Article can be accessed online at http://www. publishingindia. com

Graphene Oxide Based Dye-Sensitised Solar Cells Using Terminalia-Chebula

M. T. Ahmadi*, **, Kambiz Golmohammadi*, Adila Azman, Razali Ismail**, Hasan Sedghi***

Abstract

The use of carbon compounds and natural pigments help to build easy and cheap dye-sensitised solar cells. Accordingly, graphene oxide is used asa layer separation on the pigment with more efficiency. Also, instead of an expensive and commercial pigment, chebula terminalia plant which is cheap, abundant and environmental friendly was used. In the presence of graphene oxide, more voltage and conversion efficiency are obtained compared to the solar cell without the graphene oxide.

Keywords: Solar Cells, Graphene Oxide, Dye-Sensitised Solar Cells

Introduction

It is reported that energy shortage and environmental pollution are the major problems of the 21st century (Tsai, Chen, Hsiao, & Chuang, 2015). According tothe announced reports, world energy consumption will increase to 53% before 2035. In addition tothe increasing population, it has direct relationship with the economic growth of countries (Conti & Holtberg, 2011; Maçaira, Andrade, & Mendes, 2013). Most of the energy required for humans was provided by fossil fuels such as oil, coal, and natural gas. Therefore, the development of renewable energy sources to reduce the emission of carbon dioxide, methane and other harmful substances is necessary. Thesun is a source of energy which is free, clean and away from damaging environmental impacts which has long been used by humans in different ways. The solar cell is a device that converts the solar energy into electricity through photovoltaic effect (the direct conversion of solar energy into electricity) without connecting to an external voltage source (Imahori, Umeyama, & Ito, 2009). Due to the ease offabricationof silicon solar cells, nanostructured solar cells are highly preferred compared to silicon solar cells. Dye-sensitised solar cells (DSSCs) are one of the third generation solar cell technologies which can be considered as plenty due to its advantages such as ease of fabrication, low-cost, flexible, use of different colors in it, less sensitive to the radiation angle of the light, and performance in terms of softened (such as cloudy) (Toyoda & Sano, 2004; Rostami, Nemati, Byranvand, Mohammadpour, & Faridi, 2015; Yao & Hang, 2014). Compared to the silicon solar cells, DSSC scan be used with different types of substrate, more environmental friendly and more cost-effective (Chou, Chen, Lin, Lu, & Wu, 2011; Lewis, 2007; Kim, Kim, Choi, Kang, Song, Kang, Ko, 2008; Grätzel, 2004). For the first time, this type of cells was reported in Lausanne, Switzerland in 1991 by Grätzel lwith solar cell conversion efficiency of 7. 9% (Ellis, 2013). So far, efficiency of up to 12% was achieved for DSSC (Lanfang & Zhang, 2014; Yella, Lee, Tsao, Yi, Chandiran, Nazeeruddin, Diau, Yeh, Zakeeruddin, & Gratzel, 2011). DSSCis considered as an important topic of research with over 1000 articles being published until year 2010 (Tarsang & Promarak, 2014; Peter, 2013).

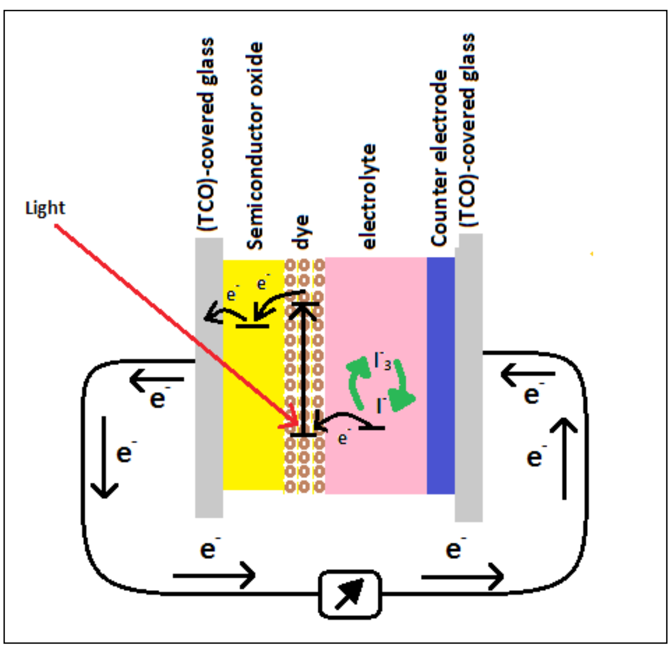
* Nanoelectronic Research Group, Nanophysics Department, Faculty of Science, Urmia University, Urmia, Iran. Email: kambizgol@yahoo. com

** Computational Nanoelectronics (CoNE) Research Group, Faculty of Electrical Engineering, Universiti Teknologi Malaysia Skudai, Johor Bahru, Johor, Malaysia.

