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REVIEW PAPER

Development of electrochemistry in Serbia-challenges and perspectives

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Abstract
In this review, the development of electrochemistry in Serbia is presented, with an accent on historical moments from the beginning up to contemporary research directions. The pioneer in the establishment of electrochemical science was Professor Panta S. Tutundzic, who was elected Assistant Professor in Physical Chemistry and Electrochemistry in 1925, when the Department of Technology, previously integrated within the Technical Faculty in Belgrade, was established as a separate department. From the time of Professor Tutundzic′s group to today, a community of many eminent researchers has been involved in electrochemistry development, creating the world-renowned Belgrade School of Electrochemistry. It was not actually a formal school of electrochemistry but rather a variety of research directions, and first of all people doing excellent electrochemical science recognized at the international level. As one of the members of the contemporary active electrochemistry community from Serbia, and successors of the Belgrade School of Electrochemistry, I have both the special honor and the responsibility of presenting the historical contribution of such outstanding and internationally recognized scientists in the most appropriate way. Having in mind that any school and research area is predominantly determined by human resources, I will focus on the great contribution of the most prominent electrochemists, from the founders up to those active today. The main research directions were and still are electrodeposition, electrochemical reaction kinetics, electrocatalysis, energy production and storage, and corrosion and corrosion protection.

Keywords Development of Serbian electrochemistry · Belgrade School of Electrochemistry · Electrodeposition · Electrocatalysis · Energy production and storage · Corrosion

Introduction

The pioneer of the Belgrade School of Electrochemistry was undoubtedly Professor Panta S. Tutundzic, who started his career in electrochemistry in 1925. The following year he managed to establish and organize the first Laboratory for Physical Chemistry and Electrochemistry within the Institute for Chemistry and Technology [1]. He introduced basic practical classes and began scientific work in the field of electrochemistry two years later. A new building for the Faculty of Technology was built in 1930 on Kralja Aleksandra Boulevard, while the earlier established Laboratory for Physical Chemistry and Electrochemistry became a well-equipped space offering great conditions for practical students′ classes, as well as scientific work for professors and their younger colleagues. Beginning in 1930, Professor Tutundzic published the first important papers in eminent international journals, listed in today's relevant index databases including Scopus [2–7]. The rotating mercury electrode for electroanalysis [4]—a nice instrument unknown and probably interesting to modern readership—is presented in Fig. 1. In a review paper in *Chemical Reviews*, this picture was redrawn and discussed as "the Tutundzic cell" [8].

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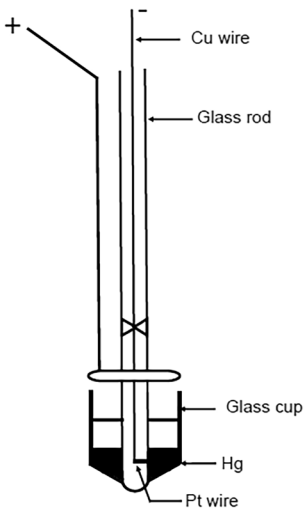
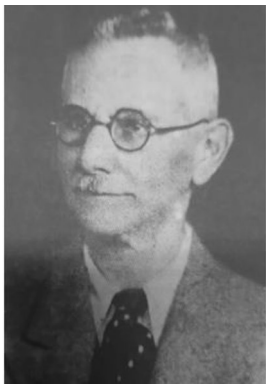


Fig. 1 The Tutundzic cell (Reprinted with permission from Ref. 8)



Professor Nikolai Antonowitsch Puschin (1875–1947), a corresponding member of the Serbian Academy of Sciences and Arts elected in 1947

Russian chemist and technologist Professor Nikolai Antonowitsch Puschin collaborated with Professor Tutundzic [3, 6]. Professor Puschin obtained his PhD from the University of Ljubljana, Slovenia, in 1927 and was Professor at the Technical Faculty of Belgrade University beginning in 1928, as well as a corresponding member of the Serbian Academy of Science and Arts (elected 1947) [9]. In Belgrade, he joined the already existing Laboratory for Physical Chemistry and Electrochemistry headed by young Panta S. Tutundzic. After the Technical Faculty was moved to a new building, the laboratory was enlarged into the Institute of Physical Chemistry and Electrochemistry with Professor Puschin as its head, keeping this position until 1947, when after a serious illness Puschin passed away [9]. It is important to emphasize that Professor Tutundzic worked on solution conductivity with Professor N. A. Puschin.

Professor Dr. Panta Tutundzic (1900–1964), Faculty of Technology and Metallurgy, University of Belgrade – founder of the Belgrade School of Electrochemistry.

After the Second World War, in new social circumstances and after the university started working again in 1948, the Technical Faculty separated from the University of Belgrade and became an independent Technical Grand School, while its Department of Technology was transformed into the Faculty of Technology and Metallurgy. However, the school ceased operations in 1954, including the Faculty of Technology, which once again became a part of the University of Belgrade. The faculty got its current name—Faculty of Technology and Metallurgy, University of Belgrade—in 1966 [1].

