Sustainable Materials and Technology

Mohammad Oves
Mohammad Shahadat *Editors*

Quantum Catalysis Reactions for Sustainability

Catalytic Reaction for Sustainability

Springer

Editors
Mohammad Oves
Center of Excellence in Environmental Studies
King Abdulaziz University
Jeddah, Makkah, Saudi Arabia

Mohammad Shahadat
Institute of Oceanography and Environment (INOS)
Universiti Malaysia Terengganu
Kuala Nerus, Terengganu, Malaysia

ISSN 2731-0426 ISSN 2731-0434 (electronic)
Sustainable Materials and Technology
ISBN 978-981-95-6046-2 ISBN 978-981-95-6047-9 (eBook)
https://doi.org/10.1007/978-981-95-6047-9

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Contents

Quantum Catalyst Advances in Photoelectrocatalytic CO_2 Reduction Technologies

Abdul Hakeem Anwer, Maroua Saadaoui, Assem T. Mohamed, Nafees Ahmad, and Abdelbaki Benamor

Abstract Growing population pressures, increasing global energy demand, and the escalating impacts of climate disruption have intensified concerns over future energy security and environmental stability. Solar-driven CO_2 reduction is increasingly recognized as a viable strategy to confront these dual challenges. In this context, photoelectrocatalysis provides a particularly attractive approach, as it merges light harvesting with electrochemical control, enabling efficient solar energy conversion under mild reaction conditions while avoiding the need for extreme temperatures or high applied voltages. This combined strategy holds significant promise for achieving efficient and selective CO_2 conversion. The chapter provides an overview of the fundamental principles underlying photocatalytic, electrocatalytic, and photoelectrocatalytic CO_2 reduction, emphasizing their distinctive operational characteristics. Different photoelectrocatalytic configurations are described and evaluated in a comparative framework. Particular attention is given to factors that govern performance, such as the interaction between catalysts and reactant molecules, operating conditions, and the physicochemical properties of photoelectrodes. Advances in mechanistic understanding and approaches for enhancing activity including the optimization of light harvesting, suppression of charge recombination, and acceleration of surface reaction dynamics are critically examined. The discussion concludes with an assessment of current limitations and potential future directions for the development of photoelectrocatalytic CO_2 reduction technologies.

Keywords Photo electrocatalytic · CO_2 reduction · Quantum catalyst · Electrocatalyst

A. H. Anwer · M. Saadaoui · A. T. Mohamed · A. Benamor (✉)
Gas Processing Center, College of Engineering, Qatar University, Doha, Qatar
e-mail: benamor.abdelbaki@qu.edu.qa

A. Benamor
Department of Chemical Engineering, College of Engineering, Qatar University, Doha, Qatar

N. Ahmad
Department of Chemistry, Integral University Lucknow, Lucknow, India

M. Oves and M. Shahadat (eds.), *Quantum Catalysis Reactions for Sustainability*, Sustainable Materials and Technology, https://doi.org/10.1007/978-981-95-6047-9_2

References

1. Anwer AH et al (2023) Simultaneous reduction of carbon dioxide and energy harvesting using RGO-based SiO_2-TiO_2 nanocomposite for supercapacitor and microbial electrosynthesis. Appl Catal B 339:123091
2. Birdja YY et al (2019) Advances and challenges in understanding the electrocatalytic conversion of carbon dioxide to fuels. Nat Energy 4(9):732–745
3. Song RB et al (2020) Electrode materials engineering in electrocatalytic CO_2 reduction: energy input and conversion efficiency. Adv Mater 32(27):1903796
4. Xie S et al (2016) Photocatalytic and photoelectrocatalytic reduction of CO_2 using heterogeneous catalysts with controlled nanostructures. Chem Commun 52(1):35–59
5. Wu HL et al (2019) Semiconductor quantum dots: an emerging candidate for CO_2 photoreduction. Adv Mater 31(36):1900709
6. Shit SC et al (2020) Integrated nano-architectured photocatalysts for photochemical CO_2 reduction. Nanoscale 12(46):23301–23332
7. Zhou Y et al (2021) Engineering 2D photocatalysts toward carbon dioxide reduction. Adv Energy Mater 11(8):2003159
8. Wang P et al (2018) Recent progress on photo-electrocatalytic reduction of carbon dioxide. Part Part Syst Charact 35(1):1700371
9. Ješić D et al (2021) Engineering photocatalytic and photoelectrocatalytic CO_2 reduction reactions: mechanisms, intrinsic kinetics, mass transfer resistances, reactors and multi-scale modelling simulations. Chem Eng J 407:126799
10. Chen P et al (2021) Photoelectrocatalytic carbon dioxide reduction: fundamental, advances and challenges. Nano Mater Sci 3(4):344–367
11. Kumaravel V, Bartlett J, Pillai SC (2020) Photoelectrochemical conversion of carbon dioxide (CO_2) into fuels and value-added products. ACS Energy Lett 5(2):486–519
12. Park YH et al (2021) Recent advances in quantum dots for photocatalytic CO_2 reduction: a mini-review. Front Chem 9:734108
13. Cao F et al (2018) A layer-by-layer growth strategy for large-size InP/ZnSe/ZnS core-shell quantum dots enabling high-efficiency light-emitting diodes. Chem Mater 30(21):8002–8007
14. Salunkhe TT et al (2023) Recent innovative progress of metal oxide quantum-dot-integrated g-C_3N_4 (0D–2D) synergistic nanocomposites for photocatalytic applications. Catalysts 13(11):1414
15. Lingampalli S, Ayyub MM, Rao C (2017) Recent progress in the photocatalytic reduction of carbon dioxide. ACS Omega 2(6):2740–2748
16. Zhang B, Sun L (2019) Artificial photosynthesis: opportunities and challenges of molecular catalysts. Chem Soc Rev 48(7):2216–2264
17. Wang X et al (2021) $CsPbBr_3$ perovskite nanocrystals anchoring on monolayer MoS_2 nanosheets for efficient photocatalytic CO_2 reduction. Chem Eng J 416:128077
18. Jiang Z et al (2019) Living atomically dispersed Cu ultrathin TiO_2 nanosheet CO_2 reduction photocatalyst. Adv Sci 6(15):1900289
19. Zhou B et al (2018) Mo–Bi–Cd ternary metal chalcogenides: highly efficient photocatalyst for CO_2 reduction to formic acid under visible light. ACS Sustain Chem Eng 6(5):5754–5759
20. AlOtaibi B et al (2015) Wafer-level artificial photosynthesis for CO_2 reduction into CH_4 and CO using GaN nanowires. ACS Catal 5(9):5342–5348
21. Barton EE, Rampulla DM, Bocarsly AB (2008) Selective solar-driven reduction of CO_2 to methanol using a catalyzed p-GaP based photoelectrochemical cell. J Am Chem Soc 130(20):6342–6344
22. Zhao Y et al (2015) Defect-rich ultrathin ZnAl-layered double hydroxide nanosheets for efficient photoreduction of CO_2 to CO with water. Adv Mater 27(47):7824–7831
23. Luo J et al (2019) A critical review on energy conversion and environmental remediation of photocatalysts with remodeling crystal lattice, surface, and interface. ACS Nano 13(9):9811–9840