Applied Surface Science 255 (2009) 5363–5367

Contents lists available at ScienceDirect

Applied Surface Science

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

Preparation of ZnO nanopowders by thermal plasma and characterization of photo-catalytic property

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ARTICLE INFO

Article history:
Available online 19 October 2008

PACS:
52.77.−j
55.77.Fv

Keywords:
Thermal plasma
Zinc oxide
Nanopowder
Photo-catalyst

ABSTRACT

Nano-sized zinc oxide (ZnO) powders were prepared via a thermal plasma process from micro-sized zinc powder while oxygen was employed as a reaction gas. Two different carrier gases, oxygen and argon, were evaluated and the flow rate of the reaction gas was controlled. The photo-catalytic activities of ZnO powders were evaluated by measuring the degradation of methylene blue (MB) in water under the UV and visible region. The prevailing goal of this study is to improve the photo-catalytic activity of nano-sized ZnO powders for the removal of environmental pollutants. The ZnO nanopowders were characterized by XRD, SEM, BET, and UV–vis spectrometry. Their mean crystallites sizes ranged from 26.5 nm to 48.6 nm. It was confirmed by a XRD analysis that the ZnO nanopowders had a high quality wurtzite structure. SEM and XRD results show that the size of the particles synthesized increased with an increase of the flow rate of the oxygen reaction gas. The powder obtained using the argon carrier gas with higher oxygen reaction gas flow rate was more rod-shape. The MB decomposition rates of the obtained ZnO nanopowders were studied under the UV and visible region. In the UV region, synthesized ZnO could decompose MB as well as commercial ZnO. However, in the visible region, the MB decomposition rate obtained using ZnO was much higher than that by commercial ZnO.

1. Introduction

The most effective functional materials for photo-catalytic applications are nano-sized semiconductor oxides. Titanium dioxide (TiO_2) and zinc oxide (ZnO) have been extensively investigated as heterogeneous semiconductor photo-catalysts, since they offer several advantages such as the use of oxygen as the only required oxidant and their capability to simultaneously carry out oxidative and reductive reactions. They also offer low cost, mild reaction conditions, high photochemical reactivity, and low environmental toxicity, while affording the use of sunlight [1–5]. TiO_2 nanoparticles are considered representative photo-catalysts [6]. In terms of band energy, ZnO is a suitable alternative to TiO_2 [7]. ZnO is an n-type II–VI compound semiconductor with a wide band gap of 3.37 eV and a large exciton binding energy of 60 meV [8,9]. ZnO is also known as a good photo-catalyst for the degradation of several environmental contaminants due to its high photosensitivity, stability, and large band gap. In addition, ZnO is an environmentally friendly material that does not form toxic byproducts [10,11]. A versatile semiconductor material, ZnO has been applied in photo-catalysts [12], varistors [13], UV photodiodes [14], piezoelectric transducers [15], transparent conducting films [16], and gas sensors [17].

In this research, nano-sized zinc oxide powders were prepared by a thermal plasma process using micro-sized zinc powder as a raw material and oxygen as a reaction gas. The DC thermal plasma offers unique advantages for the synthesis of ceramic powders due to easily achievable high temperatures and energy densities. Furthermore, a steep temperature gradient exists between the hot plasma flame and the surrounding gas phase. Raw material is easily evaporated in the plasma region, followed by rapid condensation. Thermal plasma processing using a plasma jet of high speed and high heat capacity is one of the most promising methods for synthesizing new materials [18]. Using this process, ZnO nanopowder was prepared easily and quickly in this study. In addition, the photo-catalytic decomposition of methylene blue (MB) was studied with synthesized ZnO and the results were compared with commercial ZnO (Dejung, 15 μm).

2. Experimental

2.1. Preparation of ZnO nanopowders

Nano-sized zinc oxide powders were prepared by thermal plasma processing. Fig. 1 shows a schematic diagram of the DC

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0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2008.10.028

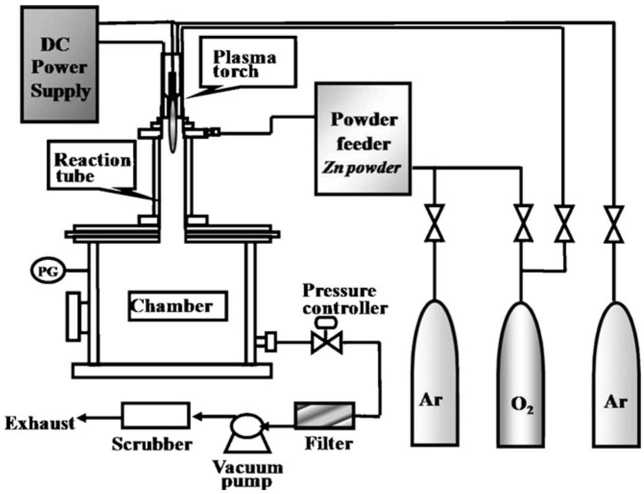

Fig. 1. Schematic diagram of the DC plasma apparatus for the production of ZnO nanopowders.

