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:	The dissertation work of Dana Kanzhigitova, entitled "Development of novel functional hybrid materials based on conducting polymers," complies with priority areas of scientific 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)	The dissertation work was performed mostly the School of Engineering and Digital Sciences of Nazarbayev University in the framework of several grant projects financed from the budget of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan and the Faculty Development Competitive Research Grant from Nazarbayev University. The first project, titled "Crosslinked 3D Nanoporous Conducting Polymer Materials via Bicontinuous Microemulsion-Based Approach," which was supported by a Faculty Development Competitive Research Grant from Nazarbayev University under Project ref. no. 021220FD4551 for the period 2021-2023, aimed to develop new materials based on conducting polymers. The second project, titled "Multifunctional Desulfurization Polymer Nanocomposites" (2021-2023), received financial support from the Ministry of Education and Science of the Republic of Kazakhstan under project No. AP09258910.
2.	Importance for science	**The work makes**/does not make a significant contribution to science, and its importance is **well disclosed**/not disclosed	The three research projects provide substantial contributions to science, and their significance is broadly understood. Each study increases our understanding and application of conducting polymers by employing novel synthesis processes and extensive

			characterisation. The first article describes a novel and scalable approach to synthesizing conducting polymer nanostructures using bicontinuous microemulsion systems, which improves the ability to modify nanostructure morphology and properties, which is critical for various applications in electronics and material science. The second work shows how V_2O_5 inorganic templates can be integrated to form hybrid thin films with increased sensing capabilities, showing the potential for rapid and sensitive trace gas detection, which could lead to advances in environmental monitoring and industrial safety. The third study investigates using p-toluene sulfonic acid as a structure-directing agent to create flexible conducting polymer nanostructures, providing new insight on the synthesis of various nanostructures with applications in medication delivery, energy storage, and adhesion materials. Collectively, this work provides significant contributions to the science of conducting polymers by demonstrating novel approaches and widening the range of their practical applications.
3.	The principle of independence	Self-reliance level: **1) High;** 2) Medium; 3) Low; 4) No independence	Upon analysis of the dissertation, it is evident that the candidate has performed an in-depth investigation of the subject area and demonstrates the ability to independently address both theoretical and practical tasks described in the research.
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 dissertation is justified by its significant contributions to the field of conducting polymers through three innovative research works. The first study describes a unique and scalable method for creating polymer nanostructures utilizing bicontinuous microemulsion systems, which is critical for advances in electronics and materials science. The second study improves gas sensing technology by including V2O5 inorganic templates, resulting in quick and sensitive trace gas detection for environmental and industrial applications. The

			third study investigates the varied use of p-toluene sulfonic acid to create various polymer nanostructures with possible uses in medication delivery, energy storage, and adhesion materials.
		4.2 The content of the thesis reflects the topic of the thesis: **1) Reflects;** 2) Partially reflects; 3) Does not reflect	The dissertation work is completely understood by the content, which represents the topic of the dissertation.
		4.3. The purpose and objectives correspond to the topic of the thesis: 1) **correspond;** 2) partially correspond; 3) do not correspond	The author competently demonstrates the achievement of the aims and objectives outlined in the dissertation work by carefully carrying out all associated responsibilities. The goals and objectives have a clear connection to the study problem.
		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 dissertation work exhibits a precisely structured and logical structure, with each chapter interconnected and systematically presenting a detailed overview of the research findings.
		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 provided precise, logically proved justifications for the dissertation work's primary points.
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)	The article called: Strategic Synthesis of 2D and 3D Conducting Polymers and Derived Nanocomposites which was published in Advanced Materials presents a new and efficient technique that uses bicontinuous microemulsion systems to produce conducting polymer nanostructures. This approach deviates from conventional methodologies and provides unprecedented manipulation of the form and characteristics of the

			nanostructures, representing a significant breakthrough in materials research. The second article called: p-Toluenesulfonic acid doped vanadium pentoxide/polypyrrole film for highly sensitive hydrogen sensor, was published in Advanced Composites Hybrid Materials introduces a novel approach by incorporating V_2O_5 as an inorganic template and using structure directing agent p-toluenesulfonic acid to increase charge carrier mobility and produce hybrid thin films of conducting polymers. This innovative method greatly improves gas sensing capabilities, particularly for detecting hydrogen, offering fresh perspectives and tangible progress in sensor technology. The third article called: Controlled Synthesis of Polyaniline-based Nanomaterials with Self-assembly and Interface-Manipulation which was published in ACS Langmuir investigates the novel application of p-toluene sulfonic acid as a structure-directing agent for the production of various and scalable conducting polymer nanostructures. The capacity to create diverse forms, including hollow nanoparticles, bowl shapes, and 2D films, shows a novel and flexible method for producing polymer nanostructures. This technique has wide-ranging uses in areas such as medication delivery, energy storage, and adhesion materials.
		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 author's results are truly unique as they propose novel ways to manipulate conducting polymer chains and improve the effectiveness of conducting polymers.
		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)	The use of bicontinuous microemulsion systems to produce conducting polymer nanostructures is a novel and innovative technical and technological methodology. This approach provides a unique level of control over the form and characteristics of the nanostructures. Using V_2O_5 as an inorganic template to improve the gas sensing abilities of conducting

