HETEROSTRUCTURES OF ANTIMONIDE-BASED SEMICONDUCTORS

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ABSTRACT

The article is devoted to semiconductors with low-dimensional systems, which are actively developing and are a relatively new direction. The concept of quantum wells, quantum threads, and quantum dots is revealed in the paper. The concept of Quantum States is important for active device technology, for example the behavior Quantum well lasers, Photo detectors, Resonant Tunneling Diodes etc. can be explained by means of this concept.

Keywords: *Molecular beam epitaxy, Quantum wells, effective mass, potential well, Schrodinger equation, finite barrier.*

АННОТАЦИЯ

Статья посвящена полупроводникам с низкоразмерными системами, которые активно развиваются и являются относительно новым направлением. В статье раскрывается понятие квантовых ям, квантовых нитей и квантовых точек. Концепция квантовых состояний важна для технологии активных устройств, например, с помощью этой концепции можно объяснить поведение лазеров с квантовыми ямами, фотодетекторов, резонансных туннельных диодов и т. Д.

Ключевые слова: *молекулярно-лучевая эпитаксия, квантовые ямы, эффективная масса, потенциальная яма, уравнение Шредингера, конечный барьер.*

INTRODUCTION

Molecular beam epitaxy allows routine production of heterostructures where composition changes over atomic length scales. The interface of a heterostructure may serve as a barrier to electrons and/or holes because of the change in band gap and the nature of the band alignments. Semiconductor alloys can have band gaps and alignments spanning their constituent semiconductor components. The band gap, E_g, is plotted against the lattice parameter for several semiconductors and their alloys in Fig. 1. The data is taken from reference [1].

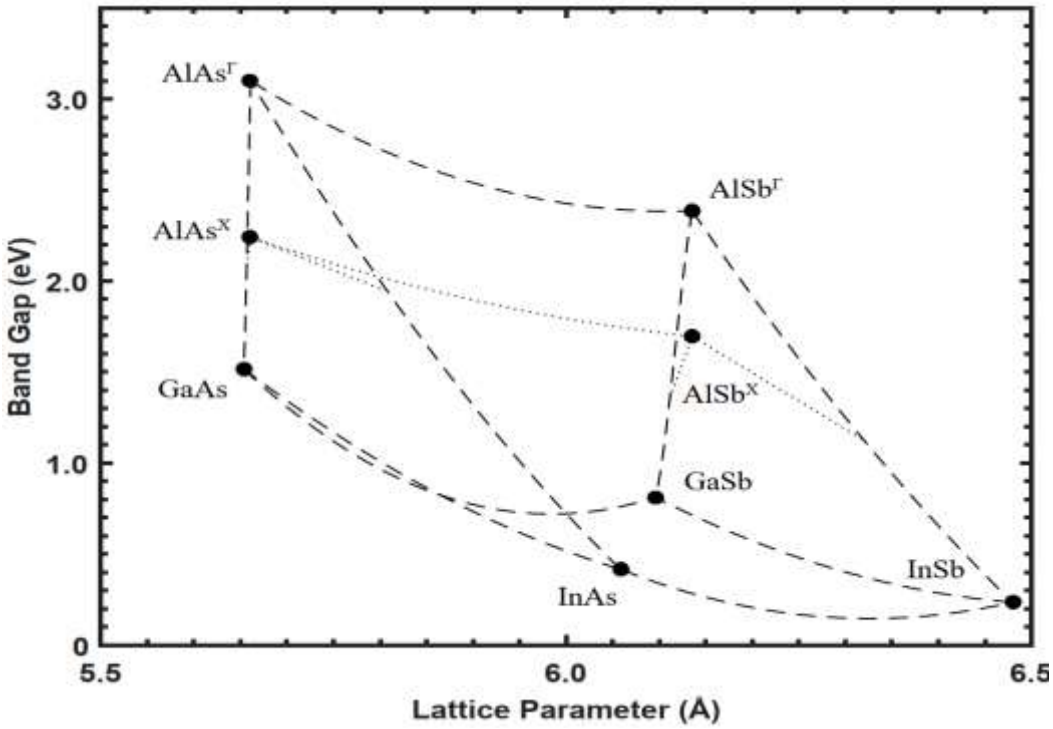

Figure 1: Band gap and lattice constants of several compound semiconductors and their ternary alloys. Band parameters were taken from Vurgaftman et al. [1].

The functional dependence of band parameters on chemical composition is not necessarily linear as suggested by Vegard's law. Bowing of band parameters is accounted for in the curves representing the band gaps of semiconductor alloys.