Rise and development of the core group of the Belgrade School of Electrochemistry after World War II

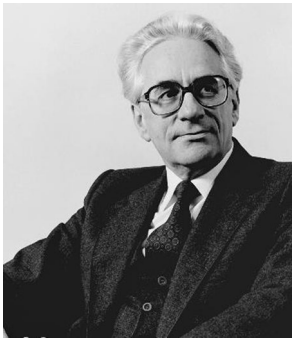
Before the outbreak of the Second World War, Professor Tutundzic had improved the education process, wrote the first textbooks in Serbian in the fields of physical chemistry and electrochemistry, and successfully performed pioneering scientific work—predominantly in the areas of non-aqueous solutions, alloys, and diagrams of multicomponent systems states [1]. Professor Tutundzic continued publication of important electrochemical scientific papers in reputed international peer-reviewed journals [10–20].

Several remarks should be written about Professor Tutundzic's coauthors, namely, Ozra Tatic-Janjic, Ivo Doroslovacki, and Milan Paunovic. As for the first two first, Tatic-Janjic and Ivo Doroslovacki, they were devoted mainly to students′ practical classes. Tatic-Janjic was an author of only one student book in Serbian (coauthored by Professors Despic and Drazic). Thus, Tatic-Janjic and Doroslovacki were not well recognized at the international level like their leader Professor Tutundzic. However, Milan Paunovic (1924–2012) was an outstanding electrochemist

of Belgrade origin, but he spent almost his whole career, beginning in 1961, in research assistant positions at US universities and research centers. He started his career practically at the University of Pennsylvania (from 1961 to 1964). During his career, Dr. Paunovic worked at Reynolds Aluminum, Photocircuits (which later became Kollmorgen), and Intel. He worked on electrochemical metal deposition for over four decades, and until his retirement, most recently in the Electrodeposition Technology Department at IBM's Thomas J. Watson Research Center. Dr. Paunovic was Chair of the ECS Electrodeposition Division and head of the Board of Directors (1993–1995). He was most proud of his book, coauthored with Mordechay Schlesinger, the ECS monograph *Fundamentals of Electroplating*, which is now in its second edition. Dr. Paunovic also co-edited, with Dr. Schlesinger, earlier editions of the ECS monograph *Modern Electroplating* (now in its fifth edition). During his career, he conducted symposia for ECS and remained an active member through retirement. Dr. Paunovic earned 11 patents and completed 42 research papers, making valuable contributions to the world of science. He passed away in 2012 in the USA.

After the Second World War, in new social circumstances among numerous students and associates, two of Panta Tutundzic's PhD students and later professors at the Faculty of Technology and Metallurgy as well, Aleksandar Despic and Dragutin Drazic, were the actual carriers and the real founders of the Belgrade School of Electrochemistry starting in the early 1960s. They contributed their diligent, devoted research and great knowledge, mainly acquired during numerous short and long-term visits to famous universities in Europe and the USA, as well as well-established international collaboration with the greatest electrochemists of the twentieth century. The most important among them included John O'Mara Bockris, Graham Hills, Alexander Frumkin, Kurt Schwabe, Jakov Kolotirkin, Roger Parsons, Lev Krishtalik, Yevgeniy Budevski, Brayan Conway, Sergio Trasatti, and Erika Kálmán. Both had a very pronounced desire and strong willingness to transfer the acquired knowledge and experience to new generations of their students and young associates, enabling Belgrade to become an important place on the electrochemical map of the world [1].

Although I had the honor and chance to be a student of both Professor Despic and Professor Drazic, I have chosen to emphasize their scientific contribution, as well as biographical data, on the basis of other prominent electrochemists′ opinions, who have written tributes on the occasions of their 70th birthdays. The reason for this choice was to try my best to stay as objective and realistic as possible. Therefore, the following paragraphs will highlight the biographical and scientific data related to their very high achievements and great contributions to the whole Serbian world of electrochemistry.



Prof. Dr. Aleksandar Despic, Member of the Serbian Academy of Sciences and Arts (1927–2005)

Professor Despic's research has made a profound impact on several areas of electrochemical science, ranging from fundamental electrode kinetics and metal deposition to electrocatalysis and electrochemical power sources. His early contributions which have influenced the electrochemical thoughts were the concept of activation-controlled limiting current, the first quantitative treatment of surface diffusion in metal deposition and a mechanism of electrodeposition and dissolution of iron.

Professor Aleksandar R. Despic was born in Belgrade, in 1927. He graduated from the Faculty of Technology, University of Belgrade. In 1954 he obtained a Diploma from the Imperial College of Science and Technology in London. In 1955 he obtained a Ph.D. in physical chemistry from the University of London. After graduation he joined the Faculty of Technology and Metallurgy, University of Belgrade, where he became a full professor in Physical Chemistry in 1971. The periods 1957–1959 and 1968, he spent as a visiting scientist and visiting professor in the Electrochemistry Laboratory of the University of Pennsylvania. Aleksander Despic has been a man of action and ideas. He is one of the founders of the Institute of Electrochemistry in Belgrade which he headed in the period 1964–1970, a position which he resumed in 1994.

