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Influence of substrate properties on the efficiency of Dye sensitized solar cells

Lakshmi K. Singh
M.Sc., Department of Physics, North Eastern Regional Institute of Science and Technology, Nirjuli, , Arunachal Pradesh. India
T. Karlo
Ph.D., Department of Physics, North Eastern Regional Institute of Science and Technology, Nirjuli, , Arunachal Pradesh. India
A. Pandey
Ph.D., Department of Physics, North Eastern Regional Institute of Science and Technology, Nirjuli, , Arunachal Pradesh. India

Abstract:
This paper explores the effect of sintering temperature of TiO_2 films on the efficiency of dye sensitized solar cells. Structural studies on the specimens were carried out using XRD which shows anatase phase with increasing crystallite size 29, 36, 43 nm with sintering temperature of 450, 550 and 650 ^{0}C respectively. The microstructure was studied by SEM analysis which shows agglomeration of TiO_2 particles for film sintered at 650^{0}C. The sintered films were characterized by FTIR studies and are reported. The maximum efficiency of DSSCs fabricated by using TiO_2 sintered at 450, 550 and 650 ^{0}C were found to be 1.3, 0.85 and 0.09 % respectively.

Keywords: *SEM, XRD, microstructure*

Introduction

The use of natural dyes and nanocrystalline TiO_2 is one of the most promising approaches to low cost dye sensitized solar cells (DSSCs). The practical application of TiO_2 normally requires a crystalline material with an appropriate particle size and morphology [1]. In the recent years it has emerged as a semiconductor which is used as photoanode in DSSCs. The photoactive electrode consists of a nanocrystalline and mesoporous network of a wide band gap semiconductor (usually TiO_2), which is covered with a monolayer of photosensitizing molecules.

The size of TiO_2 is an important factor affecting the performance of the material. Hence, one of the research areas is focused upon the use of TiO_2 nanoparticles. The porous TiO_2 electrodes provide a large surface area on which the dyes can be adsorbed. The substrate properties like thickness, particle size, phase, morphology, etc., have a direct impact on the efficiency of DSSCs.

The physical characteristic of the sintered TiO_2 nanostructured films has impact on the performance of the cell. The size and morphology of the TiO_2 particles is an important factor affecting the performance of the material. Phase and crystallite size are the important parameters that influence the physical properties of the material. Sintering temperature plays an important role in the performance of DSSCs. In this paper, we have studied the effect of sintering temperature of TiO_2 films on the performance of DSSCs. TiO_2 films were sintered at 450, 550 and 650 ^{0}C for 30 minutes.

Experimental

Tio_2 Electrode Preparation And Cell Assembly

TiO_2 paste was prepared by grinding TiO_2 powder (Anatase (< 25 nm), Sigma-Aldrich, purity 99.7%) with 3 pH deionised water followed by magnetic stirring for 1 hr. Using this paste, approximately 10 µm thick TiO_2 films were prepared on ITO glass substrate (ITO < 10 ohm/sq.cm, Kaivo, China) by doctor blading technique which is widely used due to its simplicity and reproducibility [2]. TiO_2 films were sintered at three different temperatures 450, 550 and 650 ^{0}C for 30 minutes. The films were sensitized by an ethanolic solution of begonia dye which is a leaf extract having maximum absorption at 543 nm. The cell was prepared by sandwiching the dye adsorbed TiO_2 electrodes and platinum counter electrodes as mentioned in literature [3].

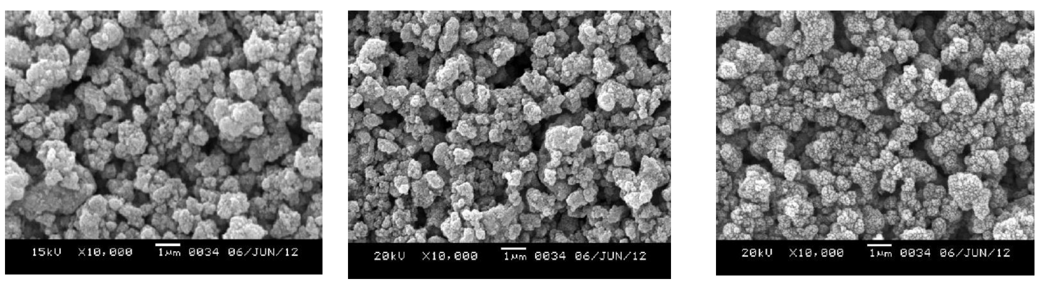
Characterization

The micro structural analyses of the sintered films were carried out using a JEOL JSM- 6360 Scanning Electron Microscope. The X- ray diffraction patterns of the sintered films were recorded using Rigaku X- ray Diffractometer (ULTIMA IV) using Cu K alpha (40 kV, 40 mA) as the X- ray source and with a scanning rate of 4^0 per minute. The FTIR studies were measured using a Shimadzu FTIR spectrometer (IRAffinity-1) in the wave number range 4000-400 cm^{-1}. The I-V characteristics of the fabricated cells were obtained using a source measure unit (model 236, Keithley instrument) under the illumination of 20 mW/cm^2.