When a thin narrow band gap material is sandwiched between wider band gap materials electrons or holes may be confined within the narrow gap material if the alignment of conduction or valence bands produce a potential well [16]. The carriers become trapped in the confining potential; their motion along the growth direction is restricted and the continuous band is quantized into sub-bands. Their motion in the plane of the well is unrestricted, and they behave two-dimensionally. Quantum wells (QWs) are critical structures in many electronic and opto-electronic devices. They are also important in the field of condensed matter research, where they provide a system in which carrier density, density of states, confinement energy, band structure and spin-orbit coupling can be controlled and modified.

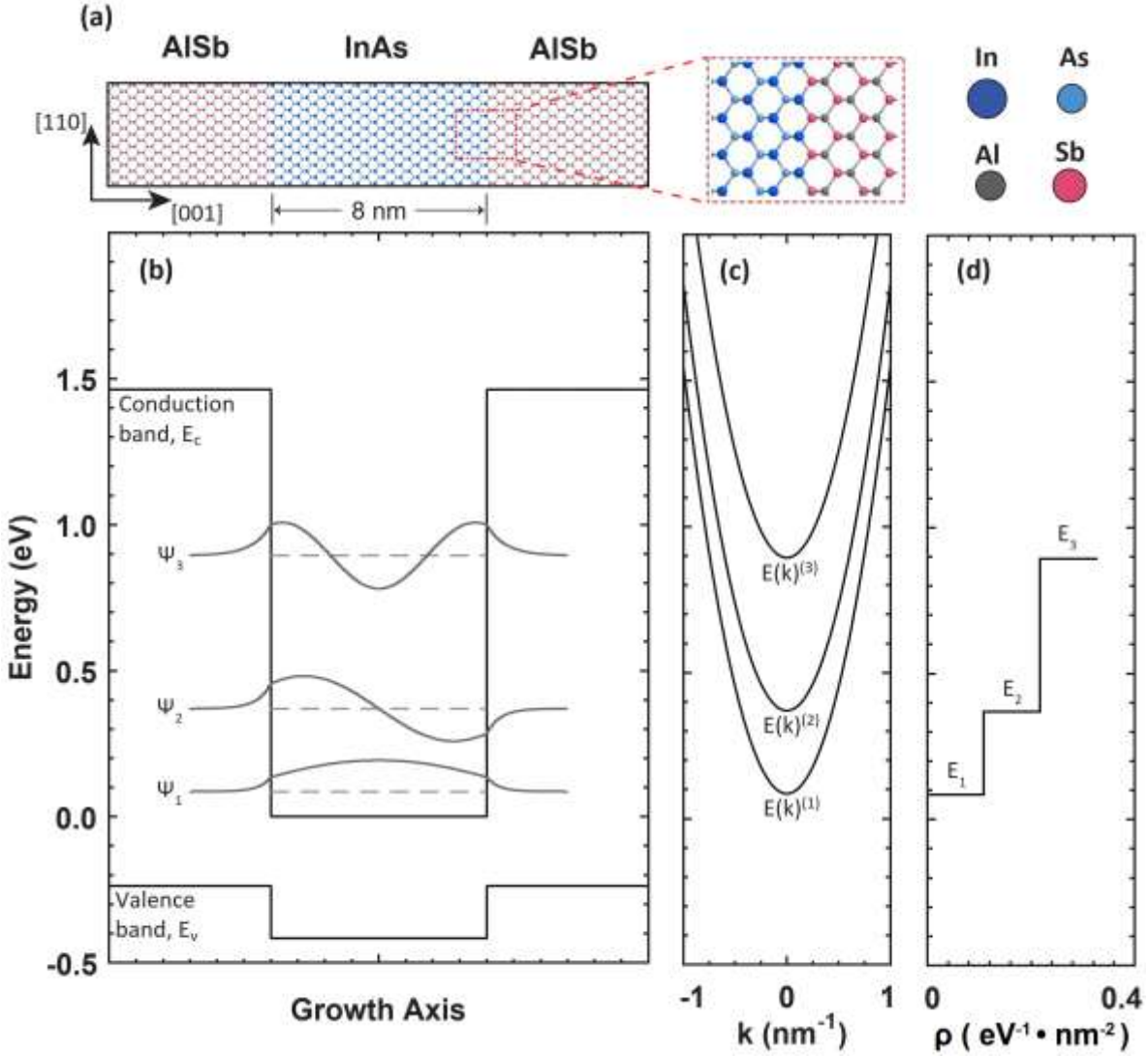

Figure 2: (a) An AlSb/InAs/AlSb heterostructure viewed along the [2-30] crystal-lographic direction. (b) The band structure along the [001] growth axis of the het-erostructure shown in (a), the bound state energy levels and wavefunctions. (c) The electronic subband dispersion of the bound states (d) The two-dimensional density of states.

