REVIEW

of the official reviewer for dissertation work of Kanzhigitova Dana on the theme: "Development of novel functional hybrid materials based on conducting polymers", submitted for the degree of Doctor of Philosophy (PhD) in the Educational Program "8D05301 - Chemistry.

№	Criteria	Eligibility (one of the options must be checked)	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 areas of science development or government programs:	
		1) The thesis was completed within the framework of a project or target program financed from the state budget (indicate the name and number of the project or program) 2) The thesis was completed within the framework of another state program (indicate the name of the program) 3) The dissertation corresponds to the priority direction of the development of science, approved by the Higher Scientific and Technical Commission under the Government of the Republic of Kazakhstan (indicate the direction)	1) The thesis was completed as part of a project titled "Multifunctional Desulfurization Polymer Nanocomposites," which was funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan under project number AP09258910. 2) Furthermore, it was supported by a Faculty Development Competitive Research Grant from Nazarbayev University under project reference number 021220FD4551, titled "Crosslinked 3D Nanoporous Conducting Polymer Materials via Bicontinuous Microemulsion-based Approach." 3) The dissertation corresponds to the following specialized scientific areas as 11. Composite and functional materials; 33. Nanodisperse systems and nanotechnologies

			of the priority areas of the development of science 2) Energy, advanced materials and transportation.
2.	Importance for science	The work makes/does not make a significant contribution to science, and its importance is well disclosed/not disclosed	The work makes a significant contribution to science, and its importance is well disclosed.
3.	The principle of independence	Self-reliance level: 1) High; 2) Medium; 3) Low; 4) No independence	The level of self-reliance in the work can be considered to be high. The dissertant is the first author in two out of the three articles proposed for the PhD degree (DOI: https://doi.org/10.1021/acs.langmuir.3c03167 and DOI: https://doi.org/10.1007/s42114-023-00796-0).
4.	The principle of inner unity	4.1 Justification of the relevance of the thesis: 1) Justified; 2) Partially justified; 3) Not justified.	The relevance of the thesis is fully justified. The research addresses a critical and timely topic in materials science, focusing on the synthesis and application of conducting polymers. Given the widespread interest and potential uses of materials like PEDOT, polypyrrole, polyaniline, and polythiophene in various advanced technologies, the work's exploration of innovative fabrication techniques and the resulting enhancements in electrical properties are highly pertinent. The thesis not only contributes to the fundamental understanding of nanostructure design but also offers practical

			solutions to current challenges in the field, thus demonstrating clear and significant relevance.
		4.2 The content of the thesis reflects the topic of the thesis: 1) Reflects; 2) Partially reflects; 3) Does not reflect	The content of the thesis fully reflects the topic "Development of Novel Functional Hybrid Materials Based on Conducting Polymers." The research comprehensively covers the development and synthesis of new functional hybrid materials, focusing on conducting polymers. Each scientific result aligns with the objective of creating and exploring novel hybrid materials, demonstrating both innovative synthesis techniques and practical applications. The advancements in electrical conductivity, structural properties, and functional applications such as gas sensing validate the relevance and depth of the research in accordance with the thesis topic. In my opinion, it would be beneficial for the dissertation to offer more specificity regarding its research object and purpose. As of now, the topic appears to be rather general in nature.
		4.3. The purpose and objectives correspond to the topic of the thesis: 1) correspond; 2) partially correspond; 3) do not correspond	The purpose and objectives of the thesis align well with the topic. They focus on synthesizing novel materials, exploring the impact of different synthesis methods, and