			polymers and using p-toluene sulfonic acid to increase charge carrier mobility are an innovative technological choice. This integration enhances the sensitivity and reduces the response time of hydrogen sensors. Using p-toluene sulfonic acid as a structure-directing agent to produce various conducting polymer nanostructures is a novel and adaptable technical choice. This method facilitates the fabrication of diverse nanostructure morphologies.
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 overall findings confirm that the conclusions are scientifically significant and are supported by substantial evidence.
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;**	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. 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%. 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. **1 provision:**

		2) no **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 **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;**	1. **Yes, the provision is proven**. The highest conductivity of 219 S/cm was indeed obtained for the nanosheet fabricated using a clean interface reactor system (DCM system). This high conductivity can be attributed to the absence of an interfacial barrier in the clean interface system, which allows for easy transport of dopants to the polymer matrix, leading to superior electrical properties 2.**No, the research is not trivial**. This significant result highlights the effectiveness of the clean interface system in promoting enhanced electrical properties by facilitating the transport of dopants to the polymer matrix without the presence of interfacial barriers 3.Yes, based on research, the achievement of the highest conductivity of 219 S/cm for the nanosheet fabricated using a clean interface reactor system **represents a novel** and innovative advancement in the field of conducting polymer nanostructures. 4. The synthesized conducting polymer nanostructures, such as the 2D nanosheets of conducting polymers with high conductivity, have **wide application potential** in various fields including: Light-emitting diodes (LEDs), Thin-film transistors, Solar cells, Batteries and Supercapacitors 5. Yes, the provision of wide application potential for the synthesized conducting polymer nanostructures, as discussed in the article, is supported by the research findings and the demonstrated enhanced electrical properties of the nanosheets. They made composites with carbon dots which makes them excellent material for medical diagnosis, bio-imaging, fluorescent sensing, light emitting diodes and photovoltaic devices. ***Note.***

		2) no 7.4 Application level: 1) narrow; 2) medium; **3) wide** 7.5 Is it proven in the article? **1) yes;** 2) no	1.It is necessary to provide a clear explanation for the selection of particular bicontinuous microemulsion technique. These selections should be rationalized according to the anticipated results and prior investigation. 2.Clear recommendations for future research directions based on the findings of the study should be provided. **2 provision:** **1.Yes, the provision is proven.** The addition of p-toluenesulfonic acid (p-TS) to vanadium pentoxide (V2O5) and polypyrrole (PPY) facilitated the formation of an ordered structure of the composites. This addition increased the mobility of charge carriers from 4.76 cm2/Vs to 14 cm2/Vs. As a result of this enhanced carrier mobility, the hydrogen gas response significantly increased. 2. **No**, the inclusion of p-toluenesulfonic acid (p-TS) in the mixture of vanadium pentoxide (V2O5) and polypyrrole (PPY) resulted in a significant enhancement of the observed hydrogen gas response, increasing it from 7.88% to 32.43%. This enhancement in charge carrier mobility is substantial. The significant enhancement in gas response underscores the importance of the research findings and demonstrates the synergistic effect of the composite structure and p-TS in enhancing the sensor's performance. 3. **Yes**. The application of this composite material for detecting hydrogen gas, combined with the proven enhancements in sensitivity and reaction time, presents a novel method for improving gas sensor performance. The addition of p-toluenesulfonic acid to alter the structure and properties of the composite enhances the originality of the research.

			4. The research findings have the potential to be applied in a **wide range of areas**. The sensor's improved performance in terms of reaction time, sensitivity, and recovery time renders it appropriate for use in environmental monitoring, industrial safety, and hydrogen fuel technologies. Efficiently detecting minute quantities of hydrogen gas can facilitate progress in gas detection systems and enhance safety and efficiency in related industries. 5. Yes, the article's experimental results and performance evaluation support the research's broad applicability. The work shows how a hydrogen gas sensor made of vanadium pentoxide, polypyrrole, and p-toluenesulfonic acid can detect small amounts of hydrogen gas with better sensitivity and response times. The article's experimental data and analysis show that the sensor's improved performance makes it suitable for environmental monitoring, industrial safety, and hydrogen fuel technologies. **Note.** More detailed explanations or discussions regarding the mechanisms behind the observed changes in carrier mobility and sensor performance should be provided. **3 provision:** **1.** Indeed, the provision has been proved. The use of a bicontinuous microemulsion reactor system has been shown to facilitate the production of different nanostructures of polyaniline derivatives, such as nanospheres, nanorods, and nanobowls. This method allows for precise control over the morphology and shape of these nanostructures, enabling the

