

OPINION

regarding the dissertation for acquisition of educational and scientific degree “doctor”, professional direction 4.1 “Physical sciences”, specialty “Condensed matter physics”, authored by Assistant Professor Stefan Dimitrov Kolchev, full time PhD student at the Central laboratory of applied physics – Bulgarian Academy of Sciences (CLAP-BAS).

Dissertation title: Development and investigation of wear-resistant nanocomposite coatings with modulated composition for multifunctional applications

Scientific supervisor: Prof. Dr. Liliana Kolaklieva, CLAP-BAS

Scientific consultant: Prof. Dr. Rumen Kakanakov, CLAP-BAS

Opinion prepared by: Assoc. Prof. Dr. Stefan Valkov, Institute of Electronics – BAS, appointed as a member of the Scientific Jury by Order No. 22/30.06.2025 of the Director of CLAP-BAS

The author of the dissertation, Assistant Stefan Kolchev, graduated from Plovdiv University “Paisii Hilendarski,” Plovdiv, with a Master’s degree in Chemistry and Ecology in 2014. Since 2020, he has been enrolled as a full-time PhD student at CLAP-BAS, and since 2021, he has been appointed to the position of Assistant.

The presented dissertation is dedicated to the development of superhard and wear-resistant coatings that retain their functional characteristics at high temperatures. It is presented on 127 pages, structured into 3 chapters, contains 64 figures, 16 tables, and 250 cited references.

In modern industry, the use of hard and wear-resistant coatings is gaining increasing importance for enhancing the reliability and durability of machine components, tools, and products. The growing requirements for performance, precision, and equipment durability necessitate the development of effective methods for protecting surfaces against friction and wear. The application of protective coatings leads to a significant extension of the service life of components, a reduction in maintenance and repair costs, as well as an improvement in the energy efficiency of manufacturing processes. This is of particular importance in sectors such as mechanical engineering, automotive manufacturing, aviation, and many others, where reliability and quality are critical factors. In this context, the relevance of the dissertation is beyond doubt.

In Section I of the dissertation, the relevance of the research is substantiated through a concise and in-depth literature review analyzing the properties of hard and wear-resistant coatings such as TiN, CrN, and complex structures like TiCrN, as well as the influence of alloying elements on their

microstructure and mechanical properties. The possibilities of multilayer coatings as an alternative approach to achieving multifunctional surfaces are also examined. On this basis, the objectives are formulated: the development of super-hard and wear-resistant coatings stable even at high temperatures. It should be noted here that the PhD student demonstrates an excellent knowledge of the global scientific literature. In this part of the dissertation, more than 100 references are cited and analyzed with deep understanding, which is indisputable evidence of a high level of awareness and competence on the subject. In the section “Materials, Deposition and Characterization Methods,” the principles of microstructure formation, strengthening mechanisms, and the specifics of Physical Vapor Deposition (PVD) methods employed in the dissertation are presented. The characterization techniques are described comprehensively: Calotest, adhesion and hardness testing, SEM/EDS, XPS, XRD, as well as methods for determining the coefficient of friction and thermal stability. High-speed steel substrates were used for the investigation. Multilayer TiAlSiN/AlSiN coatings with 3 and 30 periods of modulation, applied over transition layers of Ti and TiN, have been chosen. The technological deposition conditions are presented in detail, and the resulting structures are analyzed using the aforementioned methods. Section III presents the original results obtained within the framework of the thesis.

As a result of the experimental work, a multilayer TiAlSiN/AlSiN coating was developed, consisting of two sub-layers – TiAlSiN and AlSiN. The obtained nano-composite structure includes nano-grains of the solid solutions TiAlSiN and AlSiN embedded in an amorphous Si_3N_4 matrix. This architecture provides a combination of super-hardness and a low elastic modulus, which enhances the coating's durability and combines the advantages of both nano-composite and multilayer structures. The factors influencing the high measured hardness values are clearly defined. Similarly, the relationship between the wear mechanism and the modulation period is presented. It has been proven that the structure and functional properties of the studied coatings remain relatively stable after heat treatment up to 900 °C. The mechanism by which the brittleness of super-hard coatings is overcome and high elasticity is achieved is clearly explained. This mechanism is based on the difference in chemical composition of the individual nano-crystallites, which are characterized by different chemical bonds between the elements and different energies. These results are of contributory significance and have been structured into one scientific and five scientific-applied contributions. I fully accept the contributions as defined by the author of the dissertation.

The results obtained within the dissertation have been published in a total of two articles in the journal *Coatings* (ranked in Quartile 2, Q2) and in one utility model. This publication activity fully meets, and even exceeds, the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria, as well as those of CLAP-BAS. The fact that one of the articles has been cited four times, and the other one has already received one citation, further emphasizes the relevance and significance of the dissertation's topic.

I have had the opportunity to discuss with the candidate some important topics related to the dissertation. The impressions he left were always of a researcher with in-depth knowledge of the field in which he works. His evident enthusiasm when discussing his work illustrates that he possesses both a thorough understanding of his research and a sincere passion for it. These impressions were fully confirmed both during the preliminary defense and upon reading the dissertation.

The abstract is written with precision and clarity. It accurately reflects the main results and contributions obtained in the dissertation.

I have no critical remarks regarding the dissertation. The text is written in a clear and precise language and is easy to read. The objectives and tasks, as well as the conclusions and contributions, are formulated correctly.

In conclusion, I can confirm that the dissertation entitled “Development and Investigation of Wear-Resistant Nanocomposite Coatings with Modulated Composition for Multifunctional Applications” fully complies with the Law on the Development of the Academic Staff in the Republic of Bulgaria, its implementing regulations, as well as the internal criteria of CLAP-BAS. The objectives defined in the dissertation fully correspond to the contributions. For this reason, I express my strongest recommendation that the educational and scientific degree “doctor” has to be awarded to Stefan Dimitrov Kolchev in the professional field 4.1 Physical Sciences, specialty Condensed Matter Physics.

03.09.2025

Author:.....

/Assoc. Prof. Dr. Stefan Valkov/