			enhancing properties like conductivity and sensing capabilities, directly addressing the goals of the research. The tasks effectively support the development of innovative hybrid materials based on conducting polymers.
		4.4 All sections and provisions of the thesis are logically interconnected: 1) completely interconnected; 2) the interconnection is partial; 3) there is no interconnection	The abstract of the dissertation effectively conveys the core concepts and key findings presented in the research, which have been previously published in scientific articles.
		4.5 The new solutions (principles, methods) proposed by the author are reasoned and evaluated in comparison with the known solutions: 1) there is a critical analysis; 2) partial analysis; 3) the analysis does not represent one's own opinions, but quotes from other authors	The author critically evaluates the new synthetic techniques and materials developed, comparing them with existing methods and findings in the field of conducting polymers. This includes discussing the advantages and limitations of the proposed solutions in relation to established approaches.
5.	Scientific novelty principle	5.1 Are the scientific results and provisions new? 1) completely new; 2) partially new (25-75% are new); 3) not new (less than 25% are new)	*"Strategic Synthesis of 2D and 3D Conducting Polymers and Derived Nanocomposites"* (Article 1). The scientific results are completely new. The use of bicontinuous microemulsion systems for producing conducting polymer nanostructures and the manipulation of oxidant-to-monomer ratios represent innovative approaches that significantly advance the field of conducting polymers.

			"p-Toluenesulfonic Acid Doped Vanadium Pentoxide/Polypyrrole Film for Highly Sensitive Hydrogen Sensor" (Article 2). The scientific results are completely new. The development of a highly sensitive hydrogen sensor using p-toluenesulfonic acid doping in vanadium pentoxide/polypyrrole hybrid films introduces a novel method with substantial implications for gas sensing technology. *"Controlled Synthesis of Polyaniline-based Nanomaterials with Self-assembly and Interface-Manipulation"* (Article 3). The scientific results are partially new (25-75% are new). While the controlled synthesis of polyaniline-based nanomaterials through self-assembly and interface manipulation techniques is innovative, the concept of self-assembly and interface manipulation itself has been explored previously in the field of nanomaterial synthesis. In conclusion, Article 1 and Article 2 present scientific results that are completely new, showcasing significant advancements and innovations in their respective areas.

			Article 3 introduces partially new scientific results, building upon existing concepts while innovating in specific synthesis methods and applications.
		5.2 Are the dissertation findings new? 1) completely new; 2) partially new (25-75% are new); 3) not new (less than 25% are new)	The dissertation findings overall demonstrate a significant level of innovation, with many aspects being partially new in the range of 25-75%. Each article contributes novel insights and methods to their respective fields of conducting polymers, nanomaterial synthesis, and sensor technology, pushing the boundaries of current knowledge and applications.
		5.3 Technical, technological, economic or management decisions are new and reasonable: 1) completely new; 2) partially new (25-75% are new); 3) not new (less than 25% are new)	Overall, the technical, technological, economic, or management decisions in the dissertation findings vary in their novelty, with significant innovations particularly evident in Articles 2 and aspects of Article 1 and 3. Due to the lack of detailed information about the economic side of the proposed technological solutions published in the articles, it is not possible to draw any conclusions. Moreover, the dissertation work is presented in the form of a short abstract, which greatly limits the possibility of reviewing it as a fully completed work.

6.	The validity of the main findings	All main conclusions are/are not based on scientifically significant evidence or well-grounded (for qualitative research and areas of training in the arts and humanities)	The conclusions and main points presented in the abstract of the dissertation are well-grounded, which is reflected in the author's articles in peer-reviewed journals with a high impact factor.
7.	The main provisions for the defense	It is necessary to answer the following questions for each provision separately: **Provision 1** 7.1 Is the provision proven? 1) proven; 2) rather proven; 3) rather not proven; 4) not proven 7.2 Is it trivial? 1) yes; 2) no 7.3 Is it new? 1) yes; 2) no 7.4 Application level: 1) narrow; 2) medium; 3) wide 7.5 Is it proven in the article? 1) yes; 2) no	**Provision 1.** The highest conductivity is 219 S/cm obtained for the nanosheet fabricated using a clean interface reactor system (DCM system) due to the absence of an interfacial barrier and easy transport of dopants to the polymer matrix. 1. This statement requires further clarification and elaboration on several points. First and foremost, it is essential to specify the material being discussed, in this case, 2D polypyrrole, and provide a comprehensive description of the material. Additionally, it is necessary to identify the doping agent being used, which provides an electrical conductivity of 219 S/cm. 2. The purpose of the study must be clarified, as the statement does not convey the essence of the research. It is crucial to determine whether the objective is to increase the electrical conductivity of the polymer material for a specific application or purpose. Furthermore, the study's results

