Preface

In 170 chapters written by experts in the field and covering approximately 2500 pages, the first four volumes of the *Handbook of Fuel Cells* represent a comprehensive overview of both the fundamental aspects and the prototyping and application of the most commonly used fuel cell types. These encompass low/medium-temperature Alkaline Fuel Cells (AFCs), Proton Exchange Membrane Fuel Cells (PEMFCs), Direct Methanol Fuel Cells (DMFCs), and Phosphoric Acid Fuel Cells (PAFCs) as well as high-temperature Molten Carbonate Fuel Cells (MCFCs) and Solid Oxide Fuel Cells (SOFCs). Thus, these four volumes describe the basic scientific and engineering design concepts of the various fuel cell types (Volume 1), provide a detailed treatise on the relevant electrocatalytic mechanisms (Volume 2), discuss sustainable energy supply concepts and hydrogen generation/storage technology (Volume 3), and finally, illustrate the design and operation principles of complete fuel cell systems as well as their application envisaged in diverse markets (Volumes 3 and 4).

Since the publication of the first four volumes in 2003, both academic research and industrial fuel cell R&D have grown exponentially; this has largely been driven by major industrial fuel cell field demonstration projects for portable power applications, automotive propulsion, and stationary energy conversion. Practical systems design and field testing have revealed that the large-scale commercialization of fuel cell technology still requires significant improvements in materials performance and durability as well as a detailed understanding of the performance limiting and performance degrading mechanisms.

These new R&D challenges, which have been examined in both academic and industrial research over the past six years, are the focus of the two new volumes of the *Handbook of Fuel Cells*, comprising 68 chapters over approximately 1000 pages. Considering the large industrial fuel cell engineering programs in conjunction with industrial intellectual property concerns, it may not be surprising that the industrial state of the art in fuel cell performance and systems design is frequently superior to the perceived state of the art in the mainstream scientific literature. In addition, most of the materials degradation mechanisms have been discovered in industrial field testing and have not often been discussed in detail in the public scientific literature. Therefore, approximately one third of the chapters in Volumes 5 and 6 are authored or coauthored by industrial experts, aiming to provide a more balanced and comprehensive description of the state of the art in fuel cell materials performance and degradation.

After significant engineering improvements and optimization, it is clear that the amount of platinum or platinum-group metals (PGM) required for low-temperature fuel cell catalysts (DMFCs, PEMFCs) still presents a significant barrier to commercialization. Therefore, experimental concepts of reducing/eliminating PGMs in low-temperature fuel cells, as well as recent molecular modeling and biomimetic approaches pursued to guide the search for new catalysts, are discussed in the first 15 chapters of the new volumes. Subsequent chapters present the various catalyst degradation mechanisms that were discovered largely in the prototyping and field testing of low-temperature fuel cells (DMFC, PEMFC), deriving either from transient operating conditions or fuel/air contaminants. Further improvements of low-temperature fuel cell performance and durability may also come from either new membrane materials (both cationic and anionic) or an improved understanding of the physical-chemical properties and the chemical and mechanical durability aspects of current membranes. These topics are discussed in 10 detailed chapters.

While the materials and operating conditions of high-temperature fuel cells (SOFCs, MCFCs) are very different, the fundamental materials performance and durability challenges are in many ways similar to those of low-temperature fuel cells. In addition, during recent years, similar progress has been made in the field testing of high-temperature fuel cells and also in the fundamental understanding of the electrochemical behavior of high-temperature materials. Thus, the drive toward lower operating temperatures to improve fuel cell durability necessitates the development of new catalysts, ion-conductors, and improved electrode structures. These efforts in developing new materials and electrode designs as well as the examination of performance and durability in the presence of contaminants and mechanical stresses of current high-temperature fuel cell materials are described in a dozen detailed chapters.

In defining the shortcomings of current fuel cell materials, a prerequisite to establishing the desired properties of new materials, advanced diagnostic models and diagnostic methods are indispensable. These are described for both low- and high-temperature fuel cells in a large number of chapters, highlighting the synergistic effect between microscopic electrochemical engineering models and novel imaging (e.g., neutron imaging of liquid water...
in PEMFCs, detailed current distribution of large active-area stacks) or diagnostic (e.g., advanced AC impedance, combined Fourier Transform Infrared/Differential Electrochemical Mass Spectrometry (FTIR/DEMS) analysis) methods that are used to probe the various hypotheses emerging from ever more detailed models.

Finally, approximately one quarter of the chapters in these two new volumes describe the state of the art understanding of the complex degradation phenomena occurring in actual fuel cell systems tested in real-life operation. Naturally, more than half of these chapters are contributions from industry, reporting on field testing data and on degradation mechanisms, such as start-up/shutdown degradation, freeze degradation, sulfur poisoning, etc, that occur predominantly under these less controlled and more dynamic operating conditions. While the phenomena described are quite complex, several chapters in this section demonstrate the surprising ability of advanced models to quantify the observed degradation.

As may be apparent from the above description, the assembly of these two new volumes of the Handbook of Fuel Cells was a challenging and exciting journey for us, covering a very wide range of topics spanning the entire gamut from molecular modeling to fuel cell system field testing. While the breadth of these 68 chapters may be somewhat intimidating, it offers at the same time the most comprehensive and hopefully systematic overview of the state of the art of fuel cells. At the same time, we also hope that these volumes will enable academic researchers to understand more clearly the industrial requirements while at the same time raising the awareness of industrial researchers of the fruits emerging from the fundamental academic research efforts.

In the end, of course, it should be clear that we have merely assembled the chapters written by a large number of authors, and it is really their extensive expertise and their profound know-how that have enabled the preparation of these two new volumes. Therefore, we would like to express our sincere gratitude to the authors who made this work possible. Last but not least, we would also like to thank the Advisory Board for helping us to structure the content, as well as our friends at Wiley who have helped and supported us with great enthusiasm throughout this project.

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