Structure and Function Dye-Sensitisedsolar Cells

A dye sensitised solar cell is made up of the following components (Oprea, 2014): the transparent conductive oxide (TCO)-covered glass, light-sensitive dyes, semiconductor oxide (a porous layer of nanocrystalline with wide band gap, such as TiO_2 (anode)), the counter electrode (cathode), and electrolyte. After being exposed to the radiation light, the electrons of the pigments were transferred to the conduction band of the semiconductor oxide. The vacancies of electrons in the pigments were filled with the transferred electrons from the electrolyte to the dye molecules and the pigments returned to their base state. The electrolyte used in the solar cell usually consists of oxidation-reduction mechanism(such as electrolyte iodide/triiodide). The electrons that were transferred from the electrolyte to the pigments by reducing the triiodide electrolyte solution in the vicinity of the counter electrode (cathode) had returned to the electrolyte. The cycle of the transfer of electrons from the anode to the cathode was completed through an external circuit (Yang, 2013; Sacco, 2015).

Fig. 1: Schematic Diagram of the Structure and Function Dye-Sensitised Solar Cells



According to Fig. 1, a chemical reaction inside the cell starts with Photon absorption by the dye molecules then the injection of produced electrons to semiconductor oxide which is going to penetrate into TCO, counter electrode, electrolyte that helps to the reduction of tri-iodide and oxidation of iodide, and finally electron is transferred to the dye. Due to the good conductivity and high specific surface area of graphene and its derivative, significantly, many researchers have been using graphene and its derivatives to fabricate solar cells (Fang & Li, 2014). In this study, graphene oxide had been successfully used in the DSSC with higher conversion efficiency. It is demonstrated that graphene oxide is a modified graphene with oxygen functional groups (Gao, Lui, Lee, & Zhang, 2012; Gao & Li, 2014). Two types of TiO_2 had been used in this experiment.

Experimental

In this experiment, two different DSSCs had been fabricated, without and with the use of graphene oxide as the layer separation. Forthe fabrication of the first cell, two FTO glasses with dimensions of 2. 5 ×2. 5 cm and resistance of 15k$\Omega/\square$ (purchased from the University of Sharif in Iran)were initially washed with distilled water and ethanol. Then, the DSSC working electrodes were fabricated by firstattaching Scotch tape templates that were prepared by punching 3-mm-diameter holes in them. Forthe preparation of the paste of titanium dioxide (TiO_2), 1. 5g powderof TiO_2 was mixed with average particle size of 10-15 nm and 0. 5g powder TiO_2 was mixed with average particle size of100 nm. Then, 9 mlethylene glycol and two drops of triton X-100were added into the mixture. The paste was finally prepared by grinding the mixturein a mortar for half an hour until a homogeneous paste was obtained. Then, the paste was spread on the glass and was coated onto the blocking layer by a glass rod and sintered at 400˚C for 30 min in the air, then cooled to room temperature. The extract of terminalia chebula has been milled before 25g terminalia chebula was dissolved into 20ml of ethanol. The dye was loaded by immersing the TiO_2 anode in the terminalia chebula for 3 hours, and then the glass was washed with distilled water and ethanol. On theother glass of the conductor, paste of platinum(purchased from the University of Sharif in Iran)was spread on the glass by glass rod and sintered at 450˚C for 20 min in the air, and then the glasses were put onto each other in the form of stair. At the end, two drops of electrolyte were injected into the cell through the corner of the glasses (Solar cell(1)). For the fabrication of the second DSSC, graphene oxide was used in the cell and all fabrication processes of the cell are similar to the previous processes. After coating the layer of terminalia chebula, two drops of colloidal solution of graphene oxide 0. 04 mg/ml were dissolved in water (purchased from the University of Amir Kabirin Iran) and then sprayed onto the pigment of terminalia chebula and sintered at 100˚C for 15 min. Graphene oxide layer was coated between the dye and platinum layers.

