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Original Research Paper

Sol-gel synthesis, structural and enhanced photocatalytic performance of Al doped ZnO nanoparticles

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ABSTRACT

In this research ZnO and Zn_{1-x} Al_xO ($x = 1, 3, 5, 7\%$ mol) nanoparticles were synthesized by sol-gel method. The effect of Al concentration on the structure, morphology, absorption spectra and photocatalytic properties investigated by using X-ray, TEM, EDS and UV–Vis spectrophotometer approaches. Hexagonal, spherical and rod-like structure was achieved as the dominant structure for undoped nanoparticles, low and high concentrations of doped Al, respectively. Photocatalytic activity of nanoparticles was measured by degradation of methyl orange as a pollutant under radiation of ultraviolet (UV). The experimental test results indicate that the best photocatalytic performance is at of 5% of Al. Furthermore, the doped ZnO nanoparticles have more activity in visible area compared with undoped nanoparticles. The absorption amount in this area increases by raising the Al concentrations. Furthermore, the band gap of the particles decreases from 3.22 eV to 2.93 eV by increasing Al percentage.

1. Introduction

Nano Dimensions provide the best conditions for catalyst science. High activity level and fine selectivity in the nanocatalysts increase the rate and yield of reaction [1,2]. Photo degradation of organic and poisonous materials increases remarkably by using metal oxide nanoparticles with semi-conductive property [3]. Zinc oxide has been studied widely as a Photocatalysis due to chemical stability, suitable price, lack of toxicity and consistency in environment [4]. Photocatalytic degradation of organic and poisonous materials is a desirable process for asepsis of air and water [5]. Photocatalysts activate by radiation of light, based on provoking and moving electrons and holes on the surface of Photocatalyst. The holes oxidized the organic materials and electrons regenerated these materials to H_2O and CO_2 [6,7]. Zinc oxide activates only in ultraviolet light domain due to grate band gap while this part of the light is only 4% of the sunlight that stoked to earth [8]. Wide bandwidth, couple velocity of electrons and holes are the limitation for photocatalytic usage of ZnO [9]. To improve the properties of ZnO, several methods have been employed such as optimization of particles size [10], increment of surface relative to particles volume [11], dope with metals and nonmetals [12] and couple the ZnO with other semi-conductive particles [13]. The presence of amended ingredient in the ZnO crystals significantly decreases the velocity couple of load carriers and relocation of bandwidth into visible area [14]. Photoactivity of doped ZnO nanoparticles with metals significantly depends on preparation method, doped ion nature and, its concentration. Recently, dope of metals such as Cu [15], Fe [16], Se [17], Ce [18] and Mn [19] widely considered. Aluminum is a suitable impurity for the improvement of photocatalytic activity, which is superabundant, inexpensive and has exclusive physical properties [20].

Recently, Lee et al. [21] have reported kinetic degradation of methyl orange by means of doped ZnO nanoparticles with Aluminum. In their study particles, synthesis by precipitation method and maximum photocatalytic activity occurs at Al concentration of 3%. Also, Ahmad et al. [22] synthesized doped nanoparticles with Al by combustion method and investigated photocatalytic degradation of methyl orange under radiation of visible light at different concentrations. Their results showed that Al concentration of 4% is optimum concentration to improvement photocatalytic activity. This fact attributed to trap of electrons and holes by Al and its releases on the surface of catalyst. There are different methods for synthesis of nanoparticles such as chemical bath deposition [23], hydrothermal [24], combustion [25] and sol-gel [26].

In the present study, Al doped ZnO nanoparticles were synthesized by sol-gel method. Accurate control of material structure to its final shape and homogeneity of solution are the exclusive properties of synthesized nanoparticles by sol-gel method. On the other

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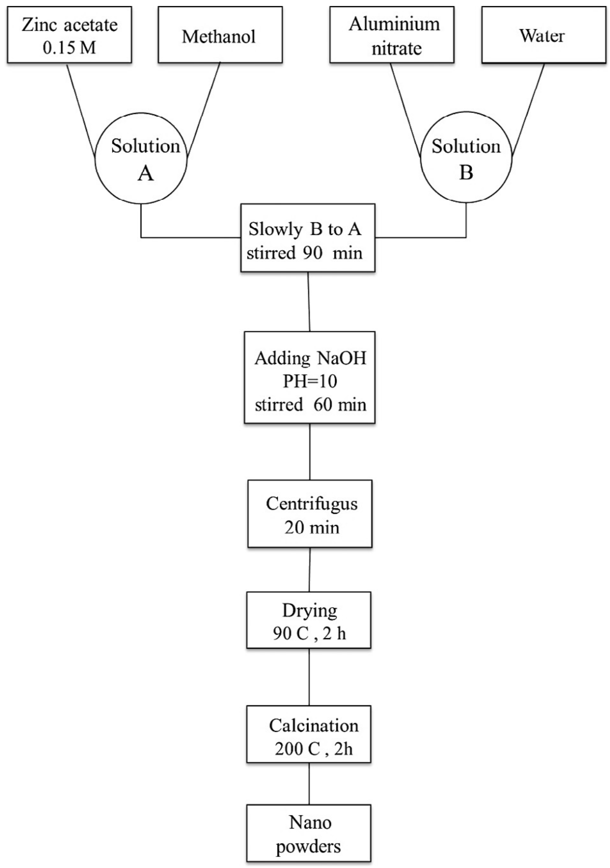

