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50. Internationales Wissenschaftliches Kolloquium
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L.S. Lunin / M.L. Lunina / A.V. Blagin / A.A. Barannik

$InSb_{1-x}Bi_x$/InSb SUPERLATTICE PROPERTIES

ABSTRACT

IN THE WORK RESULTS OF EXPERIMENTAL AND THEORETICAL STUDIES OF multilayered heterostructures InSbBi/InSb are discussed.

New Materials and Manufacturing Technologies for Structures from Macro to Micro

THE ANALYSIS OF HETEROJUNCTION PHYSICAL PROPERTIES CARRIED OUT BY out by us for heterostructures InSbBi/InSb has shown that the reason of probable frequency characteristics and Q-factors degradation of photodetectors with use of the solid solutions can be energy gaps in the band heterojunction structure. Efficiency of a heterojunction with an energy gap ΔE in the valence band on the heteroboundary is proportional $exp(\Delta E/kT)$.

Carriers capture results in delay of a photocurrent relaxation with a time constant $\tau \sim exp(\Delta E/kT) \geq 10$ nsec, that essentially reduces photodetectors velocity. For the heterojunction $InSb_{0.98}Bi_{0.02}$/InSb values of ΔE makes about 0.05 eV.

Heterojunction smoothing is achieved by application of buffer layers of constant or variable composition through the layers[1]. Here superlattice structures can appear an optimum decision; their variability is kept on the large lengths ~ 1.5 mcm.

For the realization of our project double heterostructures InSb-InSbBi were received. One of the liquid phase epitaxy variants of superthin layers obtaining was put at the base of multilayered heterostructure implementation technology modified by us[2]. The essence of the offered technological approach consists in formation of a multilayered heterostructure in one process of substrate moving across technological cartridge cells with solutions–melts that causes constant speed of substrate moving concerning all cells and as a consequence an identical quantum wells thickness. Change of thickness of variable compositions epitaxial layers is achieved due to change of the sizes of cells containing solutions–melts.

The temperature interval is chosen for the InSb substrate from 623 up to 633 K, for the GaSb substrate – 896–906 K. The top border is caused by strong increase in the basic and auxiliary layers growth rate with rise in epitaxy temperature and, hence, reduction of the method reproducibility. The bottom border was determined by the beginning of crystallization process. Besides at low temperatures one can observe an appearance of kinetic restrictions on the growth surface, and also the restrictions connected with the expansion of unmixing areas in a solid phase[3]. The temperature mode was carried out by the research of solidus–liquidus temperatures for each composition with a visual-thermal analysis method. Layers InSb alternating to layers InSbBi form a correct periodic structure with the period T_{SL} = 120 nm. X-rays measurements have shown that the total thickness of a pair layer (InSb and InSbBi) $d_1 + d_2$ = 120 nm. From a layer to a layer the band gap value through such a superlattice is modulated under the law: $E_g(x) = (E_{g1}d_1+E_{g2}d_2)/(d_1 + d_2)$.

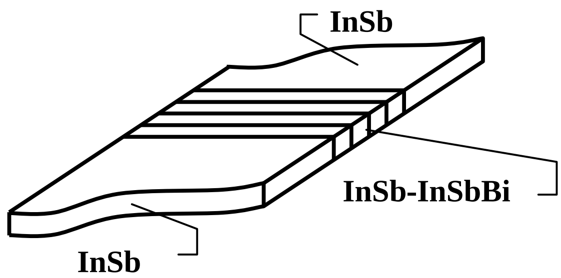

Fig. 1. A scheme of an avalanche photodiode on the base of a superlattice InSb-InSbBi

Thus the problem of setting solid solution structure changes on small lengths (~ 0.1 microns) is solved. A gradient layer decreases the energy gap value in the valence band so that $\Delta E \to 0$ and long-time relaxation component in photodetector response $\tau \to 0$. At the same time velocity increases up to values ~1 nsec. The structure of such an avalanche photodiode is submitted on fig. 1. Topologically such a deviceis resulted in a photodetector structure with raster electrodes isolated with an indirect inclusion of p-n-junctions.

With the purpose of InSbBi-InSb applications forecasting we investigated an electron energy spectrum in the quantum well system of the heteropair $InSb_{1-x}Bi_x$/InSb divided with the transparent barriers. For the description of electron conditions in semiconductor heterostructures *kp*-, matrix methods and a bending method are used. The wave function of a heterostructure in each layer is decomposed on electron functions of the appropriate layer. Despite of an approximate character of a bending method, it has shown good approximation even in the case of several internuclear layers of quantum wells and barriers that in a combination with simplicity of numerical calculation algorithm makes the method deserving attention of physicists and technologists studying low-dimensional structures.

