

Light Trapping Effect of SnO₂ Nanoparticles for Solar Cell Application

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Chemical synthesis of SnO₂ nanoparticles (NPs) were prepared by co-precipitation method using the stannous chloride (SnCl₂.2H₂O) as a precursor and ammonia solution as a precipitating agent. The as-synthesized SnO₂ colloids were centrifuged and dried at 60 °C for 24 h. The crystal structure of the prepared samples was examined by X-ray diffraction (XRD) which reveals the structure of SnO₂ NPs was tetragonal structure. The average crystallite size of SnO₂ was about 25 nm. The surface morphology of the agglomerated SnO₂ was almost spherical shape by scanning electron microscope (SEM). The effect of annealing temperature of the sample was confirmed by Fourier transform infrared spectrophotometer (FTIR). The as-synthesized SnO₂ layers were deposited onto a polycrystalline p-Si (100) wafer by screen printing method and SnO₂/Si thin films were carried out by thermal diffusion method at different deposition temperatures 400, 500, 600, 700 and 800 °C for 1 hour (h). The structural characterization of SnO₂/Si junction was observed by XRD. The photovoltaic properties of SnO₂/Si were measured by LUX meter and FLUKE 45 dual display multimeter respectively. The photovoltaic parameters including resistance, voltage and current of SnO₂/Si thin film were measured depending on the light intensities. It was found out that the annealing temperature 500 °C was the optimum temperature for the better trapping properties for light intensities of SnO₂ thin film.

1. Introduction

A light trapping of a semiconductor is the absorption of light by the active layer of semiconductor using the incoming photon energy which is less than or equal to the band gap energy of semiconductor. Light trapping can enhance the solar cell efficiency due to creation of electron hole pairs which generates a better collection of photogenerated current and a higher open circuit voltage of thin film solar cells. Therefore, the role of semiconductor material using as the active layer is the important consideration for the better light trapping. The material for light trapping has been used the transparent conductive oxide (TCO) such as tin-doped indium oxide (ITO), fluorine- and antimony-doped tin oxide (FTO, ATO) layers since they are high optical transparency in the visible region of electromagnetic spectrum, low electrical resistance, high electrical conductivity and high reflectivity in infrared range [1]. TCO are applied in numerous applications including light emitting diodes [2], dye sensitized solar cells [3], electrodes in solar cells and batteries [4, 5], sensors [6], flat panel displays [7]. SnO₂ is an n-type semiconductor with a bulk energy band gap (3.7 eV) at the room temperature and pressure. Various methods have been developed for preparing the transparent conducting oxide thin films. Some of them are sol gel [8], screen printing [9], thermal evaporation [10], chemical bath deposition [11], dc and rf sputtering [12, 13], spray pyrolysis [14], pulse laser ablation [15], electrodeposition [16] and spin coating [17].

Since the knowing the absorption coefficients of materials aids engineers in determining which material to use in their solar cell designs, the synthesized SnO₂ NPs has been deposited onto p-Si wafers to investigate the potential for light harvesting in this paper. Valuable understanding of the optical properties of NPs has been measured by meters under different illuminations for the insightful information on how the optical absorption of NPs reflects the properties of the dispersed

nanoparticles. The aim of this contribution is the use of SnO₂ NPs as the absorption layers of thin film and study on their fundamental physical and electrical properties on photovoltaic effect.

2. Experiment

0.1 M of stannous chloride dihydrate (SnCl₂·2H₂O) was dissolved in 100 mL of deionized water. After complete dissolution, 11 mL of ammonia was added by drop wise method at the room temperature. The white solution was suddenly changed into milky as soon as the ammonia was added. The solution then was vigorously stirred for a certain period until the white precipitates were obtained. During the stirring, the pH of solution was adjusted until greater than 10. When the precipitates were clearly separated from the solution, the stirring was stopped and stayed at overnight. The precipitates were centrifuged for 15 minutes at rpm 1500 and washed them by deionized water three times to remove excess ions and they were dried at 60 °C in air for 24 h. After that, dried SnO₂ were grinded by agate motor in order to get the fine powders. Then, the as-synthesized SnO₂ NPs were printed on Si wafer by screen printing method followed by the SnO₂/Si thin film by thermal diffusion method at the different annealing temperatures 400 - 800 °C for 1 h respectively. While the characterizations of SnO₂ films were investigated by XRD, FTIR, SEM and the electrical properties are measured by LUX meter and dual multimeter respectively. The crystal structure and crystallite size of the samples were confirmed by XRD (model Rigaku Multi Flux) using CuK_α radiation (40 kV, 40 mA) over a 2θ range from 10° to 70° on a powder type X-ray diffractometer equipped with a diffracted-beam graphite monochromator. The structural changes of the as-synthesized and calcinated SnO₂ samples were analyzed by FTIR. The spectra formation of SnO₂ structure were obtained by FTIR 8400 Shimadzu spectrophotometer by using a KBr pallet method in the Mid Infrared (MIR) radiation with the wavelength ranges from 4000 cm⁻¹ to 400 cm⁻¹ range with a resolution of 4.0 cm⁻¹. Surface morphology of the samples was investigated by SEM (JEOL 15 kV). Centrifuge machine (Kokusai H-200 series) with maximum 6000 rpm was used to separate the SnO₂ from the colloidal solution.

