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15. Januar 2024

Referee's Official Response to the Habilitation Thesis

Title: "Investigation of Electrodynamic and Optical Characteristics of Zero-Dimensional Quantum Structures"
Candidate: David Boris Hayrapetyan
Degree Sought: Doctor of Physical-Mathematical Sciences
Specialization: A.04.10 – "Physics of Semiconductors"

This document serves as the official response of the appointed referee to the habilitation thesis submitted by David Boris Hayrapetyan. The thesis, entitled "Investigation of Electrodynamic and Optical Characteristics of Zero-Dimensional Quantum Structures," has been thoroughly reviewed in accordance with the academic standards and criteria set forth for the degree of Doctor of Physical-Mathematical Sciences, specializing in the field of Semiconductor Physics.

Semiconductor quantum dots represent a remarkable convergence of material science and quantum mechanics, manifesting unique properties that have captivated researchers across various scientific disciplines. These nanoscale semiconductor particles, often described as artificial atoms, exhibit distinct quantum mechanical properties that distinguish them from their bulk material counterparts. One of the most notable characteristics of quantum dots is their size-dependent optical and electronic properties, a phenomenon attributed to the quantum confinement effect. This effect arises as the quantum dot's size approaches a critical dimension, confining electrons and holes in all three spatial dimensions.

The unique properties of quantum dots have led to their widespread application in various fields. In optoelectronics, they are used to improve the performance and efficiency of devices like light-emitting diodes and solar cells. Their size-tunable emission spectra make them ideal for creating vibrant displays with enhanced color purity and energy efficiency. In the realm of solar energy, quantum dots have the potential to significantly increase the efficiency of photovoltaic cells by harnessing a broader spectrum of solar radiation.

Another vital application of quantum dots is in biomedicine. Their unique optical properties, such as high brightness and resistance to photobleaching, make them excellent candidates for biological imaging and diagnostics. Quantum dots can be engineered to attach to specific proteins or structures within cells, allowing for detailed visualization and tracking of biological processes at the molecular level. Moreover, quantum dots hold great promise in the emerging field of quantum computing and information processing. Their discrete energy levels and the ability to control electron spin make them suitable candidates for quantum bits (qubits), the basic unit of information in quantum computers. This could revolutionize computing by enabling exponentially faster processing speeds for certain types of calculations compared to classical computers.

Despite the significant advancements in the field, the investigation of semiconductor quantum dots' physical and optical properties remains a crucial area of research. Understanding the underlying mechanisms that govern their behavior is essential for optimizing their performance in current applications and unlocking new technological frontiers. Further research is particularly imperative in addressing challenges related to the synthesis and integration of quantum dots, such as size and shape control, stability, and compatibility with different environments and substrates. As our knowledge of these nanostructures deepens, we can expect quantum dots to play an increasingly pivotal role in the technological advancements of the 21st century.

The dissertation, spanning 267 pages and featuring 83 figures, 15 tables, and 334 references, is structured into an Introduction, six Chapters, a Conclusion, and a References section. It commences with a "List of Abbreviations and Notations Used in the Dissertation," followed by the "Introduction," which outlines the significance of the research, provides a review of relevant literature, and presents the current state of the problem, culminating in the key assertions of the study.

Chapter I delves into the theoretical analysis of spherical and cylindrical quantum dots, exploring various confinement potential models and their implications across different size quantization regimes. This includes a detailed examination of spherical quantum dots using the modified Pöschl-Teller potential (MPTP), an investigation into light absorption in cylindrical quantum dots utilizing MPTP, and a study of the effects of hydrostatic pressure on donor impurity exciton states and interband absorption in cylindrical quantum dots with Morse confining potential.

Chapter II is dedicated to the study of ellipsoidal and spheroidal quantum dots, focusing on the binding energy and photoionization cross-section of hydrogen-like donor impurities in strongly oblate ellipsoidal quantum dots, along with comparative analyses for prolate ellipsoidal and spheroidal quantum dots.

Chapter III examines excitonic complexes in ellipsoidal and cylindrical quantum dots. This includes calculations of binding energy and photoionization cross-sections, as well as an exploration of the effects of intense laser beams on these complexes and the potential realization of the Talbot effect in coupled cylindrical quantum dot ensembles.

Chapter IV discusses the application of Kohn's theorem to quantum dots with oblate and prolate geometries. This encompasses the study of the effects of external magnetic fields and the exploration of Ge/Si quantum dots containing a hole gas.

Chapter V investigates the electronic and optical properties of core/shell nanostructures. This chapter covers topics such as linear and nonlinear optical absorption, exciton states in core/shell/shell spherical quantum dots, and the modeling of quantum dots using the finite element method, taking into account various confinement potentials and their impacts.

Chapter VI assesses the electronic and optical properties of conical quantum dots, including direct interband light absorption, magneto-absorption, and the analysis of electronic states under the influence of electric fields.

While the thesis demonstrates commendable depth and breadth, I have a few minor questions and suggestions that could further refine and enhance the quality of this work.

- The use of exclusively capital letters in the table of contents makes it harder to read.
- I would suggest a tabular format for the description of the physical constants following the description of the abbreviations.
- For the description of the confinement potentials, a figure showing the differences and similarities would be useful to the reader.
- On p.20, is really 10^{-6} meV meant? This would be a very small energy.
- I would suggest to use spaces between the number and the units, as in 26 nm, not 26nm.
- The quality of the figures could be improved in terms of their resolution. It seems that they are bitmap figures instead of a native pdf, for instance.
- A chapter devoted to the different methodologies used to address the problem of quantum dots, including atomistic descriptions, would put the work in context.

The minor remarks previously mentioned do not detract from the overall high quality of the dissertation. Undoubtedly, this Habilitation thesis represents a significant contribution to the field of semiconductor nanostructures. The thesis meets all the criteria set by the Supreme Certifying Commission of the Republic of Armenia, and its author, David Boris Hayrapetyan, is unquestionably deserving of the scientific degree of Doctor of Physical-Mathematical Sciences. Furthermore, the summary of the dissertation (auto-referat) accurately reflects the content and essence of the work presented.

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