Results and Discussion

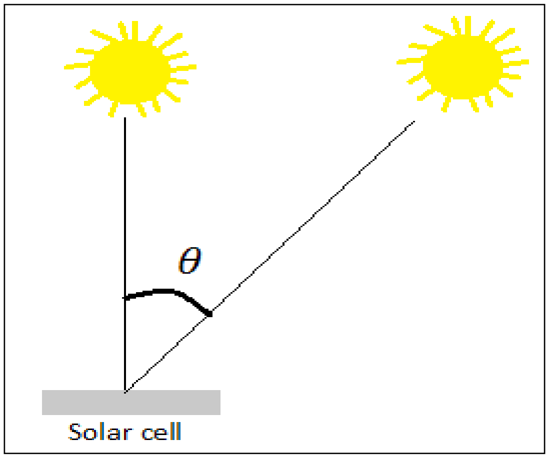
For the measurement of I-V and efficiency of solar cell, natural light of the sun was used with luminous intensity which was according to the standard that was obtained by the following (http://www. pveducation. org):

For the analysis of solar cell, Air Mass (AM) must be 1. 5. The AM is the path length which light takes through the atmosphere normalised to the shortest possible path length (that is, when the sun is directly overhead). The AM is defined as:

$$AM = \frac{1}{\cos\theta}$$

where θ is the angle from the vertical (zenith angle)

Fig. 2: Solar Cell

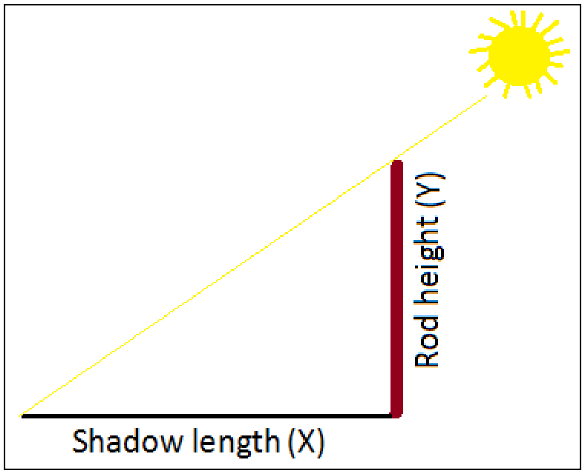


$$AM = 1.5 \rightarrow 1.5 = \frac{1}{\cos\theta} \rightarrow \cos\theta = 0.66 \rightarrow \theta = 48$$

A method to earn $\theta = 48$ and the AM = 1. 5 is by using the shadow of a vertical pole. The AM obtained by using the fixed rods were:

$$AM = \sqrt{1+\left(\frac{X}{Y}\right)^2}$$

Fig. 3: AM by Using Fixed Rods

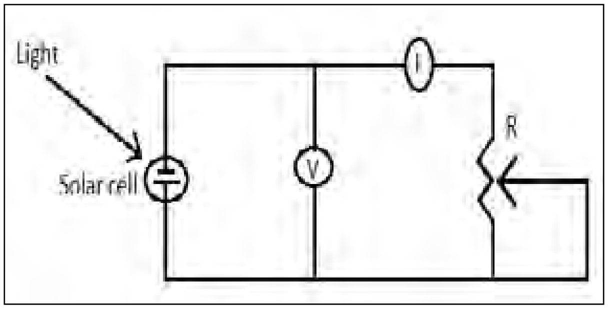


If AM = 1. 5 → Direct beam intensity(I_D) = 0. 846 kW/m^2 and the estimation of global irradiance(I_G) = 0. 9306 kW/m^2

Therefore, in this study luminous intensity = 0. 9306 kW/m^2 was used.

The following circuit was used to record results of the electric cell:

Fig. 4: Circuit



The efficiency of solar cell was obtained using the following equation:

$$\eta = \frac{V_m I_m}{P_{in}} = \frac{J_{sc} V_{oc} FF}{P_{in}}$$

Table1: Characteristics of DSSC (without the use of GO)

	$V_{oc}(v)$	$J_{SC}(mA/cm^2)$	FF%	% η
Without GO	0. 499	6. 15	63	2. 08

Where is the short circuit current density, is the open circuit voltage, = /is the fill factor, is the incident input power, is the maximum output power, J_m and are the maximum power the point current density and voltage, respectively.

