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Review

A comprehensive review on anodic TiO_2 nanotube arrays (TNTAs) and their composite photocatalysts for environmental and energy applications: Fundamentals, recent advances and applications

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ABSTRACT

Owing to their unique properties, the electrochemically self-organized TiO_2 nanotube arrays (TNTAs) have attracted great attention as promising nanomaterials for energy and environmental photocatalytic applications. This has stimulated intensive research activities that focused on the synthesis, properties, modification and applications of these 1D nanomaterials as photocatalysts. In this review, all these aspects are fully covered in a comprehensive way that was not presented previously. The review starts with discussing the main fundamentals of the photocatalytic process using TNTAs. Then, the recent developments in the synthesis methods and modification strategies of TNTAs are presented in detail. The main photocatalytic applications of TNTAs including CO_2 reduction, H_2 and O_2 production and pollutants degradation are also summarized, taking into consideration the research studies conducted in the last 10 years. Finally, the challenges and future recommendations for the use of TNTAs are highlighted. This review aims to provide an insightful step forward to a better understanding of TNTAs-based nanomaterials and their use as proficient photocatalysts in the future.

1. Introduction

The rapid economic growth has led to a significant increase in the global energy requirements which will be doubled by 2050, leading to severe shortage in the fossil fuel resources [1]. Moreover, the excessive consumption of these fuels has resulted in several environmental problems including global warming, climate change, acid rains, losses of biodiversity and respiratory diseases [2–4]. Addressing these energy and environmental issues is highly and urgently needed. Therefore, different technologies were proposed by employing various forms of renewable energy such as wind, nuclear, biomass, hydel and solar energy [5,6]. Among these approaches, solar energy is considered as one of the most auspicious and alluring research areas in terms of its utilization in producing clean solar fuels and degrading toxic pollutants by means of a photochemical process known as photocatalysis.

The main components of any photocatalytic systems are the photocatalyst, photoreactor, light, reactants and the reducing agents. However, the photocatalyst material is considered as the most important element in the whole photocatalytic process. Therefore, researchers have been focusing more in testing the efficiency of various semiconductor materials as photocatalysts and numerous studies were reported for materials like titanium dioxide (TiO_2) [7–10], zeolites [11,12], zinc oxide (ZnO) [13,14], zinc sulfide (ZnS) [15,16], magnesium oxide (MgO) [17], graphitic carbon nitrides (g-C_3N_4) [18–20], metal–organic frameworks (MOFs) [21–23], perovskites [24–26], MXenes [27–29] and layered double hydroxides (LDH) [30–32]. Among all these materials, the TiO_2-based nanomaterials are the most intensively studied and widely used ones, owing to their availability, low cost, non-toxicity, high corrosion resistance, strong redox ability, good thermal and chemical stability [33–36]. However, TiO_2 exhibits low photocatalytic performance due to its high recombination rate of photogenerated charges in addition to its low absorption of visible light.

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