plasma apparatus, which consists of a DC generator, a plasma torch, a reaction tube, a chamber, a powder feeder, an injection block, and a vacuum system. Argon (Ar) gas was employed as the plasma gas. The effect of the oxygen reaction gas flow rate and the effect of the carrier gas (O_2 versus Ar) on the product properties were investigated. When oxygen was introduced as a reaction gas into the reaction tube with a flow rate in a range of 2–5 l/min, an oxidation reaction took place in the flame of the plasma. Zn powder was injected into the plasma region through the powder feeder. The powder was readily evaporated and oxidized by the high temperature of the plasma flame, followed by rapid condensation in the reaction tube. The prepared powder was collected at the lower part of the reaction tube wall. The experimental conditions for the preparation of the powder are summarized in Table 1.

2.2. Characterization of ZnO nanopowders

The phase composition of the prepared powder was analyzed using an X-Ray Diffractometer (XRD, DMAX 2500, Rigaku Co.). The particle shape and average size of the powders were obtained by Field Emission-Scanning Electron Microscopy (FE-SEM, S-4300, Hitachi Co.). The specific surface area of the powders was measured by nitrogen adsorption at −195.8 °C using the BET equation (Physisorption Analyzer, ASAP 2020, Micromeritics). Optical properties of the powders and the residual concentration of methylene blue were investigated using UV–vis spectroscopy (UV–vis Spectroscopy, Lambda 25, Perkin Elmer) in a spectral range of 200–800 nm.

Table 1
Experimental conditions for the preparation of ZnO nanopowders.

Sample no.						
	1	2	3	4	5	6
Plasma power (kW)	6.5	6.5	6.5	6.5	6.5	6.5
Pressure (Torr)	750	750	750	750	750	750
Flow rate of plasma gas (Ar, l/min)	15	15	15	15	15	15
Flow rate of carrier gas (O_2, l/min)	1.5	1.5	1.5	–	–	–
Flow rate of carrier gas (Ar, l/min)	–	–	–	1.5	1.5	1.5
Flow rate of reaction gas (O_2, l/min)	0.5	1.5	3.5	2	3	5
Feeding rate of raw material (g/min)	0.3	0.3	0.3	0.3	0.3	0.3

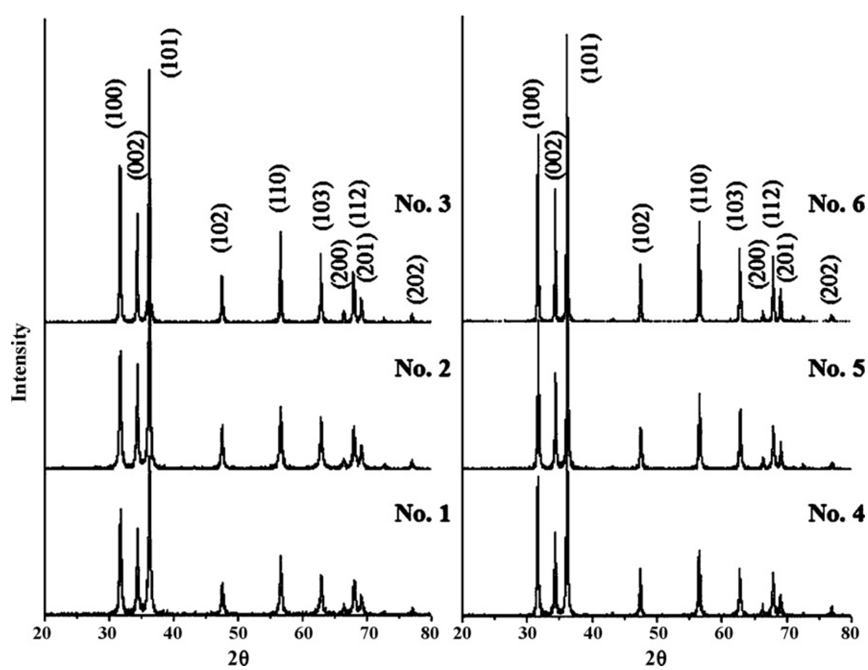

Fig. 2. XRD patterns of ZnO nanopowder with different experimental conditions.