
Encyclopedia of Applied Electrochemistry

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Editors

Encyclopedia of Applied Electrochemistry

With 1250 Figures and 122 Tables

 Springer Reference

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Preface

Electrochemistry provides the opportunity to run chemical redox reactions directly with electrons as reaction partners and against the free energy gradient via external electrical energy input into the reaction system. It also serves as a way to efficiently generate energy from stored energy in chemical bonds. Applied electrochemistry has been the basis for many industrial processes ranging from metals recovery and purification to chemical synthesis and separations since the latter half of the 1800s when large-scale electricity generation became possible. Electrochemical processes have a large impact on energy as it has been estimated that these processes consume about 6–10 % of the world's electricity generation capacity. Applied electrochemistry is now impacting industry and society more and more with technologies for waste water treatment, efficient chemical separation, and environmental sensing and remediation. Electrochemistry is the foundation for electrochemical energy storage by batteries and electrochemical capacitors and energy conversion by fuel cells and solar cells. In fact, applied electrochemistry will play a major role in the world's ability to harness and use renewable energy sources. Electrochemistry is also fundamental to biological cell transport and many aspects of living systems and their activities. It is exploited for use in medical diagnostics to detect abnormalities and in biomedical engineering to relieve pain and deliver function.

The application of electrochemistry involves not just a fundamental understanding of the sciences, but also applying engineering principles to device and technology design by considering mass and energy balances, transport processes in the electrolyte and at electrode interfaces, and multi-scale modeling and simulation for predicting and optimizing performance. The interaction of the interfacial reactions, the transport driving forces, and the electric field defines the field of electrochemical engineering. The understanding of the scientific and engineering principles of electrochemical systems has driven advances in the application of electrochemistry especially during the last half century.

The purpose of this collection is to summarize the A–Z of the application of electrochemistry and electrochemical engineering for use by electrochemists and electrochemical engineers as well as nonspecialists such as engineers and scientists of all disciplines, economists, students, and even politicians. Electrochemical fundamentals, electrochemical processes and technologies, and electrochemical techniques are described by many

experts in their fields from around the world, many from industry. Each entry is meant to be an introduction and also gives references for further study. With this collection, we hope that current technology and operating practices can be made available for future generations to learn from. We hope that this encyclopedia will stimulate understanding of the current state of the art and lead to advances in new and more efficient technologies with breakthroughs from new theory and materials. We hope you find it of value to your work.

Gerhard Kreysa
Ken-ichiro Ota
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Editors-in-Chief

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About the Editors



Prof. Dr.rer.nat. Dr.-Ing. E.h. Dr.tekn.h.c. Gerhard Kreysa Retired Chief Executive of DECHEMA e.V.

Gerhard Kreysa was born in 1945 in Dresden. He studied chemistry at the University of Dresden and received his Ph.D. in 1970. In 1973, he joined the Karl Winnacker Institute of DECHEMA in Frankfurt am Main. He developed new concepts for the utilization of three-dimensional electrodes, which became prominent for electrochemical waste water treatment in the process industry. He also played a leading role in the clarification of the "cold fusion" affaire in 1989. In 1985, he was appointed as professor in the Chemical Engineering Department at the University of Dortmund. In 1993, he was appointed as honorary professor at the University of Regensburg. From 1985 to 1995, he served as executive editorial board member of the *Journal of Applied Electrochemistry*. He was a recipient of the Chemviron Award in 1980, the Max-Buchner-Research-Award of DECHEMA and the Castner Medal of the Society of Chemical Industry in 1994, and the Wilhelm Ostwald Medal of the Saxon Academy of Sciences in Leipzig in 2006.

From 1992 to 2009, Dr. Kreysa served as chief executive of DECHEMA Society of Chemical Engineering and Biotechnology in Frankfurt am Main, Germany. During this time he also served as general secretary of the European Federation of Chemical Engineering and the European Federation of Biotechnology. He obtained many distinctions: Honorary doctor degrees of Technical University of Clausthal and of the Royal Institute of Technology in Stockholm, Foreign Member of the Royal Swedish Academy of Engineering Sciences, elected honorary fellow of the Institution of Chemical Engineers, and honorary member of the Czech Society of Chemical Engineering. In 2007

he was awarded with the Order of Merit of the Free State of Saxony, and in 2008 he became a member of the German Academy of Technical Sciences (acatech). He has 196 scientific publications and books and has given 312 scientific and public lectures. Despite the numerous duties and responsibilities of his former senior management position, he continues to have a lively interest in the further development of science and engineering and is highly regarded as an advisor on national and international issues.

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Ken-ichiro Ota is a professor at and the chairman of Green Hydrogen Research Center at Graduate School of Engineering, Yokohama National University, Japan. He received his B.S.E. in applied chemistry in 1968 and Ph.D. in engineering in 1973, both from the University of Tokyo. After graduation, he became a research associate at the university until 1979. In the same year, he became an associate professor at the Yokohama National University, and a professor in 1995. He has worked on hydrogen energy and fuel cell since 1974, focusing on materials science for fuel cells and hydrogen energy system including water electrolysis. In the fuel cell field he has worked on direct methanol fuel cell, molten carbonate fuel cell, and polymer electrolyte fuel cell. Recently, he is developing transition metal oxide-based cathode for polymer electrolyte fuel cell. He is also working on storage and transport of renewable energies by hydrogen technology. He has published more than 190 original papers, 80 review papers, and 50 scientific books. He received the Molten Salt Award in 1998 and the Industrial Electrolysis Award in 2002 from the Electrochemical Society of Japan. He received the Canadian Hydrogen Society Award in 2004 and the Society Award of the Electrochemical

Society of Japan in 2011. He is now the chairman of the National Committee for Standardization of the Stationary Fuel Cells. He was the president of the Hydrogen Energy Systems Society of Japan from 2000 to 2008 and also the president of the Electrochemical Society of Japan from 2008 to 2009. He is now the chairman of the Fuel Cell Development Information Center of Japan.



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Dr. Robert F. Savinell received his B.Chem. from Cleveland State University in 1973, and his M.S. (1974) and Ph.D. (1977), both in chemical engineering from University of Pittsburgh. He worked as a research engineer for Diamond Shamrock Corporation, then as a faculty member at the University of Akron before joining the faculty at Case Western Reserve University (CWRU) in 1986. Professor Savinell was the Director of the Ernest B. Yeager Center for Electrochemical Sciences at CWRU for ten years and served as Dean of Engineering at CWRU for seven years. Professor Savinell has been engaged in electrochemical engineering research and development for 40 years. Savinell's research is directed at fundamental science and mechanistic issues of electrochemical processes; and at electrochemical technology systems and device design, development, modeling and optimization. His research has addressed applications for energy conversion, energy storage, sensing, and electrochemical materials extraction and synthesis. Savinell has over 120 peer-reviewed and over 168 other publications, eight patents, and has been an invited and keynote speaker at hundreds of national and international conferences and workshops in the electrochemical field. He has supervised over 50 Ph.D./M.S. student projects.

Professor Savinell is the former North American editor of the *Journal of Applied Electrochemistry* and currently is the editor of the *Journal of the Electrochemical Society*. He is a Fellow of the Electrochemical Society, Fellow of the American Institute of Chemical Engineers, and Fellow of the International Society of Electrochemistry.

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