

Reviewer's OPINION

of

Prof. Dr.Sci. Tinko Eftimov
Central Laboratory for Applied Physics, Bulgarian Academy of Sciences, Plovdiv

for awarding the educational and scientific degree "Doctor of Philosophy"

Professional field: 4.1. "Physical Sciences",
Doctoral program "Condensed Matter Physics"
to

Author: Stefan Dimitrov Kolchev

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

Scientific Supervisor: Prof. Dr. Lilyana Kolaklieva

Consultant: Prof. Dr. Rumen Kakanakov

1. Brief biographical data about the doctoral student

Mr. Stefan Dimitrov Kolchev received a Bachelor's degree in Chemistry in 2013, a Master's degree in Chemistry and Ecology in 2014 from the Paisii Hilendarski Plovdiv University and held the positions of Technologist, Chemist and Research Assistant at the Central Laboratory of Applied Physics at the Bulgarian Academy of Sciences - Plovdiv in the period from 2020 till present. In the positions held at the CLPF, Plovdiv, Mr. Kolchev was responsible for qualified experimental methods for the deposition of hard protective coatings, implementation of scientific results in practice, creation and transfer of technologies in the field, as well as the implementation of technological orders.

2. Relevance of the problem developed in the dissertation work in scientific and scientific-applied terms.

The topic of the dissertation "Development and research of wear-resistant nanocomposite coatings with modulated composition for multifunctional applications" is dedicated to the study of the mechanical and tribological properties, morphology, composition and structure of hard and superhard thin coatings. The deposition of nanolayers on metal surfaces is through the well-known and established PVD (Physical Vapor Deposition) technology.

3. Knowledge of the problem

The dissertation candidate based his work on an extensive literature review of 250 specialized works for the period from 1953 to 2025, with 36 of them (15%) published in the last five years and 78 (31%) in the last 10 years. The review of publications by journals, years, and authors shows that the dissertation candidate is well-versed in and has analyzed the background and state of the problem in its development, as well as its contemporary trends.

5. Characteristics and evaluation of the dissertation work

The dissertation is structured in four parts, organized into four chapters as follows:

I. Introduction with

Chapter 1. Materials, Methods for Application and Testing of Coatings;

II. Materials and Methods with

Chapter 2. Empirical basis of the study;

III. Results and discussions with

Chapter 3: Results of studying the morphology, elemental concentration, phase composition and formed chemical compounds of TiAlSiN-AlSiN nanocomposite coatings with modulated composition and

Chapter 4: Results of studying the mechanical and tribological properties of TiAlSiN-AlSiN nanocomposite coatings with modulated composition

V. Conclusion with

Summary of the results of the work on the dissertation.

Conclusions and achieved results in the dissertation

i. Scientific achievements

ii. Scientific and applied achievements

A list of the author's publications and a useful model, noted citations and the used literature are presented. The overall layout is well executed and illustrated with 70 figures, 15 tables and 250 literary sources.

In the introduction, the author presents the relevance of the topic, the state of research on the problem, and defines the goals and objectives of the dissertation.

In *Chapter 1*, the author presented the main factors for building the microstructure of protective layers and the conditions and factors for forming hard nanocrystalline coatings, as well as the physical methods for applying coatings by magnetron sputtering and cathodic arc evaporation. Finally, the main methods for studying and characterizing coatings, surface topography and coating composition (SEM, EDS, XPS, XRD) are discussed.

In *Chapter 2*, the author presented the preparation, selection and architecture of the composition of the modulated composition coatings, the preparation of the samples, the application methods, the parameters of the deposition processes. The equipment and methods for testing nanocomposite coatings - thickness, mechanical properties, topography and structure, tribology and thermal stability - are reviewed.

In *Chapter 3*, the author presents the results of the studies of the morphology, the elemental concentration, the phase composition, the chemical compounds of reference (sl-TiAlSiN and sl-AlSiN) and of the multilayer coatings (ml3-TiAlSiN/AlSiN and ml30-TiAlSiN/AlSiN). The influence of temperature on the morphology and elemental composition, structure and phase composition of multilayer coatings is shown in detail. Five conclusions are formulated based on the results in Chapter 3, which are as follows: achieved compositionally modulated multilayer structure; achieved structure without craters and cracks; achieved nanocomposite structure of the sublayers, consisting of two phases, nanograin and amorphous phase; stable phase composition up to 800 °C and achieved superhard structure with improved elasticity, combining the advantages of nanocomposites and multilayer coatings.

