Controlled synthesis of titania using water-soluble titanium complexes: A review

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Abstract

The development of human society has led to the increase in energy and resources consumption as well as the arising problems of environmental damage and the toxicity to the human health. The development of novel synthesis method which tolerates utilization of toxic solvents and chemicals would fulfill the demand of the society for safer, softer, and environmental friendly technologies. For the past decades, a remarkable progress has been attained in the development of new water-soluble titanium complexes (WSTC) and their use for the synthesis of nanocrystalline titanium dioxide materials by aqueous solution-based approaches. The progress of synthesis of nanocrystalline titanium dioxide using such WSTCs is reviewed in this work. The key structural features responsible for the successfully controlled synthesis of TiO2 are discussed to provide guidelines for the morphology-controlled synthesis. Finally, this review ends with a summary and some perspectives on the challenges as well as new directions in this fascinating research.

1. Introduction

As the seventh most abundant metal in the Earth’s crust, titanium is widely used in the form of titanium metal, nitride, carbide and as a component of various important functional multicomponent oxides. Among them, titanium dioxide (TiO2), a semiconductor material has emerged for the past three decades as an exclusive metal oxide with an exceptionally wide range of unique physico-chemical properties and relevant potential for low cost and environmentally benign processes and energy technologies. TiO2 has been used to remove organic/inorganic pollutant in air and water for a few decades owing to its high photocatalytic activity under both UV and visible light illumination [1], they are continuously expected to play an important role to solve the challenges related to environmental pollution. TiO2 can also be effectively utilized to convert solar energy based on photovoltaic, photosynthesis and water-splitting devices [2], demonstrating that it is a promising material in transforming solar energy into chemical energy and other storage types. Due to the versatile applications of TiO2, study on the synthesis, modification, and applications of TiO2 structures is currently still attracted extraordinary research interest.

Among various chemical methods for the synthesis of titania, sol-gel process is a traditional method which has been extensively used for practical application [3–13]. Among these sol-gel methods, titanium alkoxide is commonly used as precursor. Due to their high reactivity, a complicative control over reaction condition is necessary to obtain specific crystalline structures and shapes. Thus, sol–gel method suffers from general drawbacks in control over the growth of the synthesized particles. Furthermore, some subsequent annealing needed in order to obtain a crystalline powder makes it difficult to retain the size and morphology of the nanoparticles. These drawbacks prevent sol-gel method from being practical application in large scale.

Compared to aqueous sol–gel chemistry, simpler approaches were recently developed where organic solvent or surfactant acts as a ligand used to control the growth of the nanoparticles. The method, so-called nonhydrolytic sol-gel processes, usually involves the reaction of titanium halide or titanium alkoxide with different oxygen donor molecules such as alcohol or organic acid [14–24]. This approach allows to use much higher precursor concentration with well-controlled particle size and shape. For example, Chen et al. use fluorine-assisted kinetic hydrolysis method in n-propanol to synthesize TiO2 with precise defect engineering with enhanced photocatalytic hydrogen generation [24]. However, a comparatively low reaction rate of non-