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Synthesis of novel silver vanadates with high photocatalytic and antibacterial activities

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ABSTRACT

Nano-structured silver vanadates were successfully synthesized by hydrothermal treatment assisted by ultrasound and micro-wave techniques. The obtained silver vanadates were characterized by XRD, XPS, UV–vis and TEM. It showed that the silver vanadates have a nano-structure with the shape of nano-rods (diameter of 50–200 nm and length of 0.5–2.0 μm). Interestingly, silver vanadates showed a strong light absorbance in the visible light region at 470–500 nm. In comparison to TiO_2 nanoparticles, silver vanadates exhibited much higher photocatalytic activity in the degradation of Methylene Blue under visible light irradiation. Moreover, these silver vanadates also exhibited high antibacterial activity, opening their high potential applications in environmental treatment.

1. Introduction

To resolve environmental pollution, semiconductor photocatalysts have been received considerable interest in term of their high photodegradation of organic pollutants. Nano-TiO_2 is one of the most extensively investigated heterogeneous photocatalysts due to its high photocatalytic activity. However, nano-TiO_2 is active under UV irradiation [1–6]. To take sufficient advantage of solar energy and indoor illumination predominately concentrating in the visible region, many researchers have committed themselves to expanding light absorption of TiO_2 from the UV region into the visible region and suppressing recombination rate of photogenerated electronhole pairs for the practical application of photocatalysts. Awazu et al. [7] have successfully extended the visible light absorbance by preparing TiO_2–Ag/SiO_2, in which Ag nanoparticles (Ag NPs) were covered with SiO_2 layer and then embedded in TiO_2. Zhang and Zen have reported Ag–ZnO nanocomposite photocatalyst, which exhibited superior photocatalytic performance toward Methyl Orange photodegradation [8]. They pointed out that Ag NPs not only extended the light absorption spectrum but also prevented the recombination of electron-hole pairs and modified the surface properties. Kudo et al. have reported that $BiVO_4$ and $AgNbO_3$ could produce O_2 from silver nitrate solution under visible light irradiation. The results showed that the visible light responses of the $BiVO_4$ and $AgNbO_3$ photocatalysts were attributable to a decrease in band gaps by the valence band formation by not only O 2p but also Bi 6s and Ag 4d orbitals [9,10]. Silver vanadates attract special attention because they have potential applications in rechargeable high-energy density lithium ion batteries and photocatalysts due to their excellent electrochemical and photophysical properties [11]. Great efforts have been made on the synthesis, characterization, structural analyses, and electrochemical reactivity of β-$AgVO_3$ [12]. Wang et al. [13] succeeded to synthesize the Ag@Ag_3VO_4, highly efficient and stable visible light active photocatalyst in the photodegradation of rhodamine B. Moreover, β-$AgVO_3$ also exhibited high antibacterial activity [14,15].

In our previous paper [16] we have showed that Ag_3PO_4 exhibited high photocatalytic degradation of Methylene Blue (MB). In this paper, we report the photocatalytic and antibacterial activities of silver vanadates synthesized by hydrothermal treatment with ultrasound and microwave assistance.

2. Experimental section

Silver vanadate synthesis. In a typical synthesis procedure, certain amount of $AgNO_3$ was dissolved in distilled water and then poured dropwise into a vessel containing NH_4VO_3 solution. The obtained mixture was vigorously stirred for 30 min and then ultrasonically treated for 30 min. The mixture pH was adjusted by NH_4OH addition and then introduced into a teflon lined autoclave