Largely through his efforts, the Institute of Electrochemistry became a renowned laboratory under conditions which were far from optimal. He is also one of the founders of the Center for Multidisciplinary Studies of the University of Belgrade and its Energy Conversion Group. The Museum of Science and Technology in Belgrade was founded mainly through his initiative. Most recently, he formed the Young Scientists and Artists Foundation created to help their work. Throughout his career Professor Despic has been a dedicated teacher and has had many students and research collaborators, some of them scattered world-wide. He coauthored a textbook on electrochemistry used by many generations of students in Yugoslavia.

He was an honorary president of the Serbian Chemical Society where he served as secretary, vice-president,

president and editor-in-chief of its Bulletin. From 1977 to 1979, he was a Vice-President of the International Society of Electrochemistry and National Secretary of ISE for Yugoslavia, as well. He was a member of the editorial boards of the Journal of Applied Electrochemistry and the Journal of the Serbian Chemical Society and a past president and honorary president of the Union of Chemical Societies of Yugoslavia. Professor Despic was a full member of the Serbian Academy of Science and Arts, a member of the European Academy of Surface Technology and the European Academy of Science and Arts and Member Correspondent of the Croatian and Slovenian Academy of Sciences and Arts. In 1981 he was elected a Vice-President of the Serbian Academy and in 1994 became a President of the Academy. – by Radoslav Adzic, A tribute to Professor Aleksandar Despic in honour of his 70th birthday [21]

He published 124 international peer-reviewed journal papers cited 3705 times, with an *h*-index of 33, according to the Scopus database (December 23, 2022), while the most cited are listed in Refs. [22–31]. Certainly, some of these works were coauthored by Professor Drazic, as it is well known that they were close collaborators and friends as well.

Prof. Dr. Dragutin Drazic, Member of the Serbian Academy of Sciences and Arts (1930–2008)

Professor Dragutin Drazic was born on May 5, 1930, in Belgrade. He graduated from the Department of Chemical Technology with the highest grade in 1956. After graduation he joined the teaching staff of the same school, in the Department of Physical Chemistry and Electrochemistry where he spent his entire career, commencing as an assistant lecturer and becoming a full professor. Profesor (*sic*) Drazic taught very successfully a variety of subjects, such as Electrode Kinetics, Corrosion, Electrochemical Double Layer and Adsorption (postgraduate) and finally, Physical Chemistry – a General Course. At the prime of his professional career he was the Head of the Chair and Department of Physical Chemistry and Electrochemistry for several years. In July 1959 he went to the USA, to join the Electrochemistry Laboratory of the University of Pennsylvania in Philadelphia, led by Professor John O'Mara Bockris, which at the time was the leading electrochemistry research center of the Western World. In 1970 he returned to that Laboratory by invitation of Professor Bockris, to spend another year there as a group leader in several subject areas within electrochemistry. As a parallel occupation, he joined the Electrochemistry Department of the Institute of Chemistry, Technology and Metallurgy (ICTM) at the time of its formation in 1961, as the research base of the Faculty of Technology and Metallurgy. He was an active project and group leader through all the years till his retirement in 2001, being the Director of that institution as it changed to the Institute of Electrochemistry ICTM. Among numerous engagements it should be noted that he was very active in the Serbian Chemical Society performing the duties of Bursar, Secretary, Vice-President and finally President of the Society. In 1985 he was elected as a life Honorary President of the Society On the international scene. He was a National Secretary of the International Society of Electrochemistry, a Vice-President of that Society (1992–1994) a member of the Commission on Electrochemistry of IUPAC and of the Working Group on Electrochemistry of the European Federation of Chemical Engineers. In recognition of his achievements, in 1983 he was elected a Member correspondent and in 1991 a full Member of the Serbian Academy of Sciences and Arts. In 1995 he was awarded the Medal of the Serbian Chemical Society for Exceptional Contribution to Science. The scientific work of Professor Drazic resulted in 2 books, 3 chapters in international series of monographs, 160 papers published in scientific journals, 28 professional studies and 7 patents. The main scientific interests of Professor Drazic can be grouped into three lines of research: a) new electrochemical power sources, b) measuring methods and new technological systems and c) electrochemical processes of deposition, dissolution and corrosion of metals. In the first group, most of the published work is related to hydrogen–air fuel cells and metal–air systems, aluminum–air cells in particular. He also investigated new three-dimensional electrochemical reactors with fluidized metal particles, especially suitable for processing dilute electrolytes, such are those encountered during elution of metal ores with very low metal contents, in waste water treatment and other similar systems. Finally, the most important fundamental contribution of Professor Drazic was that of elucidating the mechanism of anodic dissolution of iron. In conclusion, it is possible to state that Professor Drazic through his work became one of the leading figures in Serbian electrochemistry who, with his numerous followers, played a key role in forming what is known as the Belgrade Electrochemistry School. – by Professor Aleksandar Despic, on the occasion of the 70th birthday of Professor Drazic [32]

As for his impressive scientific work, he published 107 international peer-reviewed journal papers cited 3619 times, with an

h-index of 32, according to the Scopus database (December 23, 2022), and the most cited are listed in Refs. [33–39].