Calculations show that at resonances anticrossing is observed (fig. 2). At complication of the system hierarchy the band gap decreases and probable bands areas increases. With the addition of two layers (well/barrier) energy levels appear as one strip in each band. Thus, the unit of structure is one layer (a pair - well/barrier).

When the number of wells is six or more relative stabilization of a spectrum is also observed: at the levels addition in the permitted bands their width and band gap value remain practically constants (fig. 3). As calculations have shown these values were 0.013 эВ and 0.0013 эВ for the permitted bands and 0.062 эВ for band gap.

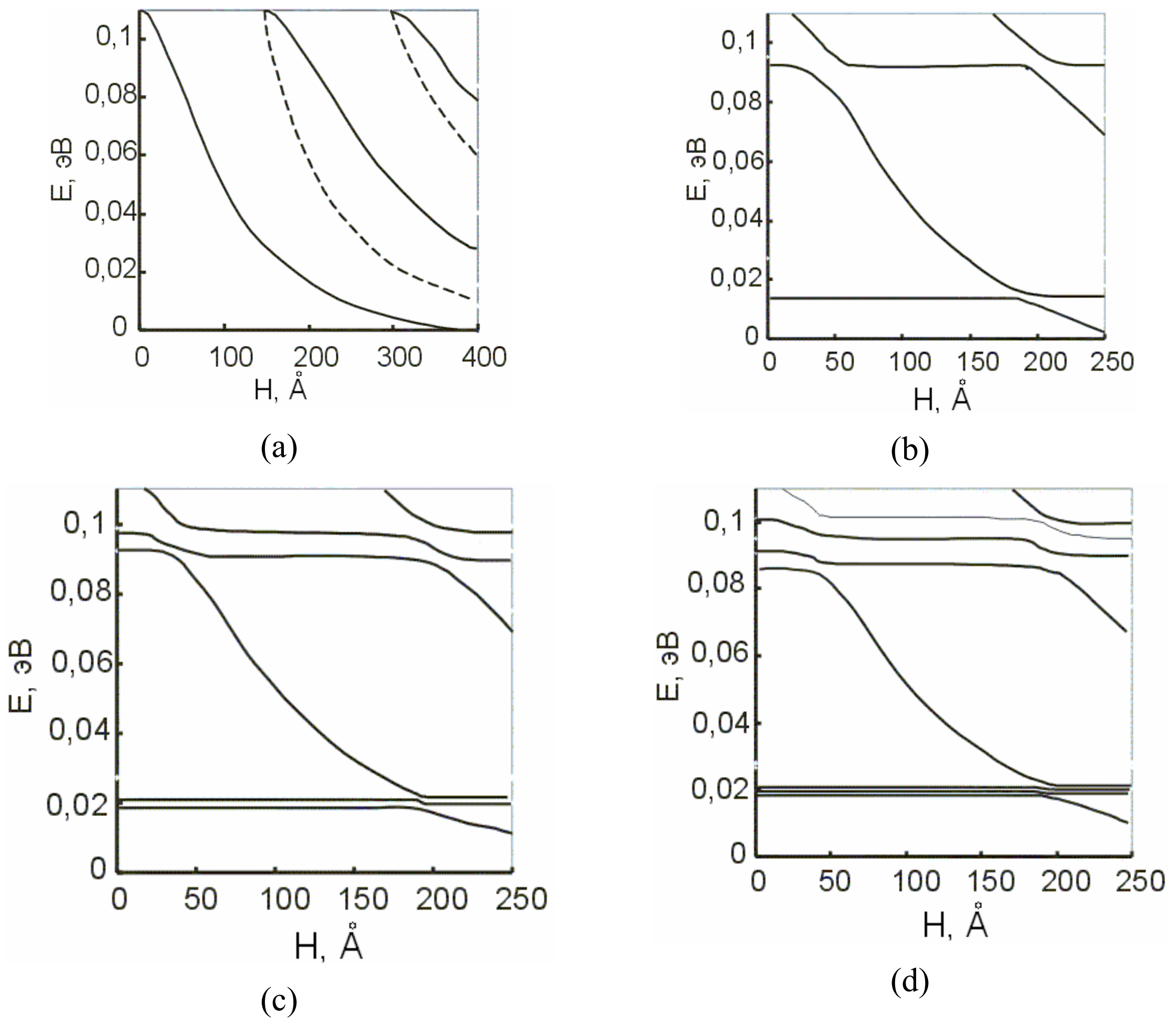

Fig. 2. Energy levels of dimensional quantization of n-well structures (eV) versus width of the n-th well (each barrier width – 200Å): a) n = 1, b) n = 2, c) n = 3, d) n = 4

