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Nanophotocatalysis and Environmental Applications

Energy Conversion and Chemical Transformations

Springer

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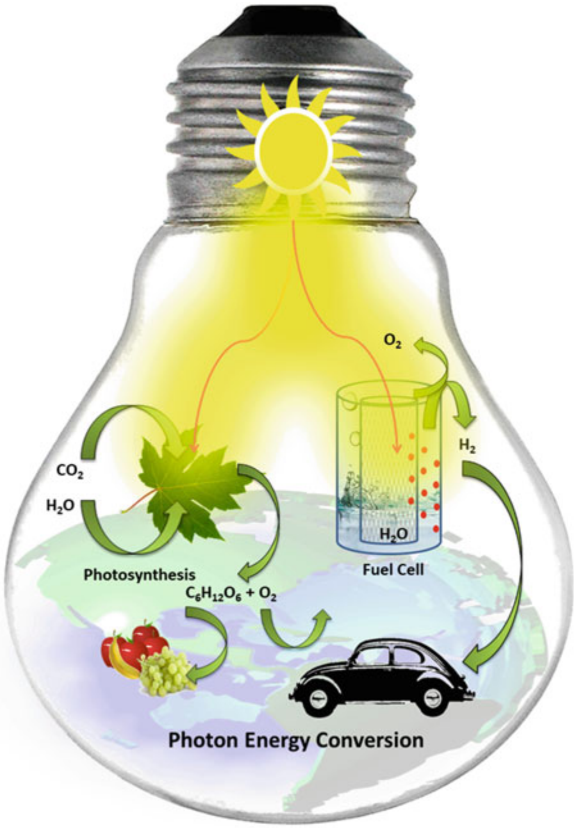
Preface



O_2
H_2
CO_2
H_2O
H_2O
Photosynthesis
Fuel Cell
$C_6H_{12}O_6 + O_2$
Photon Energy Conversion

The global energy crisis and climate change have been labelled as the most critical environmental challenges in terms of both research and remediation. Non-renewable energy resources fulfil nearly 85% of world energy demands leading to global warming and depletion of resources. The exhaustion of finite fuels should be addressed for a sustainable energy future. Therefore, research is ongoing to harness the renewable energy during the processes such as photocatalytic and bioproduction of hydrogen and other fuels. The use of renewable sources of energy and the mitigation of climate change or global warming are interrelated, and, if both are worked upon simultaneously, it certainly will make a difference.

The increasing global demand for energy is a result of a population explosion, which is demanding the intention towards the development of effective strategies for energy conversion and the reduction of greenhouse gas emissions. This can obviously be achieved by focussing on non-fossil sources of energy such as solar, thermal, hydrogen and nuclear energy as well as CO_2 capture and photoconversion of CO_2 into fuels. Advanced oxidation processes have evolved during the years, and scientists are using photocatalysis for energy conversion especially harnessing of solar energy.

Photocatalytic water splitting for H_2 and O_2 production using semiconductors is the most promising fields as a green technology that is accounted for economic importance. The direct semiconductors mediated water splitting for hydrogen generation as clean fuel can be performed on a large scale for practical applications. In general, there are many efficient catalysts reported for the same, but these are active in ultraviolet light only. The challenge still lies in designing low-cost catalysts that show high quantum efficiency, ability to work under visible and sunlight as well as the ability to work without noble metals as co-catalysts. Many works with high quantum efficiencies have reported on solar- and visible-powered hydrogen emission by designing novel catalysts by surface modifications, sensitizations, immobilization, formation of Z-scheme junctions, dye-sensitized solar cells, etc. Recently, significant progress is made to develop and engineer various photocatalysts for this purpose. The prime solution is bandgap engineering that involves bandgap broadening or narrowing, interparticle electron coupling, reducing recombination of charge carriers, plasmon-exciton coupling and high surface energy of the catalysts.

