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REVIEW PAPER

Electrochemistry at Krakowian research institutions

Katarzyna Skibińska[1] · Piotr Żabiński[1]

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Abstract

The electrochemistry research team activity from Poland is marked by significant increase in the last 20 years. The joining of European Community in 2004 gives an impulse for the development of Polish science. The development of electrochemistry has been stimulated by cooperation with industry and the establishment of technology transfer centers, technology parks, business incubators, etc. and the mostly by simplified international collaborations. Five research institutions from Krakow reports work in the field of electrochemistry. The achievements of all teams are briefly described.

Introduction

The political transformation in 1989 strongly influences the development of Polish science, through its connection with industry and the establishment of technology transfer centers, technology parks, business incubators, etc. [1]. Then, joining the European Union by Poland in 2004 significantly simplified international collaborations. These days, there are many opportunities for Polish scientists to receive funds for projects in cooperation with foreign centers. Researchers can apply for a scientific stay abroad. It is possible thanks to the Polish Science Centre (NCN), the National Centre for Research and Development (NCBR), and the Polish National Agency for Academic Exchange (NAWA). Nowadays, there are almost 380 public and private universities in Poland divided into academic and vocational institutions [2]. Additionally, in 2010, due to the reform of science, research and development units were transformed into research institutes. Sources from 2015 reported that there are 115 research institutes, 58% of which work in the field of science and engineering and 34% in life sciences [3]. There are 70 research institutes of the Polish Academy of Sciences (PAN). Political transformation connected with opening to collaboration with foreign research groups and injection of funds to build or buy advanced research instrumentation results in blooming of research activity in a field of electrochemistry.

Only in Krakow, five research institutions report work in the field of electrochemistry. The achievements of all teams, over the last 20 years, are briefly described below. The research area of mentioned laboratory groups is strongly connected with the field of electrochemistry. The units are divided by the main research centers.

Electrochemistry at Krakowian research facilities

AGH university of science and technology

The AGH University of Science and Technology (the AGH UST) is a public university strongly involved in many national and international research projects. It is composed of sixteen faculties and one research institute. The research in the field of electrochemistry is performed at six of them. The biggest group works at the Department of Physiochemistry and Metallurgy of Non-Ferrous Metals at the Faculty of Non-Ferrous Metals. In the first years of the 2000s, the research teams guided by professors Lidia Burzyńska, Wanda Gumowska, and Krzysztof Fitzner performed intensive experiments in the field of, e.g., anodic dissolution [4–7], metal recovery [8, 9], and electrodeposition of transition group composites [10–12] and metal alloys [13, 14]. Then, with the growth of the research group, many new directions of interest have appeared, such as catalytic properties of transition group metals and alloys [15–19], tellurium thin films [20, 21], and synthesis of nanostructures in the anodic alumina oxide templates [22–24]. The influence of the magnetic field on the properties of the electrodeposited coatings has been investigated [25–27]. Nowadays, 3 groups

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✉ Piotr Żabiński
zabinski@agh.edu.pl

[1] Faculty of Non-Ferrous Metals, AGH University of Science and Technology, A. Mickiewicza 30, 30-059 Kraków, Poland

guided by professors Ewa Rudnik, Remigiusz Kowalik, and Piotr Żabiński can be distinguished. Professor Żabiński is also a head of the department. Under their supervision, young scientists and Ph.D. students are working on the co-deposition of chalcogenides with noble [28] and transition metals [29, 30]. The synthesis of noble and transition metal alloys [31, 32] has been still developing. The synthesis of Zn–Ni [33], Zn–Mg [34], and Zn–Ni–Mg [35] from gluconate baths has been also investigated. Besides that, the metallization of 3D prints [36–38] and electrochemical synthesis of 1D nanostructures by the one-step method [39–42] have been studied. The superhydrophobic properties of coatings are also in interest of scientists [43]. Research groups have been collaborating with international groups from Germany [44–47], Japan [48–52], France [53], Algeria [54], Bulgaria [55, 56], Italy [57], Serbia [58, 59], and Turkey [32]. In 2015, one of the members of the Department, Professor Krzysztof Mech, moved to the Academic Centre for Materials and Nanotechnology to perform his own research. In his experiments, he mostly focuses on the electrodeposition of Ni coatings [60] and composites [61]. He took under the consideration also the influence of the magnetic field on, interalia, the deposition rate, composition, current efficiency, structure, surface states, and morphology of the synthesized materials [62–64].

At the Faculty of Metals Engineering and Industrial Computer Science, Professor Tomasz Moskalewicz has been the head of the project entitled “Development of electrophoretic co-deposition of bioactive and antibacterial ceramics with biodegradable polymers to produce novel composite coatings for biomedical applications.” The project has been funded by NCN within the Beethoven competition. The research is focused on the development and characterization of novel composite coatings exhibiting bioactive and antibacterial functionalities for orthopedic and dental applications employing electrophoretic deposition (EPD) [65]. The experiments are performed in the collaboration with Professor Aldo R. Boccaccini from the Institute of Biomaterials at the University of Erlangen-Nuremberg.

