

**REVIEW**  
**of the official reviewer for the thesis work**  
**of Tulegenova Malika Askarovna on the topic «Anticorrosion protective coatings based on graphene nanostructures», provided for the**  
**degree of Doctor of Philosophy (PhD) in the specialty «6D071000 - Materials Science and Technology of New Materials».**

№	Criteria	Compliance with the criteria (one of the options must be marked)	Justification of the position of the official reviewer
1.	The topic of the thesis (as of the date of its approval) corresponds to the directions of development of science and/or state programs	1.1 Compliance with priority directions of science development or state programs:	Thesis work of Tulegenova Malika Askarovna fully corresponds to the priority directions of science development or state programs in the field of materials science.
		1) <b><u>The thesis was carried out within the framework of a project or target program funded from the state budget (specify the name and number of the project or program)</u></b> 2) The thesis was carried out within the framework of another state program (specify the name of the program) 3) The thesis corresponds to the priority direction of science development, approved by the Higher Scientific and Technical Commission under the Government of the Republic of Kazakhstan (specify the direction)	The thesis was carried out within the grant financing on scientific and (or) scientific and technical projects for 2018-2020: № AP05130413 «Development of technology for creating protective coatings based on functionalized graphene nanostructures and researching their properties».
2.	Importance for science	The work <b><u>makes</u></b> /does not make a significant contribution to science, and its importance is <b><u>well disclosed</u></b> /not disclosed	The results of this work are new in the field of ultrathin anticorrosion coatings and make a significant contribution to science. In the thesis work, the advantages of using anticorrosion protective coatings based on graphene nanostructures are well disclosed, both with the help of computer simulation and in practice when graphene is used to protect the surface of copper and nickel from thermal oxidation, and the possibility of using a graphene oxide coating in the

			interaction with water and saline solution was shown.
3.	Principle of independence	<p>Level of independence:</p> <p>1) <b><u>High;</u></b>  2) Medium;  3) Low;  4) There is no independence</p>	<p>Author demonstrated a high level of independence, which is reflected in his work. Computer simulation of systems and quantum-mechanical numerical calculations, obtaining of anticorrosion protective coatings based on graphene nanostructures, the study of the obtained coatings with SEM and EDS author performed independently. Also the author independently presented the results of this work at the scientific conferences.</p>
4.	Principle of internal unity	<p>4.1 Justification of the relevance of the thesis:</p> <p>1) <b><u>Justified;</u></b>  2) Partially justified;  3) Not justified</p>	<p>The relevance of the thesis work is justified. Corrosion of metal products is quite a significant problem in production, so the use of effective and ultrathin coatings based on graphene nanostructures in thermal exposure and in contact with saline solution can make a significant contribution to science.</p>
		<p>4.2 The content of the thesis reflects the topic of the thesis:</p> <p>1) <b><u>Reflects;</u></b>  2) Partially reflects;  3) Does not reflect</p>	<p>The content of the thesis fully reflects the topic of the thesis. The main provisions for the defense of the thesis correspond to the topic of the thesis. The thesis consists of an introduction, three sections, a conclusion and a list of references. The first section is devoted to the literature review, the second - to computer simulation and quantum-mechanical numerical calculations of the studied systems, the third - to the methods of obtaining protective coatings based on graphene nanostructures and the study of their anticorrosion</p>

