{ nm x 3 nm}) \) and to (ii) complete cross-section of the heterowires \( (4 \text{ nm x 6 nm} \) or \( 6 \text{ nm x 9 nm} \)). The values of material parameters, used in our calculations were taken from Refs. [13, 16]. Due to a large number of phonon branches of all polarizations present in the rectangular nanowire we mostly represent and discuss data for the dilatation polarization. The number \( n \) of quantum branches (levels) in the wire can be expressed as \( n_{\text{max}} = d_1 d_2 / (4a_1 a_2) \), where \( a_1, a_2 \) are lattice constants in the cross-sectional plane of the wire. So the number of quantified branches in wire is \( d/2a \) times greater than in the planar structure and growth \( \sim d^2 \) with the increase of the cross-section of the wire.

The dispersion curves of the dilatational polarization are presented in Fig. 1 for GaN wire of \( 2\text{nm x 3nm} \) cross-section (Fig. 1(a)); for GaN wire of \( 4 \text{ nm x 6 nm} \) cross-section (Fig. 1(b)); for GaN/AlN heterowire of \( 4 \text{ nm x 6 nm} \) cross-section with GaN core of \( 2 \text{ nm x 3 nm} \) cross-section (Fig. 1(c)) and for GaN/plastic heterowire of \( 4 \text{ nm x 6 nm} \) cross-section with GaN core of \( 2 \text{ nm x 3 nm} \) cross-section. In the considered case, when the wire axis is directed along reference axis \( c \), \( a(\text{GaN}) = 0.318 \text{ nm} \) and \( a(\text{AlN}) = 0.311 \text{ nm} \) (where \( a \) is the lattice constant in the plane perpendicular to axis) [16].
Fig.1. Phonon energy spectrum as functions of the phonon wave number $q$ for (a) GaN wire with 2 nm x 3 nm cross-section (ground levels $n = 0$ are given for all polarizations); (b) GaN wire with 4 nm x 6 nm cross-section; (c) GaN/AlN heterowire with 4 nm x 6 nm cross-section and for (d) GaN/Pl heterowire with 4 nm x 6 nm cross-section. The results are shown for dilatational polarization.

Therefore in GaN wire of 2 nm x 3 nm cross-section the number of phonon quantum branches $n_{\text{max}} = 15$ for each polarization. In the wires with cross-section of 4 nm x 6 nm $n_{\text{max}}$ is already equal to 59, but in the heterowires of 6 nm x 9 nm cross-section $n_{\text{max}} = 135$. Since the lattice constants for GaN and AlN are similar, the calculation of $n_{\text{max}} = d_d / l(4a^2)$ for the GaN/AlN heterowire gives approximately the similar values of $n_{\text{max}}$ at the using of $a(GaN)$ or $a(AlN)$. In the case of the plastic material the characteristic constant $a(Pl)$, playing the role of the lattice constant can be larger than $a(GaN)$. As a result, the computation of $n_{\text{max}}$, using the value of $a(GaN)$ gives rather overestimated value of $n_{\text{max}}$. Remaining in the limit of continual approximation it is difficult to determine precisely the position of high level. However, the high branches do not participate in the majority of representing interest effects. In Figs.1(b)-1(d) 5 lowest levels and higher levels with numbers 8, 18, 28, 38, 48, and $n_{\text{max}} = 58$ are depicted.

The main conclusion from the obtained results is as follows. All energy levels are dimensionally quantized and the cross-sectional sizes of the wire and difference in the elastic constant between the heterowire core and barrier considerably influence the lower part of the energy spectrum.
As one can see from the comparison of the graphs in Figs. 1(a) and 1(b) the reduction of the wire cross-section leads to the reinforcement of the size-quantization in the lower part of spectrum but weakly influences the structure and position of higher energy levels. It is explained by the fact that position of the higher levels is determined by the inverse value of the lattice parameter 1/a whereas dimensional quantization in the lower part of spectrum depends on 1/d, i.e. it is determined by the wire sizes. The influence of the elastic properties of the barriers is shown very strongly in the energy spectra of the heterowires. “Acoustically slow” barriers narrowed spectrum but “acoustically fast” widened it. In the GaN wire of 4 nm x 6 nm cross-section (see Fig. 1 (b)) the first ten phonon levels are concentrated in the energy interval of 9.5 meV, while the whole spectrum \( h\omega(q = 0) \) is placed in the interval 22 meV. In the GaN/plastic heterowire (Fig. 1 (d)) the same number of lower levels is concentrated in the considerably less energy interval of 3 meV. But in the case of GaN/AlN heterowire first 10 levels are in the 11.9 meV energy interval. All spectra at \( q = 0 \) are placed in interval of 27.3 meV.

The described modifications of the phonon energy spectrum in the wires, embedded into acoustically mismatched shell can become the important element of the phonon engineering.

\[
\text{Fig.2. Averaged phonon group velocities as a function of the phonon frequencies for different GaN wires and different heterowires.}
\]

Group velocity of the phonon plays an important role in the phenomena of heat conductivity. The group velocities averaged over all quantum branches from \( n = 0 \) to \( n_{\text{max}} \) and over all polarization types (D, Flex1, Flex2, Sh) are given by:

\[
\bar{v}(\omega) = \frac{1}{4} \sum_{\alpha} \sum_{n(\alpha)} g(\omega) \left( v_n^{(\alpha)}(\omega) \right)^{-1}.
\]

In this formula the summing up is carried out by the numbers of dispersion branches \( n \), containing the frequency \( \omega \), but \( g^{(\omega)}(\omega) \) is the number of given branches. Curves \( \bar{v}(\omega) \) (see Fig. 2), calculated in accordance with the given formula, are strongly oscillating due to the presence of many phonon branches and sharp changes of the function \( (v_n^{(\alpha)}(\omega))^{-1} = \frac{dq_n^{(\alpha)}(\omega)}{d\omega} \).

