

WOODHEAD PUBLISHING IN MATERIALS



Multifunctional Photocatalytic Materials for Energy

Edited by Zhiqun Lin, Meidan Ye and Mengye Wang

WP
WOODHEAD
PUBLISHING

Contents

List of contributors	ix
1 Introduction: Multifunctional photocatalytic materials: A perspective	1
<i>Meidan Ye, Mengye Wang, Zhiqun Lin</i>	
2 Metal oxide powder photocatalysts	5
<i>Mohammad M. Khan</i>	
2.1 Historical developments and introduction	5
2.2 Semiconductors and photocatalysis	6
2.3 Fundamentals of photocatalysis	7
2.4 Metal oxides as powder photocatalysts	9
2.5 Applications of powdered metal oxides photocatalysts	11
2.6 Future perspectives	15
2.7 Conclusions	16
References	16
3 Metal oxide electrodes for photo-activated water splitting	19
<i>Davide Barreca, Giorgio Carraro, Alberto Gasparotto, Chiara Maccato</i>	
3.1 Introduction	19
3.2 Fundamentals of photoelectrochemical water splitting: An overview	21
3.3 Relevant case studies for photoanode development	23
3.4 Conclusions and future trends	38
Acknowledgments	41
References	41
4 Energy band engineering of metal oxide for enhanced visible light absorption	49
<i>Jiangtian Li, Deryn Chu</i>	
4.1 Introduction	49
4.2 Electronic energy band structure of semiconductors	50
4.3 Principle of photocatalysis for solar fuel generation	54
4.4 Metal oxide photocatalysts	58
4.5 Energy band engineering of metal oxides for enhanced visible light absorption	62
4.6 Concluding remarks	72
Acknowledgments	73
References	73
Further reading	78

5	Graphene photocatalysts	79
	<i>Luisa M. Pastrana-Martínez, Sergio Morales-Torres, José L. Figueiredo, Joaquim L. Faria, Adrián M.T. Silva</i>	
5.1	Introduction	79
5.2	Graphene and its derivatives	80
5.3	Graphene-based semiconductor photocatalysts	82
5.4	Energy applications	88
5.5	Conclusions and outlook	94
	Acknowledgments	95
	References	95
6	Carbon nitride photocatalysts	103
	<i>Jinqiang Zhang, Hongqi Sun</i>	
6.1	Introduction	103
6.2	Graphitic carbon nitride for hydrogen evolution	105
6.3	Carbon nitride for reduction of CO ₂	119
6.4	Carbon nitride for other energy applications	120
6.5	Conclusion and outlook	120
	References	121
7	Graphene-based nanomaterials for solar cells	127
	<i>Syed Farooq Adil, Mujeeb Khan, Dharmalingam Kalpana</i>	
7.1	Introduction	127
7.2	Properties of graphene	130
7.3	Synthesis of graphene-based materials	130
7.4	Graphene in dye-sensitized solar cells (DSSCs)	134
7.5	Conclusion	145
	Acknowledgment	145
	References	146
8	Metal-based semiconductor nanomaterials for thin-film solar cells	153
	<i>Wenxi Guo, Zijie Xu, Teng Li</i>	
8.1	Introduction	153
8.2	Fabrication of metal-based semiconductor nanomaterials	155
8.3	Semiconductor nanomaterials as interfacial materials for solar cells	165
8.4	Semiconductor nanomaterials as mesoporous layers for DSSCs	170
8.5	Concluding remarks and outlook	180
	References	181
	Further reading	185
9	Metal-based semiconductor nanomaterials for photocatalysis	187
	<i>Laura Clarizia, Danilo Russo, Ilaria Di Somma, Roberto Andreozzi, Raffaele Marotta</i>	
9.1	Introduction	187
9.2	Thermodynamics and kinetics of the water splitting process	187