3. Results and Discussion

The crystal structures of the SnO₂ NPs were examined by XRD. The XRD spectra of the SnO₂ NPs (Fig. 1a) and SnO₂ thin film (Fig. 1b) at the annealing temperatures 600 °C for 1 h each were shown in Fig 1. The diffraction peaks from SnO₂ NPs (110), (101), (111), (211), (220), (002), (310) and (301) were observed in both Figs. They were broaden due to the crystallite sizes of SnO₂ particles in the samples were very small. All diffraction peaks were matched with the tetragonal structure of SnO₂ with the standard library file (ICDD-PDF #88-0287). The average lattice constant of a=4.7365 and c=3.1727. It was noted that the two prominent peaks (311) and (400) were found only in Fig. 1b which were attributed to diffraction peaks from Si wafer. Apart from these peaks, no other additional peaks were observed in XRD spectra. This showed that the samples have no more impurity after annealing. The predicted crystallite size of NPs was 25 nm by using Sherrer's formula.

$$D = \frac{K\lambda}{\beta \cos \theta} \quad (1)$$

Where λ is the wavelength of the incident X-ray beam (1.5405 Å for CuK_{α1}), K is a constant equal to 0.89 for spherical shape of particle, β is the FWHM (full width at half maximum), θ is the diffraction angle and D is the crystallite size.

FTIR spectra of as-synthesized and calcinated SnO₂ NPs were shown in Fig. 2a to study the effect of annealing temperature on the chemical bonding of SnO₂ NPs. The peaks were similar for all samples. The well configured band at 3400 cm⁻¹ could be seen before the heat treatment on as-synthesized SnO₂ NPs. This was due to absorption of water. After the heat treatment at 600 °C and 800 °C, this band was not very strong as before because of dehydration / condensation [18]. Figure 2b showed the comparison of the IR spectra of the as-synthesized SnO₂ NPs after annealing at 600 °C and SnO₂/Si film at the deposition temperature 600 °C. In the spectrum (a), the observed two intense bands 663.53 cm⁻¹ and 547.80 cm⁻¹ were attributed to the vibrations of Sn-O [18-20]. In the spectrum (b), the band at 1107.18 cm⁻¹ was assigned to the vibration mode of Si-O-Si/ O-Si-O group [21]. These were well known absorption bands of the SiO₂ network formed by the surface

oxidation of Si substrate. Another well absorption band appeared at 620 cm^{-1} was associated at Sn-O-Sn covalent bonds vibration [22].

To investigate the surface morphology and film thickness of the SnO_2 NPs, the sample was examined by SEM. Figure 3a shows the SEM micrographs of SnO_2 NPs at $600\text{ }^\circ\text{C}$. The size of observed particles shows the agglomeration of many single crystallites due to the inhomogeneous size distribution. This micrograph shows that the agglomeration of NPs has almost spherical shape. The film thickness of this sample was about $12.6\text{ }\mu\text{m}$ (Fig. 3b) which were measured by cross section position of film by SEM. For all samples, the measured film thicknesses were more than $10\text{ }\mu\text{m}$.