Fig. 1. Scheme of Al-doped ZnO nanoparticles by sol-gel method.

hand, the synthesis method was developed in such way that the pivotal parameters such as size, morphology, and the amount of effectivity of nanoparticles on photocatalytic properties, are easily controllable. This method in comparison with other synthesis methods is economical and applicable in large scales for industrial usage [27]. Moreover the effect of Al concentration on structure, morphology and absorption spectrum was studied. Photocatalytic activity of nanoparticles was investigated by degradation of methyl orange chromatic material under radiation of ultraviolet lamp. Significant increment in photocatalytic activity of doped particles was observed and compared to undoped nanoparticles.

2. Experimental

2.1. Materials

Zinc acetate (Zn $(CH_3COO)_2{\cdot}2H_2O$) and Aluminum nitrate (Al $(NO_3)_3$) were used as the source of Zinc and Aluminum. Moreover, Methanol (CH_3OH) and deionized water (H_2O) used as the solvents of synthesis. Sodium hydroxide (NaOH) and ethanol (C_2H_6O) were used as the motive in the gel formation and to wash the particles, respectively. Chromatic material of methyl orange as pollutant was chose to investigation of photocatalytic activity. All materials were purchased from Merck chemical company.

2.2. Synthesis of nanoparticles

ZnO nanoparticles at Al concentrations of 1, 3, 5 and 7% are prepared by sol-gel method. Zinc oxide sol is prepared by adding 0.15 M zinc acetate into methanol (solution A). Al^{3+} ion was prepared with addition and solving of 0.15 M Aluminum nitrate in the water (solution B). Then, solution B was gradually added to solution A and to get a diaphanous and homogeneous solution the mixture was stirred for 90 min by magnetic stirrer. Diaphanous sol changed to white color by adding of 1.5 M sodium hydroxide and pH of solution were obtained to 10. Milky white solution was stirred again for 60 min. In the next step the sol was centrifuged for 20 min at 10,000 rpm. To completely remove organic materials on surface, white color sediment washed two times with ethanol and water mixture with mass fraction ratio 60–40. Produced sediment was dried and calcined for 2 h at 60 °C and

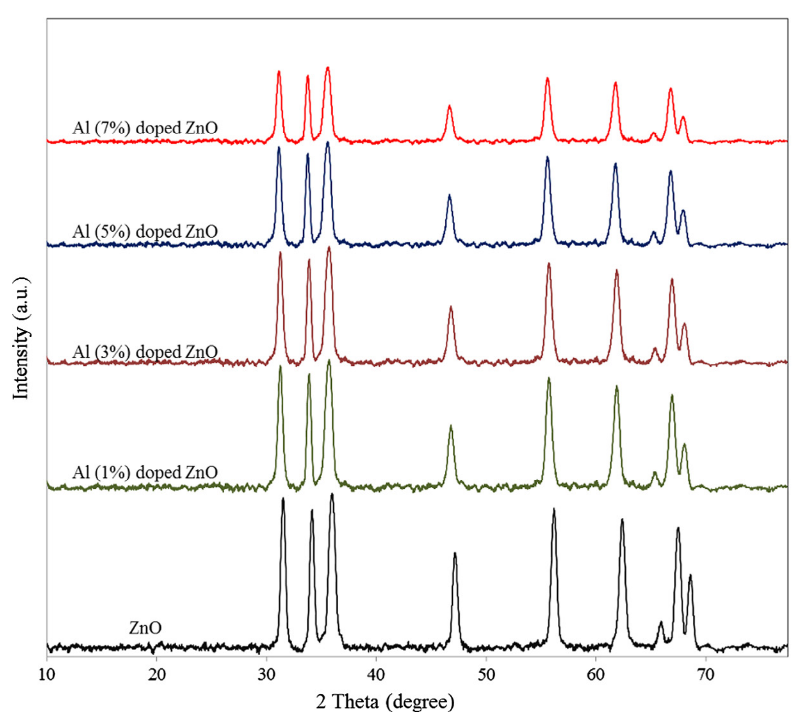

Fig. 2. XRD patterns of the pure ZnO and the Al-doped ZnO nanoparticles.