			properties.
		4.3 The purpose and the tasks correspond to the topic of the thesis: 1) <b><u>correspond;</u></b> 2) partially correspond; 3) do not correspond	The purpose of the thesis is the theoretical and experimental study of the effectiveness of anticorrosion protective coatings based on graphene nanostructures, which fully reflects the topic of the thesis. The tasks are set in such a way as to consistently achieve the stated purpose.
		4.4 All sections and provisions of the thesis are logically interconnected: 1) <b><u>completely interconnected;</u></b> 2) the interconnection is partial; 3) there is no interconnection	All sections and provisions of the thesis are logically interconnected. The presented thesis is a completed work.
		4.5 New solutions (principles, methods) proposed by the author are reasoned and evaluated in comparison with known solutions: 1) <b><u>there is a critical analysis;</u></b> 2) the analysis is partial; 3) the analysis does not represent the one's own opinions, but quotes from other authors	The results of computer simulations and quantum-mechanical numerical calculations predict the high protective properties of anticorrosion coatings based on graphene nanostructures against oxygen penetration, which is a new solution that can evaluate the properties of interest at the nanoscale. Also, the results of the experimental work are critically analyzed and are in good agreement with quantum-mechanical numerical calculations and are comparable with the results of other authors.
5.	Principle of scientific novelty	5.1 Are the scientific results and provisions new? 1) <b><u>completely new;</u></b> 2) partially new (25-75% are new); 3) not new (less than 25% are new)	The presented scientific results and the main provisions for the defense of the thesis are completely new, which is confirmed by the author's publications. In addition, the scientific team, where the author worked, with the direct participation of the author developed a new installation, which can grow ultrathin layers of anticorrosion

			protective coatings based on graphene nanostructures and measure Auger spectra in situ.
		<p>5.2 Are the conclusions of the thesis new?</p> <p>1) <b>completely new;</b></p> <p>2) partially new (25-75% are new);</p> <p>3) not new (less than 25% are new)</p>	The conclusions of the thesis are completely new and reflect the set tasks. In the conclusion the theoretical part, presented in the form of computer simulations and quantum-mechanical numerical calculations is consistent with the experimental part, where the high efficiency of anticorrosion protective coatings based on graphene nanostructures is shown.
		<p>5.3 Technical, technological, economic or management decisions are new and reasonable:</p> <p>1) <b>completely new;</b></p> <p>2) partially new (25-75% are new);</p> <p>3) not new (less than 25% are new)</p>	Technical, technological, economic or management decisions are new and reasonable. The novelty lies in the use of Dmol3 module of the Materials Studio program to study the barrier properties of graphene nanostructures. Also an important solution is the development of the installation, which allows synthesize graphene by diffusion method and in situ control their composition and structure using the created Conical Face-Field Electrostatic Energy Analyzer.
6.	Validity of the main conclusions	All the main conclusions are <b>based</b> /not based on scientifically sound evidence or well grounded (for qualitative research and areas of study in the arts and humanities)	All the main conclusions are justified scientifically and based on experimental data and computer simulation.
7.	The main provisions for the defense	<p>It is necessary to answer the following questions for each provision separately:</p> <p>7.1 Is the provision proven?</p> <p>1) proven;</p> <p>2) rather proven;</p> <p>3) rather not proven;</p> <p>4) not proven</p> <p>7.2 Is it trivial?</p> <p>1) yes;</p>	<p>The thesis lists four main provisions for the defense of the thesis:</p> <p>1. Ideal graphene, graphenes with structural defects in the form of vacancy, divacancy and a small gap in the sheet (0.25 nm) have a high efficiency of protective effect against oxygen penetration due to the formation of a</p>