The main research directions of the Belgrade School of Electrochemistry are listed below:

- Kinetics of electrode processes
- Electrochemical deposition and dissolution of metals and alloys
- Corrosion and corrosion protection
- Electroplating and coatings—protective, functional, decorative
- Electrocatalysis – development of catalysts and catalyst supports
- Conversion and storage of energy—batteries, fuel cells, supercapacitors
- Carbonaceous materials and composites based on carbon
- Chlor–alkali electrolysis
- Electroanalytics
- Electrochemical sensors
- Electrochemistry in medicine—biocompatible materials for implants
- Electrochemical engineering
- Electrometallurgy
- Wastewater treatment

The main successors and collaborators of Professors Despic and Drazic among Serbian electrochemists 1980–2000

Professors Despic and Drazic were close collaborators and two principal investigators leading different long-term projects in electrochemistry: ″Electrodica-Electrodes and Electrocatalysis″ (1981–2000), led by Professor Drazic, and ″Metalica″ (1976–1995) and ″Electrochemical and Metallurgical Production of Metals and Alloys″ (1995–2000), both led by Professor Despic. Within the frame of these projects, many of their PhD students and later internationally famous electrochemists have been involved. Some of the most recognized will be listed here: Professor Sreten Mladenovic (1924–2004), Professor Milan Vojnovic (1937–2011), Professor Darko Sepa (1935-), Professor Konstantin Popov (1941–2019), Professor Vladimir Jovic (1947-), Professor Ljiljana Vracar (1949-), Professor Nedeljko Krstajic (1954–2017), and Professor Vesna Miskovic-Stankovic (1957-). All of them have been recognized in international electrochemical science. Their supervisors and principal investigators of the projects already described above will be mentioned to prove the continuance of the Belgrade electrochemistry school, from founder Professor Tutundzic through to contemporary Serbian electrochemistry.

Professor Sreten Mladenovic was a great expert in corrosion science, teacher at the Faculty of Technology and Metallurgy, University of Belgrade, and a supervisor of many excellent future electrochemists. His main PhD students—and later internationally recognized electrochemists—were Professor Milan Vojnovic (1937–2011), Professor Darko Sepa (1935-), and Professor Nedeljko Krstajic (1954–2017). Professor Vladimir Jovic (1947-) was a PhD student of Professor Despic, Professor Ljiljana Vracar (1949-) was a PhD student of Professor Sepa, and Professor Vesna Miskovic-Stankovic (1957-) was supervised by Professor Drazic. Professors Krstajic and Jovic can certainly be considered as the most outstanding and well recognized in their variety of fields of expertise among the great electrochemists mentioned above. Professor Jovic's main research field was electrodeposition and dissolution of metals and alloys. Together with Professor Despic he was practically founder of a new sub-direction in electrodeposition and dissolution of alloys—namely, anodic linear sweep voltammetry—for the phase characterization of electrodeposited alloy layers (applicable for layer thickness up to 10 μm). Professor Jovic coauthored 109 papers in international peer-reviewed journals (Scopus February 1, 2023) cited 2553 times, with an *h*-index of 31. The most relevant and also most cited among them are given in Refs. [27, 40–44], in line with his main research directions, as well as with collaborator and friend Professor Krstajic: electrodeposition, electrochemical impedance spectroscopy (EIS) characterization, and electrocatalysis—hydrogen evolution, oxygen evolution, and hydrogen oxidation reactions. Professor Nedeljko Krstajic was one of the preeminent Serbian electrochemists. He worked in a variety of electrochemical fields: electrocatalysis, energy conversion, electrodeposition, electro-organic synthesis, and corrosion. Besides his huge number of published papers in highly reputed international journals, he devoted many years to applied electrochemistry. Among his main achievements are already commercially applied dimensionally stable anodes for chlor-alkali electrolysis application and "Hlorogen"—the commercially named system for hypochlorite production and water purification on-site, without the use of gas chlorine. Sigma company from Kula (Serbia) commercialized his patent and constructed a prototype of the electrolyzer for hypochlorite production. For the prototype he received an award for innovation, "Water chlorine at the Place of Use," from the Economic Chamber of the city of Belgrade. Besides the work on the development of anodes, Professor Krstajić, together with Professor Jovic, developed and patented procedures for the production of cathodes for application in industrial plants for one of the most important companies for chlorine production, "De Nora" (Italy).

He published 134 papers in reputed international journals, cited 3519 times, with an *h*-index of 32 (Scopus, February 2023). The most important among them are in the fields of catalysis, energy conversion, and corrosion.

US diaspora – the most recognized members of the Belgrade School of Electrochemistry successors

Among the successors of Professors Despic and Drazic, the most outstanding Serbian electrochemists have been working and active in the USA—Professor Emeritus Radoslav Adzic and Professor Emeritus Nenad Markovic. They were named Senior Scientist Emeritus owing to their great internationally recognized contribution to the development of electrochemical science, especially in energy-related fields, becoming the only two electrochemists granted this title among the community that was not born and formally educated in the USA. All active electrochemists from Serbia today could be proud to live in these historical times related to our former colleagues from the University of Belgrade, today recognized at a broad international level. The basic biographical and scientific career-related data are summarized below.

