ARTICLE IN PRESS

Materials Science in Semiconductor Processing xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

Novel and simple method to synthesize donut-like TiO_2 with photocatalytic activity

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ARTICLE INFO

Keywords:
Titanium dioxide (TiO_2)
Polyvinyl pyrrolidone (PVP) polymer
Electrospray
Photocatalytic activity
Methylene blue (MB)

ABSTRACT

This paper presents a novel and simple method to fabricate donut-like TiO_2 with efficient photocatalytic activity. Donut-like TiO_2 was successfully prepared via electrospraying technique using a low molecular weight polyvinyl pyrrolidone (PVP) polymer. X-ray diffraction measurements show that donut-like TiO_2 maintains a pure anatase structure. A transmission electron microscopy image reveals hollow donut-like TiO_2. The effects of applied voltage parameter on energy gap, atomic force microscopy micrographs, field emission scanning electron microscopy pictures, and photoluminescence spectra are examined. The photocatalytic properties of donut-like TiO_2 were evaluated with photocatalytic degradation of methylene blue (MB) in water under UV light irradiation. Donut-like TiO_2 exhibits an efficient photocatalytic activity that reaches 67% after the degradation of MB in aqueous solution for 200 min.

1. Introduction

TiO_2 is considered as the most promising known material because of its superior photoreactivity, non-toxicity, long-term stability, and low cost. TiO_2 has attracted extended attention in the fields of environmental purification, solar energy cells, photocatalysts, gas sensors, photoelectrodes, and electronic devices. Among various oxides, the two phases of TiO_2 (i.e., anatase with band gap ~3.2 eV and rutile with band gap ~3.0 eV) have received the most attention because of their excellent electronic, chemical, and optical properties [1]. Recently, the photocatalytic degradation of organic compounds (e.g., detergents, dyes, and pesticides in water and in the atmosphere) has been extensively studied [2]. Photocatalytic activity is based on the form of a photogenerated electron-hole pair upon absorption of a UV photon. This activity includes holes oxidizing the adsorbed organic species and electrons reducing the hydroxyls adsorbed on the surface of·OH radicals, which act as an oxidizing agent toward organic species. Photocatalytic activity produces simple byproducts, such as CO_2 and H_2O. Thus, organic species deposited on the surface of photocatalysts can be decomposed upon UV irradiation [3]. Among various semiconductor photocatalysts, the anatase crystalline form of TiO_2 is mainly used in photocatalytic studies because of its unique attributes (e.g., high physical and chemical stability) [4]. Apart from possessing a crystalline form, TiO_2 possesses structural parameters (e.g., morphology, particle size, and specific surface area) that influence photocatalytic activity [5]. Compared with bulky crystal structures, TiO_2 nanostructures can improve their photocatalytic performance because of their large specific surface area [6].

Electrospraying is similar to electrospinning, but the former is used when the liquid viscosity is sufficiently low. The electrospraying technique has been considered as a low-cost and simple process to directly deposit thin films from their colloidal solutions. The electric charge draws the liquid from the capillary nozzle in the form of a fine jet, which eventually disperses into droplets [7]. The droplets produced by electrospraying are highly charged, usually close to half of the Rayleigh limit, and can be smaller than 1 mm. The size distribution of the droplets is commonly narrow and characterized by low standard deviation. Electrospraying can be used in producing small, nearly monodisperse particles when a colloidal suspension of solid nanoparticles or a solution of a material is sprayed [8]. In electrospraying, the size of the droplets can be controlled mainly by the liquid flow rate and the droplet charge by adjusting the voltage applied to the nozzle. The charged aerosol is self-dispersing, which prevents the droplets from coagulation [9].

The solution delivered to the tip of the electrospray capillary experiences the electric field associated with the maintenance of the tip at high potential. Based on the assumption of positive potential, positive ions in a solution will accumulate on the surface, which is drawn out in

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http://dx.doi.org/10.1016/j.mssp.2017.05.034
Received 10 February 2017; Accepted 12 May 2017