Several research groups work at the Faculty of Materials Science and Ceramics in three different Departments. Professor Tomasz Brylewski, from the Department of Physical Chemistry and Modelling, is the co-author of the reviews about the hydrogen market, research, and development progress in central and Eastern European countries [66, 67]. With other researchers, he also performed experiments strongly connected with the solid oxide fuel cells (SOFC) operating in the higher temperatures [68–70]. The influence of applied solid electrolyte on the properties of obtained composites was investigated [71]. With the groups from German and Italian institutes, the first prototypes of dual membrane cell were electrochemically tested [72]. Another person, at the Department of Physical Chemistry and Modelling, performing some experiments connected with the field of the electrochemistry is Professor Robert Filipek. With other co-authors, he modeled corrosion of steel [73] and electrodiffusion processes for ion-selective electrodes [74]. Generally, in his works, he focuses mostly on simulations of diffusion in various materials at higher temperatures [75–77]. At the Department of Analytical Chemistry and Biochemistry, the research teams were guided and formed by professors, inter alia, Bogusław Józef Baś, Władysław Wojciech Kubiak, Andrzej Lewenstam, Jan Migdalski, and Mieczysłąw Rękas. They work, e.g., on the design and calibration of measuring equipment for electrochemistry and applications of electrochemical sensors [78–81], including conducting polymers [82, 83] and ion-selective membrane electrodes [84]. The investigation of voltammetric methods and their improvement was performed [85, 86]. The development of new signal processing algorithms for analytical chemistry research methodologies [87–91] is also an important issue for scientists. The topic of SOFC [92] is explored as well. There are three research groups at the Department of Inorganic Chemistry related to electrochemistry. Scientists perform research in synthesizing of ceramic, metallic, and composite layers, as well as materials based on intermetallic phases [93, 94]. They determine the physical and chemical properties of the coatings, including the resistance to high-temperature oxidation [95, 96] and corrosion in electrolyte solutions [97]. They study the kinetics and mechanism of diffusion [98, 99]. Additionally, the research related to the development of materials such as compounds with the perovskite structure [100, 101], composite, including carbon–metal oxide systems [102], thermoelectric materials [103], and materials with catalytic properties [101], is performed. Also, the topics related to the materials, including transition metal oxides in the form of micro- and nanomaterials and thin layers, for the various applications, such as anodes for photoelectrochemical cells (PEC) [104–106], and semiconductor gas sensors [107, 108] are explored.

Researchers from the Faculty of Energy and Fuels at the AGH UST focus on the currently developed issues of Li-ion [109, 110] and Na-ion batteries [111, 112], SOFC [113, 114], oxygen storage [115, 116], etc. Professor Janina Molenda is the head of the Department of Hydrogen at this faculty. Besides the mentioned topics expanded at the faculty, her research interests relate to, among other things, catalytic properties of perovskite oxides [117, 118] and structural defects in solid electrolytes [119, 120]. Professor Konrad Świerczek, the Deputy Dean for Science at the Faculty of Energy and Fuels, also pays attention to oxide materials, their characterization, and measurements of their catalytic activity [121–123]. He works with ceramic membranes possessing mixed ionic-electronic conductivity [124]. He has collaborated with scientists from, inter alia, China [125, 126], Japan [127], and the USA [128].

The last unit at the AGH UST where the research connected with the electrochemistry is performed is the Faculty of Foundry Engineering represented by the group from the Department of Metal Chemistry and Corrosion governed now by Professor Maria Starowicz. The research is carried out by great specialists in the field of corrosion on the micro- [129–131] and nanoscale [132], as well as in Krakow water supply network [133]. Professor Halina Krawiec was awarded inter alia by DCNS-French Embassy-French Institute for her scientific achievements in the field of corrosion. Professor Urszula Lelek-Borkowska focuses on, inter alia, the electrochemistry of metals and semiconductors in alcohol solutions [134]. The scientists at the department focus on synthesis of nanomaterials [135–137] and electrochemical behavior of metals [138, 139] and semiconductors [140, 141] in aqueous and organic electrolyte solutions. The research group also works on modern directions such as green chemistry and biomaterials [142, 143]. The team has collaborated with the group from, inter alia, France [144–146], Germany [147], UK [148], Austria [149], and Spain [150].