DISCUSSION

Quantum mechanics predicts the properties of particles confined to quantum heterostructures. Solving the Schrodinger equation for a one-dimensional particle in an infinitely deep well of width a produces energy eigenvalues,

$$E_n = \frac{1}{2m}\left(\frac{\hbar n\pi}{a}\right)^2, \quad (1)$$

where $m = m^* m_e$, and m^* is the effective mass. In reality confinement potentials have finite barrier heights, as in the case of an AlSb/InAs/AlSb

heterostructure, Fig. 2a. The confinement potential for electrons is the conduction band offset between InAs and AlSb. The bound-state electron wavefunctions are able to penetrate the finite potential barriers and a change in the energy levels with respect to the infinitely deep well of the same width is observed. The energy levels and wavefunctions are determined numerically by a self-consistent solution of the Schrodinger-Poisson equations [17]. The band edges and wavefunctions are shown in Fig. 2b. The conduction sub-band dispersion relation, Fig. 2c, describes the allowed quantum mechanical states as a function of in-plane wavenumber (momentum), $k_{x,y}$,

$$E(k) = E_n + \frac{\hbar^2(k_x^2+k_y^2)}{2m} \quad (2)$$

for electrons confined in the growth direction but free in the plane of the quantum well.

Confinement alters the density of states from the parabolic form for three dimensional electrons to a step-like density of electronic states of the form $m/\pi\hbar^2$, starting at E_n, shown in 2d. The number of occupied subbands depends of the density of electrons and the temperature.

The ability to control the carrier density, density of states, confinement energy, band structure and spin-orbit coupling in heterostructures are critical reasons for their use in creating topologically protected states. Controlling these parameters reduces to controlling the energy level of quantized states and the chemical potential of charge carriers with respect to the energy levels of those states. An example follows illustrating this process.

Heterostructures of InAs, GaSb and an electrically insulating barrier, for example AlSb, are predicted to form a two-dimensional topological insulator phase (a quantum spin Hall phase), when the electronic conduction sub-bands in InAs form below the electron valence sub-bands in GaSb. Quantum mechanical coupling between these states result in a hybridization gap in the dispersion, which is spanned by spin-polarized counter-propogating edge states [18]. When the InAs/GaSb heterostructure is made the conduction channel of a dual-gated Hall bar, as shown in Fig. 3 (a), the sub-band structure and Fermi-level can be independently tuned by the action of the two gates, on which electrostatic potentials are applied relative to the conduction channel.

A measurement of the longitudinal resistance in an InAs/GaSb heterostructure under an applied bias that approximately keeps the sub-band structure constant while changing the Fermi level is shown in Fig. 3(b). This structure and additional transport measurements were discussed in [4]. A calculated in-plane two-dimensional

dispersion and schematic helical edge-states are shown in Fig. 3(c). The corresponding two-dimensional density of states are shown in Fig. 3(d). The colored bars track the approximate position of the Fermi level under applied bias and along the dispersion and density of states.