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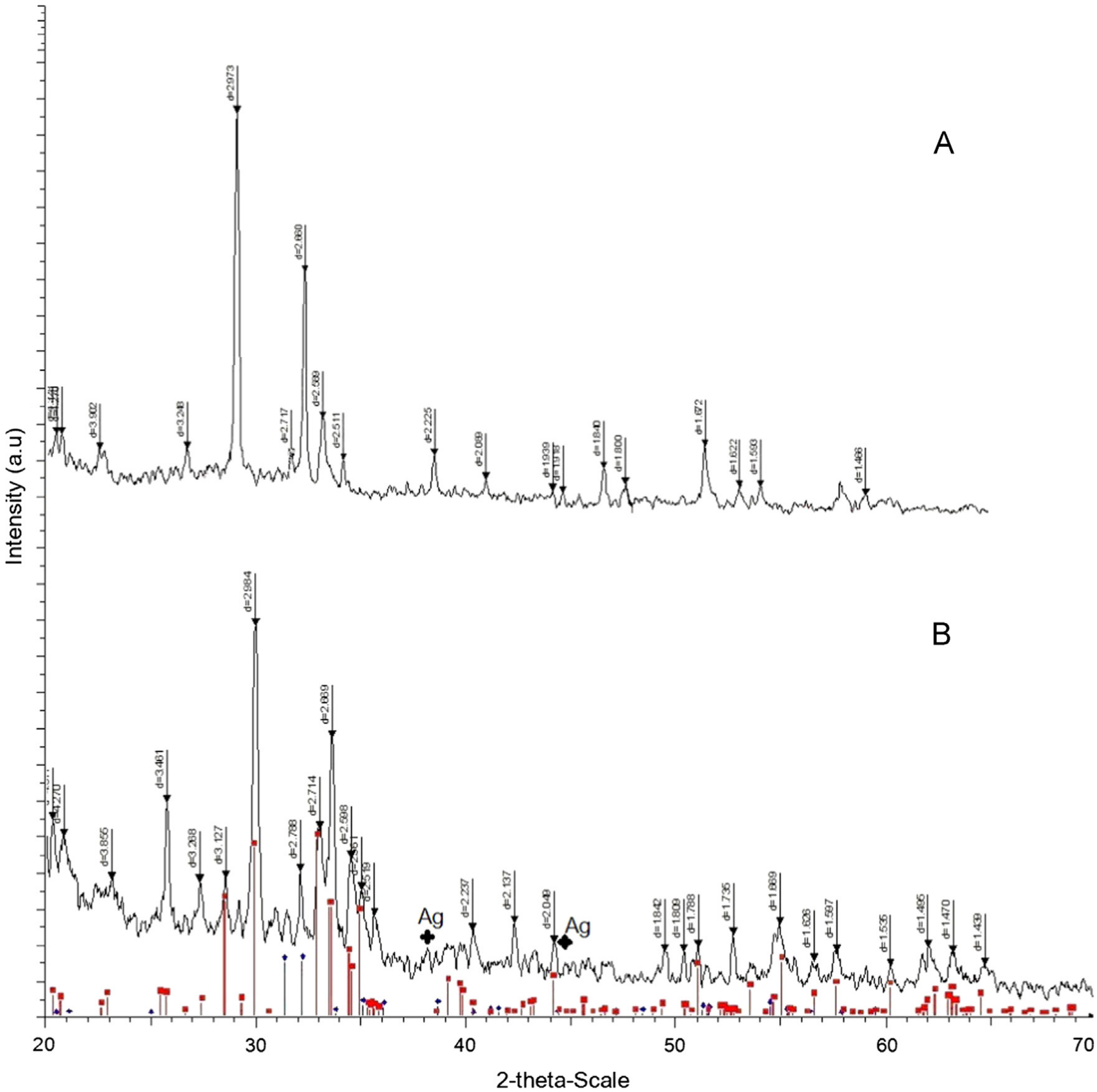

Fig. 1. XRD patterns of silver vanadate samples S1 (A) and S2 (B).

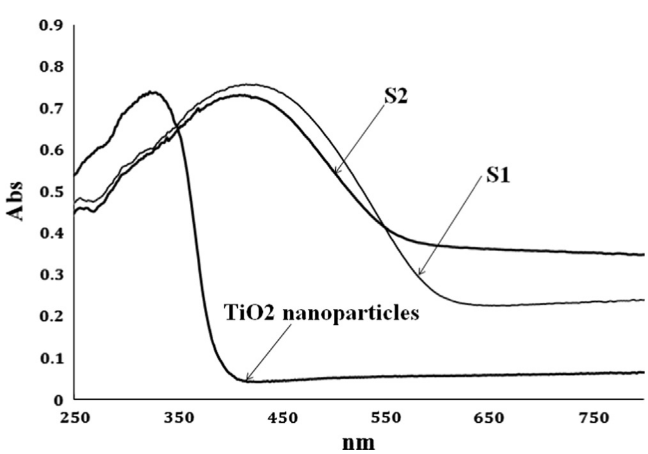

Fig. 2. UV–vis diffuse reflectance spectra of TiO_2 nanoparticles and silver vanadate samples.

and hydrothermally treated by using microwave at 120 °C for 30 min. Obtained products were washed for several times and dried at 80 °C overnight. Silver vanadate synthesized at pH of 6 and 7 was denoted as S1 and S2, respectively.

Characterization. The powder X-ray diffraction (XRD) patterns of the samples were recorded on a Shimadzu XRD-6100 analyzer with Cu Kα radiation ($l=1.5417^{\circ}$). The diffuse reflectance UV–vis spectra of the catalysts were measured using a Shimadzu UV-2200A spectrophotometer 250 to 650 nm using a Shimadzu UV–vis spectrophotometer at 295 K. Transmission electron microscopy (TEM) using JEOL 1010 instrument operating at 80 kV with magnification of 25,000–100,000, The X-ray photoelectron spectroscopy (XPS) measurement was performed on the ESCALab MKII spectrometer using MgKα radiation.

Photocatalytic activity testing. A mixture of MB aqueous solution (15 ppm, 100 ml) and the given photocatalyst (30 mg) was magnetically stirred in the absence of light for 90 min to ensure adsorption–desorption equilibrium between the photocatalyst and MB. The mixture was then stirred under visible light irradiation using a 40 W compact fluorescent lamp. At given time intervals, 10 ml of the suspension was collected and centrifuged to remove photocatalyst particles and analysized by UV–vis.

Anti-bacteria's activity testing. Five bacterial strains and one fungal strain used in our assay are *Staphylococcus aureus* (ATCC 13709), *Escherichia coli* (ATCC 25922), *Pseudomonas aeruginosa* (ATCC 15442), *Lactobacillus fermentum* (Lp B14) and *Candida albicans* (ATCC 10231). We used Tryptic Soy Broth (TSB), Tryptic