Preface

Hydrogen is a highly versatile fuel that may become one of the key pillars to support our future energy infrastructure. It can be efficiently converted into electricity using a fuel cell, or it can directly drive an internal combustion engine. Using hydrogen is clean; the only reaction product upon oxidation is pure water, with little or no exhaust of greenhouse gases. It can even be converted into more convenient form of fuel, a liquid hydrocarbon, using excess CO_2 and well-established Fischer–Tropsch technology. However, hydrogen does not occur freely in nature, and producing hydrogen in a clean, sustainable, and economic way is a major challenge.

This book is about tackling that challenge with semiconductors, using water and sunlight as the only ingredients. The ultimate aim is to make a monolithic photoelectrode that evolves hydrogen and oxygen at opposite sides of the electrode, so that they can be easily separated. Finding semiconductors that can do this efficiently, at low cost, and without suffering from corrosion is far from trivial. The emphasis in this book is on transition metal oxides, a low-cost and generally very stable class of semiconductors. There is a darker side to these materials, though. The bandgap of metal oxide semiconductors is often a bit too large, and the optical absorption coefficient is usually small. In addition, the catalytic activity for water oxidation or reduction at the surface is generally poor, and the electronic charge transport properties can be downright horrible. This issues have thwarted many earlier efforts in the late 1970s and early 1980s to reach the "Holy Grail" of solar water splitting. In the past few years, however, exciting breakthroughs in nanotechnology have stimulated a huge amount of renewed interest in this field. This book attempts to summarize both the basic principles and some of the important recent developments in photoelectrochemical water splitting. While we cannot even hope to approach completeness in a single volume, we nevertheless hope that both experts and newcomers in this field find something useful here that helps their research.

The book is organized into four parts. The first part covers basic principles and is specifically aimed at undergraduate and graduate students, as well as colleagues who are new to the field. Chapter 1 provides a brief motivation for our interest in solar hydrogen production. The properties of semiconductors, the semiconductor/

electrolyte interface, and basic PEC device operation are covered in Chap. 2, while an overview of photoelectrochemical measurement techniques is given in Chap. 3. The second part of the book is on materials properties and synthesis. In Chap. 4, Kevin Sivula discusses the intrinsic properties of α-Fe_2O_3 (hematite) that limit its performance as a photoanode, and how these limitations can be overcome by nanostructuring. Kazuhiro Sayama outlines the properties of ternary and mixed metal oxide photoelectrodes in Chap. 5, showing recent results on $BiVO_4$ and a high-throughput screening method. In Chap. 6, Bruce Parkinson takes the high-throughput concept to the next level by discussing combinatorial approaches to discover new candidate materials and to screen thousands of compositions in a quick and systematic fashion. The third part of the book is on devices and device characterization. This part consists of a single, extensive chapter by Eric Miller, Alex DeAngelis, and Stewart Mallory on multijunction approaches and devices for solar water splitting (Chap. 7). They analyze the merits of various tandem configurations and materials combinations, and give an overview of key aspects to be considered in future research efforts. The fourth and final part of the book gives an overview of some of the future perspectives for photoelectrochemical water splitting. In Chap. 8, Julian Keable and Brian Holcroft take a closer look at the economic and business perspectives, and set the device performance targets that need to be met in order to commercialize the technology. In the final chapter, Scott Warren describes how some of the recent developments in nanotechnology and nanophotonics can be leveraged in solar water splitting materials, offering an exciting glimpse at future performance breakthroughs (Chap. 9).

Putting together a volume like this is a big undertaking in which many people are involved. First and foremost, the editors express their sincere thanks to all the contributors. We hope they are pleased with the fruits of our collective labor, and greatly appreciate their patience during the lengthy course of this project. We thank the people of Springer for their encouragement and support throughout the project: Elaine Tham, Lauren Danahy, Merry Stuber, and especially Michael Luby. A final and special thanks goes to the series editor, Prof. Harry Tuller, for inviting us to edit a volume on the exciting subject of solar water splitting.

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