So, in Fig. 2 “smoothed” curves without minor vibrations are presented. Due to the size quantization the reducing of the phonon group velocities takes place in the slab in comparison with their values in the bulk at the same values of wave vectors \( q \) (so called slab-effect). In the wires, due to the lateral confinement, this effect is shown more strongly. Moreover selecting the elastic properties of the barriers we can influence considerably the value of the phonon group velocities. From the comparison of the graphs in Fig. 2 one can see that plastic
(AlN) barriers decrease (increase) sound velocity in the heterowire in comparison with GaN wire without barriers. This effect is further reinforced if the barrier thickness increases.

Simple averaging of the elastic modules and mass densities in the structure does not allow explaining such strong influence of the barriers. The physical origin of the described effects is redistribution of the displacements $\vec{w}_n(x_1, x_2, q)$ in the cross-sectional plane of the heterowire.

![Fig.3. Distribution of the displacement vector components of the normal dilatational mode ($n=0$, $q=0.1$) in the cross-sectional plane of GaN/Pl heterowire: (a) the component $w_3(x_1, x_2, q = 0.1)$ and (b) the vector $\vec{w}_2(x_1, x_2, q = 0.1)$.

![Fig.4. Distribution of the displacement module $w = \sqrt{w_1^2 + w_2^2 + w_3^2}$ of the normal dilatation mode ($n=0$, $q=1.0$). The results are shown for: (a) GaN wire; (b) GaN/AlN heterowire; (c) GaN/Pl heterowire.](image)

![Fig.5. The same as in Fig.4 but for the phonon mode ($n=4$, $q=1.0$).](image)
The distribution of the displacement vector component \( w_{x}^{0}(x_{1}, x_{2}, q = 0.1 \text{nm}^{-1}) \) and of the vector \( w_{x}^{0}(x_{1}, x_{2}, q = 0.1 \text{nm}^{-1}) \) in the wire cross-section are shown in Fig. 3 (a, b) for the dilatational mode. One can see from these figures that displacements of given mode are mainly concentrated in the “acoustically slow” plastic barrier of the heterowire.

The dependences of the distribution of the displacement vector module \( w(x_{1}, x_{2}, q) = \sqrt{w_{1}^{2} + w_{2}^{2} + w_{3}^{2}} \) on the value of \( n \) (\( n = 0, 4, 8 \)) are presented in Figs. 4-6. In GaN/Pl heterowire for all values of \( n \) the displacements are concentrated in Pl barrier and practically absent in GaN core (see Figs.4 (c)-6 (c)). If GaN is the quantum well of the nanostructure the weakening of the electron-phonon interaction will happen in it.

Fig.6. The same as in Fig.4 but for the phonon mode \((n=8, q=1.0)\).  
Fig.7. Distribution of the displacement vector module \( w_{x}^{0}(x_{1} = 0, x_{2}, q) \) on dependence on the phonon wavenumber \( q \) for (a) GaN wire, (b) GaN/AlN heterowire and (c) GaN/Pl heterowire in the cross-sectional plane \( x_{1} = 0 \).
The decrease of the $w$ function takes place in the GaN/AlN heterowire in the external AlN region in comparison with its values in GaN wire (see Figs. 4 (b)-6 (b)). Besides that, in the case $n=4$ the central saddle point in GaN wire is transforming in the local peak in GaN/AlN heterowire. But in the case $n=8$ the local minimum in the center of the GaN wire transforms also in the local peak. The latter should lead to the enhancement of the electron-phonon interaction in GaN core of the heterowire.

For the description of the dependence of the displacement vector module distribution on $q$ the surfaces $w_n^{(a)}(x_i = 0, x_2, q)$ and $w_n^{(b)}(x_i = 0, x_2, q)$ are shown in Figs. 7 and 8 correspondingly for the GaN wire (a), GaN/AlN heterowire (b) and GaN/Pl heterowire (c). These graphs describe the evolution of the $w$ function in the cross-section plane $x_i = 0$. As one can see from these figures, the amplitude of the displacements increases in the “acoustically slow” barriers of GaN/Pl heterowires (see. Fig.7 (c), 8 (c)) and decreases in the “acoustically fast” barriers of GaN/AlN heterowires (see. Fig.7 (b), 8 (b)) with increasing of the value of $q$. General tendency consists in the accumulation of the displacements in the “acoustically slow” material with the increasing of both $n$ and $q$ (phonon depletion and accumulation effects in core wire).

In consequence of insignificant difference in the acoustic parameters of GaN and AlN in GaN/AlN heterowire the effect of the redistribution of deformations is not exhibited so strikingly as in GaN/Pl heterowire.

Fig.8. The same as in Fig.7 but for the phonon modes $n = 2$.

4. Conclusion

The acoustic properties of rectangular GaN wires covered by elastically dissimilar barriers with clamped outer surfaces had been considered. The equations of motion were solved numerically taking into account the non-uniform distribution of the elastic properties and mass densities in nanowires. There were obtained the phonon energy spectra and phonon group velocities. The spatial distributions of the displacement vectors of the normal modes in the wire cross-section had been described. It was established that “acoustically slow” barriers “compress” the phonon energy spectrum but “acoustically fast” ones “widen” it. It was also shown that acoustically dissimilar barriers strongly influence the phonon group velocities, increasing or decreasing them, depending on material of the shell. The established effects should have important manifestations in the thermal processes and electron-phonon phenomena in the nanodimensional heterowires.
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