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An Evaluation of Double Heterostructure and Its Application in Physics and Electronics

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ABSTRACT

In this paper, we have studied the concept of the double heterostructure and its application in Physics, electronics and technology. The success in this research was mostly determined by the application of heterostructure concepts and methods of growth which had been developed for III-V quantum wells and superlattices. Recently very impressive results for short-wavelength light sources have ben achieved for the basis of II-VI and nitrides. The natural and most predictable trends is the application of heterostructure concepts as well as technological methods and peculiarities of new materials. Different III-V, V-VI and IV-VI heterostructures developed in recent times, are food examples of this statement.

Keywords : Heterostructure, Superlattices, Quantum Wells, Wavelength Light, Semiconductor

I. INTRODUCTION

It is impossible to imagine now modern solid-state physics without semiconductor heterostructures. Semiconductor heterostructures and particularly, double heterostructures, including quantum wells, wires and dots, are today the subject of research of two-thirds of the semiconductor physics community.

The ability to control the type of conductivity of a semiconductor material by doping with various impurities and the idea of injecting non-equilibrium charge carriers could be said to be the seeds from which semiconductor electronics developed. Heterostructures developed from these beginnings, making it possible to solve the considerably more general problem of controlling the fundamental parameters inside the semiconductor crystals and devices band gaps, effective masses of the charge carriers the Mobilities, refractive, electron energy spectrum etc.

Development of the physics and technology of semiconductor heterstructures has resulted in remarkable charges in our everyday life. Heterostructure electronics are widely used in many areas of human civilization. It is hardly possible to imagine our recent life without double heterostructure-based telecommunication systems, heterostructures-based light-emitting, dioides (LED's), heterostructures bipolar transistor or low noise high-electron-mobility transistors for high-frequency applications including, for example, satellite television. Double-heterostructure lasers now enter practically every house with CD players. Heterostructure solar cell have been widely used for space and terrestrial applications.

II. CONCEPT OF DOUBLE HETEROSTRUCTURE

The idea of using heterojunctions in semiconductor electronics was put forward at the very dawn of the electronic era. In The first patent concerned with p-n junction transistors, Shockly (1951) proposed wide-gap emitter to obtain unidirectional injection. A.I. Gubanov at our Institute first theoretically analysed current-voltage characteristics of isotype and anisotype heterojunctions (Gubanov, 1950,1951)but the important theoretical considerations at this state of heterostructure research were put forward by H.Koremer, Who introduced the concept of quasielectric and quasimagnetic fields in a graded heterojunction and made an assumption that heterojunctions might exhibit extremely high injection efficiencies in comparison to homojunctions, In the esame period there wereee various suggestions about applying heterostructures in semiconductors solar cells.

The recombination, light-emitting and population inversion zones coincide and are concentrated in the middle layer. Due to potential barriers at the boundaries of semiconductors having forbidden bands of different width, the through currents of electrons and holes are completely absent, even under strong forward voltage and there is no recombination in the emitters (in contrast to p-i-n, p-n-n$^+$ homostructures, in which the recombination plays the dominant role).. Because of a considerable difference between the permittivities, the light is completely concentrated in the middle layers, which acts as a high-grade waveguide and thus there are no light losses in the passive region (emitters) (Alferov, 1966)."

Here are the most important peculiarities of semiconductor heterostructures one emphasized at that time : (i) superinjection of carriers, (ii) optical confinement, and (iii) electron confinement.

The realization of the wide-gap window effect was very important for photodetectors, solar cells and LED applications. It permitted us to broaden considerably and photodetectors and to improve drastically the efficiency of LED's. The main physical phenomena in double and single classical heterostructures . Then it was only necessary to find heterostructures in which these phenomena could be realized.

At the same time, one created some important devices that realized the main advantages of the heterostructure concepts:

- DHS lasers with low threshold at room temperature (Alferov, Andreev, partony and Trukan, 1969).
- Highly effective LED's using semiconductor heterostructures and double heterostructures (Alferov, Andreev, Korol'kov, Portnoi and Yakovenko, 1969b).
- Heterostructure bipolar transition (Alferov, Ahmedov et.al., 1973).
- Heterostructure p-n-p-n switching devices (Alferov, Andreev, Korol'kov, Nikitin and Yakovenko, 1970).

One of the first successful applications in industrial scale production in our country was heterostructure solar cells in space research.

CLASSICAL HETEROSTRUCTURES

Fundamental physical phenomena

- One-side injection
- Superinjection
- Diffusion in built-in quasielectric fields
- Electron confinement
- Optical confinement
- Wide-gap window effect
- Diagonal tunneling through heterostructure interface

Important applications in electronics

- Semiconductor lasers- Low threshold and continuous waves at room temperature, distributed-feedback and distributed- Bragg-reflector lasers, vertical surface emitting lasers
- High-efficiently LED's
- Solar cells and photodetectors, based on wide-gap window effect.
- Semiconductor integrated optics, based on semiconductor distributed-feedback and distributed –Bragg-reflector lasers
- Bipolar wide-gap transistors
- Transistors, thyristors and dynistors with photonic signal transmission
- High-power diodes and thyristors
- Infrared to visible converters
- Efficient cold cathodes

Important technological peculiarities

- Lattice-matched structure are necessary in principle
- Multicomponent solid solutions are used for lattice matching.
- Epitaxial growth technology is needed in principle.