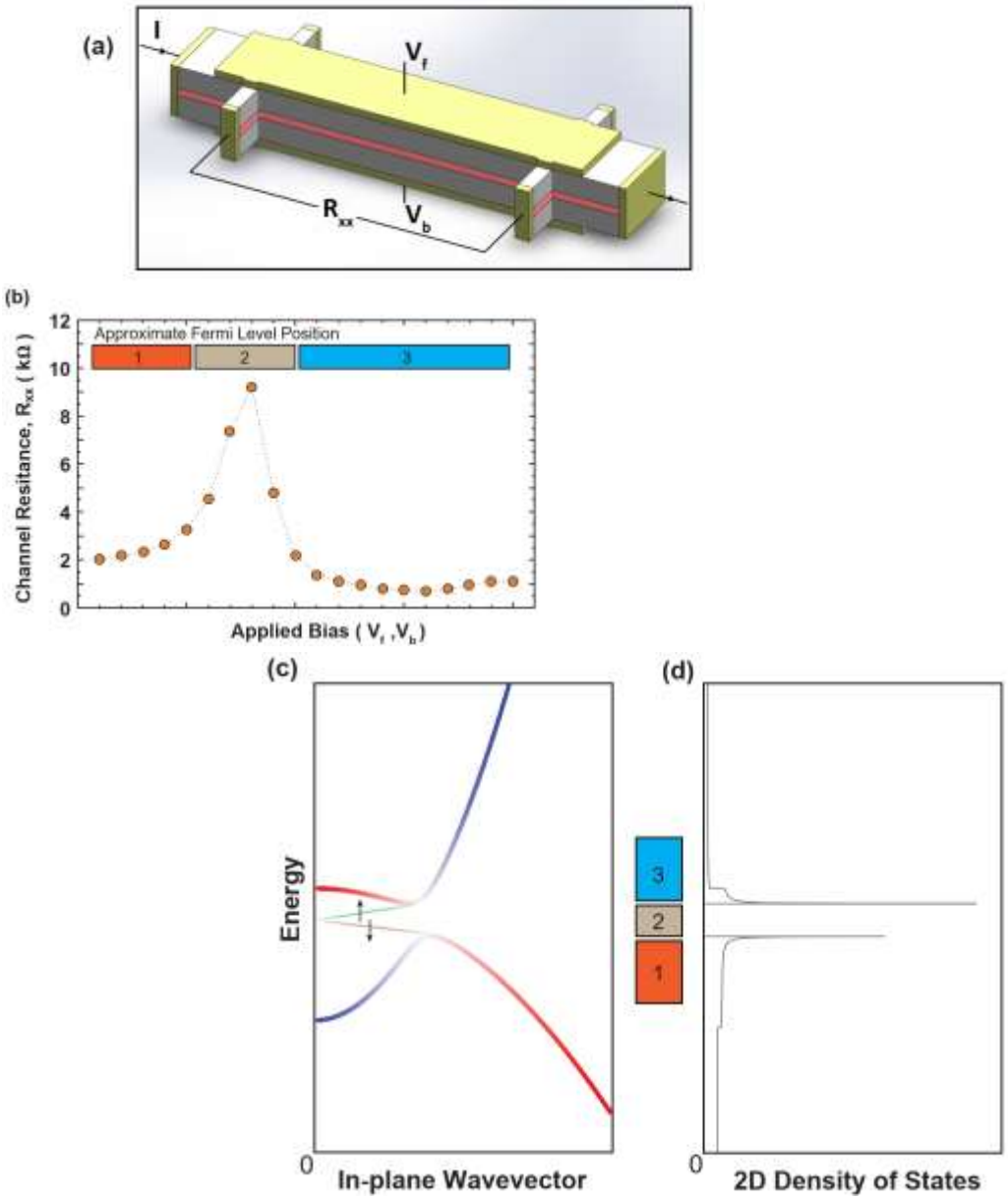

Figure 3: (a) The dual-gated Hall bar structure discussed in the text. (b) The channel resistance measured in an InAs/GaSb heterostructure along a line of applied bias by the front a back gate that maintains an approximately constant electric field over the heterostructure but varies the Fermi level. (c) A calculated two-dimensional dispersion of an InAs/GaSb bilayer structure with schematic spin-polarized edge states. (d) The calculated two-dimensional density of states.

CONCLUSION

Electronic structure of the heterostructures is discussed, as well as the impact of defects on electronic properties and the application of these heterostructions for their use in different area.

