Erratum to: Structural and optical properties of (Zn, Co) co-doped SnO₂ nano particles

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The original version of the article unfortunately contained errors in the equations, miscalculation and changes in figure. The detailed description of the error and corrections are given below.

The optical band-gap energy of a semiconductor can be derived from the reflectance spectrum. The reflectance (R) is converted to absorbance ($F(R)$) using the Kubelka–Munk function,

$$F(R) = \frac{(1 - R)^2}{2R} \quad (1)$$

The band gap is determined by the $(F(R) \times E)^2 \sim E$ curve with the extrapolated line at $(F(R) \times E)^2 = 0$, where E is the incident photon energy ($h\nu$).

To plot the curve, the data were processed in the origin software, in which Eq. (1) might be displayed as,

$$col(E) = (1 - col(D))^2 / (2 * col(D)) \quad (2)$$

where $col(E)$ and $col(D)$ are $F(R)$ and R , respectively. However, Eq. (2) was miswritten as,

$$col(E) = ((1 - col(D))^2 / 2 * col(D)) \quad (3)$$

Because of this mistake, the obtain $F(R) \sim \lambda$ and $(F(R) \times E)^2 \sim E$ curves are wrong and the thus determined optical band-gap energies are incorrect.

Figures 8, 9 and 11 appeared incorrectly in the published version of this article. The corrected figures are shown below. Based on the corrected figure, the optical band-gap energies are found to be 4.00, 3.90, and 3.92 eV for Sn_{0.94}Zn_{0.05}Co_{0.01}O₂, Sn_{0.92}Zn_{0.05}Co_{0.03}O₂, and Sn_{0.90}Zn_{0.05}Co_{0.05}O₂ nanoparticles, respectively.

The analyses and conclusion will have to be corrected, accordingly. The details of changes are illustrated in this Erratum, with corrected texts listed as followings.

Abstract

Optical bandgap variation is observed in Sn_{0.94}Zn_{0.05}Co_{0.01}O₂, Sn_{0.92}Zn_{0.05}Co_{0.03}O₂, and Sn_{0.90}Zn_{0.05}Co_{0.05}O₂ nanoparticles synthesized by the chemical co-precipitation method. The estimated particle size and optical band gap of Sn_{0.94}Zn_{0.05}Co_{0.01}O₂, Sn_{0.92}Zn_{0.05}Co_{0.03}O₂, and Sn_{0.90}Zn_{0.05}Co_{0.05}O₂ nanoparticles are 16.51, 11.75, and 6.6 nm and 4.00, 3.90, and 3.92 eV, respectively. A blue shift is noticed for all samples as compared to band gap value (3.6 eV) for bulk SnO₂. Increasing Co content results in decreased particle size, narrowed band gap in the main, and enhanced emission intensities in visible range of light. Small sized particles have larger surface areas and these large surface areas lead to more defects (oxygen vacancies, tin interstitials). The increasing defects concentration (especially oxygen vacancies, tin interstitials) results to narrowed band gap and enhanced visible light emission. With increasing Co

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content, the particles are in oxygen-poor state indicating the presence of many O vacancies and Sn interstitials. The oxygen content decreases steadily with increasing Co content, with the Sn:O atomic ratio increases suggesting the high density of defects. Large number of defects (oxygen vacancies) creates several donor levels within the forbidden energy gap and these defects in the band gap act as luminescent centers to enhance the emission intensities in visible spectrum.

Introduction

The 2nd paragraph in the “Introduction” section (in Page 12120):

In this work, we study enhancement in emission intensities and band gap variation of SnO_2 nanoparticle by doping. SnO_2 nanoparticles are co-doped with Zn and Co. Zn content is fixed at 5 wt% while Co content is increased from 1 to 5 wt%. With increasing Co content particle size reduced having more surface specific area, which increased the defect density (oxygen vacancies, tin interstitials) and hence narrowed the band gap to a relatively small value [15], as well as an enhanced the visible light emission. The increased visible emission intensities make these nanoparticles very important from technological point of view in the fields of visible light catalysis and optoelectronic devices. In the next sections we exhibit to present our experimental results along with detailed discussion of our findings.

Results and discussion

- (1) The 8th paragraph in the “Results and discussion” section (in Page 12123):

Variation of absorbance for samples is shown in Fig. 8. The absorption edges are centered in the 270–330 nm region. The relatively sharp rise of the absorption edge in case of $\text{Sn}_{0.94}\text{Zn}_{0.05}\text{Co}_{0.01}\text{O}_2$ nanoparticles demonstrates the high crystallinity with less number of defects in sample. It is well known that more defects will cause the broadening of the absorption spectra at the absorption edge.

- (2) The 9th paragraph in the “Results and discussion” section (in Page 12124–12125):

The optical band gap energy (E_g) is directly calculated from Kubelka–Munk equation, where $(F(R) \times E)^2$ is plotted on vertical-axis and the incident photon energy $E = h\nu$ on horizontal-axis. By extrapolation of the linear portion at $(F(R) \times E)^2 = 0$, band gap energy can be evaluated, as shown

in the inset of Fig. 9. Thus the evaluated band gap energy values are 4.00, 3.90, and 3.92 eV for $\text{Sn}_{0.94}\text{Zn}_{0.05}\text{Co}_{0.01}\text{O}_2$, $\text{Sn}_{0.92}\text{Zn}_{0.05}\text{Co}_{0.03}\text{O}_2$, and $\text{Sn}_{0.90}\text{Zn}_{0.05}\text{Co}_{0.05}\text{O}_2$, respectively, as shown in Fig. 9. All nanoparticles show a blue shift in the band gap as compared to their bulk band gap value (3.6 eV). The increased bandgap may be owing to the Burstein–Moss effect. This is the phenomenon that the Fermi level merges into the conduction band with increasing of the carrier concentration. Thus, the low energy transitions are blocked. Note that band gap becomes narrow in the main with increasing Co content, which is due to increased number of defects (e.g., oxygen vacancies and tin interstitials) in nanoparticles [35, 36]. With increasing Co content particle size decreases, which enhances defect density (oxygen vacancies, tin interstitials). The interaction between oxygen and interfacial tin vacancies would lead to formation of a significant number of trapped states which are responsible for band gap narrowing.