			should be evaluated in context, with a comparison of the electrical conductivity value to other similar materials or studies. 3. Moreover, the article referenced (DOI: 10.1002/adma.202208864) does not provide sufficient information regarding the experimental method, procedure, and equipment used to measure the electrical conductivity of the polymer. It is necessary to include details about the temperature at which the electrical conductivity was measured to ensure accurate results. Comments: 1. The specific procedure and method for measuring electrical conductivity are not detailed in the article, so it is unclear whether the impact of air humidity was considered during the measurement process. If it was, what is the impact of this factor on the final result in terms of percentage? 2. The SEM images of the synthesized polypyrrole films show that 3D polypyrrole (as seen in Figure 1 c) has a relatively large surface area. Given this, what is the probability of side reactions occurring due to the

		Provision 2 7.1 Is the provition proven? 1) proven; 2) rather proven; 3) rather not proven; 4) not proven 7.2 Is it trivial? 1) yes; 2) no 7.3 Is it new? 1) yes; 2) no 7.4 Application level: 1) narrow; 2) medium; 3) wide 7.5 Is it proven in the article? 1) yes; 2) no	absorption of moisture from the air? Has the impact of the environment on material degradation been examined? 3. Polyaniline is a well-studied conducting polymer. What is the advantage of the method proposed in the article over electrochemical methods, which are inherently simple and controllable in terms of thickness? **Provision 2.** The addition of p-toluenesulfonic acid (p-TS) to vanadium pentoxide (V_2O_5) and polypyrrole (PPY) made it possible to form an ordered structure of the composites and increase the mobility of charge carriers from 4.76 cm^2/Vs to 14 cm^2/Vs and due to this, the hydrogen gas response increased from 7.88% to 32.43%. The first and second statements are not well connected. It would be logical to modify the obtained in previous article 3D polypyrrole with vanadium oxide and then test it for hydrogen detection as a sensor. Comments: 1. In the article (DOI: https://doi.org/10.1007/s42114-023-00796-0) the principle of operation of

			the sensor and whether it is physical or electrochemical is not entirely clear. The statement on page 8 (between reference 52 and the conclusion) regarding the role of vanadium oxide is ambiguous. 2. The experimental section lacks information on the surface area of the electrode or composite material, making it difficult to understand the relationship between the signal (as shown in Figure 5 d) and the active material. The composite material exhibits a response in the form of current, with values in the nanoampere range, indicating the need for high-precision equipment with a signal amplifier cable. This lack of detail may hinder practical applications. 3. Additionally, the measurement procedure is not specified, including whether the signal is constant (DC) or alternating (AC), its amplitude and frequency. Applying more than 20 mV potential increases the probability of electrochemical discharge-ionization of the conductive polymer layer or vanadium oxide, which can lead to material degradation. These points need to be clarified.

		Provision 3 7.1 Is the provition proven? 1) proven; 2) rather proven; 3) rather not proven; 4) not proven 7.2 Is it trivial? 1) yes; 2) no 7.3 Is it new? 1) yes; 2) no 7.4 Application level: 1) narrow; 2) medium; 3) wide 7.5 Is it proven in the article? 1) yes; 2) no	**Provision 3.** The method of obtaining various nanostructures of polyaniline derivatives (nanospheres, nanorods and nanobowls) using a bicontinuous microemulsion reactor system makes it possible to control their morphology and shape from rod to adhesive film structures. Comments: 1. This statement is in need of significant revision, as it is overly general and lacks a quantitative description of the specific results achieved.
8.	The principle of reliability Reliability of sources and information provided	8.1 Choice of methodology - is justified or the methodology is described in sufficient detail 1) yes; 2) no	The methodological components of the work presented include comprehensive and lucid techniques. I am of the opinion that the detailed techniques described can facilitate the verification of the experiment's reproducibility and performance, thereby ensuring the consistent attainment of the obtained results.
		8.2 The results of the thesis were obtained using modern methods of scientific research and methods of processing and interpreting data using computer technologies: 1) yes; 2) no	The thesis results were achieved through modern scientific research methods and advanced data processing techniques using computer technologies. This includes