1. Radoslav Adzic, Professor Emeritus, Brookhaven National Laboratory Chemistry Division, Upton, NY (1942-)

On the occasion of Radoslav Adzic's promotion to Senior Scientist Emeritus, he gave an interview to Joe Gettler, entitled "Radoslav Adzic Named Senior Scientist Emeritus," November 16, 2017 [45]. In a congratulatory letter to Adzic, Lab Director Doon Gibbs wrote several sentences about Adzic as well [45].

> Emeritus status was granted to Radoslav Adzic of Brookhaven Lab's Chemistry Division, effective Oct. 21. The emeritus position at Brookhaven Lab was established to recognize retired scientists who have made particularly noteworthy contributions to the Laboratory's reputation as a world-class scientific institution.
>
> Adzic started his career in Serbia, working at the Institute of Electrochemistry at the University of Belgrade from 1965 to 1992. He earned a Ph.D. in chemistry there in 1974, and served as research director from 1978 to 1983 and as director until 1992. He first came to Brookhaven Lab and stayed briefly as a visiting scientist in 1979, returning for good as a senior research associate in 1992. At the Lab, he was promoted to scientist in 1993, chemist in 2001, and chemist with tenure in 2005. He was leader of the Surface Electrochemistry and Electrocatalysis group for the past decade and retired on Oct. 20th 2017.
>
> Electrocatalysts increase the rate of chemical reactions that produce or use electricity. Adzic's highest impact research and development (R&D) at Brookhaven has been with electrocatalysis for energy applications, particularly with fuel cells that produce electricity—with the only byproducts being water and heat. Adzic pioneered scientific understanding of electrocatalysis in surface structures and monolayers, showing that carefully tuning materials in layers where reactions occur could increase activity and stability while reducing the required amounts of expensive metals, such as platinum. Adzic introduced and championed the concept of core-shell electrocatalysts to increase performance and durability while decreasing the cost of low-temperature hydrogen fuel cells. His group also applied these concepts to demonstrate more cost effective electrolyzers—which use electricity to split water into hydrogen and oxygen—that reduce costs for future sustainable hydrogen production from renewable electrical energy.
>
> Adzic's research group has demonstrated that small amounts of performance-enhancing "dopants"—gold, in particular—can improve activity and durability in platinum-based electrocatalysts for fuel cells. His research also advanced multicomponent and monolayer electrocatalysts for electro-oxidation of organic compounds, such as methanol and ethanol, that are promising liquid fuels for fuel cell operation, but are difficult to efficiently catalyze.
>
> Adzic has authored or coauthored more than 300 publications that have been cited more than 20,000 times. He has 21 issued patents and approximately 15 pending applications filed. Several patents have been licensed by two catalyst companies for commercial products. He is a fellow of the Electrochemical Society and the International Society of Electrochemistry and correspondent member of Serbian Academy of Sciences and Arts. In addition to being named a Battelle Inventor of the Year and receiving several other inventor prizes, he was presented with the U.S. Department of Energy's Hydrogen Program R&D Award twice—in 2008 and 2012—and an R&D100 Award in 2012.
>
> In a congratulatory letter to Adzic, stated in Ref. [45], Lab Director Doon Gibbs wrote:
>
> "You are recognized by peers around the world for your contributions to basic and applied research in electrochemical energy conversion. Throughout your career, you have combined fundamental research in electrochemical processes, materials, and structures with innovative, practical applications. Your research leadership of the Laboratory's Surface Electrochemis-

try and Electrocatalysis group has contributed greatly to the worldwide reputation of the Laboratory's catalysis science efforts…Your work at Brookhaven over the past 26 years exemplifies the goal of basic research translated to improved energy technologies."
Adzic said: "I have been fortunate in that my arrival at Brookhaven coincided with strong national support for broad research in electrocatalysis of reactions of direct energy conversion in fuel cells. Historically, this was the third major campaign to develop this clean energy source. With the support from colleagues from Brookhaven, and funds from the DOE and the automotive industry, I am proud that my group made a contribution to better understanding of electrocatalysis and to the development of electrocatalysts for fuel cells that make electric vehicles a reality. I hope that the environmental benefits that will follow will secure a continuation of this research to accelerate critically needed improvements of our environment." [45]

Finally, as the most important, his scientific contribution to the development of electrochemistry was expressed in 321 international peer-reviewed journal papers of eminent publishers, cited 28,793 times, with an *h*-index of 84 (Scopus December 23, 2022). The most cited among the impressive number of references are listed in Refs. [46–55].

It should be emphasized that some very important already cited references of Professors Despic and Drazic were coauthored by Adzic ([23, 26] for instance), undoubtedly confirming the continuity between Belgrade research at the time of Professor Adzic and his collaboration with two outstanding Serbian electrochemists and members of the Serbian Academy of Science and Arts.