Fig. 5: Diagram of Current Density–Voltage (DSSC Without the Use of Graphene Oxide)

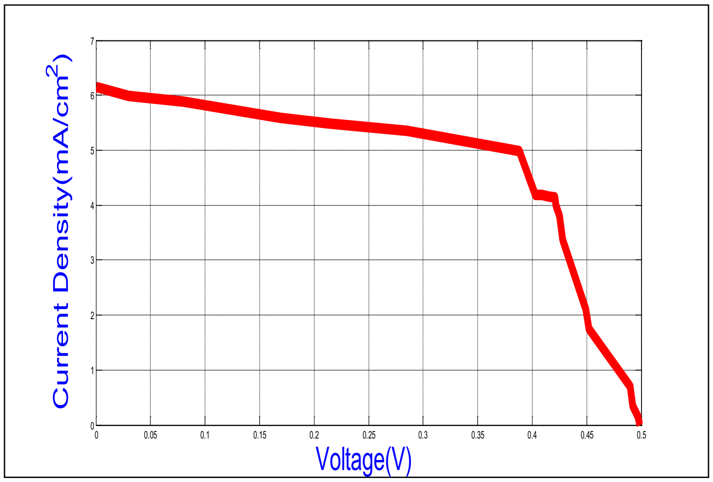
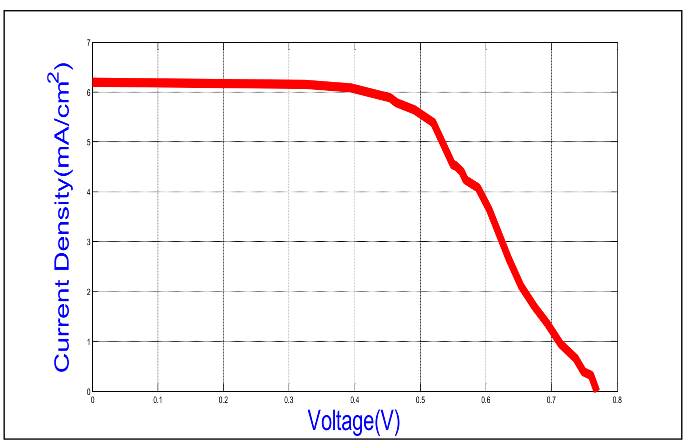


Table 2: Characteristics of DSSC (With the Use of GO)

	$V_{oc}(v)$	$J_{sc}(mA/cm^2)$	*FF%*	%η
With GO	0. 769	6. 22	58	3. 01

Fig. 6: Diagram of Current Density–Voltage (DSSC With the use of Graphene Oxide)



According to Tables 1 and 2 and Figs. 5 and 6, the value of short circuit current(was varied a little. However, the open circuit voltage(was enhanced from 0. 499 to 0. 769 V when the graphene oxide was used as the separation layer. In fact, the presence of graphene oxide layer between the dye and the platinum in DSSC had enhanced the distance between the fermi level of TiO_2. The voltage of the cell had also been enhanced, and finally the conversion efficiency of the cell had also been enhanced.

Photos of solar cells (DSSCs) fabricated in the laboratory were indicated in Figs. 7 and 8.

Fig. 7: DSSC Without the Use of Graphene Oxide

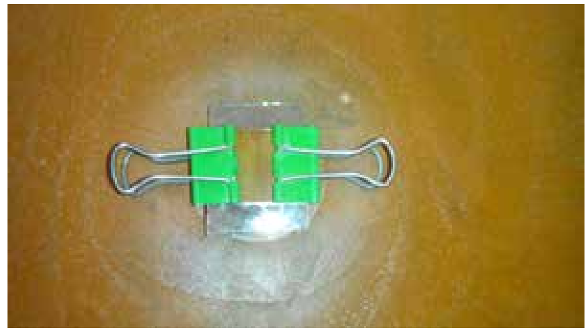
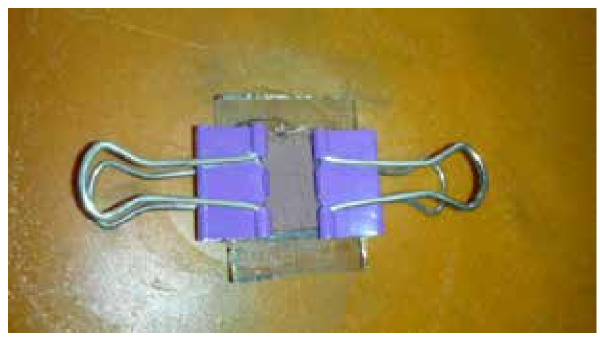


Fig . 8: DSSC With the Use of Graphene Oxide



Conclusion

In this study, to enhance the conversion efficiency of dye-sensitised solar cells, graphene oxide in the form of separate layer between the semiconductor and platinum was used. Graphene oxide embedded solar cell indicates higher voltage and therefore the enhanced efficiency as well. Also, the mixture of TiO_2 with different sizes as a new titanium dioxide paste is employed and marvelously the results is improved. The mixed paste contains two types of TiO_2 particles with different sizes, one nano and another one is in micro size, which can be explained in the form of good dye absorption by the mixture as well.

