

OPINION

concerning

dissertation for obtaining the scientific degree "Doctor of Sciences" in a professional direction
4.1. Physical sciences under a defense procedure at the Faculty of Physics of Sofia University "St.
Kliment Ohridski"

The opinion was prepared by **Prof. Nikolay Vitanov Vitanov**, Sofia University "St. Kliment Ohridski", Faculty of Physics, in his capacity as a member of the scientific jury according to Order № RD-38-148 / 15.03.2021 of the Rector of Sofia University.

Topic of the dissertation: **"Energy transport in optically-created densely populated organic triplet ensembles"**

Author of the dissertation: **Assoc. Prof. Dr. Stanislav Balushev Balushev**

I. General description of the submitted materials

1. Data on the submitted documents

The candidate has presented a dissertation, abstract, as well as a reference for the implementation of the mandatory additional requirements for the Faculty of Physics from the Regulations on the terms and conditions for obtaining scientific degrees and holding academic positions at Sofia University "St. Kliment Ohridski". Curricula vitae, master's and doctoral diplomas, articles, patents and auxiliary tables are also presented. The defense documents submitted by the applicant comply with the requirements of the national law ZRASRB and PPZRASRB, the Regulations on the Terms and Conditions for Acquiring Scientific Degrees and Holding Academic Positions at Sofia University "St. Kliment Ohridski" (PURPNSZADSU), as well as the additional increased requirements of the Faculty of Physics.

2. Details of the candidate

Assoc. Prof. Dr. Balushev completed his master's degree at the Faculty of Physics of Sofia University "St. Kliment Ohridski" in 1990. In 1998 he obtained the educational and scientific degree "Doctor" after defending a dissertation on "Phase modulation of light beams. Dark Spatial Solitons" in front of the SNS in Radiophysics, Physical and Quantum Electronics of the Higher Attestation Commission. Until 2009, the candidate was an assistant professor and a senior assistant professor at the Technical University in Sofia, and also worked for many years in a number of elite German, Austrian and Israeli universities and companies, as can be read in the information provided by him.

In 2009 he won a competition for associate professor at the Department of Optics and Spectroscopy at the Faculty of Physics of Sofia University "St. Kliment Ohridski", retaining his position at the Max-Planck-Institute for Polymer Research as head of the group for photophysical chemistry. In 2014-

2015, Assoc. Prof. Dr. Balushev won a scholarship under the Marie Curie program of the European Commission as a senior researcher.

I should note the serious contribution of Assoc. Prof. Dr. Balushev in the creation and development of Optometry programs for students – bachelors and masters – in the Faculty of Physics, of which he has been the head for many years. These programs have established themselves as some of the most sought after and most successful in the Faculty of Physics. Such programs, when created more than ten years ago, were completely unknown and far from the traditional areas in which students studied. Their success is largely due to the energy, ambition and experience gained in specializations abroad of Assoc. Prof. Dr. Balushev and other lecturers from the Department of Optics and Spectroscopy.

3. General characteristics of the scientific achievements of the candidate

The scientific interests of Assoc. Prof. Dr. Balushev are in several different but related fields of modern atomic, molecular and optical physics, as well as in some fields of chemistry and biology. They start with quantum electronics (creation and optimization of lasers, conversion of frequencies and solitons), go through the physics of ultra-cold atoms (laser cooling of atoms, coherent capture of population, Bose-Einstein condensate, atomic clocks, etc.) and concentrate on photophysics/photochemistry. It is in this last area that the most significant research of the candidate is conducted, on which his dissertation is based. A significant part of this research was conducted in Germany and was financially supported by 12 major research projects from Sony-Germany, the Seventh Framework Program, Horizon 2020, NSF and others. Research in this area has led to 58 scientific publications since 2003, cited more than 2200 times according to the Web of Science. The candidate claims 2463 citations of his publications without self-citations and Hirsch Index 25, which are above the world average for a scientist with similar experience.

The dissertation is based on 21 publications published between 2011 and 2018, as well as 9 worldwide patents. According to my Web of Science check, these publications have been cited 719 times. The results were presented in 14 oral and poster conference papers. The candidate has indicated 12 more publications and 3 world patents on the topic of the dissertation in refereed journals, which, however, are not included in it.

The scientific publications, on which the dissertation is based, exceed the minimum national requirements (under Art. 2b, para. 2 and 3 of ZRASRB) and the additional increased requirements of the Faculty of Physics of Sofia University “St. Kliment Ohridski” for obtaining the scientific degree “Doctor of Sciences”. The scientific publications included in the dissertation do not repeat those from previous procedures for acquiring a scientific title and academic position. There is no legally proven plagiarism in the submitted dissertation and abstract.

4. Content analysis of the scientific and applied-scientific achievements of the candidate contained in the materials for participation in the competition

The activity of the candidate in the subject of the dissertation has an emphasized applied character, evidence of which are 9 world patents, which is probably a precedent for similar dissertations in Bulgaria. The candidate has indicated 3 world patents on the topic of the dissertation, which are not included in it. The topic has a strong interdisciplinary character, covering various fields of physics, chemistry and biology, which is also rare in Bulgaria.