Results and Discussion

SEM

Scanning electron micrographs of TiO_2 sintered at different temperatures are shown in Fig.1 (a-c)



(a) *(b)* *(c)*

Figure 1: SEM micrographs of nanocrystalline TiO_2 electrode sintering temperature: (a) 450 ^0C, (b) 500 ^0C (c) 650 ^0C.

Surface morphology of these films shows that sintering has led to better necking between TiO_2 particles and reduction in the number of open pores facilitating dye adsorption and electron transport. There is not much difference in the microstructures except that agglomeration has increased in the film sintered at 650 ^0C which has led to degradation in the performance of DSSC as obvious from the electrical studies due to increased particle size.

XRD

The X-ray diffraction patterns of the sintered films are shown in Fig. 2.

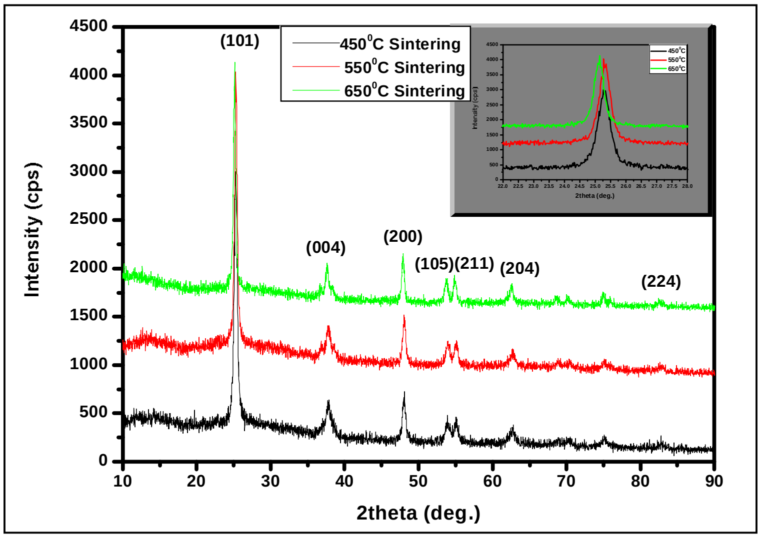


Figure 2: X-ray diffraction pattern of TiO_2 films sintered at 450, 550 and 650 ^{0}C

The XRD patterns exhibit strong diffraction peaks at 25.26^0, 37.84^0, 48.12^0 for films sintered at 450 ^{0}C; 25.28^0, 37.72^0, 40.08^0 for films sintered at 550 ^{0}C and 25.14^0, 37.64^0, 47.92^0 for films sintered at 650 ^{0}C, indicating anatase phase. All the peaks are in good agreement with the standard spectrum (JCPDS no. 84-1286). The inset shows the shifting of [101] peaks with increasing sintering temperature and decrease in peak broadening. This may be due to starting of phase transition from anatase to rutile at 650 ^{0}C along with grain coarsening resulting in degradation of nanostructure [4].

The crystallite size L [h k l] can usually be related to the broadening of the corresponding signal via the semi-empirical Scherrer equation [5, 6] (Eq. 1), in which K is a correction factor (depending on the particle shape and is usually about 0.9), λ the wavelength of X-ray (Cu Kα = 0.154056 nm), β_L the peak full-width at half-maximum and θ, the diffraction angle.

$$L\,[h\,k\,l] = K\,\lambda / \beta_L \cos\theta \qquad (1)$$

Sintering Temp.	Prominent peaks, 2θ	FWHM	Crystallite size

(^{0}C)	**(deg.)**	**(deg.)**	**(nm)**
450	25.26, 37.84, 48.12	0.56	29
550	25.28, 37.72, 40.08	0.46	36
650	25.14, 37.64, 47.92	0.38	43

Table 1: Parameters calculated from the XRD spectra and the calculated crystallite size

FTIR

Fig. 3 shows the FTIR spectra of TiO_2 films sintered at 450, 500, 550, 600 and 650 ^{0}C. The spectra show broad band at 420 to 700 cm^{-1} which is due to normal TiO_2 stretching [7]. All the spectra show one broad band around 3400 cm^{-1} and one around 1640 cm^{-1} which can be attributed to surface adsorbed H_2O and –OH of TiO_2 [8]. From the spectra it is clear that the intensity of above mentioned peaks decreases with the increase in sintering temperature which may be due to the change in TiO_2 particle size as obvious from XRD and SEM studies.