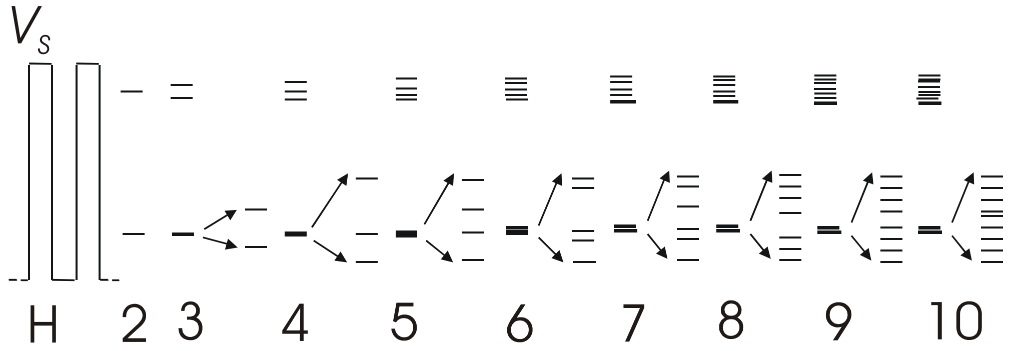

Fig. 3. The power circuit of hierarchical structures $InSb_{1-x}Bi_x/InSb$.
In columns 2-10 the structure of a spectrum is given in case of 2-10 wells. Arrows limit a spectral site and show the increase of scale

The distance between levels for the top permitted band is ~10^{-3}eV, for the bottom permitted band is ~10^{-4}eV. Anticrossing of energy levels already takes place at the well width about 20 nm.

These effects result in such new physical phenomena in low-dimensional systems, as tunneling of carriers under the action of an electric field when the basic condition of one well coincides with the excited condition of the following; amplification and generation of fluctuations with limiting frequency from above 10^{12} Hz.

The obtained structures are also attractive from the view point of light distribution optics (fig. 4–7). In the work investigations of electron energy spectrum dependence from thickness (l) and number (N) of layers are carried out as well as treating with rays process in 5-11 layer heterostructures $InSb_{0.97}Bi_{0.03}/InSb$ is considered by *kp*- and matrix methods. Calculations verified by experiments[4] show that with an addition of every pair of layers (well/barrier) there is an energy level appearance. N-increasing leads to spectrum displacement into the infrared field. For thick (l>0.1 mcm) layers it's typical high infrared sensitivity.

Because of the continuity of electromagnetic field tangential constituents at the heteroboundary the transfer matrix Z is single. Through the all multilayer structure Z is the product of Z_i through N_i layers beginning at the side of illumination. With N-increasing there is a rise of the superlattice reflection coefficient R. When N=11, $R \to 1$, i.e. structure is almost an ideal reflective coating (illumination angle α=0, λ=7.7 and 11 mcm, l=0.1 mcm). For α=0 there is a transparency maximum. If N=3, the transparency coefficient $P \to 0.8$, with N-increasing up to 17 P decreases to 0.3. When α=0–π/2, P=0.8–0. So varying illumination angle one can obtain required P and R without changing of multilayer structure configuration.

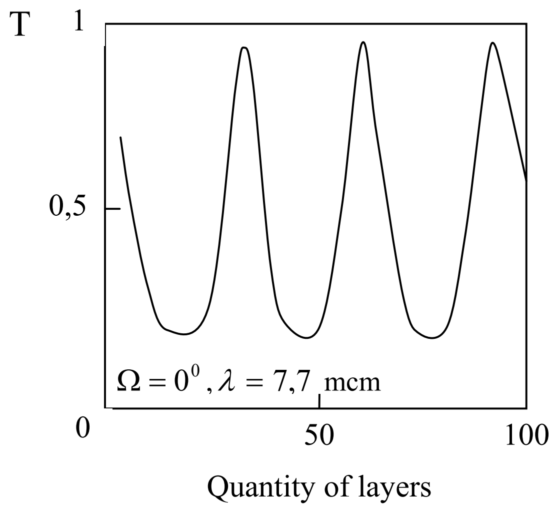

Fig. 4. Transparent coefficient T of multilayered structure $InSb_xBi_{1-x}/InSb$ versus quantity of layers. x=0,03, illumination angle $\Omega = 0^0$, wavelength $\lambda = 7,7$ mcm, layers thickness 0,1 mcm.

