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Investigation of the effect of annealing on the photoluminescence properties of ZnO nanoparticles, synthesized at low temperature

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ABSTRACT

ZnO nanoparticles were synthesized by a simple chemical precipitation method at 0 °C and annealed in air at temperatures of 200, 400 and 600 °C. Effect of annealing temperature on the optical properties were characterized by the UV–Vis and photoluminescence (PL) spectroscopy. The PL spectra of as prepared ZnO nanoparticles exhibits a narrow UV and a broad yellow emission peaks which are related to defect levels in the band gap. With the annealing temperature increasing, the intensity of yellow emission is strongly decreased, whereas the green emission is revealed. In addition, it was found that, there is a slight red shift in the UV absorption peak and a blue shift in the visible emission peak when the annealing temperature increases.

1. Introduction

Zinc oxide is a wide band gap (E_g = 3.4 eV) semiconductor that is an attractive material for many advanced devices because of its large binding energy, optical transparency, hardness and piezoelectric [1,2], cathodoluminescence (CL) and photoluminescence (PL) [3,4] properties.

Most ZnO nanoparticles prepared at room temperature exhibit two emission peaks in the UV and visible regions [3–6].

Some researchers investigated the origin of the visible emission of cathode-luminescence and photoluminescence spectra in ZnO nanoparticles [3–7]. A number of these researchers proposed a correlation between visible emission and various point defects [8–10]. Lin et al. [11] estimated the defect level related to the green emission using the muffin-Tin potential. They suggested that the yellow, green and orange luminescence bands are mainly related to Zn vacancies, oxygen antisite and interstitial oxygen, respectively. On the other hand, several research groups have studied the influence of the annealing temperature on the photoluminescence properties of ZnO nanoparticles [12–14]. Zhang et al. [15] proposed that at an annealing temperature range of 300–600 °C, the green luminescence band becomes the strongest one. However, understanding the origin of the visible emission band in ZnO nanostructures is still a key topic in improving the emission efficiency of optical materials.

In this work effects of annealing temperature on the PL emission and the band gap energy of ZnO nanoparticles, synthesized at 0 °C, are investigated. For this mean, some instrumental methods such as X-ray diffraction (XRD), UV–Vis and photoluminescence (PL) spectroscopy were performed to characterize the unannealed and annealed ZnO nanoparticles.

2. Experimental

The synthesis of ZnO nanoparticles was performed by three following steps: First, 1.76 g of $Zn(Ac)_2$, $2H_2O$ was added into a breaker with 160 ml ethanol under magnetic stirring at 70 °C. Then a solution of 0.8 g NaOH in 160 ml ethanol was added drop wise into the above solution at 0 °C under rigorous magnetic stirring for 1 h. In the third step, 0.5 ml oleic acid was added into the solution as capping material to avoid agglomeration of the nanoparticles.

The precipitate was collected by centrifugation of the solution and finally, the white precipitate was washed with acetone and deionized water sequentially. Then, wet precipitate was dried in vacuum at room temperature to obtain the white powder. Three samples were annealed for 1.5 h in the programmable furnace at 200, 400 and 600 °C.

3. Results and discussion

Fig. 1 shows the XRD pattern of as prepared and annealed at different temperatures of ZnO powder. All the XRD peaks are indexed to the hexagonal wurtzite phase of ZnO having most preferred

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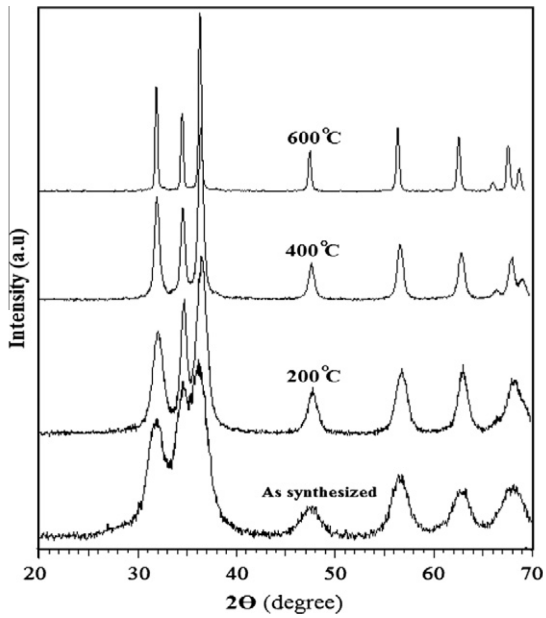

Fig. 1. XRD pattern of ZnO nanopowder annealed at different temperatures.

Table 1
Size and confinement energy (ΔE_g) of the ZnO nanoparticles annealed at different temperatures.