			innovative approaches like bicontinuous microemulsion systems for synthesizing conducting polymer nanostructures, sophisticated doping methods with substances like p-toluenesulfonic acid to tailor material properties, and precise control over nanomaterial morphology through self-assembly and interface manipulation.
		8.3 Theoretical conclusions, models, identified relationships and patterns have been proven and confirmed by experimental research (for areas of training in pedagogical sciences, the results have been proven on the basis of a pedagogical experiment): 1) yes; 2) no	The theoretical conclusions, models, identified relationships, and patterns proposed in the thesis have been substantiated and validated through experimental research. This confirmation underscores the robustness of the theoretical frameworks and models employed, ensuring that the derived conclusions are firmly rooted in empirical evidence. The experimental findings provide concrete support for the theoretical constructs, affirming the reliability and applicability of the identified relationships and patterns within the context of conducting polymers and nanomaterial synthesis.
		8.4 Important statements are confirmed / partially confirmed / not confirmed by references to current and reliable scientific literature	Important statements in the published articles are confirmed by references to current and reliable scientific literature.

		8.5 Used literature sources are sufficient/not sufficient for a literature review	Used literature sources are sufficient for an introduction part of the published articles.
9	Practical value principle	9.1 The thesis has theoretical value: 1) yes; 2) no	The theoretical benefits of this work lie in advancing knowledge, optimizing nanostructure design, contributing to fundamental scientific understanding, fostering innovation, and supporting cross-disciplinary applications in various technological and scientific domains.
		9.2 The thesis is of practical importance and there is a high probability of applying the results obtained in practice: 1) yes; 2) no	The thesis is of practical importance, and there is a high probability of applying the results obtained in practice. Applications in hydrogen gas sensing demonstrate practical relevance for environmental monitoring and industrial safety, where responsive and advanced sensor technologies are crucial.
		9.3 Are the practice suggestions new? 1) completely new; 2) partially new (25-75% are new); 3) not new (less than 25% are new)	Overall, the practice suggestions put forth in the thesis exhibit varying degrees of novelty. Articles 1 and 2 present completely new practices that innovate within their respective fields, while Article 3 introduces partially new practices by refining existing methods and applying them in novel ways. The corresponding articles are listed in the criteria No.5. The practice suggestions related to self-assembly and interface manipulation for creating diverse

			polyaniline-based nanostructures are partially new (25-75% are new), as these techniques build upon existing concepts in nanomaterial synthesis but introduce novel applications and methods.
10.	The quality of writing and design	Academic writing quality: 1) high; 2) average; 3) below average; 4) low.	The quality of academic writing is high.

Based on the aforementioned findings, I recommend awarding the degree of Doctor of Philosophy (PhD) to Ms. Kanzhigitova Dana in the specialty "8D05301 - Chemistry" for her dissertation work titled "Development of novel functional hybrid materials based on conducting polymers", and for developing a novel high-performance H_2 sensor based on vanadium pentoxide, toluene sulfonic acid-doped polypyrrole thin film, and investigating the fundamental scientific issues in conducting polymers by enhancing conductivity through structural modifications.

Reviewer, PhD, senior lecturer
Analytical, colloidal chemistry and
technology of rare elements department
Al-Farabi Kazakh National University

Avchukir Khaisa

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18.06.24г