Concluding this concise summary of the early development of bulk heterostructures, one may say that the invention of an 'ideal' heterojunction and the introjunction and the introduction of the heterostructure concept into semiconductor physics and technology have led to the discovery of new physical effects, pivotal improvement in the characteristics of practically all known semiconductor devices, and the invention of new ones.

HETEROSTRUCTURE QUANTUM WELLS AND SUPERATTICES

Fundamental physical phenomena

- 2D electron gas
- Steplike density-of –state function
- Quantum Hall effect
- Fractional quantum Hall effect
- Excitons at room temperature
- Resonant tunneling in double-barrier structure and superlattice
- Energy spectrum in superlattics determined by choice of potential and strain
- Stimulated emission at resonant tunneling in superlattices
- Pseudomorphic growth of strained structures

IMPORTANT CONSEQUENCES FOR APPLICATION

- Shorter emission wavelength, reduced threshold current, largerdifferential gain and reduced temperature dependence of the threshold current for semiconductor lasers
- Infrared quantum cascade laser
- Short-period superlattic quantum well laser
- Optimazation of electron and light confinement and waveguding for semiconductor lasers
- 2D electron-gas transistor (high-electron-mobility transistors)
- Resonant-tunneling diodes
- Precise resistance standards
- SEED's and electro-optical modulatorsInfrared photodetectors based on quantum size level absorption

Important technological peculiarities

- Lattice match unnecessary
- Low-growth-rate technology (MBE MOCVD) needed in principle
- Submonolayer growth techniques used
- Blockading of mismatch dislocations during epitaxial growth
- Sharp increase in the variety of heterostructure components.

HETEROSTRUCTURE QUANTUM WIRES AND QUANTUM DOTS

The principal advantage of using quantum-size hetrostructures in lasers is the noticeable increase in the density of states when the dimensionality of the electron gas is reduced

During the 1980s. progress in 2D quantum well heterostructure physics and its applications drew many scientists to the study of systems of far less dimensionality- quantum wires and quantum dots. In contrast to quantum well, where carriers are localized in the direction perpendicular to he layers but move freely in the layer plane, in quantum 'wires' carriers are localized in two directions and move freely along the wire axis. With confinement in all three directions, quantum 'dost'- 'artificial atoms' with a totally discrete energy spectrum-are created'

Quantum dot lasers are expected to have properties superior to those of conventional quantum well lasers. High differential gain, ultralow threshold current density and high-temperature stability of the threshold current density are expected to occur simultaneously. Additionally, ordered arrays of scatterers formed in an optical waveguide region may result in distributed feedback and/or in stabilization of single-mode lasing. Interinsically buried quantum dot structures spatially localized carriers and prevent them from recombining non-radiatively at resonator faces. The overheating of facets, which is one of the most important problems for the high-power and high-efficiency operation of AIGaAs-GaAs and AIGaAs-InGaAs lasers, may thus be avoidable.

DISCUSSION AND RESULTS:

In this paper, we have studied the concept of the double heterostructure and its application in Physics, electronics and technology. The success in this research was mostly determined by the application of heterostructure concepts and methods of growth which had been developed for III-V quantum wells and superlattices. Recently very impressive results for short-wavelength light sources have ben achieved for the basis of II-VI and nitrides. The natural and most predictable trends is the application of heterostructure concepts as well as technological methods and peculiarities of new materials. Different III-V, V-VI and IV-VI heterostructures developed in recent times, are food examples of this statement.

The study of classical heterostructures quantum wells and superlattices in quit nature and one is now exploiting many of their unique properties. The study of quantum wire and dot structure is still very young and exciting discoveries and new unexpected applications are awaiting us. Even at this early stage, however, one can say that ordered equilibrium arrays of quantum dots may be used in many devices, lasers, light modulators, far-infrared deterctors and emitting etc. Resonant tunneling via semiconductor atoms introduced in laser band-gap layers amy lead to significant improvement in device characteristics. More generally speaking, QD structures will be developed both in width and in depth.

In width means new material systems to cover a new energy spectrum. The lifetime limitation of the green and blue semiconductor lasers and even more general problems of the creation of defect free structures band on wide gap II-VI and III-V (nitrides) would be solved by using QD structures in these systems.

As to a depth it is necessary to mention that the degree of ordering depends on very complicated growth condition, material constants and concrete values of the surface free energy. To achieve resonant tunneling and single electron devices, including optical ones, require a through investigation and evaluation of these parameters in order to obtain the maximal possible degree of ordering. In general, it is necessary to find stronger self-organization mechanisms for ordered arrays of quantum dots.

Thus, one can summarize the whole scenario in the following facts:

1. heterostructure- a new kind of semiconductor material expensive, complicated chemically and technologically but most efficient.
2. Modern optoelectronics is based on heterostructure application.
   (a)The DHS laser- a key device of modern optoelectronics.
   (b) The heterostructure protodiode- the most efficient and high spend photodiode
   (c) Optoelectronic Integrated Circuits (OEFCs) will solve problem of high information density of an optical communication systems.
3. Future high speed microelectronics will mostly use heterostructure.
4. High temperature, high speed power electronics-a new broad field of heterostructure applications.
5. Heterostructures in solar energy conversion, the most expensive photo cells and the chepest solar electricity producer.
6. In the 21 st century heterostructure in electronics will reserve only 1 % for homojunctions.

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