2. Professor Emeritus Nenad Markovic is still working in Argonne National Laboratory in Illinois, USA, as Head of the Energy Department. I have chosen to introduce him by citing his official biography from the institutional webpage:

Nenad M. Markovic received his BSc, MsD and PhD at the University of Belgrade. His academic carrier started in 1978 as Research Associate at Institute of Electrochemistry, University of Belgrade. As a junior scientist he spent two years in Prof. Yeager's laboratory at the CWRU in Cleveland, OH. He returned at the University of Belgrade in 1984 and a year later he became a Group Leader in the Department for Surface Electrochemistry. In 1991 he got a Staff Scientist position at Lawrence Berkeley National Laboratory, where he stayed fourteen years. In the middle of 2005 he joined ANL in Material Sciences Division as a Senior Chemist. He is a Group Leader of the Energy Conversion and Storage Group. His major research interest is understanding surface processes at the electrified metal-solution interfaces. Utilizing ex-situ (AES, LEED, UPS, XPS) and in-situ (SXS, STM/AFM) surface sensitive probes in combination with vibrational spectroscopy (FTIR, ATR) and classical electrochemical methods he established relations between the microscopic surface atomic/electronic structures of mono-metallic and multi-metallic single crystal surfaces and the macroscopic kinetic rates of (electro)chemical reactions [56].

Professor Markovic has published 291 scientific papers in eminent international journals, cited 51,341 times, with an *h*-index of 105 (Scopus December 23, 2022). The most cited of these papers are written in Refs. [57–66].

Besides the abovementioned facts on the most important scientific contributions of the two professors emeritus, it is necessary to add two younger electrochemists from the University of Belgrade, also now working in the USA. Namely, Professor Vojislav Stamenkovic and Professor Stanko Brankovic have made great contributions to the world of electrochemical science and have been working as outstanding active scientists today, as well.

3. Professor Vojislav Stamenkovic, University of California, Irvine (1967-)

Professor Stamenkovic is one of the most widely recognized electrochemists and Belgrade Electrochemistry School successors today. The most important data related to his career are presented below from the official webpage of the University of California, Irvine [67].

Joint Professorship in UCI's Department of Chemical and Biomolecular Engineering and Department of Chemistry (Ph.D. in Physical Chemistry, University of Belgrade, Serbia, 2001).
Prof. Stamenkovic came from a career at the U.S. National Labs to UCI in 2020. He is also affiliated with AirUCI's partner group, the Advanced Power and Energy Program, as an expert in electrochemical systems for energy conversion and storage, in heterogeneous catalysis, and with expertise in fundamental, functional biomaterials design for fuel cells, electrolyzers and batteries.
Voja was the natural choice to serve as the inaugural Director of the Horiba Institute for Mobility and Connectivity, a new hub for implementing renewable, sustainable, and environmentally neutral technologies such as fuel cells, electrolyzers and batteries in transportation and the electric grid, while evaluating impacts on mobility and connectivity.
Research Interests: Energy conversion and storage; surface modifications; thin films; nanoscale synthe-

sis; electrochemical interfaces; fuel cells; electrolyzers; batteries.

Selected Honors and Awards:

Member, American Chemical Society, Member, Materials Research Society, Member, Electrochemical Society, Member, American Vacuum Society, Highly Cited Researcher 2018–2020, top 1% worldwide researchers citations in all fields, Web of Science, Cross-Field U.S. Department of Energy Hydrogen and Fuel Cells Award, 2014 Excellence in Science Award, Gordon Research Conference, 2009 [67].

Professor Stamenkovic has published 150 scientific papers in high-impact international peer-reviewed journals cited 34,150 times, with an *h*-index value of 178 (Scopus December 23, 2022). The most cited among this impressive number of publications are listed in Refs. [68–77]. It should be emphasized that Professor Stamenkovic has been and still is one of the main collaborators of Professor Markovic, so it is difficult to separate their most important and most cited references since—naturally—many were coauthored by both of them.

4. Professor Stanko Brankovic, University of Houston, Texas, USA (1969-)

Professor Brankovic is, together with Professor Stamenkovic, among the preeminent electrochemists of Belgrade origin. His career and scientific contributions are presented at the official webpage of the University of Houston, Texas, USA [78].

Education: BSE Chemical and Biochemical Engineering, University of Belgrade, Serbia
PhD Science and Engineering of Materials, Arizona State University, Tempe, Arizona
Professional Experience: Seagate Research Center, Pittsburgh, PA, 2001–2005; Brookhaven National Laboratory, Upton, NY, 1999–2001.
Awards & Honors: Fellow of the Electrochemical Society, 2021; The Electrodeposition Research Award of The Electrochemical Society, 2017; Best Fundamental Paper in 2017 –AIChE-South Texas Section Chair; The Electrodeposition Division of the Electrochemical Society, 2017-2019; Chair, Materials Science Division, International Society of Electrochemistry, 2015–2017; The Faculty Early Career Development Award, National Science Foundation, 2010; University of Houston Award for Excellence in Research and Scholarship, University of Houston, 2010; Cullen College of Engineering Junior Faculty Research Award, Cullen College of Eng. Univ. of Houston, 2009; Serbian Academy of Arts and Sciences Student Fellow, Serbian Academy of Arts and Sciences, 1993–1994; Panta S. Tutundzic Foundation Student Fellow, College of Technology and Metallurgy, Univ. of Belgrade, 1992–1994.
Research Interests: Electrocatalysis; Sensors; Electrochemical Material Science and Nanofabrication; Corrosion [78].