In *Chapter 4*, the author presented the results of the study of the mechanical and tribological properties of nanocomposite coatings with modulated composition (TiAlSiN-AlSiN): hardness, Young's modulus, resistance, plastic deformation, elastic recovery, adhesion and cohesive strength, tribological properties. The dependence of mechanical and tribological properties, adhesion and cohesive strength on temperature during the annealing process has been examined in detail. Seven conclusions are formulated based on the achieved and presented results and the importance of internal stresses on hardness, thermal stability of three-period coatings, the positive role of the number of interfaces on the increase of internal stresses, are highlighted, the appropriate combinations of sublayers to increase elasticity, as well as the influence of the modulation period on the behavior of the coating.

6. Contributions and significance of the dissertation work for science and practice

The following scientific and applied achievements have been formulated.

- i) For the first time, a TiAlSiN/AlSiN multilayer architecture with a period consisting of two sublayers has been proposed, in which the period has a completely nanocomposite structure.
- ii) For the first time, a technology for a TiAlSiN/AlSiN nanocomposite multilayer coating with different modulation periods has been developed and optimized
- iii) Results were obtained for the mechanical properties of the developed multilayer nanocomposite coating TiAlSiN/AlSiN, and the achieved superhardness is due to three factors: the nanocomposite structure, formation of a solid solution in the crystallites, and a reduction in their size.

- iv) Results were obtained for the tribological properties of the developed TiAlSiN/AlSiN multilayer nanocomposite coating and it was found that the wear mechanism depends on the modulation period
- v) The results for the thermal stability of the structure and composition, mechanical and tribological properties of the developed multilayer nanocomposite coating TiAlSiN/AlSiN show that heat treatment up to 900 °C does not change the structure and architecture of the coating and it possesses high strength, combined with superhardness with improved elasticity, which remains sufficiently stable at high temperatures up to 900°C.

7. Evaluation of the publications on the dissertation work

The results of the dissertation work were published in 2023 and 2025 in two comprehensive articles in the specialized open access journal Coatings MDPI (with an impact factor for 2024 of 2.8 and a five-year IF of 3.0), in which Mr. Kolchev is the first author, as well as co-authorship in a utility model from 2023.

A list of 5 independent citations is presented as follows: i) 4 independent citations for the first article (2023), two of which are informal, and ii) 1 informal citation for the second article (2025), which attest to the value and interest in the published results.

Based on these facts, the total number of points to meet the requirements is 125, accumulated as follows:

Indicator 1:	50	the dissertation
Indicators 5 to 10:		
indicator 7:	2 x 20 = 40	Q2 journal articles
indicator 9:	1 x 25 = 25	registered utility model
indicator 11:	5 x 2 = 10	citations
Total:		125

This covers the minimum number of 125 points.

8. Personal contribution of the doctoral student

According to established practice, MDPI journals officially list the contributions of the co-authors, and for those of Mr. Kolchev, "research work", "formal analysis" and article "writing" are indicated, which activities correspond to the participation of a doctoral student.

9. Thesis abstract

The thesis abstract corresponds to the content of the dissertation work and includes the most significant results, illustrated with appropriate graphs, spectra and photographs. It is prepared according to the requirements of the relevant regulations and reflects the main results achieved in the dissertation.

10. CONCLUSION

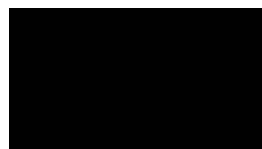
The dissertation contains scientific, scientifically-applied and applied results that represent an original contribution to science and fully meet all the requirements of the Act on the Development of the Academic Staff in the Republic of Bulgaria (ADABRB).

The presented materials and dissertation results comply with the specific requirements of the Regulations on the conditions and procedure for obtaining scientific degrees and occupying academic positions of the Central Laboratory of Applied Physics, Bulgarian Academy of Sciences, Plovdiv.

Based on the above, I confidently propose a positive assessment of the dissertation work of **Mr. Stefan Dimitrov Kolchev** for the award of the educational and scientific degree of Doctor of Philosophy in the professional field: 4.1. Physical Sciences, doctoral program "Condensed Matter Physics".

Plovdiv, 12.09.2025 г.

Author of reviewer's opinion:



Prof. Dr.Sci. Tinko Eftimov