		<p>2) no</p> <p>7.3 Is it new?</p> <p>1) yes;</p> <p>2) no</p> <p>7.4 Level for application:</p> <p>1) narrow;</p> <p>2) medium;</p> <p>3) wide</p> <p>7.5 Is it proven in the article?</p> <p>1) yes;</p> <p>2) no</p>	<p>potential barrier when the oxygen molecule interacts with the surface of the graphene layer.</p> <p>7.1 proven</p> <p>7.2 no</p> <p>7.3 yes</p> <p>7.4 medium</p> <p>7.5 yes</p> <p>2. In the graphene sheet with sufficiently large gaps (0.45 nm) the maintenance of high efficiency of protective effect against oxygen penetration is achieved by its functionalization with impurity gallium atoms due to the formation of a strong Ga-C covalent bond (2.6 eV) and high oxygen adsorption energy of gallium (1.8 eV).</p> <p>7.1 proven</p> <p>7.2 no</p> <p>7.3 yes</p> <p>7.4 medium</p> <p>7.5 yes</p> <p>3. Anticorrosion graphene coatings obtained by chemical vapor deposition demonstrate reliable protection of copper and nickel surfaces from thermal corrosion, which is associated with the high quality of the coatings (D/G ratio <math>\approx</math> 0.08).</p> <p>7.1 proven</p> <p>7.2 no</p> <p>7.3 yes</p> <p>7.4 wide</p> <p>7.5 yes</p> <p>4. Auger spectrometer, designed and implemented using the Conical Face-</p>
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8.	Principle of reliability Reliability of sources and information provided	8.1 Choice of methodology –is justified or methodology is described in sufficient detail: 1) <u>yes</u> ; 2) no	The choice of methodology is well justified at each stage of the thesis work performed and is described in sufficient detail.
		8.2 The results of the thesis work were obtained using modern methods of scientific research and methods of processing and interpreting data using computer technologies: 1) <u>yes</u> ; 2) no	The results presented in the thesis were obtained using modern proven methods of scientific research and computer technologies, which were tested at scientific conferences and in the author's publications.
		8.3 Theoretical conclusions, models, identified relationships and regularities have been proved and confirmed by experimental research (for areas of training in the pedagogical sciences the results have been proved on the basis of a pedagogical experiment): 1) <u>yes</u> ; 2) no	Theoretical conclusions, models, identified relationships and regularities have been proved and confirmed by experimental study of the effectiveness of anticorrosion protective coatings based on graphene nanostructures under the influence of external factors.
		8.4 Important statements are <u>confirmed</u> /partially confirmed/ not confirmed by references to relevant and reliable scientific literature	Important statements are confirmed by references to relevant and reliable scientific literature. Most of the sources are published in highly rated journals.
		8.5 Used literature sources are <u>sufficient</u> /not sufficient for a literature review	The list of references used by the author includes 232 references to scientific sources, which fully reflects the completeness of the literature review.

9	Principle of practical value	9.1 The thesis has a theoretical value: 1) <b>yes;</b> 2) no	The results of computer simulation and quantum-mechanical numerical calculations presented in the work have a theoretical value.
		9.2 The thesis is of practical importance and there is a high probability of applying the results obtained in practice: 1) <b>yes;</b> 2) no	The thesis is of significant practical importance because corrosion protection is one of the important practical areas in physics and chemistry.
		9.3 Are the suggestions for practice new? 1) <b>completely new;</b> 2) partially new (25-75% are new); 3) not new (less than 25% are new)	Proposals for practice are completely new. The use of ultrathin anticorrosion coatings based on graphene nanostructures to protect metals is a promising direction in solving the problems associated with corrosion.
10.	Quality of writing and design	The quality of academic writing is: 1) <b>high;</b> 2) average; 3) below average; 4) low.	The quality of academic writing is high, the work is presented clearly and consistently.

### Conclusion on the possibility of awarding the degree of Doctor of Philosophy (PhD)

Thesis work performed on the topic: "Anticorrosion protective coatings based on graphene nanostructures" is a completed research work. I believe that the thesis on the relevance of the problems solved and the quality of the results obtained, in terms of their scientific and practical significance, is a serious scientific research and meets all the requirements of the rules of awarding the degree of Doctor of Philosophy (PhD) of the Committee for Quality Assurance in the Field of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, and its author Tulegenova Malika Askarovna deserves to be awarded the degree of Doctor of Philosophy (PhD) in the specialty "6D071000 - Materials Science and Technology of New Materials".

### Official reviewer:

Research Infrastructure Coordinator  
Core Facilities, Nazarbayev University



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Arbuz Alexandr, PhD