Faculty of chemistry jagiellonian university

Jagiellonian University is the oldest university in Poland and one of the oldest in Europe [151]. It consists of 16 faculties. The team specialized in Electrochemistry, previously guided by Professor Marian Jaskuła, and now by Professor Grzegorz Sulka, and has been working at the Faculty of Chemistry. The group has impressive achievements in fields of anodization of Al [152–155]; electrochemical synthesis of nanostructured oxides of, e.g., Sn [156, 157] and Zn [158, 159]; and nanoporous titanium dioxide [160–162]. The obtained anodic alumina oxide (AAO) templates are widely used for the fabrication of nanostructured electrodes of metals [163], alloys [164, 165], and polymers [166, 167]. Produced nanostructures and oxides can be applied in catalysis [168], photoelectrochemistry, and photocatalysis [169–174], as H_2O_2 sensors [175–178], semiconductors [158, 179], and in biomedical applications [180–184]. The research group worked also on the synthesis of Au [185, 186] and Au–Ag [187] for electrochemical epinephrine sensing. Furthermore, the team works on bioelectrodes [188] and materials for energy storage [189]. The scientists have attended many projects funded by NCN, NAWA, the Polish Ministry of Science and Higher Education (MNiSW), and the European Cooperation in Science and Technology (COST). They have collaborated with groups from, e.g., the Czech Republic [190], the USA [191], Portugal [192], and Ukraine [193].

Jerzy haber institute of catalysis and surface chemistry of the polish academy of sciences

The research aim for scientists from the Jerzy Haber Institute of Catalysis and Surface Chemistry is the application of obtained results in fields of protection of health, environment, and cultural heritage, as well as to improve technological processes [194]. One of the scientists working in the field of electrochemistry was Professor Alicja Drelinkiewicz. With other researchers, she performed experiments, inter alia, on the synthesis and characterization of mono- and bimetallic-supported catalysts [195–197]. Professor Paweł Nowak and his research group have worked on the synthesis of metal alloys and metal/ceramic composites by electrodeposition [198–201]. They have investigated the prevention of corrosion of metal and its alloys by using anti-corrosion coatings [202]. The research group is also a specialist in surface doping of titanium dioxide with transition metals and transition metal ions and their photocatalytic properties [203–206]. The group tests also materials for SOFC [207–209]. In 2000, the American Electroplaters and Surface Finishers Society awarded Professor Nowak for an outstanding work published in 1999 in the Plating and Surface Finishing magazine published by this society. He has collaborated with research groups from, inter alia, Germany [210, 211], the USA [212–214], Finland [215], and Switzerland [216].

Institute of metallurgy and materials science of the polish academy of sciences

In the Institute of Metallurgy and Materials, two research groups, under the supervision of Professors Ewa Bełtowska-Lehman and Piotr Ozga, can be recognized. Professor Bełtowska-Lehman is a specialist in the kinetics and mechanism of the processes occurring in complex electrolytes during electrocrystallization of metal, alloy, and composite coatings with increased tribological and anti-corrosion properties [217, 218]. The group performed research in electrochemical synthesis and micromechanical properties of nanocomposite coatings with a metal matrix containing the addition of a refractory metal, reinforced with a nanodisperse ceramic phase [219–221]. Professor Bełtowska-Lehman works also on photovoltaic silicon cells [222, 223]. In 2006, she was nominated by the MNiSW for the position of Polish representative in the Mirror Group of the European Union Technology Platform in the field of photovoltaics. Professor Ozga works on, inter alia, the electrochemical deposition of materials for different applications, such as lead-free solders (e.g., Sn–Ag and Sn–Ag–Cu [224], In–Sn [225], Sn–Zn–Cu [226]), and solder nanocomposites, alloys, and protective layers of high corrosion resistance, e.g., Zn–Ni [227, 228], are investigated by Professor and his team. He collaborates with researchers from Israel [229] and Ukraine [230].

Łukasiewicz research network — Krakow institute of technology

Krakow Institute of Technology is a part of the Łukasiewicz Research Network, the third largest research network in Europe [231]. At the Institute of Advanced Manufacturing Technology in Krakow, Doctor Maria Zybura-Skrabalak was working on electrochemical machining (ECM). The experiments were performed within the INNOTECH project. The aim of the project was the implementation of the proposed process. The investigation of the influence, inter alia, of the features of ECM processes on the surface roughness of the workpiece material was performed [232]. The modeling of the process considering the application of the flat rectangular universal electrode in the ECM [233] or current in the ECDM (electrochemical discharge machining) process [234] was made among others by Doctor Zybura-Skrabalak. In her work, she also investigated the possible application of the electrode, made by the milling process, for electrochemical smoothing [235].

Conclusions

Krakow is the headquarter of many research groups working in the field of electrochemistry. There are a few common topics for all, e.g., electrodeposition of metal, its alloys, and composites; the phenomenon of the corrosion and enhancement of anti-corrosion properties of coatings; and catalytic activity of the samples. The new directions, such as photovoltaics, biomaterials, and green chemistry, are in accordance with the interests of scientists all over the world. The teams collaborate with research facilities from various countries but also with each other. It results in high-quality results, new projects, and implementations.

Declarations

Competing interests The authors declare no competing interests.

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