Improvement of the Photovoltaic Performance of Dye-Sensitized Solar Cell by Using TiO_2:CNT Nanocomposite Photoanode

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1- Introduction

Dye-sensitized solar cells (DSSCs) have gained great attention due to their low production cost, favorable efficiency, and simple fabrication process, in comparison with conventional silicon solar cells. Generally, titanium dioxide (TiO_2) has been used as the working electrode in DSSCs owing to higher resulting efficiency than other semiconductors. In order to increase TiO_2-based solar cells efficiency, photogenerated charge carriers recombination should be prevented. Carbon nanotubes (CNTs) have been studied widely because of their high electrical conductivity, chemical stability, high surface area, and tube-like structure. CNTs' high electron affinity can be useful for the electrons collecting that improves carrier mobility in DSSCs.

In this paper, TiO_2:CNT nanocomposites containing different percentages of CNTs, have been synthesized via the sol–gel method and utilized as the anodes in DSSCs, in order to investigate the possibility of developing the performance of them.

2- Experimental

At first, chemical oxidation treatment was done on the multi-wall carbon nanotubes (MWCNTs), for the functional groups generation on their surface. TiO_2 sol was prepared by the partial hydrolysis and condensation of titanium butoxide with water. In the next step, TiO_2 thin films including various percentages of MWCNTs (0-4 wt.% of the sol) were coated on fluorine-doped tin oxide (FTO) substrates via the sol–gel dip coating technique. The coated substrates were immersed in N719 dye solution for the dye sensitization. Finally, the sandwich DSSCs were assembled by using these anodes, iodide/triiodide redox couple electrolyte and platinum coated FTO cathodes.

3- Results and Discussion

TiO_2:MWCNT thin films XRD patterns correspond to the anatase phase in all coatings. Appeared peaks correspond to (101), (004), (200), (105), (211), (204), (116), (220), (215) and (224) planes, respectively. It should be noted that characteristic peak of CNT in $2\theta=26°$ cannot be observed in spectra, because of overlapping with anatase (101) peak. Another reason can be mass difference between MWCNTs and TiO_2 in nanocomposite thin films. By TiO_2 crystallite size measurement by Williamson-Hall equation, it was found that the size of anatase crystallite decreases with increasing the amounts of MWCNTs in the sol due to MWCNT hinders the crystallite growth of TiO_2. The grain boundaries act as trap sites in the electrons motion pathways. Consequently, TiO_2 crystallite size decline results in recombination increment which is not favorable.

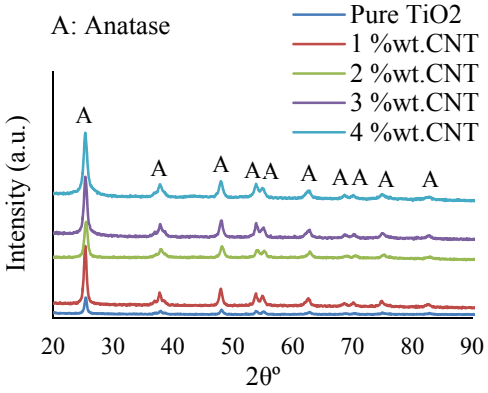

Fig. 1 XRD patterns of TiO_2: MWCNT thin films

Fig. 2 shows FE-SEM image of TiO_2:MWCNT thin film morphology. In this image, clusters of TiO_2 nanoparticles with approximately spherical shape and 45 nm size, and CNTs are observed. MWCNTs are dispersed monotonously in TiO_2 matrix and there is a desirable contact with the nanoparticles. Coating porous structure is caused by solvent exit during annealing.

Nyquist curves of DSSCs fabricated of TiO_2-MWCNT anodes (Fig. 3) show that charge transfer resistance in the interface of electrolyte/dye/TiO_2 is decreased in comparison to the cell fabricated of pure TiO_2 anode; because CNT one-dimensional structure helps photogenerated electrons transfer and leads to charge carriers recombination decline. Coating conductance increment can be another reason for this event. DSSC fabricated of TiO_2:3%wt.MWCNT thin film have the least charge transfer resistance and as a result, the most electron transport rate. It is seen that an increase in MWCNT amounts leads to interface resistance increment. Excessive presence of MWCNTs results in a competition in the light harvesting between it and dye-sensitizer.

