Patras, Greece, 07 April 2022

REFEREE RESPONSE

to the PhD thesis of Bleyan Yuri Yura entitled *"Investigation of optical properties of complicated excitonic complexes in quantum dots"* for the degree of candidate of physical – mathematical sciences on specialization of 01.04.10 – Physics of Semiconductors".

The PhD thesis is devoted to the theoretical investigation of the optical properties of complicated excitonic complexes in GaAs strongly oblate ellipsoidal quantum dot (SOEQD).

Technological progress has made possible to produce low-dimensional semiconductor structures in which the movement of charge carriers is limited in one, two and three directions. Such structures encompass the size-quantized wells, the size-quantized wires, and the quantum dots. Low-dimensional semiconducting structures present a radical change in the physical processes with respect to bulk semiconductors due to the influence of size quantization (SQ) since the de Broglie wavelength of charge carriers becomes commensurate with the size of the sample. Semiconductor structures in which the movement of charge carriers is limited in three directions are called Quantum Dots (QD). In the last two to three decades, interest in QDs of various shapes and sizes (spherical, cylindrical, pyramidal, lens shaped, ellipsoidal, conical, etc.) has especially increased due to a wide range of promising applications in nanoelectronics and optoelectronics, as well as possible applications in photovoltaic cells, based on QDs, application in microcircuits, and also possible use as qubits in quantum computing, quantum cryptography, quantum information, room-temperature lasers based on QDs, etc

The energy spectrum of charge carriers in QD is fully quantized. Manipulations of energy states can be used to create semiconductor nanoelectronic devices of a new generation, as well as to study the fundamental principles of quantum mechanics. Different growing methods have allowed the growth of QDs of various shapes and sizes. It should be noted that spheroidal and ellipsoidal QDs have an advantage over spherical ones, since they have additional geometrical parameters for controlling the energy spectrum. This allows more flexible manipulation of the physical properties of QDs. For the description of physical processes in semiconductor QDs, the correct mathematical modeling of QD's confining potential plays an important role, which characterizes the interaction of charge carriers with the walls of a QD, i.e. by modeling it, the effect of SQ in QD is taken into account. Thanks to the effect of SQ, the physical properties of a QD can be controlled, thereby creating devices with predetermined characteristics.

Electrons and holes in semiconductors can be combined to form excitons. The creation and recombination of excitons is one of the main mechanisms through which light interacts with semiconductors. In addition, excitonic systems possess a number of unusual properties, such as the ability to transport energy without transporting charge, offering a wide range of applications in new electronic devices. Biexcitons are no less interesting quasiparticles. Biexciton is a boson, which consists of two particles, namely, two holes and two electrons. The binding of excitons into biexciton complexes leads to a number of different effects: a sharp increase in two-photon absorption, the appearance of new resonance lines, and a change in the nonlinear susceptibility. In this regard, a very interesting problem is the study of biexciton states in various quantum systems, in particular, in QDs. In semiconductor nanostructures, so-called "charged" excitons – trions can also be formed. In contrast to the biexciton, the trion is charged, and, depending on the combination of electrons and holes, two types of trions are distinguished: positive trion, when the trion consists of two holes and one electron, and negative trion, when the trion consists of two electrons and one hole. The study of complexes of three particles is of fundamental importance, especially in semiconductors, where it is possible to vary the parameters in a wide spectrum. Another class of quasiparticle is four-component exciton systems, namely the quaternions. A quaternion has two possible types of realization: the negatively (consisting of three electrons and one hole) and the positively (consisting of three holes and one electron) charged quaternions. Of importance is also the theoretical investigation of excitonic complexes in QDs, when an external magnetic field is applied. A magnetic field can be used for giving an additional confinement on the charge carriers, which will lead to the increase of the system energy.

