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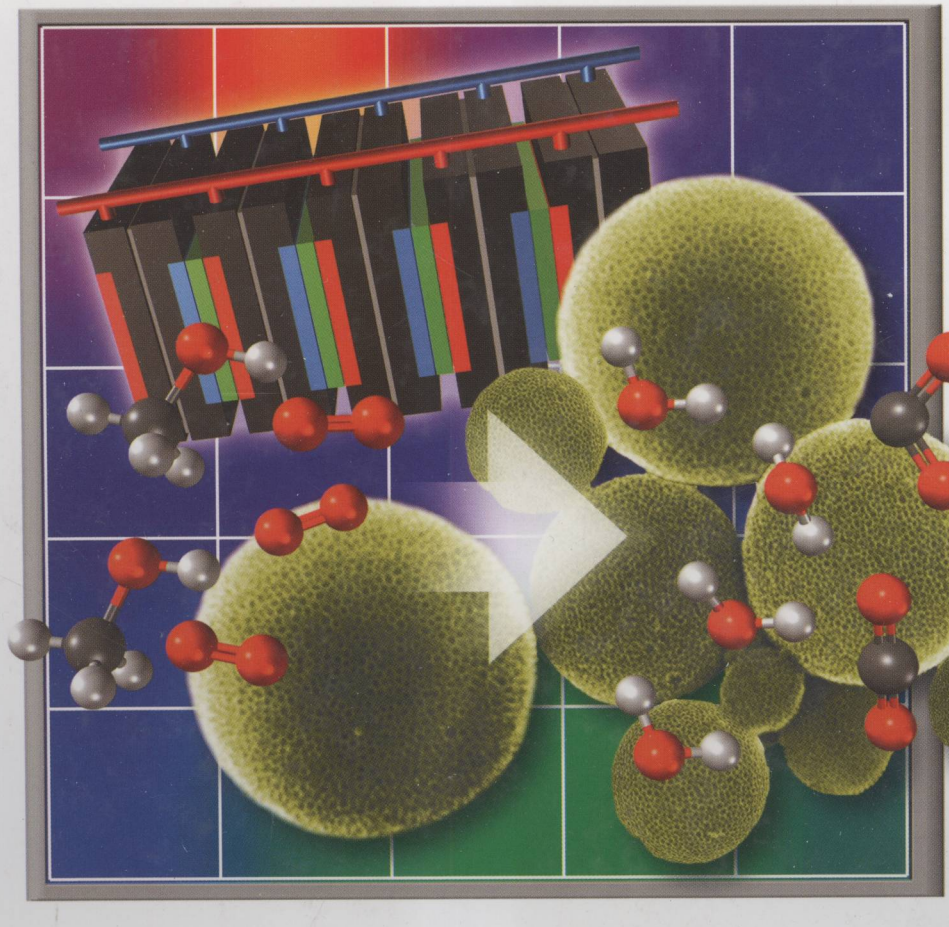
Electrocatalysis of Direct Methanol Fuel Cells

From Fundamentals to Applications



GREEN CHEMISTRY

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Further Reading

Kolb, G.
Fuel Processing
for Fuel Cells
2008
ISBN: 978-3-527-31581-9

Elvers, B. (ed.)
Handbook of Fuels
Energy Sources for Transportation
2008
ISBN: 978-3-527-30740-1

Sundmacher, K., Kienle, A., Pesch, H. J., Berndt, J. F., Huppmann, G. (eds.)
Molten Carbonate Fuel Cells
Modeling, Analysis, Simulation, and Control
2007
ISBN: 978-3-527-31474-4

Logan, B. E.
Microbial Fuel Cells
2008
ISBN: 978-0-470-23948-3

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ISBN: 978-3-527-32081-3

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2010
ISBN: 978-3-527-32401-9

Ozawa, K. (ed.)
Lithium Ion Rechargable Batteries
Materials, Technology, and New Applications
2009
ISBN: 978-3-527-31983-1

Preface

In today's world, human energy demands are continually on the rise, and the prospect of an energy shortage, or even crisis, is likely in the near future. Among the various efforts being made to meet global energy needs, the energy carried by hydrogen and liquid biofuels such as methanol and ethanol has become an attractive option in terms of sustainability and low environmental impact. Within this category of energy conversion technologies, the fuel cell is one of the most environmentally friendly and sustainable possibilities. In the past several decades, governments, along with academic communities and industries, have made enormous investments to develop fuel cells, especially proton exchange membrane fuel cells (PEMFCs), into a viable technology for stationary, portable, and transportation applications. As a result, great advances have been achieved in fuel cell technology in recent years. To date, several kinds of fuel cells, including direct methanol fuel cells (DMFCs), have shown great promise for near-term commercialization.