Additionally, combustion of fuels and industrial effluents has been threatening as they release alarming amounts of greenhouse gas as CO_2. According to the various studies, the CO_2 level may reach 750 ppm and raise the global temperature further. Photocatalytic reduction of CO_2 into syngas, methane, carbon monoxide, methanol, formic acid and formaldehyde has its own advantages as lowering of greenhouse gas levels and energy production simultaneously. Photocatalytic reduction of CO_2 into fuels is, however, more complicated process as compared to water splitting. This is because of its dependence on thermodynamics and kinetics of light absorption, band potentials, charge separation and largely the activation of catalyst, i.e. adsorption of CO_2. Various organic materials as part of catalysts or supports such as carbon nanotubes, graphene, graphene oxide, carbon nitride, etc. for CO_2 activation as adsorption and interaction with the catalyst is an important requirement of the reaction. In addition, very few solar active catalysts are available which are capable of reducing carbon dioxide. The photocatalytic conversion of CO_2 into fuels is in its embryonic stage, and a substantial development and progress are still required. It is therefore important to study and analyse various catalysts and technologies developed so far for better modification and upgradation. Among various energy conversion applications, photocatalysis has also been promising for removal of NO_x gases, volatile organic carbon removal, air clean-up filters and catalytic converters for vehicle exhausts.

Nanophotocatalysis and Environmental Applications: Energy Conversion and Chemical Transformations is focussed on fuel production as a source of renewable energy using photocatalysis. The application of photocatalysis is discussed in areas such as fuel production including carbon monoxide, formic acid, methanol, methane and hydrogen and CO_2 reduction and water splitting, water purification and purification of food industry wastewater and organic synthesis using various types of photocatalytic materials such as quantum dots, graphitic carbon nitride, metal oxides, Z-scheme photocatalysts, metal organic frameworks, composites and polymeric semiconductors. This is beneficial for analysing the current progress underway, which certainly paves ways for new directions for breakthrough technologies to be developed. Based on thematic topics, the book edition contains the following nine chapters:

Chapter 1 gives an overview of the main methods to obtain quantum dots and some examples of their use as a photocatalyst for fuel production.

Chapter 2 summarizes the works on the photocatalytic hydrogen production using highly stable TiO_2-based heterostructured photocatalysts. The emphasis is given on three important characteristics, namely, UV-active TiO_2-based photocatalysts, visible-active TiO_2-based photocatalysts and the effects of various carbon nanostructures on the photocatalytic hydrogen production efficacy of TiO_2-based heterostructured photocatalysts.

Chapter 3 highlights the method of synthesis of photocatalysts and their possible modification for performance enhancement in water splitting and CO_2 reduction.

Chapter 4 provides the basic principles, terminologies, concepts, state-of-the-art achievements and the charge transfer mechanism of the photocatalytic reduction of CO_2 using artificial Z-scheme photocatalysts. In spite of these, the development on semiconductor photocatalytic materials from the perspective of light harvesting as well as the co-catalyst strategy for potentially boosting the activity and/or product selectivity for the photocatalytic reduction of CO_2 along with the future direction of research using Z-scheme systems are also discussed and highlighted.

Chapter 5 deals with the importance of photocatalysts and their applications for artificial photosynthesis. The primary photosynthetic applications of photocatalysts such as supramolecular artificial photosynthetic systems, covalently linked molecular systems and general mechanism of photosynthesis are also discussed in detail.

Chapter 6 discusses various chemical methodologies, properties and photocatalytic applications of polymeric semiconductors (carbon nitride, C_3N_4), graphene, and metal-organic framework (MOF)-based hybrid nanostructured photocatalysts for the water purification and the solar hydrogen production.

Chapter 7 summarizes the innovative aspects of the applicability of photocatalysis and technological advances with particular attention to the photocatalytic energy recovery, organic synthesis and new reactor configurations. In particular, the chapter discusses the possibility to produce an energy source such as hydrogen and/or methane from the degradation of organic substance present in wastewater by heterogeneous photocatalysis. The chapter also reports simultaneous valorization and purification of food industry wastewater using structured photocatalysts.

Chapter 8 focusses on some important nano-semiconductor photocatalysts like TiO_2, ZnO and graphitic carbon nitride and various strategies adopted for improving their photocatalytic activity under sunlight. Different methods for improving visible light active photocatalysts including metal/nonmetal doping, the addition of photosensitive materials, the incorporation of other nanoparticles, the composite formation with other semiconductors and the formation of heterojunctions and nanohybrids are discussed.

Chapter 9 reviews the state-of-the-art progresses in the use of common photocatalytic materials for the purpose of four important classes of organic synthesis, namely, oxidation of alcohols, oxidative cleavage of olefins, reduction of nitro compounds and cyclisation; carbon-hetero bond formation and alkylation will be reviewed.

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