Ellipsoidal QDs, particularly spheroidal ones, in comparison with the spherical QDs, have two geometrical parameters, namely small and large semiaxes which gives the opportunity to control the QD's energy spectrum in a wide range. This fact, in its turn, leads to the more flexible control of physical characteristics of the system, especially the optical properties. Another advantage of ellipsoidal QDs with oblate or prolate geometry is the possibility to implement Kohn theorem for such systems due to the specific parabolic adiabatic potential. Experimentally the liquid phase epitaxy technique has been applied to grow self-assembled InAsSbP-based strain-induced islands and QDs on InAs (1 0 0) substrates. Moreover also GaInAs ellipsoidal QDs have been successfully grown. Thus, the ellipsoidal QDs can be realized experimentally for different types of semiconductors.

The work in the present phd thesis is devoted to the theoretical investigation of the optical properties of complicated excitonic complexes in GaAs strongly oblate ellipsoidal quantum dot (SOEQD).

The thesis, which consists of Introduction, three Chapters, Conclusion and References, comprises 109 pages, contains 58 figures, 5 tables and 121 references.

In the Introduction the actuality of the dissertation topic is stated.

In Chapter 1 author concentrates on the investigation of the wave function and the energy spectrum of positive and negative trions, biexcitons, positive and negative quaternions. The energies of the above mentioned particles are obtained in the framework of the variational method. The binding energies of all quasiparticles are calculated as a function of the ellipsoidal QD's geometrical parameters.

Chapter 2 includes the theoretical investigation of the optical properties of excitonic complexes. The recombination energy of all quasiparticles, the absorption and photoluminescence of excitonic complexes, the oscillator strength and the recombination radiateive lifetime of considered quasiparticles are calculated as a function of the ellipsoidal QD's large and small semiaxes. Additionally, the non-linear optical properties of the biexcitons for the ground and excited levels are considered in the case of ellipsoidal QDs.

Chapter 3 is devoted to the investigation of biexciton states in strongly oblate ellipsoidal quantum dots in the presence of an external magnetic field. The wave function and the energy spectrum of magnetobiexcitons are calculated. The optical properties such absorption, oscillator strength and radiative lifetime, as well as the magnetic properties like the magnetization of the magnetobiexciton as a function of the geometrical parameters of the ellipsoid and magnetic field are also calculated.

Conclusions and outlook. The results are summarized in conclusions.

The results obtained in the thesis are novel, original and interesting both from a fundamental and applied point of view. The PhD candidate has proven to be able to perform theoretical work on excitonic systems with great accuracy, given the outstanding theoretical results presented in the thesis. Considering the amount of references in the thesis, it is clear that the candidate has a very good knowledge of the physics that rules the semiconducting nanostructures. Also, the thesis gives a nice overview of previous work and also the latest evolutions in the field. The work was performed on a high theoretical level and results are published in leading physical Journals and presented at numerous International Conferences. Bleyan Yuri Yura is also first author in the seven of eight publications.

Notwithstanding the very nice work, I have a few remarks which could give guidelines to improve the thesis:

- For the figures and tables captions, a different font with different size should be used with respect to the main text to avoid confusion.

- In some cases, figures are discussed very shortly in the text (for example figures 2.9 and 2.10).

- In the conclusion chapter, although the word "OUTLOOK" is used in the title no outlook is actually given. A paragraph focusing on unsolved problems and future work would be very interesting for the readers.

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Above mentioned minor remarks, do not affect the high quality of the dissertation. Certainly, the PhD thesis is an important contribution to the field of optical properties of quantum dots. .

PhD thesis satisfies all requirements of Supreme Certifying Commission of RA, and its author Bleyan Yuri Yura undoubtedly deserves the scientific degree of candidate of Physical – Mathematical sciences.

The Summary of dissertation (autho-referat) correctly corresponds so the contents of dissertation.

Official referee at the Department of Materials Science, University of Patras, Greece

Iosif Galanakis, Professor

I certify the signature of Iosif Galanakis

Penelope Kapsali-Oikonomopoulou, Secretary,

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