Direct Alcohol Fuel Cells

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Editors

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Materials, Performance, Durability and Applications

Springer

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Preface

Fuel cell energy generation is one of the fundamental electrochemical discoveries of the nineteenth century (William Grove 1839), which became a technology reality at the middle of the twentieth century mainly due to the development of alkaline fuel cells for the aerospace industry. All the fuel cells developed during the last century, from the low-temperature proton exchange membrane (PEM) fuel cells to the high-temperature solid oxide fuel cells, are fueled with hydrogen, although the high-temperature fuel cells can electrooxidize hydrocarbons, such as methane.

Low-temperature PEM fuel cells have reached a certain degree of maturity, and they are nowadays commercialized for some specific applications and are thought to compete with advanced batteries for powering future electric vehicles. One of the major drawbacks in the massive utilization of PEM fuel cells is associated with the storage and distribution of hydrogen, both as compressed gas and as a liquid at very low temperatures. The use of hydrogen-containing room-temperature liquids is an interesting alternative that has been proposed since long ago, alcohols being the best candidates to replace hydrogen due to their availability and low cost. However, the electrooxidation of the simplest alcohol, methanol, in a PEM fuel cell is still far from the electrochemical efficiency obtained with hydrogen. Thus, the direct methanol fuel cells technology is still in its early development stage, and the use of higher alcohols, such as ethanol or glycerol, is restricted to laboratory prototypes.

Several books and book chapters dealing with components of direct methanol fuel cells, mainly electrocatalysts and membranes, have been written during the last decade, some of them providing excellent revisions of the state of the art of the research and technology in the area. This book intends to cover a gap existing in the fuel cell literature, including not only the new electrocatalyst and ionomeric membranes developed in the last 5 years for direct methanol fuel cells, but extending the survey to materials for fuel cells fed with higher alcohols. We include recently developed anodic electrocatalysts for alcohol oxidation, alcohol- and CO-tolerant cathodes, and low alcohol permeability membranes, along with other relevant components of direct alcohol fuel cells, such as catalyst supports, gas diffusion layers, and bipolar plates with flow fields adapted to the two-phase fluid dynamics present in a direct alcohol fuel cell.

In the first chapter, we introduce the concept of methanol economy, as an alternative to the most popular but still elusive hydrogen economy, and we also provide a brief historical description of fundamental research on electrochemical oxidation of methanol and the development of the first alkaline direct methanol fuel cells more than 60 years ago. The operating principles of PEM and alkaline direct alcohol fuel cells are analyzed, as well as their components, configuration, and operation modes, with a final remark on the state of the art of the technology.

The second chapter is dedicated to analyzing the mechanism of methanol electroxidation on platinum, bi- and tri-metallic platinum materials, with a special emphasis on the effect of CO and formic acid oxidation on these electrocatalysts.

The electroxidation mechanism of ethanol and ethylene glycol is discussed in Chap. 3, along with an analysis of the use of these alcohols in fuel cells, and the search for tolerant cathodes. Chapter 4 is devoted to the electroxidation of 3-carbon alcohols (mainly glycerol), including fundamental studies and a comparison of direct glycerol fuel cells with hydrogen and direct ethanol fuel cells. The recent developments of platinum and non-platinum-based catalysts as methanol- and ethanol-tolerant oxygen reduction catalysts for direct alcohol fuel cells are described in Chap. 5.

Chapter 6 deals with the description of different membranes used in direct alcohol fuel cells. Firstly, the properties of Nafion and its inorganic and organic composites are analyzed, focused on the proton conductivity and alcohol permeability, which determine the alcohol selectivity of the modified Nafion membranes. Then, a number of alternative non-fluorinated proton conducting membranes, including sulfonated polyimides, poly(arylene ether)s, polysulfones, poly(vinyl alcohol), polystyrenes, and acid-doped polybenzimidazoles, are described in relation to their selectivity in comparison to Nafion. The chapter includes a comprehensive summary of the relative selectivity of these membranes and their performance in direct alcohol fuel cells. Anion exchange membranes for alkaline direct alcohol fuel cells are also reviewed.

The analysis of carbon materials used as catalyst support, gas diffusion layer, and current collector and bipolar plates is performed in Chap. 7. A number of carbon materials including carbon blacks, nanotubes, nanofibers, and structured porous carbon materials are analyzed and compared as catalyst support in direct methanol fuel cells. Commercial and non-commercial gas diffusion layers are described along with the role of the mesoporous layer on the fuel cell performance. Finally, synthetic graphite and carbon composites used as current collector and bipolar plates are discussed, focusing on their mechanical and electrical properties and production costs.

The physical modeling for fundamental understanding, diagnostics, and design of new materials and operation conditions of direct alcohol fuel cells is addressed in Chap. 8. The modeling of mechanisms and processes at atomistic and single-cell levels is critically reviewed, as well as the theoretical challenges. A multiscale model developed by the author is described, and a possible extension to direct alcohol fuel cells is discussed.

Last but not least, fundamental issues for the deployment of direct alcohol fuel cells—application niches, costs, and durability—are introduced in Chap. 9. The major drawbacks for commercialization, such as miniaturization, product balance, cost reduction, and lifetime extension, are addressed.

It is our expectation that this book will provide updated information on the direct alcohol fuel cell principles, materials, and performance for students, electrochemists, chemical engineers, and material scientists, as well as public interested in cleaner energy sources.

A major contribution of this book has been to collect the results of many experimental studies cited in more than 1,400 references, and partially reflected in 140 figures selected. We salute all the researchers who have contributed to the advancement of our knowledge in this field of fuel cell science and technology.

We would like to express our gratitude to Springer for inviting us to lead this book project, particularly to Sonia Ojo and Karin de Bie for their support and guidance in the preparation and editing phases. Finally, it is a great pleasure to thank all the young coauthors that have enthusiastically contributed in seven chapters of the book, providing their reliable expertise and critical views. H.R.C dedicates this book to Catalina and Martin, his grandchildren born this year, who hopefully will grow up in a more sustainable world.

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