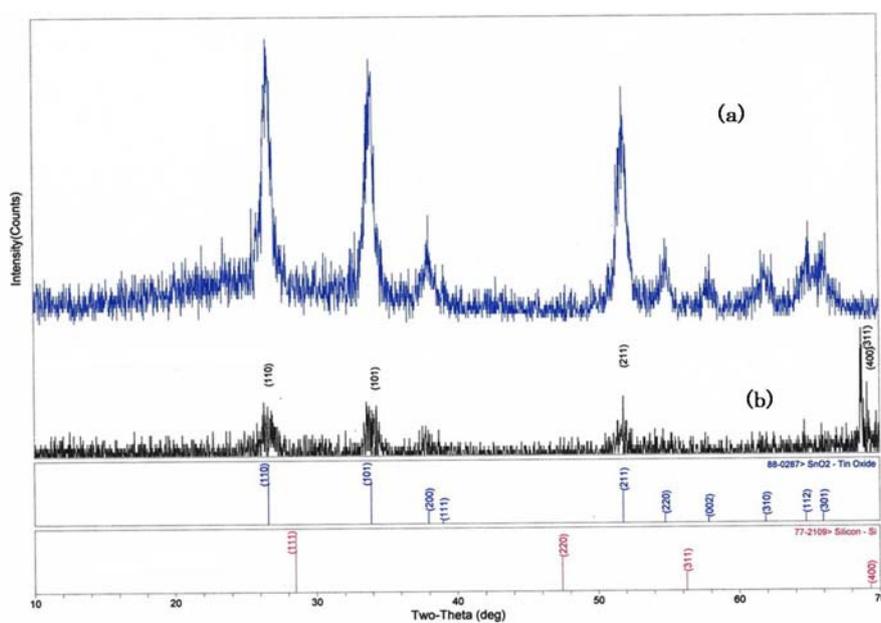


Fig. 1 XRD diffractograms of (a) SnO_2 NPs (b) SnO_2 thin film

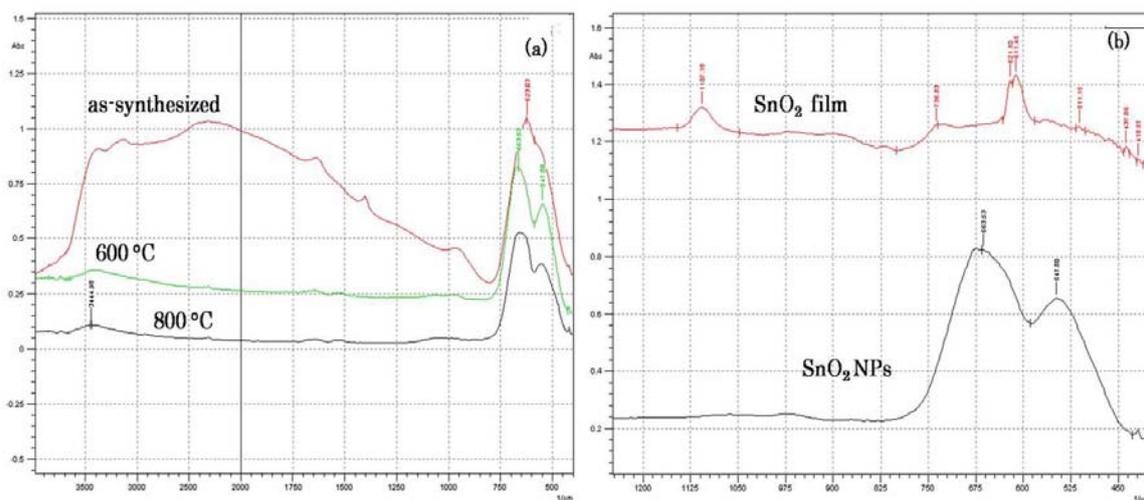


Fig. 2 FTIR spectra of SnO_2

I-V characteristic of each SnO_2/Si thin films were measured by using the LUX meter for illumination and FLUKE 45 dual display multimeter for measuring resistance, voltage and current.

The graphs measuring values of resistance, voltage and current depending on different illuminations were shown in Fig. 4. The graph revealed that the greater the illuminations, the lower the resistance values in all samples. Besides, the more increased the illuminations, the gradually higher values of voltage were resulted only for the film annealing at the deposition temperature 500 °C. As a result, the current values were also increased for that sample. In contrast, the voltage and current values were not sharply increased for other samples although the light intensities were increased. It can be concluded that the resistance and voltage values were depended on the light intensities which in turn depended on the deposition temperatures during the preparing of SnO₂ NPs deposited on Si substrate. It was observed that SnO₂ thin film showed photovoltaic characteristics since the resistance values were inversely proportional and the voltage values were directly proportional to the light intensities.