Annealing temperature	As synthesized	200 °C	400 °C	600 °C
Size (nm)	8.5	16.7	27.3	52.2
ΔE_g (eV)	0.030	0.007	0.003	0.001

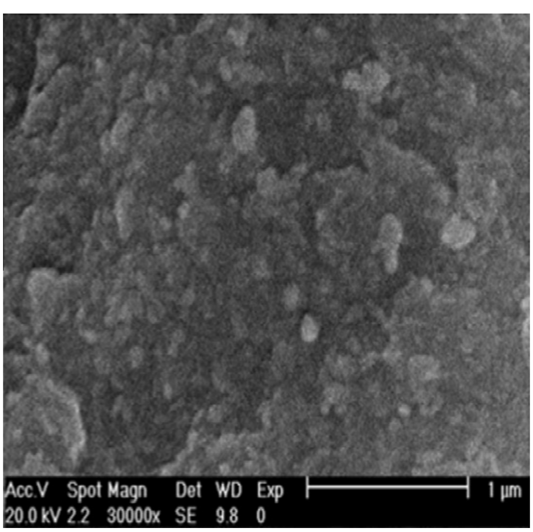

Fig. 2. SEM image of annealed ZnO nanopowder.

orientation along (1 0 1) plane. The peaks broadening in the XRD pattern clearly indicate the existence of the nanoparticles in the sample.

The approximated crystallite size of the ZnO nanoparticles can be calculated by using the Debye Scherrer formula, $D = 0.9\,\lambda/\beta\cos\theta$, where λ is the wavelength, β is the full width at the half – maximum (FWHM) and θ is the diffraction angle. The results, based on the (1 0 1) plane, are given in Table 1. These data indicate that the size of ZnO nanoparticle increases with increasing annealing temperature from room temperature to 600 °C.

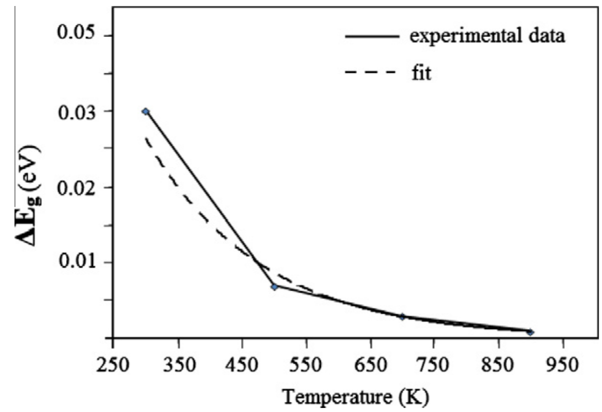

Fig. 3. Dependence of the change in the band gap energy on the annealing temperature.

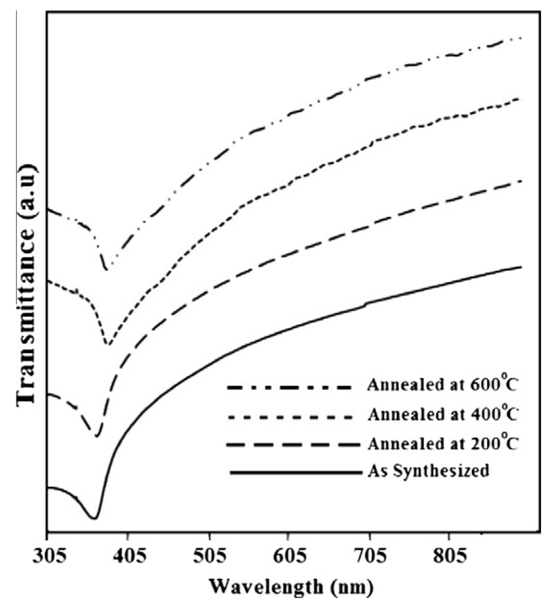

Fig. 4. UV–Vis absorbance spectra of ZnO NPs annealed at different temperatures.

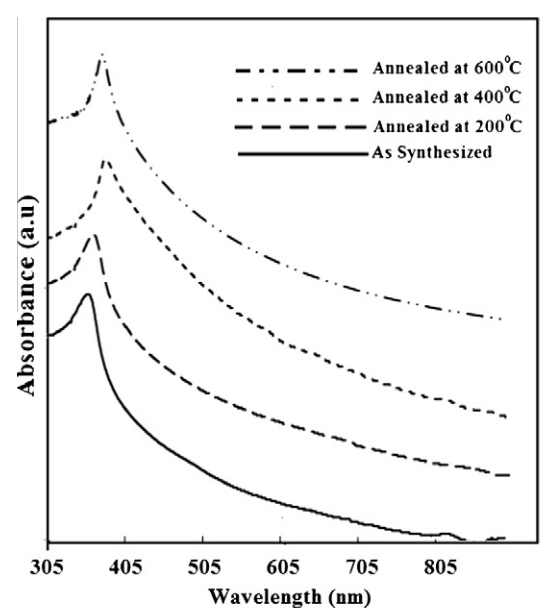

Fig. 5. Transmission spectra of ZnO NPs annealed at different temperatures.