References

Chou, C. H., Chen, C. Y., Lin, S. H., Lu, W. H., & Wu, P. (2011). Preparation of TiO2/nio composite particles and their applications in dye-sensitized solar cells. *Advanced Powder Technology*, 26(3), 711-717.

Conti, J., & Holtberg, P. (2011). *International energy outlook*. U. S. Energy Administration.

Ellis, H. (2013). Pedot counter electrodes for dye-sensitized solar cells prepared by aqueous micellar electrodeposition. *Electrochimica Acta*, 107, 45-51.

Fang, X., & Li, M. (2014). Graphene quantum dots optimization of dye-sensitized solar cells. *Electrochimica Acta*, 137, 634-638.

Gao, P., Lui, J., Lee, S., & Zhang, T. (2012). High quality graphene oxide–cds–pt nanocomposites for efficient photocatalytic hydrogen evolution. *Journal of Materials Chemistry*, 22(5), 2292-2298.

Gao, P., & Li, A. (2014). Effects of various tio2 nanostructures and graphene oxide on photocatalytic activity of tio2. *Journal of Hazardous Materials*, 279, 96-104.

Grätzel, M. (2004). Conversion of sunlight to electric power by nanocrystalline dyesensitized solar cells. *Journal of Photochemistry and Photobiology A: Chemistry*, 164(1-3), 3-14.

Imahori, H., Umeyama, T., & Ito, S. (2009). Large pi-aromatic molecules as potential sensitizers for highly efficient dye-sensitized solar cells. *Accounts of Chemical*, 42(11), 1809-1818.

Kim, S., Kim, D., Choi, H., Kang, M. S., Song, K., Kang, S. O., & Ko, J. (2008). Enhanced photovoltaic performance and long-term stability of quasi-solid-state dyesensitized solar cells via molecular engineering. *Chemical Communications*, 40, 4951–4953.

Lanfang, Q., & Zhang, L. (2014). Titanium dioxide quantum dots: Magic materials for high performance underlayers inserted into dye-sensitized solar cells. *Journal of Power Sources*, 268, 670-676.

Lewis, N. S. (2007). Toward cost-effective solar energy use. *Science*, 315(5813), 798-801.

Maçaira, J., Andrade, L., & Mendes, A. (2013). Review on nanostructured photoelectrodes for next generation dye-sensitized solar cells. *Renewable and Sustainable Energy Reviews*, 27, 334-349.

Oprea, Q. I. (2014). A combined experimental and theoretical study of natural betalain pigments used in dye-sensitized solar cells. *Journal of Photochemistry and Photobiology A: Chemistry*, 240, 5-13.

Peter, L. M. (2013). The grätzel cell: Where next? *Journal of Physical Chemistry Letters*, 2(15), 1861-1867.

Rostami, P., Nemati, A., Byranvand, M. M., Mohammadpour, R., & Faridi, H. (2015). One-pot synthesis of zno nanoparticles and submicron-aggregates for dye-sensitized solar cells. *Materials Letters*, 139, 433-436.

Sacco, A. (2015). Toward quasi-solid state dye-sensitized solar cells: Effect of c-al2o3 nanoparticle dispersion into liquid electrolyte. *Solar Energy*, 111, 125–134.

Tarsang, R., & Promarak, V. (2014). Tuning the electron donating ability in the triphenylamine-based d--a architecture for highly efficient dye-sensitized solar cells. *Journal of Photochemistry and Photobiology A: Chemistry*, 273, 8-16.

Toyoda, T., & Sano, T. (2004). Outdoor performance of large scale DSC modules. *Photochemistry and Photobiology A: Chemistry*, 164(1-3), 203-207.

Tsai, C. H., Chen, C. H., Hsiao, Y. C., & Chuang, P. Y. (2015). Investigation of graphene nanosheets as counter electrodes for efficient dye-sensitized solar cells. *Organic Electronics*, 17, 57-65.

Yang, C. H. (2013). Spectroscopic evidences of synergistic co-sensitization in dye-sensitized solar cells via experimentation of mixture design. *Electrochimica Acta*, 107, 170-177.

Yao, P. C., & Hang, S. T. (2014). Enhancing photovoltaic performances of dye-sensitized solar cells by multi-layered nanostructured titanium oxide photoelectrode. *Solar Energy*, 108, 322-330.

Yella, A., Lee, H. W., Tsao, H. N., Yi, C., Chandiran, A. K., Nazeeruddin, M. K., Diau, E. W., Yeh, C. Y., Zakeeruddin, S. M., & Gratzel, M. (2011). *Science*, 334, 629-634.

http://www. pveducation. org.