The main phenomenon that dominates the dissertation is up-conversion - a process in which the frequency of photons increases. This process is a basic method for generating different frequencies in laser physics with wide applications in atomic and molecular physics, as well as in condensed matter physics. This process also plays an important role in material science, as well as in various processes in biology. The mechanisms for this process are described in sufficient detail at the beginning of the dissertation – a part that can serve as a guide for students and PhD students, as well as for more experienced scientists who do not work in this field.

What distinguishes this dissertation is that it considers the processes of up-conversion (UC), which do not require nonlinear processes, respectively do not require large peak radiation powers, nor coherent sources. The ability to increase the frequency (and therefore energy) of photons at low intensities of incoherent light (as are almost all the sources around us, including sunlight) opens up a huge number of possibilities for practical applications. It should be emphasized that the main purpose of the presented results is not the demonstration of one or another phenomenon (proof of principle), usually in idealized laboratory conditions, but the detailed study of the phenomena in a real environment, allowing their direct application in practice.

From my point of view, among the contributions in this dissertation, special attention should be paid to overcoming a number of fundamental limitations of the up-conversion process using the process of triplet-triplet annihilation up-conversion (TTA-UC) in a soft matter matrix. It allows: (i) to drastically reduce (more than 10^6 times) the intensity of the exciting light; (ii) modify the spectral power density of the exciting light to be similar to that of sunlight; (iii) use incoherent radiation, such as sunlight.

One example is the study of the discrepancy between the established model of delayed p-type fluorescence and the research in the dissertation of the TTA-UC process in soft matter (Chapter 2), as well as the influence of molecule mobility (Chapter 8), temperature (Chapters 2 and 12) and oxygen content (Chapters 10 and 11). As a result of these studies, the candidate formulates 4 empirical rules for the selection of the parameters of the singlet and triplet energy states of organic molecules, which guarantee high efficiency of the TTA-UC process in a soft matter matrix (Chapter 3). As a result of these rules, a large number of new molecular systems with high efficiency of the TTA-UC process have been found.

One of the main problems discussed in the dissertation is to increase the efficiency of photovoltaic devices by converting the red and infrared parts of the spectral composition of sunlight into a spectral region where the sensitivity of photovoltaic cells is maximum (Chapter 6). There is no doubt that this result has a very serious applied potential.

A very interesting and important result is the use of the sensitivity of UC processes to temperature to determine the local temperature in different environments with very high spatial resolution (Chapter 2). This idea has been used in practice as the molecules performing the UC process are embedded in nanoparticles, which can be used to study the temperature distribution in organic matter and living organisms (Chapter 9) – a problem of great practical interest. Because oxygen in living matter reduces the efficiency of frequency conversion, Chapters 10 and 11 propose several original solutions to reduce this effect. They allow the determination not only of the temperature distribution in living matter, but also of the oxygen content in the test media (Chapter 12).

The contributions of Assoc. Prof. Balushev are summarized at the end of the abstract in eight points. They adequately reflect the content of the dissertation and the candidate's achievements. Contributions can be described as enrichment of existing knowledge and application of scientific achievements in practice. The relevance and significance of the results is proved by the numerous citations, international patents and participation in a large number of scientific conferences with invited papers.

5. Critical remarks and recommendations

The dissertation is 364 pages long and is in English, and the abstract is 149 pages in Bulgarian. Both the dissertation and the abstract are richly illustrated with figures and can serve as a guide for introducing young scientists to the topic, as well as scientists from other fields. With the exception of some inaccuracies in the terminology in the Bulgarian text, I have no significant remarks. I realize how difficult it is for an established scientist who communicates and publishes only in English to switch to Bulgarian and that is why I tend to ignore these small inaccuracies.

6. Personal impressions of the candidate

I know Assoc. Prof. Dr. Balushev from the time when, as a member of the SNS of the Higher Attestation Commission, we considered the competition for an associate professor in the Department of Optics and Spectroscopy, in which he participated. I've been following his scientific publications, especially those on ultra-cold atoms, for a long time. He is an extremely active and creative scientist, completely dedicated to science. I can safely say that he is one of the scientists who give the scientific image and high reputation of the Faculty of Physics. I am glad that he finally found time to write his dissertation, for which there were results 10 years ago.

7. Conclusion

After getting acquainted with the presented dissertation, abstract and other materials, and based on the analysis of their significance and the scientific and applied contributions contained in them, I **confirm** that the scientific achievements meet the requirements of ZRASRB and The Regulations for its application and the respective Regulations of Sofia University "St. Kliment Ohridski" for obtaining the scientific degree "Doctor of Sciences", as well as the increased requirements of the Faculty of Physics. The candidate satisfies the minimum national requirements in the professional

field and no plagiarism has been established in the dissertation, abstract and scientific papers submitted at the competition.

I give my **positive** assessment of the dissertation.

II. OVERALL CONCLUSION

Based on the above, I strongly **recommend** to the scientific jury to **award** the scientific degree "Doctor of Science" to Assoc. Prof. Dr. Stanislav Balushev in the professional field 4.1. Physical sciences.

Prepared the opinion:

01.06.2021