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Review Article

A review: Effect of nanostructures on photocatalytic CO_2 conversion over metal oxides and compound semiconductors

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ABSTRACT

Photo-conversion of CO_2 into valuable solar fuels under the light irradiation is one of the most environmentally-friendly and economical technologies for reducing the CO_2 emissions. Nanostructured metal oxides and compound semiconductors have been applied as photocatalysts for CO_2 conversion. Especially, nanoparticulate and nanoporous materials have been studied extensively as photocatalysts owing to their reduced dimensions for electron transport, high surface areas, catalytic activity, and shorter diffusion pathway for the reactants. Transition metal oxides have long been studied as photocatalysts, however, these materials show low CO_2 conversion efficiencies because of their wide band gap, which results in poor light absorption characteristics in the visible range. To improve the photocatalytic activity of CO_2 conversion, alternative compound semiconductors with high visible absorption light absorption properties have been considered as photocatalysts for CO_2 conversion. In this study, the effect of nanostructures on the photocatalytic conversion of CO_2 to other chemicals on transition metal oxides and compound semiconductors are compared and the promising research directions to design photocatalysts for CO_2 conversion performance enhancement are proposed.

1. Introduction

Since the industrial revolution, humans have been faced with serious environmental pollution and the exhaustion of natural resources due to accelerated industrial development. Furthermore, the increased use of fossil fuels, which have a high energy density, results in the explosive increase in CO_2 emission to the atmosphere, causing environmental problems such as global warming. To ensure sustainable industrial growth without environmental problems, the development of environmental cleanup systems, green technologies and alternative renewable energy sources such as solar energy, wind power, tidal energy and biomass are needed to meet the increased energy demands [1].

In photocatalytic CO_2 conversion technology, the development of a perfect artificial photosynthesis ($CO_2 + h\upsilon \rightarrow$ useful chemicals) system on a stable inorganic nanostructured photocatalyst material is a major goal. Artificial photosynthesis on an inorganic photocatalyst leads to zero emission of greenhouse gases during energy production and the manufacturing exhaust streams can be converted into valuable chemicals [2–4]. Thus far, many researchers, who have shown interest in the development of synthetic pathways to prepare highly efficient photocatalysts, have focused mainly on water splitting. As a result, photocatalytic CO_2 conversion technology is considered a significant challenge [5]. The development of facile synthetic techniques for the preparation of novel photocatalysts with outstanding optical response and catalytic acitivities is needed [6].

Transition metal oxides with oxygen vacancies are the most widely investigated photocatalysts for the conversion of CO_2 to hydrocarbons, because oxygen vacancies can act as catalytically active site, and enhance the photocatalytic activity and visible light absorption ability. For example, H_2 treated defective TiO_2, $TiO_{2\text{-}x}H_x$, in which some oxygen sites are replaced with hydrogen in TiO_2, shows increased light absorption and photocatalytic activity for water splitting [7,8]. Improved CO_2 adsorption on the surface of particulate photocatalysts can also enhance the CO_2 conversion efficiency [9]. Surface hydroxides can enhance the attractive interactions between CO_2 and the surface of the photocatalyst, which can affect the catalytic activity and reaction rates. An understanding of the surface, optical and electronic properties of photocatalysts for CO_2 conversion with H_2O, and the relationship between the physicochemical properties of the photocatalyst and the conversion efficiency is essential for making advances towards realistic large-scale carbon capture and utilization technology [10–13].

Traditionally, nanostructured materials with various morphologies such as particles, tubes, wires, rods and sheets have been evaluated as photocatalysts for CO_2 conversion [14–17]. Recently, nanoporous materials such as zeolites, metal organic frameworks (MOFs), mesopor-

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