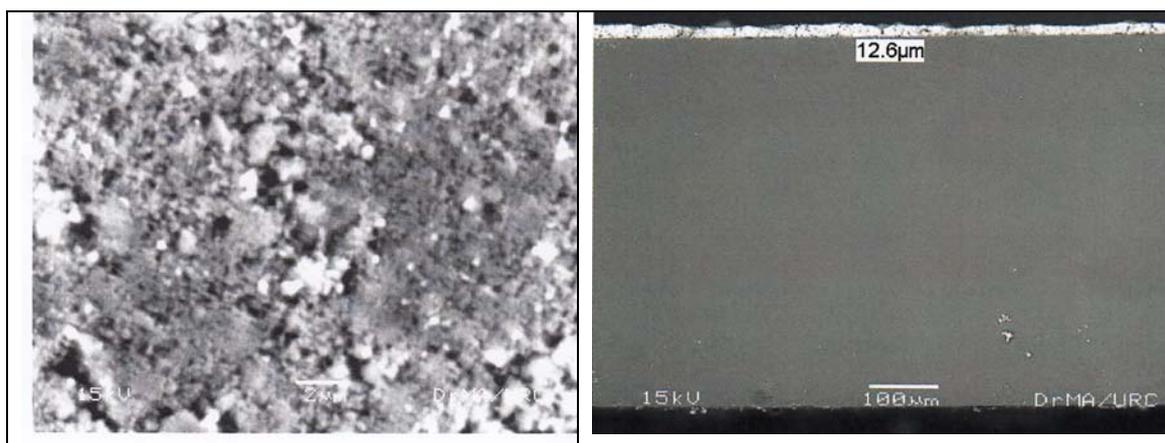


Fig. 3 SEM image of (a) surface morphology of SnO₂ NPs (b) cross-section of SnO₂ film

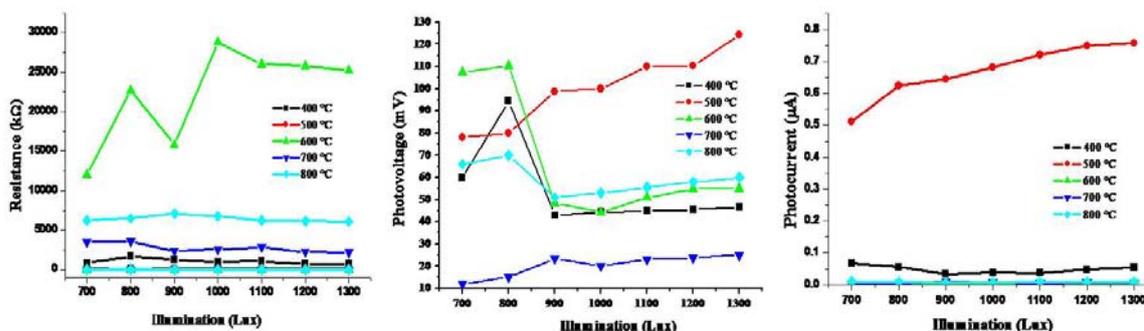


Fig. 4 The graph of SnO₂ /Si films showing (a) resistance, (b) photovoltage and (c) photocurrent depending on different illuminations

4. Conclusion

SnO₂ NPs were successfully synthesized by co-precipitation method. The crystal structure of SnO₂ NPs was tetragonal and the crystallite size was 25 nm by XRD. As-synthesized SnO₂ was deposited onto Si substrate at various diffusion temperatures from 400 °C to 800 °C by thermal diffusion method. The characterizations of the films were also investigated by XRD, SEM, FTIR and optical parameters depending on light intensities were measured by meters. According to measurements, SnO₂/Si junction resistance decreased with increasing illumination for all samples. However, the photovoltage values for the film at the diffusion temperature 500 °C were increased while the other films at the diffusion temperatures 400, 600, 700 and 800 °C were almost constants when the light intensities were increased. As a result, diffusion temperature 500 °C is the optimum temperature for the highest photovoltaic performances in this work.

Since the resistance values were inversely proportional and the photovoltage and photocurrent were directly proportional to the light intensities, the SnO₂/Si thin film behaved as a solar cell. This could be attributed to the absorption of light energy by SnO₂ NPs which converted then into the electrical energy. Therefore, SnO₂ NPs has the light trapping effect which can be applied in photovoltaic cells.

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