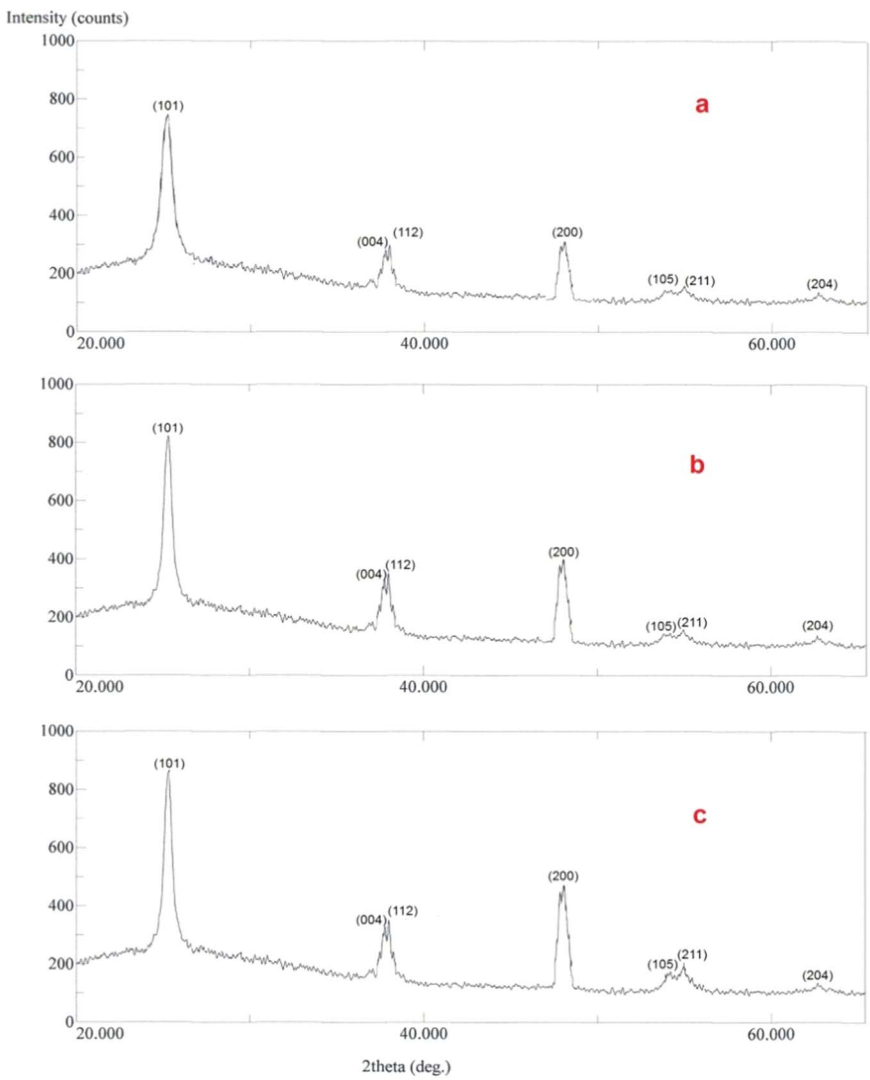

Fig. 1. XRD spectra of donuts likeTiO_2 prepared in different applied voltages. (a) 12 kV (b) 15 kV (c) 18 kV.

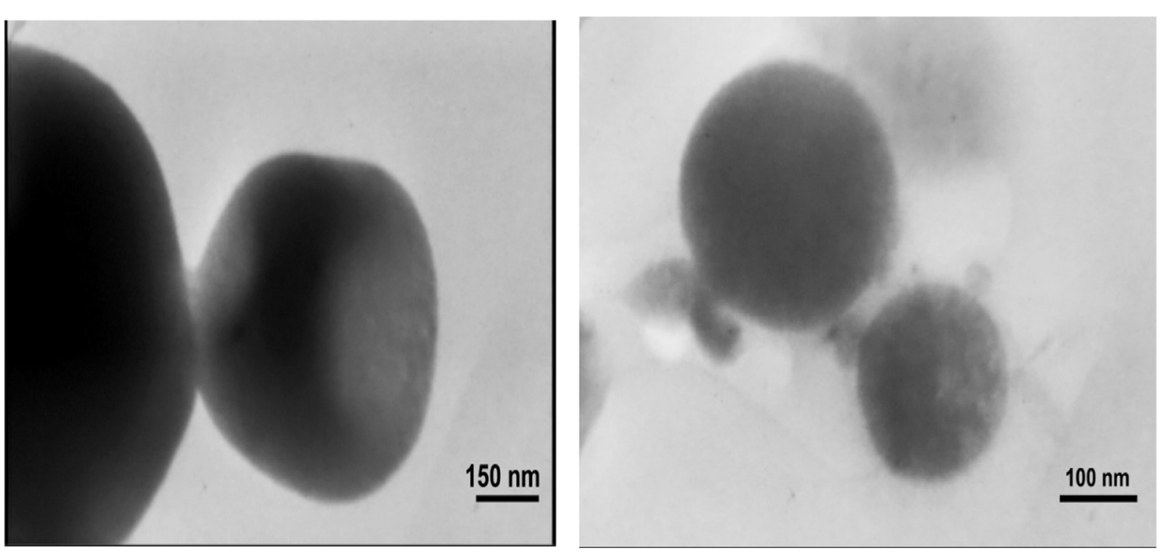

Fig. 2. TEM images of hollow donuts likeTiO_2.

field direction to establish a “Taylor cone.” At a sufficiently high imposed field, the cone is drawn to a filament, thereby producing positively charged droplets via a “budding” process when the surface tension is exceeded by the applied electrostatic force [10]. Initially formed droplets traverse a pressure gradient toward the analyzer of the mass spectrometer. The evaporation of solvent from these droplets leads to a reduction in diameter. Coalitional warming prevents freezing. Fission (i.e., Coulomb explosion) occurs at the point in which the magnitude of