REFERENCES

1. Vurgaftman I., Meyer J. R., Ram-Mohan L. R. Band parameters for III–V compound semiconductors and their alloys //Journal of applied physics. – 2001. – Т. 89. – №. 11. – С. 5815-5875.
2. Rasulov V. R. et al. Investigation of dimensional quantization in a semiconductor with a complex zone by the perturbation theory method //September–October. – 2018. – С. 253.
3. Rasulov R. Y. et al. Crystals with tetrahedral and hexagonal lattices //Fergana. Classic. – 2021.
4. Rasulov R. Y. et al. Diagonal matrix elements of the effective Hamiltonian in a semiconductor (taking into account spin-orbit interaction) //European science review. – 2020. – №. 1-2.
5. Rasulov R. Y. et al. On the theory of one-photon absorption of polarized light in narrow-gap crystals. taking into account the effect of coherent saturation // Eurasian Union Scientists. – 2021. – Т. 5. – №. 1 (82). – С. 56-59.
6. Rasulov R. Y. et al. On the theory of one-photon absorption of polarized light in narrow-gap crystals. excluding the effect of coherent saturation //Eurasian Union Scientists. – 2021. – Т. 5. – №. 1 (82). – С. 53-56.
7. Rasulov R. V. et al. Single-photon linear-circular dichroism in narrow-gap crystals. taking into account the effect of coherent saturation //European science review. – 2021. – №. 1-2. – С. 44-47.
8. Rasulov R. V. et al. Coefficient of interband two-photon absorption of light and its linear-circular dichroism //European science review. – 2021. – №. 1-2. – С. 39-43.
9. Rasulov V. R. et al. Interband one-and two-photon absorption of polarized light in narrow-gap crystals //Scientific-technical journal. – 2021. – Т. 4. – №. 1. – С.
10. Rasulov V. R. et al. Two-and Three-Photon Linear-Circular Dichroism in Cubic-Symmetry Semiconductors //Semiconductors. – 2020. – Т. 54. – №. 11. – С. 1381-1387.
11. Расулов В. Р. и др. Теоретическое исследование спин-зависимого размерного квантования в двухбарьерной полупроводниковой структуре //«Узбекский физический журнал». – 2020. – Т. 22. – №. 1. – С. 16-19.

12. Rasulov V. R. et al. Two-photon linear-circular dichroism in narrow-zone semiconductors //European Science Review. – 2020. – №. 7-8. – С. 54-59.
13. Rasulov V. R. et al. Linear-circular dichroism of one-photon absorption of light in narrow-zone semiconductors. contribution of the effect of coherent saturation //European Science Review. – 2020. – №. 7-8. – С. 49-53.
14. Rasulov V. R. et al. Two-photon linear-circular dichroism in narrow-zone semiconductors //European Science Review. – 2020. – №. 7-8. – С. 54-59.
15. Rasulov R.Y. et al. Diagonal matrix elements of the effective Hamiltonian in a semiconductor (taking into account spin-orbit interaction) //European science review. – 2020. – №. 1-2.
16. Rasulov V. R. et al. Phenomenology of two and three photon linear-circular dichroism of light absorption in p-GaAs //European science review. – 2020. – №. 1-2.
17. Rasulov V. R. et al. Matrix elements of two and three-photon absorption of polarized radiation in a cubic symmetry semiconductor //European science review. – 2020. – №. 1-2.
18. Rasulov R.Y. et al. Diagonal matrix elements of the effective Hamiltonian in a semiconductor (taking into account spin-orbit interaction) //European science review. – 2020. – №. 1-2.
19. Rasulov R. Y. et al. On the theory of the effective Hamiltonian of current carriers in a semiconductor //Scientific-technical journal. – 2020. – Т. 24. – №. 3. – С. 22-27.
20. Расулов В. Р. и др. Двух-и трехфотонный линейно-циркулярный дихроизм в полупроводниках кубической симметрии //Физика и техника полупроводников. – 2020. – Т. 54. – №. 11. – С. 1181-1187.
21. Daliev K. S., Rasulov V. R., Akhmedov B. To the theory of electron states in a semiconductor multi-layer structure //Euroasian Journal of Semiconductors Science and Engineering. – 2019. – Т. 1. – №. 4. – С. 1.
22. Rasulov V. R. et al. Linear-circular dichroism of one-photon absorption of light in narrow-zone semiconductors. contribution of the effect of coherent saturation //European Science Review. – 2020. – №. 7-8. – С. 49-53.
23. Rasulov V. R. et al. Diagonal and nondiagonal matrix elements of the effective Hamiltonian of electrons in a semiconductor (taking into account spin-orbit interaction) //EPRA International Journal of Multidisciplinary Research (IJMR). – С. 120.
24. Расулов Р. Я. и др. К теории зонной структуры халькогенидов свинца //Ilmiy xabarnoma. – Т. 6. – №. 1. – С. 18.

25. Расулов Р. Я., Ахмедов Б., Мамадалиева Н. Исследование размерного квантования в полупроводнике со сложной зоной методом теории возмущения //технологическое развитие науки: тенденции, проблемы и перспективы. – 2018. – С. 38-41.
26. Rasulov V. R. et al. About absorption of polarized radiation in structures with dimensionally induced states //Europaische Fachhochschule. – 2014. – №. 9. – С. 76-79.
27. Mamadaliyev B. et al. About distribution of a potential barrier on borders of grains of the polycrystalline semiconductor //Europaische Fachhochschule. – 2014. – №. 9. – С. 73-76.