Materials Letters 75 (2012) 57–60

Contents lists available at SciVerse ScienceDirect

Materials Letters

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

Synthesis and visible light photocatalytic activity of transition metal oxide (V_2O_5) loading on TiO_2 via a chemical vapor condensation method

Sungmin Chin, Eunseuk Park, Minsu Kim, Gwi-Nam Bae, Jongsoo Jurng *

Environment Division, Korea Institute of Science and Technology (KIST), 39-1, Hawolgok, Seongbuk, Seoul 136-791, Republic of Korea

ARTICLE INFO

Article history:
Received 21 November 2011
Accepted 1 February 2012
Available online 9 February 2012

Keywords:
Chemical vapor condensation
Transition metal oxides
Vanadium
Methylene blue
Photocatalyst

ABSTRACT

TiO_2 nanoparticles that were synthesized using a chemical vapor condensation (CVC) method were loaded on transition metal oxides (V_2O_5) using the impregnation method followed by thermal treatment. The primary particle size of the CVC-made TiO_2 sample after vanadium was decreased drastically to 5.7 nm. The particle sizes before and after vanadium loading on the commercial TiO_2 (Degussa, P25) were similar. The vanadium-loaded CVC-made TiO_2 sample exhibited the best absorption performance of visible light from the absorption spectra. Moreover, the CVC method through transition metal impregnation was favorable for its enhanced photocatalytic properties.

1. Introduction

TiO_2 is one of the most attractive photocatalysts for environmental problems. Nevertheless, its practical application as a photocatalyst has been limited because of its wide band gap (3.2 eV), which requires ultraviolet (UV) light with a wavelength <385 nm, and it is difficult to apply a TiO_2 photocatalyst to control environmental pollutants. Therefore, many studies have reported enhanced photocatalytic activities according to the synthesis methods [1–6]. Among the synthesis methods, chemical vapor condensation (CVC) is an alternative method for the direct synthesis of TiO_2 nanoparticles. In particular, the CVC method allows for individual adjustment of synthesis conditions such as synthesis temperature, precursor vapor residence time in the heating zone, and precursor vapor concentration. Therefore, the resulting TiO_2 nanoparticles have small particle sizes and improved crystallinity, resulting in good photocatalytic activity [1,3].

The other approach to augmenting the TiO_2 photocatalytic performance involves doping and/or loading with materials such as N, C, Fe, Pt, Pb, Sn, V, and Mo [7–18]. The photocatalytic activity of the TiO_2 system depends on its intrinsic properties, such as crystal phase, crystallinity, and specific surface area. Furthermore, the catalytic activity of TiO_2 depends strongly on electron–hole separation. The key to the photocatalytic process is to inhibit the electron–hole recombination rate [12]. Doping and/or loading with transition metals is a promising approach to reducing the TiO_2 absorption threshold and extending its optical absorption range from the UV light region to the visible light region [14–18].

In this study, TiO_2 nanoparticles that were synthesized using the CVC method were further loaded with vanadium oxide using the impregnation method followed by thermal treatment. The resulting composite photocatalysts were systematically examined using a range of techniques. Based on the characterization results, the effect of the vanadium oxide loading on the photocatalytic properties of CVC-made TiO_2 was examined.

2. Material and methods

2.1. Catalyst synthesis

The CVC method was used to synthesize the TiO_2 particles. Detailed methods for the preparation of TiO_2 nanoparticles are described elsewhere [1]. Titanium tetraisopropoxide ($[(CH_3)_2CHO]_4Ti$, TTIP, Aldrich, >97%) was used as the TiO_2 precursor. The synthesis conditions for the TiO_2 nanoparticles included a precursor heating temperature and synthesis temperature of 95 °C and 900 °C, respectively. The V_2O_5 was prepared by impregnating the TiO_2 nanoparticles with an aqueous solution containing the appropriate amount of ammonium metavanadate (NH_4VO_3) followed by stirring for 1 h and heating at 150 °C for water evaporation. Finally, the prepared samples were dried overnight at 110 °C and calcined at 500 °C for 2 h in static air. The vanadium loading was kept at 5.0 wt.%. For comparison, commercial TiO_2 (Degussa, P25) was loaded with V_2O_5.

