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Pore Size Enhancement in TiO2 Thin Films and its Effects on Dye Sensitized Solar Cells

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Abstract

Light harvesting efficiency in dye sensitized solar cell is currently enhanced by the employment of an additional TiO2 scattering layer hence increasing the overall film thickness. This has limitations on effective charge transport especially in dense electrolyte media due to the increased film thickness. The additional film layer further reduces light intensity on the adsorbed dye hence decreasing photocurrent generation. Therefore, there is still the challenge of light scattering optimization versus charge transport and photocurrent generation. In addition, though TiO2 is a relatively cheap material, the addition of TiO2 layer raises the production cost of the dye sensitized solar cell effectively and rendering it not cost effective. In this study, carbon black was employed to create artificial pores in TiO2 thin films to enhance light harvesting and hence photocurrent generation. TiO2 films deposited by screen printing method had 0, 1.0, 1.5, 2.0 and 3.0 wt% carbon black. On annealing of the films at 500oC in air for 30 minutes, carbon black decomposed leaving behind voids. Transmittance, reflectance and absorbance spectra of the films determined by a UV-Vis-NIR show that transmittance decreased as the carbon black concentration increased. On the other hand, both reflectance and absorbance increased with increase in carbon black concentration. Micrograph images obtained from both Scanning Electron Microscope (SEM) and Atomic Force Microscope (AFM) show that the pore size of the films increased as the carbon black concentration increased.

Furthermore, the XRD results of these films show that the TiO2 are anatase and without any carbon contamination. Conductivity of the films determined using a four point probe was found to decrease with increase in pore size due to decrease in electrical contacts among the TiO2 molecules. The values 384.61, 352.11, 103.41, 52.41 and 35.29 Siemen's cm-1 were determined for 0, 1.0, 1.5, 2.0 and 3.0, respectively. Current-Voltage (I-V) characteristics of the cell fabricated with different pore sizes were determined using a solar cell simulator at 100 mW/cm2 illumination. The results show that photocurrent generated by these cells increased from 6.1 mA/cm2 to a maximum value of 9.9 mA/cm2 as the wt % carbon black increased from 0 wt% to 1.5 wt %, respectively. Beyond 1.5 wt%, photocurrent begun to drop until it got to its minimum value of 4.7 mA/cm2 at 3.0 wt%. The overall efficiencies for 0, 1.0, 1.5, 2.0 and 3.0 wt% were found to be 2.3, 2.6, 4.3, 2.4 and 1.4 %, respectively. The result shows an improvement in the photovoltaic performance of DSSC as a result of the artificial voids created. However, beyond the optimum concentration of 1.5 wt%, the cell performance begun to decline. This approach greatly enhanced the current density of the cells and consequently the overall conversion efficiency significantly.

Dye sensitized solar cells (DSSCs) rely on the absorption of photons by the dye molecules which are transported to the conduction band of the TiO2 electrode. The microstructure, energy gap and the absorption spectra of the TiO2 electrodes highly affects the efficiency of the cell. In this paper, the absorption spectra and energy gap has been studied by varying the thickness of the TiO2 paste. Nanocrystalline TiO2 thin films were deposited on ITO glass substrate with three different thickness (4.54µm, 7.12µm and 12.3µm) by using doctor blade method. After deposition all the samples were sintered at 450˚C after deposition to enhance the particle bonding and for achieving better adhesion. The samples were characterized by UV-VIS spectra for determining the absorption spectra and Scanning Electron Microscopy (SEM) for investigating the thickness and the surface morphology. Fabricating the electrodes with different thickness showed significant changes in the energy gap and from the results it can be concluded that the energy gap increases with the increased thickness. The highest energy gap of 2.25ev and absorption 3.791 was achieved by 12.3µm thick sample. The absorption spectra also shows better absorption throughout the whole visible light range but the SEM images suggests that 12.3µm thick sample shows cracks all over the deposited region which will cause current leakage when the cell is assembled. Therefore, the optimum result was achieved by 7.12µm thick sample providing 1.9 ev energy gap and 3.91 absorption peak.

DSSCs has been accepted widely to be used as potential solar cell apart from traditional solid-state cells. It is considered as photo electrochemical solar cell that consists of mesoporous metal oxide semiconductor layer on transparent conductive glass, which is used as working electrode [1]. Other major components are the organic or inorganic dye material, electrolyte and the counter electrode. Oxide semiconductors possess decent stability under irradiation but due to the large bandgap this kind of material cannot absorb visible light directly [2]. In case of dye-sensitized solar cell, TiO2 is mostly used as the oxide semiconductor having 3.2ev energy gap [3]. To recover the absorption issue organic/inorganic dyes are used to sensitize the TiO2 based electrode. Dyes help to excite the electrons received from the sunlight to change its state and upon excitation; the dye molecule injects the electron towards the conduction band of the TiO2 based electrode. The semiconductor electrode then transports the electron to external load. The efficiency of this kind of solar cell highly affected depending on the performance of the TiO2 coated electrode [4]. The TiO2 paste formulation is very crucial since it helps to adsorb large amount of dye molecule to the 2 1234567890‘’“” ICAMME 2017 IOP Publishing IOP Conf. Series: Materials Science and Engineering 290 (2018) 012004 doi:10.1088/1757-899X/290/1/012004 electrode surface and using Ru-complex dye the energy conversion efficiency was achieved 11% with standard measurements [5]. The most important parameters like surface area, roughness, pore size, film thickness, sintering temperature, chemicals greatly affects the result and these properties can be controlled during the film preparation process.