Professor Brankovic has published 83 scientific papers in high-profile and high-impact international peer-reviewed journals, cited 2196 times, with an *h*-index of 21. The most cited papers are listed in Refs. [53, 79–81].

Contemporary electrochemistry in Serbia—challenges and perspectives

Among all internationally renowned electrochemists actively working today in Serbia, several have made and continue to make important contributions to Serbian electrochemistry, and electrochemistry in general. Namely, they are outstanding and internationally recognized in their area of expertise.

I will introduce the most eminent of them here. Namely, I am going to present in brief two of each born in the 1960s, 1970s, 1980s, and 1990s, belonging to a community that is active today in the fields related to electrochemistry. The variety of criteria used for the choice of these outstanding representatives of today's active electrochemists will be listed below.

First of all, data related to numbers of quality publications, citations, and *h*-index are absolutely impressive for both of them (see section below). Moreover, their very important involvement in international collaboration and strong willingness to accept and supervise master and PhD students qualified them for this list. Last, but not least, they have been actively involved in other, so-called outreach activities—promotion of electrochemistry among the students generally—to encourage them to choose this relatively small and underrecognized scientific discipline. In line with this, the roles and contributions of Professor Branimir Grgur and Professor Jelena Bajat should be emphasized—they have both been trying their best to achieve all of the abovementioned goals. Thus, Professors Bajat and Grgur have established numerous fruitful international collaborations and involved many of their younger colleagues, as well. They supervised numerous BSc, MSc, and PhD students, in efforts to transfer their knowledge and scientific experience to them. Their devotion to promoting electrochemistry among high school and BSc students, and encouraging them to understand and choose studies of electrochemistry, has also been widely known in the active Serbian electrochemical community.

1. Professor Dr. Branimir Grgur is Full Professor at the Faculty of Technology and Metallurgy (TMF), Department of Physical Chemistry and Electrochemistry, University of Belgrade, Serbia. He was born in 1965. Degrees include BSci 1992, MSci 1994, and PhD 1999 at the Faculty of Technology and Metallurgy, University of Belgrade. His PhD supervisors were Professor Milan Vojnovic and Professor Nedeljko Krstajic, abovementioned outstanding members of the Belgrade electrochemistry school. Specialization at Lawrence Berkeley National Laboratory (LBNL), Berkeley, USA, was done during 1996–1998 and postdoctoral study during 2000. In 2018 he was elected as a corresponding member of the Academy of Engineering Sciences of Serbia.

Research fields include energy conversion and storage, nanoparticles, material characterization, adsorption, heterogeneous catalysis, polymerization, and nanomaterial synthesis.

He has published 126 international peer-reviewed journal papers cited 5403 times, with an *h*-index of 33, according to Scopus (November 10, 2022). The most cited papers are listed in Refs. [82–86].

2. Professor Dr. Jelena Bajat, Full Professor of the Faculty of Technology and Metallurgy, University of Belgrade, was born in 1964 in Belgrade. Jelena B. Bajat is currently Professor at the Faculty of Technology and Metallurgy, Head of the Department of Physical Chemistry and Electrochemistry, University of Belgrade, Serbia. She received her PhD in Electrochemistry in 2003 at the same institution. Her PhD thesis experimental work was mostly performed within the frame of Project "Electrodica" led by Professor Drazic, already mentioned above. She is a coauthor of numerous papers in national and international scientific peer-reviewed journals, university textbook, monographs and a few chapters, with participation in numerous plenary keynote and invited lectures. She is a member of the editorial boards of two journals and was a guest editor of two international journals. She has been serving as regional representative in the International Society of Electrochemistry since 2020. Her research studies abroad were in Magdalene College, Oxford, UK, 2006; Max Planck Institute of Microstructure Physics, Halle, Germany, 1997; and Analytical Research, Neste OY, Finland, 1995.

Research fields include corrosion protection by metallic and nonmetallic coatings, anodization, adhesion, corrosion of biomaterials, concrete corrosion, and electrodeposition in aqueous and deep eutectic solutions.

She has published 86 international peer-reviewed journal papers cited 1417 times, with an *h*-index of 24, according to Scopus (November 10, 2022). The most cited papers of Professor Bajat are listed in Refs. [39, 87–90].

3. Dr. Nebojsa Nikolic, Research Professor, ICTM, University of Belgrade (1970-)

His research interests include electrochemical deposition and dissolution of metals, the application of periodically changing regimes of electrolysis in the processes of metal electrodeposition, the formation of dispersed metal deposits by electrochemical techniques, and electrochemical engineering. His PhD thesis was supervised by Professor Konstantin Popov.

