Improvement of the Photovoltaic Performance of Dye-Sensitized Solar Cell by Using TiO₂:CNT Nanocomposite Photoanode

S. Daneshvar e Asl, 1 S.K. Sadrnezhaad 2

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 (TiO₂) has been used as the working electrode in DSSCs owing to higher resulting efficiency than other semiconductors. In order to increase TiO₂-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, TiO₂: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. TiO₂ sol was prepared by the partial hydrolysis and condensation of titanium butoxide with water. In the next step, TiO₂ 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
TiO₂: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 2θ=26° cannot be observed in spectra, because of overlapping with anatase (101) peak. Another reason can be mass difference between MWCNTs and TiO₂ in nanocomposite thin films. By TiO₂ 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 TiO₂. The grain boundaries act as trap sites in the electrons motion pathways. Consequently, TiO₂ crystallite size decline results in recombination increment which is not favorable.

Fig. 1 XRD patterns of TiO₂: MWCNT thin films

Fig. 2 shows FE-SEM image of TiO₂:MWCNT thin film morphology. In this image, clusters of TiO₂ nanoparticles with approximately spherical shape and 45 nm size, and CNTs are observed. MWCNTs are dispersed monotonously in TiO₂ 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 TiO₂-MWCNT anodes (Fig. 3) show that charge transfer resistance in the interface of electrolyte/dye/TiO₂ is decreased in comparison to the cell fabricated of pure TiO₂ 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 TiO₂:3%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.

Email: sadrnezh@sharif.edu

---

1 Ph.D. student Department of Materials Science and Engineering, Sharif University of Technology, Tehran, Iran.

2 *Corresponding Author: Professor, Department of Materials Science and Engineering, Sharif University of Technology, Tehran, Iran.
Current density-voltage curves of DSSCs fabricated of TiO2: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 TiO2 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 (JSC). The reasons for JSC 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 JSC 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 TiO2 electrode electrical conductance improvement.

4- Conclusions

TiO2–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 TiO2–3wt.% MWCNT anode showed maximum solar to electric energy conversion efficiency of 5.31%, which is 69% higher than the conventional TiO2 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 TiO2/dye/electrolyte interface.