9.3	Photocatalyst requirements	189
9.4	Catalytic water photosplitting	193
9.5	Catalytic photoreforming	199
9.6	Operating variables affecting photocatalyst activity	201
9.7	Conclusion	205
	References	205
10	Photocatalysts for hydrogen generation and organic contaminants degradation	215
	<i>Rupali Nagar, Eswaraiah Varrla, Bhaghavathi P. Vinayan</i>	
10.1	Introduction	215
10.2	Hydrogen economy and photocatalytic splitting of water	224
10.3	Photocatalytic degradation of organic contaminants	227
10.4	Conclusion	232
	Acknowledgments	233
	References	233
11	Multidimensional TiO₂ nanostructured catalysts for sustainable H₂ generation	237
	<i>Jingsheng Cai, Jianying Huang, Mingzheng Ge, Yuekun Lai</i>	
11.1	Introduction	237
11.2	Preparations of multidimensional TiO ₂ nanostructures	238
11.3	Solar WS by nanostructured TiO ₂ materials	250
11.4	Conclusions and perspectives	265
	Acknowledgments	266
	References	267
	Further reading	288
12	Hybrid Z-scheme nanocomposites for photocatalysis	289
	<i>Ryo Kuriki, Kazuhiko Maeda</i>	
12.1	Introduction	289
12.2	Powder-based Z-scheme photocatalysts of metal-complex/semiconductor hybrids	292
12.3	Photoelectrochemical CO ₂ reduction using molecular-based photocathode coupled with a semiconductor photoanode	297
12.4	Photoelectrochemical CO ₂ reduction using semiconductor electrodes modified with a catalytic metal complex	302
12.5	Summary and outlook	304
	References	305
13	Ferroelectrics for photocatalysis	307
	<i>N.R. Yogamalar, S. Kalpana, V. Senthil, A. Chithambararaj</i>	
13.1	Introduction	307
13.2	Ferroelectric fundamentals	307
13.3	Ferroelectric semiconductor photocatalysts	308

13.4	Synthesis and characterization of ferroelectric photocatalysts	310
13.5	Theoretical and computational methods proposed for ferroelectric photocatalysts	310
13.6	Architectural design of ferroelectric semiconductor photocatalysts	312
13.7	Factors influencing photocatalytic reaction	318
13.8	Conclusion	320
13.9	Outlook	320
	Acknowledgments	321
	References	321
	Index	325

Key Features

- Comprehensively covers all aspects of recent developments in multifunctional photocatalytic materials
- Provides fundamental understanding of the structure, properties and energy applications of these materials
- Contributions from leading international experts in the field working in multidisciplinary subject areas

This book discusses recent developments concerning multifunctional photocatalytic materials, such as semiconductors, quantum dots, carbon nanotubes, and graphene, with an emphasis on their novel properties and synthesis strategies, fundamental principles, and their applications in energy fields (for example, hydrogen generation from water splitting, CO₂ reduction to hydrocarbon fuels, degradation of organic pollutants, and solar cells).

Multifunctional Photocatalytic Materials for Energy will serve as not only a valuable reference book for researchers, but also as an instructive text for undergraduate and postgraduate students to increase their knowledge about multifunctional photocatalytic materials and stimulate their interest in designing and creating advanced materials.

Related Titles

- Sorrell et al, *Materials for Energy Conversion*, 2005, 9781855739321
- Melhem, *High Temperature Superconductors*, 2011, 9780857090126
- Ye, *Handbook of Advanced Dielectric, Piezoelectric, and Ferroelectric Materials*, 9781845691868

About the Editors

Zhiqun Lin is currently a professor in the School of Materials Science and Engineering at the Georgia Institute of Technology. His research areas include: solar cells (organic-inorganic hybrid solar cells, dye-sensitized solar cells, and perovskite solar cells), batteries (lithium ion and sodium ion batteries), photocatalysis (e.g., hydrogen generation), polymer-based nanocomposites, block copolymers, conjugated polymers, quantum dots (rods, tetrapods, and wires), functional nanocrystals (metallic, magnetic, semiconducting, ferroelectric, multiferroic, upconversion, and thermoelectric) of different architectures (plain, core/shell, hollow, and Janus), hierarchically structured and assembled materials, and surface and interfacial properties.

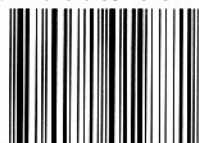
Meidan Ye is an associate professor in the Research Institute for Biomimetics and Soft Matter, Department of Physics at Xiamen University. She received her PhD in physical chemistry from Xiamen University in 2014. Her research interests include advanced materials for energy and environment, such as perovskite, dye-sensitized and quantum dot-sensitized solar cells, water-splitting hydrogen production, photocatalytic degradation of organic pollutants, and energy storage devices. She is an author and co-author for over 30 papers published in peer-reviewed journals, including *Nano Letters*, *Journal of the American Chemical Society*, *Advanced Materials*, *Advanced Energy Materials*, *Energy & Environmental Science*, etc.

Mengye Wang is a post-doctorate fellow in the Department of Applied Physics at the Hong Kong Polytechnic University. She received her PhD in physical chemistry at Xiamen University in 2015. She did part of her PhD thesis at the Georgia Institute of Technology. She was selected to be a community board member for *Materials Horizons* in 2015. Her research interests include advanced functional materials for environmental and energy-related applications, such as photocatalytic degradation of organic pollutants, water splitting and dye-sensitized solar cells. She is an author and co-author of 29 papers, including *Journal of the American Chemical Society*, *Energy & Environmental Science*, etc.



WP
WOODHEAD
PUBLISHING
An imprint of Elsevier
elsevier.com/books-and-journals

ISBN 978-0-08-101977-1



9 780081 019771