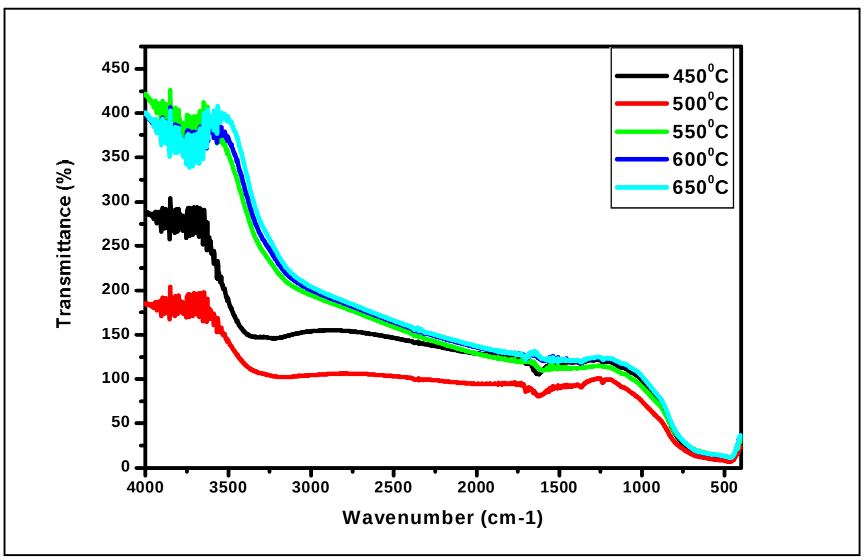
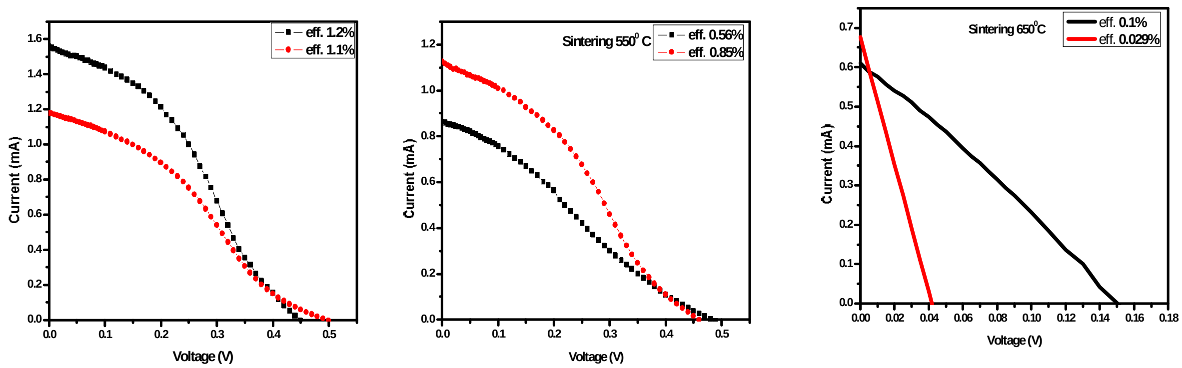


Figure 3: FTIR spectra of TiO_2 films sintered at 450, 500, 550, 600 and 650 ^{0}C

I-V Characteristics Of The Fabricated Dsscs

The effect of sintering temperature on the efficiencies of the DSSCs was studied by fabricating cells with TiO_2 sintered at 450, 550 and 650 ^{0}C. Fig. 4 (a-c) shows the I-V characteristics of the fabricated cells sensitized by begonia dye and Table 2 shows the parameters calculated from the I-V characteristics of the fabricated cells.



(a) *(b)* *(c)*

Figure 4: I-V characteristics of the cells with sintering temperature: (a) 450 ^{0}C, (b) 500^{0}C (c) 650 ^{0}C.

Sintering Temp.(^{0}C)	**Cell no.**	**I_{sc} (mA)**	**V_{oc} (V)**	**FF (%)**	**η (%)**
450	1	1.55	480	35	1.30
	2	1.20	480	36	1.10
550	1	1.12	470	33	0.85
	2	0.86	450	30	0.56
650	1	0.60	150	26	0.09
	2	0.67	45	20	0.03

Table 2: Photoelectrochemical parameters of the fabricated DSSCs.

There is a decrease in efficiencies of the cells with increase in sintering temperature. For the films sintered at 650 ^{0}C the value of I_{sc} and V_{oc} is comparatively very less which may be because of increase in crystallite size as obvious from Table 1 which has lead to decrease in surface area for dye absorption eventually decreasing the performance of DSSCs.

Conclusion

TiO_2 films (~10 μm thick) were screen printed on the ITO plates and then sintered at three different temperatures 450, 550 and 650 ^{0}C. XRD diffractogram suggest that there is not much change in the crystal structure with increase in the temperature. The particle size evaluated following FWHM suggests increase in crystallite size with increasing temperature. The SEM micrographs show formation of agglomerates in the TiO_2 films sintered at higher temperatures. FTIR studies carried out on these films show decrease in intensity with increasing temperature which could be attributed to the increase in crystallite size at higher sintering temperatures. The efficiency of DSSCs decreases with the increase in sintering temperatures of the films which could be attributed to degradation of nanostructure of TiO_2 films.

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