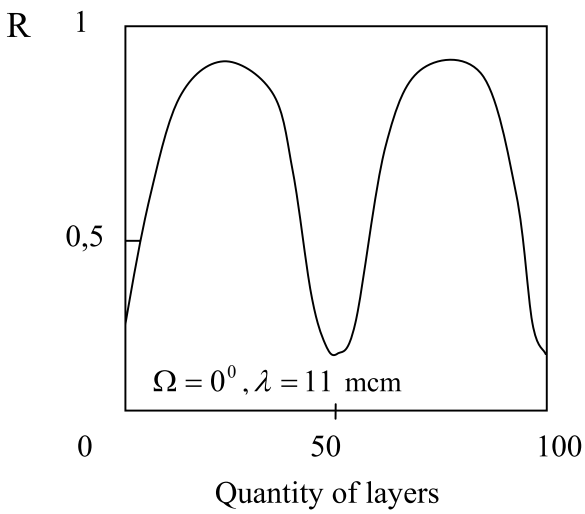

Fig. 5. Reflection coefficient R of multilayered structure $InSb_xBi_{1-x}/InSb$ versus quantity of layers. x=0,03, illumination angle $\Omega = 0^0$, wavelength λ=11 mcm, layers thickness 0,1 mcm.

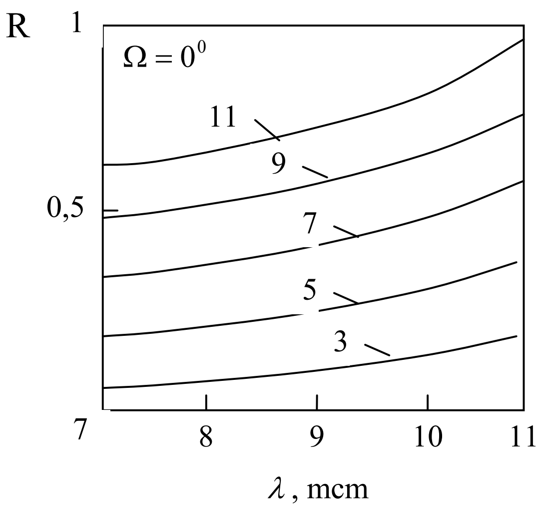

Fig. 6. Reflection coefficient R of multilayered structure $InSb_{1-x}Bi_x/InSb$ versus wavelength of light. x=0,03, illumination angle $\Omega = 0^0$, layers thickness 0,1 mcm, number of layers 3-11.

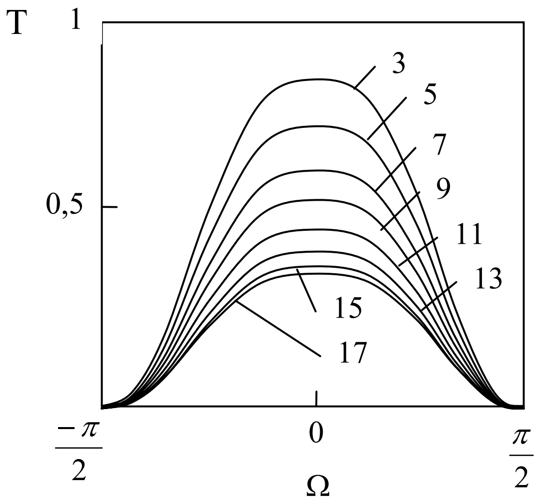

Fig. 7. Transparent coefficient T of multilayered structure $InSb_{1-x}Bi_x/InSb$ versus illumination angle of light for different number of layers. x=0,03, number of layers 3-17.

Superlattice properties can be used in infrared photodetectors (photoluminescence spectra have a maximum near 8.7 microns), clarified coatings, heterojunction smoothing to avoid degradation of frequency characteristics and Q-factor because of the energy band gaps in sharp heterojunctions.

References:

[1]. *M.Razeghi and A.Rogalsky.* Semiconductor ultraviolet detectors // Applied physics reviews. 1996, V.79. №10. P.7433-7473

[2]. *Z.I.Alferov, D.Z.Garbuzov, I.N.Arsent'ev, B.J.Ber, L.S.Vavilova, V.V.Krasovsky, A.V.Chudinov.* Semiconductor Physics and Technique, 19, 1108 (1985).

[3]. *Akchurin R.H., Saharova T.V., Zhegalin V.A.* // Proceed. Of High Educational Establishments. Ser. Nonferrous metals. 1994. Release 7. P.23-27.

[4]. L.S.Lunin, M.L.Lunina, A.V.Blagin Avalanche photodiodes on the base of InSbBi-InSb superlattice. / Proc. Of VII International conference "Actual problems of solid state electronics and microelectronics". Divnomorskoe, Russia, 2000, V.2. P.172.

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