Highly Functionalized Materials for Electrochemical Science, Nanotechnology and Sustainable Energetics

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RESEARCH PROFILE:

Our interests concern various aspects of fundamental and applied electroanalytical chemistry related to materials chemistry as well as to kinetics and mechanism of electrode reactions. Our major research achievements are at the borderline of electrochemistry, inorganic chemistry and materials chemistry with special emphasis on elucidation of mechanisms of charge propagation in model mixed-valent polynuclear inorganic systems (polyoxometallates, Prussian Blue type metal hexacyanometallates, hybrids with organic conducting polymers) and, later, on the relation between the structure of novel materials and their electrocatalytic activity in electrochemical and photoelectrochemical energy conversion devices (e.g. P. J. Kulesza, I. A. Rutkowska). The advanced functional materials can find application in alternative energy sources such as fuel cells (e.g. B. Dembinska), biofuel cells and photoelectrochemical cells (e.g. dye-sensitized solar cells, electrolyzers for hydrogen generations). Furthermore, we are interested in fabrication, characterization and utilization of various functionalized and intentionally decorated noble metal nanoparticles (e.g. S. Żołądek). The feasibility of demonstrating possible analytical applications, such as determination of highly inert analytes, potential-controlled preconcentration of certain ions and reactants, amperometric sensing and biosensing should be mentioned here. We also concentrate on the description of mechanisms and dynamics of charge propagation of solid, crystalline or semi-liquid materials involving reversible redox transitions allowing for charge mediation and storage. Special attention is paid to the development and characterization of highly porous nanostructured carbons (including graphene nanoplatelets) for charge storage in supercapacitive type devices (e.g. M. Skunik-Nuckowska).

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Of particular interest is design and characterization of bioelectrocatalytic nanostructured systems with potential applications in biofuel cells and analytical biosensors (e.g. B. Kowalewska). In the research, enzymes from the oxidoreductase family are used as biocatalysts for the oxidation reaction of the fuel, i.e. glucose, lactates, ethanol. Finally, the biomedical aspects of electrochemical research are explored, e.g. to elucidate interactions of plazmid DNA with pentamidine in comparison to potential anticancer drug, Cl-IPBD (e.g. H. Elzanowska). Fundamental chemical properties of inorganic systems are of our concern as well (e.g. C. Gumiński).

CURRENT RESEARCH ACTIVITIES:

Our research aims at better understanding of the role of the metal oxide nanostructured additivities that affect the catalytic performance of noble metal nanoparticles with respect to adsorption, desorption and catalytic steps during oxidation of simple organic fuels (e.g. I. A. Rutkowska) or oxygen reduction (e.g. B. Dembińska, S. Żołądek). We demonstrate and emphasize the importance of interactions with the metal oxide support and emphasize its chemical state and activity toward removal of undesirable hydrogen peroxide intermediate during the oxygen reduction reaction. We also develop new catalytic systems permitting selective conversion (electrochemical, photoelectrochemical) of CO_2 to small organic molecules (e.g. I. A. Rutkowska, P. J. Kulesza). In bioelectrochemical research, carbon nanostructures (carbon nanotubes, graphene, fullerene) that are appropriately modified are utilized as highly conductive matrices, enabling effective electron transfer from the enzyme redox center to the electrode surface (e.g. B. Kowalewska). Finally, electrochemical studies aiming at elucidating interactions of plasmid DNA with antifungal and antibacterial compounds are also pursued (e.g. H. Elżanowska). High-power capacitor-like batteries are of our concern as well (e.g. M. Skunik-Nuckowska).

SELECTED PUBLICATIONS:

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3. B. Kowalewska, K. Jakubów, The impact of immobilization process on the electrochemical performance, bioactivity and conformation of glucose oxidase enzyme, Sensors and Actuators B: Chemical. 238 (2017) 852-861.
4. L.G. Bloor, R. Solarska, K. Bieńkowski, P.J. Kulesza, J. Augustyński, M.D. Symes, L. Cronin, Solar-driven water oxidation and decoupled hydrogen production mediated by an electron-coupled-proton buffer. J. Am. Chem. Soc. 138 (2016) 6707.
5. I.A. Rutkowska, A. Wadas, P.J. Kulesza, Mixed layered WO_3/ZrO_2 films (with and without rhodium) as active supports for PtRu nanoparticles: Enhancement of oxidation of ethanol. Electrochim. Acta. 210 (2016) 575-587.
6. W.A. Lotowska, I.A. Rutkowska, E. Seta, E. Szaniawska, A. Wadas, S. Sęk, A. Raczkowska, K. Brzostek, P.J. Kulesza, Bacterial-biofilm enhanced design for improved electrocatalytic reduction of oxygen in neutral medium. Electrochim. Acta. 213 (2016) 314-323.
7. D. Janiszek, M.M. Karpińska, A. Niewiadomy, A. Girstun, H. Elżanowska, M. Maj-Żurawska, P.J. Kulesza, Phase Transition Detection in Accumulation of a Potential Anticancer Drug Cl-IPBD with DNA: Supercoiled and Linear pUC19 Plasmids, Electrochimica Acta. 210 (2016) 422-431.
8. M. Skunik-Nuckowska, P. Bącal, P.J. Kulesza, Charge storage and capacitance-type properties of multi-walled carbon nanotubes modified with ruthenium analogue of Prussian Blue, J. Solid State Electrochem. 19 (2015) 2753-2762.
9. B. Dembińska, A. Dobrzeniecka, M. Pisarek, P.J. Kulesza, Selenourea-assisted synthesis of selenium-modified iridium catalysts: Evaluation of their activity toward reduction of oxygen, Electrochim. Acta. 19 (2015) 162-171.
10. I.A. Rutkowska, M. Marszałek, J. Orłowska, W. Ozimek, S.M. Zakeeruddin, P.J. Kulesza, M. Grätzel, Nanocomposite Semi-Solid Redox Ionic Liquid Electrolytes with Enhanced Charge-Transport Capabilities for Dye-Sensitized Solar Cells, ChemSusChem. 8 (2015) 2560.
11. J.K. Żak, E. Negro, I.A. Rutkowska, B. Dembińska, V. Di Noto, P.J. Kulesza, "Graphene-Based Nanostructures in Electrocatalytic Oxygen Reduction" in Encyclopedia of Interfacial Chemistry: Surface Science and Electrochemistry", Elsevier (2018).
12. P.J. Kulesza, I.A. Rutkowska, A. Wadas, "Electrocatalytic and Photoelectrochemical Reduction of Carbon Dioxide in Aqueous Media: Toward Generation of Fuels and Utility Chemicals" in Encyclopedia of Interfacial Chemistry: Surface Science and Electrochemistry, Elsevier (2018).