2.2. Catalyst characterization

The crystal phases of the prepared samples were examined using X-ray diffraction (XRD, Rigaku D/Max 2500) with Cu Kα radiation.

* Corresponding author. Tel: +82 2 958 5597; fax: +82 2 958 6711.
E-mail address: jongsoo@kist.re.kr (J. Jurng).

0167-577X/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.matlet.2012.02.001

Transmission electron microscopy (TEM) analysis was conducted using a CM-30 microscope (Philips; 300 kV; image resolution, <0.23 nm). The powder-specific surface area (SSA, $m^2\ g^{-1}$) was determined by nitrogen adsorption (>99.999%) at77 K on a Micromeritics Tristar 3000 apparatus using the Brunauer–Emmett–Teller (BET) method. Assuming monodispersity and spherical primary particles, the BET-equivalent particle diameter (d_{BET}) was calculated using the formula $d_{BET} = 6/(\rho \times SSA)$, where ρ is the particle density. X-ray photoelectron spectroscopy (XPS) was performed using a VG Scientific ESCA Lab II Spectrometer (resolution,0.1 eV) with Mg Kα (1253.6 eV) radiation as the excitation source. All binding energies were referenced to the C 1-s peak at 285.0 eV for adventitious carbon. The UV–visible light (UV–vis) diffuse reflection spectra were obtained for the dry-pressed disk samples using a Scan UV–vis spectrophotometer (UV–vis DRS: TU-1901).

2.3. Photoactivity measurement

The photocatalytic activity of TiO_2 was characterized by measuring the methylene blue (MB) degradation rate. MB was selected because of its strong adsorption to metal oxide surfaces, well-defined optical absorption, and good resistance to light degradation. The photocatalytic experiments were carried out at an initial pH of 7.0. The catalyst (80 mg) was mixed with 500 cm^3 of a MB solution (~153 ppm) in a 500 cm^3 beaker. The mixture was kept in the dark for 30 min to establish adsorption–desorption equilibrium before light irradiation was performed. The visible light illumination was carried out using a fluorescent lamp (FL15D-T25) with the wavelength range of 400–700 nm and a maximum intensity of 550 nm, producing a power of 10 W. The slurry was stirred constantly to avoid settling. The MB remaining in the solution was measured at absorbance of 600 nm using a spectrophotometer (Hach, DR-2800).

Table 1
Physicochemical properties of the prepared samples.

Sample	S_{BET} ($m^2\ g^{-1}$)	d_{BET}[a] (nm)	Edge wavelength (nm)	Band gab energy(eV)	r_i (%)[b]	
					Ti–O	OH
P25-TiO_2	52.2	26.9	420	2.95	85.5	14.5
V_2O_5/P25-TiO_2	53.1	29.1	450	2.76	84.0	16.0
CVC-TiO_2	107.47	10.2	400	3.10	73.8	26.2
V_2O_5/CVC-TiO_2	270.5	5.7	600	2.07	61.6	38.4

[a] Particle size by equation using by BET surface area.
[b] Area percentage (r_i) in the results of XPS spectra curve fitting in the O1s region for each sample.