- (3) The 11th paragraph in the “Results and discussion” section (in Page 12125–12126):

Figure 11 shows the correlation between the Sn:O atomic ratio and optical band gap energy in $\text{Sn}_{0.94}\text{Zn}_{0.05}\text{Co}_{0.01}\text{O}_2$, $\text{Sn}_{0.92}\text{Zn}_{0.05}\text{Co}_{0.03}\text{O}_2$, and $\text{Sn}_{0.90}\text{Zn}_{0.05}\text{Co}_{0.05}\text{O}_2$ nanoparticles. The high Sn:O atomic ratio means the high concentration of oxygen vacancies and tin interstitials. Based on the previous analyses, generally now it can be concluded that the more defects (e.g., oxygen vacancies and tin interstitials) are, the narrower band gap is. The increase of defects (especially oxygen vacancies) results in the narrowing of band gap. Li et al. [10] predicted theoretically the possibility of band gap narrowing due to large number of oxygen vacancies in crystals [32]. In this work, the narrowing effect of band gap due to these defects can also be confirmed.

Conclusion

In summary, we have synthesized $\text{Sn}_{0.94}\text{Zn}_{0.05}\text{Co}_{0.01}\text{O}_2$, $\text{Sn}_{0.92}\text{Zn}_{0.05}\text{Co}_{0.03}\text{O}_2$, and $\text{Sn}_{0.90}\text{Zn}_{0.05}\text{Co}_{0.05}\text{O}_2$ nanoparticles by the chemical co-precipitation method. The average particle size decreases from around 16.51–6.6 nm with enhancement in Co content from 1 to 5 wt%. The band gap energies are 4.00, 3.90, and 3.92 eV for $\text{Sn}_{0.94}\text{Zn}_{0.05}\text{Co}_{0.01}\text{O}_2$, $\text{Sn}_{0.92}\text{Zn}_{0.05}\text{Co}_{0.03}\text{O}_2$, and $\text{Sn}_{0.90}\text{Zn}_{0.05}\text{Co}_{0.05}\text{O}_2$ nanoparticles, respectively, which are larger than the bulk SnO_2 (3.6 eV). With incorporation of Zn and Co, there is a slight decrease in band gap, which is due to increased defect density with increasing concentration of dopants. The emission intensities of all the samples are extended to the visible region as confirmed by room temperature photoluminescence spectra. With increasing

Fig. 4 d Dependence of Sn:O atomic ratios in $\text{Sn}_{0.94}\text{Zn}_{0.05}\text{Co}_{0.01}\text{O}_2$, $\text{Sn}_{0.92}\text{Zn}_{0.05}\text{Co}_{0.03}\text{O}_2$, and $\text{Sn}_{0.90}\text{Zn}_{0.05}\text{Co}_{0.05}\text{O}_2$ nanoparticles on Co content, with the *inset* showing the Sn and O contents (at.%)

Fig. 8 Absorption spectra of $\text{Sn}_{0.94}\text{Zn}_{0.05}\text{Co}_{0.01}\text{O}_2$, $\text{Sn}_{0.92}\text{Zn}_{0.05}\text{Co}_{0.03}\text{O}_2$, and $\text{Sn}_{0.90}\text{Zn}_{0.05}\text{Co}_{0.05}\text{O}_2$ nanoparticles

Co content, the intensity of visible light emission increased. All these samples with extended emission intensities are ideal candidates for visible light catalysis and optoelectronic devices. Also, this method can be extended to other wide band gap semiconductors to enhance their visible light emission for effectively making use of solar spectrum.

Fig. 9 Optical bandgap energy of $\text{Sn}_{0.94}\text{Zn}_{0.05}\text{Co}_{0.01}\text{O}_2$, $\text{Sn}_{0.92}\text{Zn}_{0.05}\text{Co}_{0.03}\text{O}_2$, and $\text{Sn}_{0.90}\text{Zn}_{0.05}\text{Co}_{0.05}\text{O}_2$ nanoparticles as a function of Co content. The *inset* shows the plot of $(F(R) \times E)^2$ versus photon energy nanoparticles

Fig. 11 Correction between the optical band gap energy and the Sn:O atomic ratio of $\text{Sn}_{0.94}\text{Zn}_{0.05}\text{Co}_{0.01}\text{O}_2$, $\text{Sn}_{0.92}\text{Zn}_{0.05}\text{Co}_{0.03}\text{O}_2$, and $\text{Sn}_{0.90}\text{Zn}_{0.05}\text{Co}_{0.05}\text{O}_2$ nanoparticles

In addition, Fig. 4d appeared inappropriately in the published version of this article. The corrected figure is shown above. The change of this figure has no influence on the text in the original article.