DMFCs, using renewable liquid methanol as fuel, have some advantages over the hydrogen-fuelled PEMFCs, such as easy fuel production, storage, and transportation, simple feed strategy, as well as system simplification. In comparison with other advanced energy devices such as lithium ion batteries, DMFCs show one order of magnitude higher energy density, making them a better choice for meeting the high energy density requirement of traditionally battery-powered devices. In the past two decades, great progress has been made in DMFC technology. For example, a few pre-commercial products based on this technology are currently emerging in the portable device category, including laptop computers and cell phones. However, several challenges still hinder commercialization, such as inadequate performance and high cost. The sluggish electrocatalytic reactions, that is, the anodic methanol oxidation reaction (MOR) and the cathodic oxygen reduction reaction (ORR), are largely responsible for this low performance. Methanol crossover from anode to cathode through the membrane can also cause performance deterioration. In order to overcome these technical difficulties, high-loading and high-cost Pt and Pt alloy catalysts must currently be used in DMFCs to mitigate the negative effects of the sluggish MOR and ORR, as well as the methanol crossover. In the past few years, numerous studies have been devoted to developing DMFC electrocatalysis, in an effort to further understand the reaction mechanisms, develop cost-effective and

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high-performance or methanol-tolerant catalysts, and optimize the fabrication of catalyst layers and membrane electrode assemblies membrane electrode assembly (MEA).

This book is designed to draw a clear picture of the current status of DMFC technology, with a particular focus on the technical progress, challenges, and perspectives in the field of DMFC electrocatalysis. A group of top fuel cell scientists and engineers, who have not only excellent academic records but also strong industrial fuel cell expertise, were invited to contribute chapters. These leading researchers from universities, government laboratories, and fuel cell industry companies in North America, Europe, and Asia share in this volume their knowledge, information, and insights on recent advances in the fundamental theories, experimental methodologies, and research achievements in DMFC electrocatalysis.

In the first chapter, Arico and his colleagues provide a comprehensive review of DMFC history, the current status of fundamental studies, and the technical advances that have been made in catalyst preparation, MEA fabrication, as well as stack/system design. They also give a global summary of DMFC prototypes in portable and transportation applications, and discuss the techno-economic challenges still confronting DMFC technology. In Chapter 2, Liu and his co-workers describe various methods of synthesizing nanostructured electrocatalysts for DMFCs, including both conventional carbon-supported, Pt-based catalysts and novel unsupported catalyst nanostructures. In Chapter 3, Sarma and Hwang give an overview of versatile characterization techniques for elucidating nanoscale characteristics and activity validation methodologies for DMFC electrocatalysts. In Chapter 4, Jiang and Chu introduce the principles and modern technologies of combinatorial methods used in the synthesis and high throughput screening of electrocatalyst libraries for DMFCs. In Chapter 5, Lei and his co-workers introduce DMFC catalyst development in industry, particularly focusing on Cabot's spray conversion reaction (SCR) platform for the discovery and manufacturing of high-performance fuel cell electrocatalysts. In Chapter 6, Antolini surveys the progress in preparation methods, activity validation, and stability studies of Pt binary and ternary alloys for DMFC anodes. In Chapter 7, Lamy and his colleagues discuss the thermodynamics and kinetics of the oxygen reduction reaction on DMFC cathodes, and introduce strategies to mitigate the methanol-crossover effect; they also describe the progress made in developing methanol-tolerant catalysts. In Chapter 8, Chen and his co-authors review recent advances in carbon nanotube (CNT)-supported DMFC catalysts. In Chapter 9, Pak and Chang cover studies of mesoporous carbon-supported DMFC catalysts. In Chapter 10, Kim and Guiver discuss strategies for making proton exchange membranes with high proton conductivity and lower methanol permeability, mainly describing their own work on developing hydrocarbon-based copolymers containing sulfonic acid groups for DMFC membranes. In Chapter 11, Xing and his co-authors review the progress that has been made in the fabrication and optimization of DMFC catalyst layers and membrane electrode assemblies, with an emphasis on the effects of catalyst layer components, structures, and fabrication methods on DMFC performance. In Chapter 12, Kulikovsky and Wippermann present their experimental and modeling efforts to understand local current distribution during

DMFC operation. In Chapter 13, Scott and Yu provide a detailed description of direct methanol alkaline fuel cells in terms of MOR catalysts, ORR catalysts, and membranes in alkaline circumstances. In Chapter 14, Blair and Law introduce electrocatalysis in other direct liquid fuel cells, mainly focusing on direct ethanol fuel cells and on their own work with direct formic acid fuel cells at Tekion Inc.

It is our hope that this volume will prove to be a good resource for electrochemists, chemical engineers, material scientists, students, and the public, providing up-to-date information on DMFC principles, the current status of DMFC electrocatalysis, and the future prospects for DMFC technology. We anticipate that this book will also be used as a reference by undergraduate and graduate post-secondary students, as well as scientists and engineers who work in the areas of energy, electrochemistry science/technology, fuel cells, and electrocatalysis.

We would like to express our appreciation to Wiley-VCH for inviting us to lead this book project, and we thank Dr. Elke Maase and Dr. Heike Noethe for their guidance and support in smoothing the book preparation process. We also extend our thanks to all our colleagues at the National Research Council of Canada's Institute for Fuel Cell Innovation (IFCI), and especially to the members of the catalysis team, for their support and help. We gratefully acknowledge all the chapter authors for their enthusiastic, collaborative, and reliable contributions. Special thanks go to Prof. Arico, Dr. Lei, Dr. Chang, and Dr. Kulikovsky for providing raw materials for the book's cover design. (Kulikovsky's current distribution picture and IFCI's mesoporous catalysts pictures were incorporated into the cover art.) Finally, our special appreciation goes to our families, for their understanding and their ongoing support of our work.

Vancouver, Canada
February 2009

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