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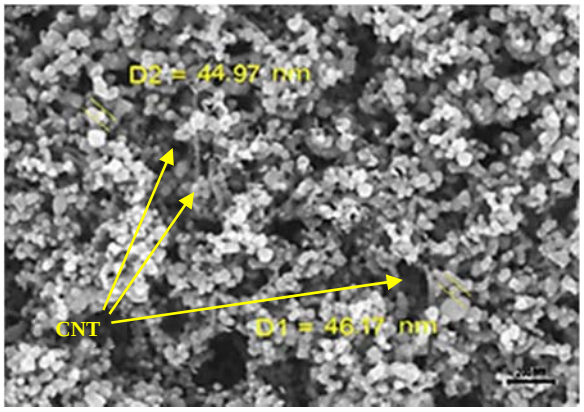

Fig. 2 FE-SEM image of TiO_2:4%wt.MWCNT thin film morphology

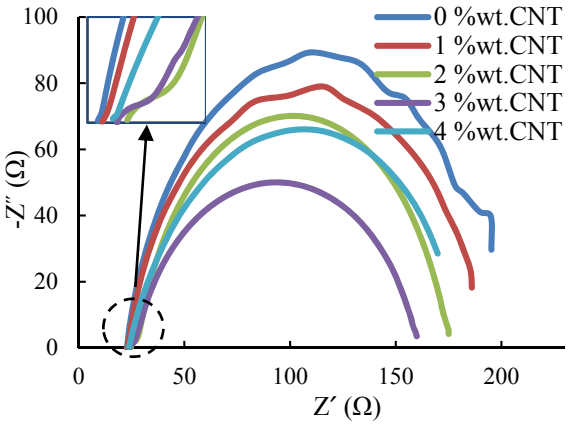

Fig. 3 Nyquist curves of DSSCs fabricated of TiO_2:MWCNT anodes

Current density-voltage curves of DSSCs fabricated of TiO_2-MWCNT anodes (Fig. 4) represent that by increasing the amounts of MWCNTs, open circuit voltage (Voc) values arise at first and then decrease. The reason is that low incorporation of MWCNTs in TiO_2 layer can reduce charge carriers recombination and resistance. Meanwhile, it has been reported that surface treatment usually increases Voc values regardless of the nature and properties of the coated material on the electrode. The short circuit between FTO and electrolyte through MWCNTs can also be a reason for Voc decrease in excessive amounts of MWCNTs. A same observation is seen in the case of short circuit current density (J_{SC}). The reasons for J_{SC} improvement in low amounts of MWCNTs is increment of electron collection and transfer in porous layer due to electrical conductance enhancement. However, excessive amounts of MWCNTs reduce J_{SC} due to decreasing the adsorption sites for the dye, caused by the crack formation on the surface of the electrode, and also increasing the back electron transfer to the electrolyte through MWCNTs. Increment in the values of fill factor (FF) is caused by resistance decline in the interface of electrolyte/dye/nanoparticle, because of TiO_2 electrode electrical conductance improvement.

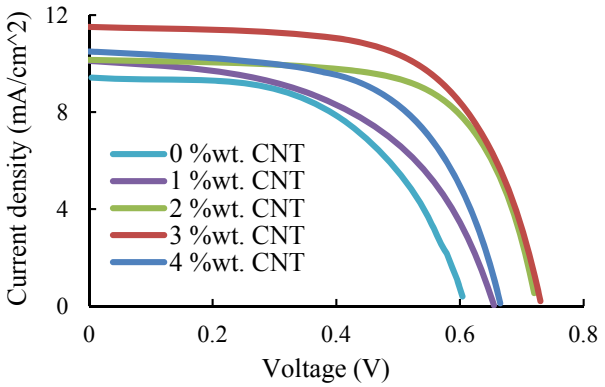

Fig. 4 Current density-voltage curves of DSSCs fabricated of TiO_2:MWCNT anodes

4- Conclusions

TiO_2–MWCNT nanocomposite thin films containing various percentages of MWCNTs were coated on FTO substrates by sol–gel dip coating technique. Then, DSSCs were assembled by using anodes made of the nanocomposite films, iodide/triiodide redox couple electrolyte and platinum coated FTO cathodes. Cell having TiO_2–3wt.% MWCNT anode showed maximum solar to electric energy conversion efficiency of 5.31%, which is 69% higher than the conventional TiO_2 solar cell. The enhancement of conversion efficiency was attributed to the increased electrical conductivity of the anode, decreased charge carriers recombination in it and low charge transport resistance at the TiO_2/dye/electrolyte interface.