			transformation from rod-shaped structures to adhesive film structures. 2. No, the approach given in the article is not trivial. The precise fabrication of polyaniline-based nanostructures through the use of a bicontinuous microemulsion reactor system for controlling their morphology and shape, resulting in the creation of adhesive film structures, is an innovative and important advancement in the field of materials science and nanotechnology. 3. This approach is considered innovative and represents **a new advancement** in the field of materials science and nanotechnology. This innovative synthesis approach provides a means to customize the characteristics and arrangements of conducting polymer nanostructures for diverse applications. 4. The use of the controlled synthesis of polyaniline-based nanostructures utilizing a bicontinuous microemulsion reactor technology has significant and wide benefits. This method allows for the precise manipulation of morphology and shape to produce sticky film structures, which creates prospects for a **wide range of applications**. 5. The work demonstrates the purposeful modification of the physical structure and form to create adhesive film structures, and the subsequent analysis of the resulting nanostructures using techniques such as SEM, DSC, Raman spectroscopy, and AFM. The article's findings confirm the efficacy and practicality of the suggested synthesis method for producing customized conducting polymer nanostructures with a wide range of uses.

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	Scientific methodology was used combined with well-chosen, precise, and recent analysis techniques to verify the collected data. For the purpose of providing a comprehensive overview of the research, all tests were carried out in multiple runs to guarantee reliability and reproducibility. **General observation** The ability to manipulate the morphology and shape of conducting polymer nanostructures to create adhesive film structures demonstrates a high level of creativity and technical expertise.
		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 dissertation work provided results through using of modern scientific research methods and extensive characterisation approaches: 1. X-ray photoelectron spectroscopy (XPS) 2. ^{1}H and ^{13}C-NMR spectroscopy 3. X-Ray diffraction analysis (XRD) 4. Confocal microscopy 5. Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) 6. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) 7. Elemental analysis 8. Four probe apparatus 9. Gas sensing device 10. Atomic force microscopy (AFM)
		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;**	The effectiveness of the innovative synthesis approach using bicontinuous microemulsion systems in Article 1 is confirmed by comprehensive experimental data that shows the ability to manipulate the form and characteristics of nanostructures. The utilization of V_2O_5 as an inorganic template in Article 2 is substantiated by experimental proof, which demonstrates

		2) no	enhanced gas sensing capabilities, particularly in terms of increased sensitivity and accelerated response times for hydrogen detection. Article 3 validates the adaptability of p-toluene sulfonic acid in producing various polymer nanostructures by conducting thorough characterization and analysis, thereby supporting the theoretical models and established relationships. The studies collectively offer strong concrete evidence that supports all theoretical assumptions and highlights advancements.
		8.4 Important statements **are confirmed** / partially confirmed / not confirmed by references to current and reliable scientific literature	The findings of the study match with the previously published research. Accurate citations to relevant sources are included.
		8.5 Used literature sources **are sufficient**/not sufficient for a literature review	The main findings in this study are supported by citations from current and reliable scientific literature. Each of the three research improves on current knowledge and methodology, using recent and reliable sources to support the innovative approaches and discoveries.
9	Practical value principle	9.1 The thesis has theoretical value: **1) yes;** 2) no	Yes, these works have significant theoretical value. They offer profound understanding of the processes involved in the arrangement of polymer chains, the impact of additives on the movement of electric charges, and the influence of different methods of synthesis on the shape and structure of nanomaterials. These theoretical insights enhance the fundamental comprehension of conducting polymers and their characteristics, so providing valuable guidance for future study and development in this sector.
		9.2 The thesis is of practical importance and there is a high probability of applying the results obtained in practice: **1) yes;**	These methods have the potential to be scaled up for use in industrial applications in the fields of electronics and materials research. This technology has the potential to be used in environmental monitoring and industrial safety due to its ability

		2) no	to identify hydrogen quickly and accurately. The multifunctional nanostructures exhibit promising applications in the delivery of drugs, energy storage, and adhesion materials.
		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)	Suggestions are new
10.	The quality of writing and design	Academic writing quality: **1) high;** 2) average; 3) below average; 4) low.	The work is written using precise scientific and technical language, and the research method is properly explained.

In reviews, official reviewers indicate one of the following solutions:

1) to award the degree of Doctor of Philosophy (PhD) or Doctor of Specialization;

The dissertation work shows scientific novelty through its explanation of results, discussion, and conclusions. Dana Kanzhigitova has developed expertise in the synthesis and application of polymers, making her qualifications highly relevant for driving forward progress in our country's scientific area. I highly recognize her work and strongly suggest awarding her the Doctor of Philosophy (PhD) degree in the field of Chemistry.

Copies of the reviews of the official reviewers are handed over to the doctoral student no later than 5 (five) working days before the defense of the thesis.

Official Reviewer:

Seitkhan Azat

PhD, Associate Professor,
Director of the Engineering profile Laboratory,
Satbayev University

Подпись

Заверяю: Главный менеджер Горно-металлургического института им. О.А. Байконурова НАО «КазНИТУ им. К.И. Сатпаева»

ФИО подпись, дата