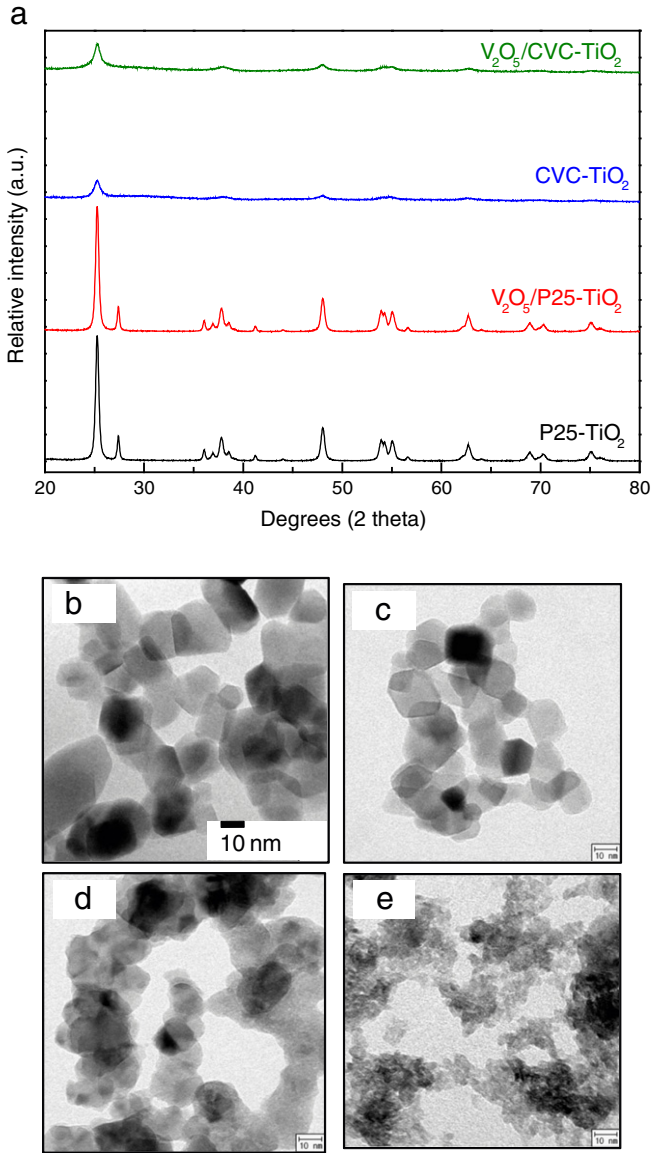

Fig. 1. (a) X-ray diffraction patterns ("A" and "R" indicate anatase and rutile, respectively) and transmission electron microscopy images of (b) P25-TiO_2, (c) V_2O_5/P25-TiO_2, (d) CVC-TiO_2, and (e) V_2O_5/CVC-TiO_2.

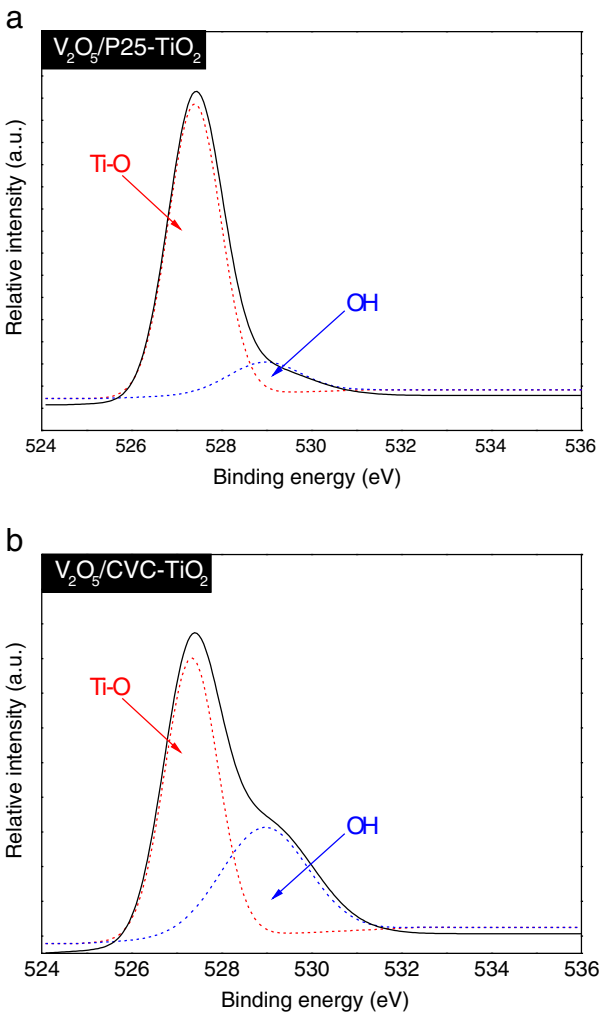

Fig. 2. X-ray photoelectron spectra of the O1s region for (a) V_2O_5/P25-$TiO_2$and (b) V_2O_5/CVC-TiO_2.