1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title: Modern electrochemical energy storage

1.1. Project goals

- ✓ Building of ready-for-use prototypes of electrochemical energy storage devices.
- ✓ To explore the relation between the chemical structure of carbon materials (morphology, presence of heteroatoms, surface modification) and their electrochemical activity for potential application in Zn-air batteries, fuel cells, supercapacitors and photovoltaic cells (DSSCs).
- ✓ To upgrade the knowledge and skills in the area of "green" energy harvesting devices design.
- ✓ To upgrade social competences as team working and cooperation spirit.

1.2. Outline

Energy storage and management are the key issues of the growing world population and the environment protection. Storying energy by electrochemical devices is the most common approach since it this way electric energy produced by "green" installations (wind mills, photovoltaics, energy dams, electrochemical burning of "green" hydrogen, etc.) may be directly stored since electric energy is the product of such technologies. There are several applicable solutions like batteries and supercapacitors, however the existing devices suffer from several shortcomings like high cost, complicity of manufacturing, use of rare components etc. The current project aims at the development of new electrode materials for such devices basing on some emerging materials like graphene and borophene. A successful development of such electrode materials needs to solve problems like tailoring of pore structure and surface area, insertion of heteroatoms to non-specific graphene/borophene matrices (creation of catalytic centers) and optimizing of working conditions of electrodes and complete devices.
This project aims to develop, investigate and characterize novel, stable and cost-efficient electrodes for Zn-air batteries, fuel cells, supercapacitors and photovoltaic cells (DSSCs). The knowledge and experience in materials chemistry and electrochemistry, as well as access to highly specialized equipment (TEM, Raman spectrometer, Potentiostat/Galvanostat), is required for the successful realization of the planned studies.

1.3. Work plan

The following research stages will be included in the research to obtain the doctoral degree:

1) Literature studies towards the establishment of the-state-of-the-art regarding the recent achievements in electrochemical energy storage.
2) Formulation of main research goals to be achieved within the project along with the overall concepts of energy storage device (type of device, type of electrodes, type of electrolyte, type of memebrane).
3) Synthesis of electrode materials and developing of electrode fabrication method.
4) Electrochemical testing of the constructed device in laboratory scale.
5) Physico-chemical characterization of obtained carbon matrixes by instrumental methods: nitrogen adsorption (porous structure and surface area), elemental analysis (chemical composition), XPS

spectroscopy (chemical structure of the surface), X-ray (crystal structure), Raman spectroscopy (identification of carbons agglomeration degree), SEM/HRTEM microscopy (identification of spatial structure).

6) Building of a prototype energy storage device: in the ready-for-use formula.

1.4. Literature *(max. 10 listed, as a suggestion for a PhD candidate)*

1) Ilnicka, A.; Skorupska, M.; Szkoda, M., Zarach, Z., **Łukaszewicz, J.P.** N-doped carbon materials as electrodes for highly stable supercapacitors, Materials Research Letters 2023, 11 (3), 213-221.
2) **Kamedulski, P.;** M. Skorupska, P. Binkowski, W. Arendarska, A. Ilnicka, **J.P. Łukaszewicz**, High surface area mesoporous graphene for electrochemical applications, Scientific Reports, 2021, 11, 22054.
3) **P. Kamedulski, J.P. Łukaszewicz,** Ł. Witczak, P. Szroeder, P. Ziolkowski, The Importance of Structural Factors for the Electrochemical Performance of Graphene/Carbon Nanotube/Melamine Powders towards the Catalytic Activity of Oxygen Reduction Reaction, Materials 2021, doi:10.3390/ma14092448.
4) Y. Zhao, et al.; Can Boron and Nitrogen Co-doping Improve Oxygen Reduction Reaction Activity of Carbon Nanotubes?; J. Am. Chem. Soc. 2013, 135, 1201−1204.
5) J. Yu, et al.; Pristine and Defective 2D Borophene/Graphene Heterostructure as the Potential Anode of Lithium-Ion Batteries; Adv. Mater. Interfaces 2022, 9, 2102088.
6) A. Ambrosi, et al.; Electrochemistry of Graphene and Related Materials; Chem. Rev. 2014, 114, 7150−7188.
7) J. Deng, et al., Multiple roles of graphene in electrocatalysts for metal-air batteries, 2023, doi:10.1016/j.cattod.2022.01.003.
8) Z. Chen, et al., Waste-Derived Catalysts for Water Electrolysis: Circular Economy-Driven Sustainable Green Hydrogen Energy, 2023, doi:10.1007/s40820-022-00974-7.
9) A.Z. Arsad, et al., Hydrogen electrolyser technologies and their modelling for sustainable energy production: A comprehensive review and suggestions, 2023, doi:10.1016/j.ijhydene.2023.04.014.
10) G.F. Smaisim, A.M. Abed, H. Al-Madhhachi, S.K. Kadrawi, Graphene-Based Important Carbon Structures and Nanomaterials for Energy Storage Applications as Chemical Capacitors and Supercapacitor Electrodes: a Review, BioNanoSci (2023), doi:10.1007/s12668-022-01048-z.

1.5. Required initial knowledge and skills of the PhD candidate

1) Basic knowledge on electrochemical devices and their design
2) Orientation in contemporary and future trends in the area of "green" energy harvesting methods
3) Analytical thinking
4) Eager to learn
5) Ability to work in the laboratory (plan and perform synthesis, spectral measurements, electrochemical tests)
6) Understanding of materials synthesis and chemistry
7) Thinking oriented on innovation and application
8) Knowledge of carbon material science
9) Knowledge about basic methods to characterize obtained compounds
10) Eager to work hard

1.6. Expected development of the PhD candidate's knowledge and skills

1) Project management: the ability to plan and organize the project as well as delegating and negotiating tasks among project members.
2) Perseverance: the driver and determination to continue and finish a PhD student project.
3) Supervising and coaching: the ability to transfer knowledge and inspire others.
4) Communication skills in English at conferences and in writing publications.
5) Writing grant proposals.
6) Research data collection, analysis and conversion to research papers.