He has published 117 international peer-reviewed journal papers cited 1284 times, with an *h*-index of 18, according to Scopus (November 10, 2022). The most cited papers are listed in Refs. [91–95].

4. Dr. Dusan Trikovic, Research Professor, ICTM, University of Belgrade (1978-)

Dr. Tripkovic's main research interests include surface characterization using electrochemical spectroscopic and microscopic techniques, and the development of new catalysts for reactions in fuel cells. His PhD thesis experimental work was mainly performed in the USA, in Professor Nenad Markovic's laboratory.

He has published 44 international peer-reviewed journal papers cited 6885 times, with an *h*-index of 22, according to Scopus (November 10, 2022). The most cited among these papers are listed in Refs. [60, 61, 73, 96, 97].

5. Dr. Igor Pasti, Full Professor. Faculty of Physical Chemistry, University of Belgrade (1984-)

He is a Professor at the University of Belgrade, Faculty of Physical Chemistry, teaching electrochemistry and electrochemical kinetics. His PhD supervisor was Professor Slavko Mentus. His research is devoted to new materials for energy conversion applications, and he combines experimental and computational approaches.

Thus, his research includes the development of new materials for energy conversion applications, synthesis and characterization of the catalysts for fuel cells, and density functional theory (DFT) calculations. He is definitely one of the youngest full professors of electrochemistry in Serbia, as well as the most productive among today's active electrochemists. He has published 145 international peer-reviewed journal papers cited 2412 times, with an *h*-index of 26, according to Scopus (November 10, 2022). The most cited papers authored by Igor Pasti are listed in Refs. [98–101].

6. Dr. Milica Vujkovic, Assistant Research Professor, Faculty of Physical Chemistry. University of Belgrade (1983-). Her research fields are energy storage and conversion, and the development of various materials for energy-related applications, including (i) intercalation materials for metal-ion rechargeable batteries and (ii) carbon materials for the development of batteries, supercapacitors, water electrolysis, and fuel cells. Her PhD supervisor was Professor Slavko Mentus, a member of the Serbian Academy of Science and Arts. She has published 42 international peer-reviewed journal papers cited 808 times, with an *h*-index of 15, according to Scopus (November 10, 2022). The most cited are listed in Refs. [102–106].
7. Dr. Ana Dobrota, Assistant Professor, Faculty of Physical Chemistry, University of Belgrade (1990-). Her main research interests are materials modeling, DFT calculations, surface functionalization, electrochemical energy conversion and storage systems, and graphene-based materials. Her PhD thesis supervisor was Professor Igor Pasti, mentioned above.

She has published 30 international peer-reviewed journal papers cited 602 times, with an *h*-index of 16, according to Scopus (November 10, 2022). The most cited papers are listed in Refs. [107–109].

8. MsC Jovanka Kovacina Pejic is a PhD student, Junior Researcher, ICTM University of Belgrade (1993-). Her research interests include corrosion and corrosion protection

She has published 7 international peer-reviewed journal papers cited 13 times, with an *h*-index of 2, according to Scopus (November 10, 2022). Bearing in mind that she has been doing her PhD, she already has two cited papers [110, 111]. She has been performing her PhD under the supervision of Professor Jelena Bajat.

A list of almost all Serbian electrochemistry members (in approximately chronological order) was presented in a paper by Dekanski on the occasion of the 71st ISE Annual Meeting – Belgrade online, 2020 [112].

Last, but not least, I would like to mention some of the most promising among the youngest electrochemists working in Serbia today—Jovanka Kovacina, Aleksandra Popovic, Aleksandar Petricevic, Jelena Gojgic, Andjela Simovic—all of them great PhD students at this time. To be continued…

Concluding remarks and perspectives

Considering all the facts discussed above, it is obvious that electrochemistry is a well-established and developed research discipline in Serbia. Although many of the preeminent and internationally recognized experts have retired, new-age young and very productive electrochemists who are quite well known in related fields are working today. The most developed and relevant research areas of electrochemistry in Serbia are electrochemical energy conversion and storage, electrodeposition, characterization and morphology of metals and alloys, and corrosion and corrosion protection. Thus, it can be concluded that electrochemistry will be a focus of younger successors of the Belgrade School of Electrochemistry in upcoming decades. It should be emphasized that electrochemists in Serbia will probably be able to continue research predominantly in fundamentally oriented electrochemical science due to the very challenging and expensive high-profile equipment and total costs associated with up-scaling.

However, I would like to cite Professor Despic related to the statement above: "The fundamental science is absolutely needed to keep and transfer the critical level of knowledge in Electrochemistry, to save it for future better times and more adequate conditions." Otherwise, it could be lost for all future times and generations of electrochemists to come.

It should also be emphasized that younger colleagues will have the chance to continue very rich international collaboration established by our former outstanding professors, as well as new ones established by today's active older electrochemists, to compensate the lack of sophisticated equipment and insufficient financial support for direct costs of research, related in particular to equipment, consumables, and travel costs.

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