Improving the Efficiency of Dye-Sensitized Solar Cells Using Platinum-Graphene Composite Based on Terminalia Chebula

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Abstract: Dye-sensitized solar cell is one of the nano-structured solar cells which have attracted much attention compared to silicon solar cells (first generation), because it can be made easier and cheaper. Researchers usually use commercial pigments such as (N-719), and (N-3) in dye-sensitized solar cells to absorb photons. In this project, we have used the extract of natural plant of Terminalia chebula instead of commercial pigments that are expensive, which is cheap, abundant, and environmentally friendly, but its efficiency is low. Accordingly, carbon derivatives were used in order to improve the efficiency of solar cells. Graphene is one of the carbon derivatives which have extraordinary properties in electronic devices such as solar cells. So, using graphene-platinum composite as counter electrode, current and voltage and eventually efficiency of solar cells increased.

Keywords: Solar Cells, Dye-Sensitized Solar Cells, Graphene, Terminalia Chebula.

I. Introduction

Global energy consumption growth in the last century, and with it, an increase in greenhouse gas emissions has been associated with the pollution of the environment, and irreparable damage to vital resources. In fact, according to the reports, the lack of energy and environmental pollution are considered as some important problems of the 21st century [1]. Also, it is reported that, prior to the 2035 global energy consumption will increase to 53% [2, 3]. In order to reduce global dependence on exhaustible resources and environmentally destructive fuels, many public efforts are made to reduce the cost of producing energy from renewable sources, including efforts to produce electrical energy using sunlight, which is done using an intrinsic property of semiconductors. If, only 0.1% of the surface of earth is covered with solar energy converters, and only have 10% efficiency, and is sufficient to meet human energy needed [4]. Solar cell is a device that converts solar energy directly to electricity (using the photovoltaic effect) without a connection to an external voltage source [5]. Photovoltaic phenomenon only occurs at certain wavelengths. This is because packets of light (photons) must have a minimum energy to excite the electrons in the material. Part of the photons which don't have enough energy to excite the electrons in molecules or semiconductors are not absorbed by the photovoltaic materials. On the other hand, if the photon energy is greater than the energy required to excite electrons, excess energy is wasted. This phenomenon causes 70% of the sun's energy remains without being consumed [6]. Various materials have been used in the manufacture of solar cells which have different efficiency and costs. In fact, these cells must be designed in such a way that can convert with (with high efficiency) wavelengths of sunlight that reaches the surface to useful energy [7]. In 1991, Professor Grätzel et al produced a solar cell with a conversion efficiency of more than 7% of energy by a successful combination of nanostructured electrodes and Charge Injecting Dye. This solar cell was named as "dye-sensitized nanocrystalline solar cell" or "Grätzel cell".Due to low cost, lack of structural complexity, good efficiency, and long lasting of dye-sensitized solar cells sensitized, research in this technology has progressed rapidly over the last two decades. Dye-sensitized solar cell in recent years have attracted much attention because of low cost, simple construction, flexible, using different colors in it and low sensitivity to contaminated and cloudy air [8-13]. Dye-sensitized solar cell components include important sectors such as glass coated with a transparent conductive oxide, semiconductor oxide (a porous layer of nanocrystals of titanium dioxide nanoparticles with wide band gap (3.5 eV)), light-sensitivedyes, oxidation-reduction electrolytic and counter electrode (cathode).In general, with an overview of the structure of dye-sensitized solar cells, these cells should be considered similar to a commercial alkaline batteries, in which, an anode and a cathode are placed on either side of a liquid electrolyte. In dye-sensitized solar cells, sunlight entered a layer of dye through a transparent electrode (conductive oxide), and excites its electrons. Then, the electrons will be transferred to the titanium dioxide nanoparticles of semiconductor.By absorbing the electrons in this bandgap, current is generated. The current has entered the circuitand transferred to the cathode. Cathode plays an important role as a catalyst, and enters electrons the electrolyte solution (iodide / triiodide) to re-enter the dye molecules through chemical reaction in the electrolyte, in fact, electron vacancies in Pigments are filled by electrons which are transferred from the electrolyte to the dye molecules, and pigment returns to the ground state. In dye-sensitized solar cell, the two processes are separated, these were carried in the old cell (silicon) by silicon. In the old cells, silicon is used as a source of photo-electrons and also it produces the electric field necessary for charge separation and generating current, while in the dye-sensitized solar cells semiconductors is used only for load transfer , and photo-electrons are provided by a light-sensitive dye [3,14, 15].But a closer look at a dye-sensitized solar cells, to examine step by step, photons of sunlight as shown in (Fig.1), and are converted to electric current according to the following steps:

(S ground state, S^* excited state and S^+pigment oxidized state).

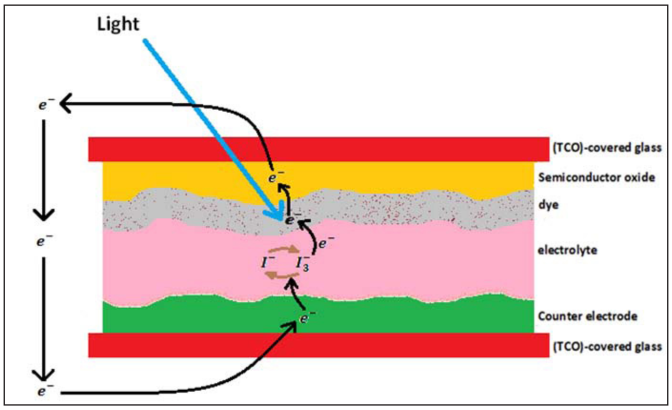

Fig. 1: Dye-sensitized Solar cell Performance

1. $hv + S \Rightarrow$
2. $S^* \Rightarrow S^+ + e^-$
3. $I_3^- + 2e \Rightarrow 3I^-$
4. $3I^- \Rightarrow I_3^- + 2e$
5. $S^+ + e^- \Rightarrow S$

In this study, we intend to examine presence of one of the derivatives of carbon (graphene) in dye solar cell. Graphene, due to the extraordinary properties of electrical conductivity and thermal conductivity, high density and mobility of charge carriers, high transparency, optical conductivity [16], mechanical properties [17] as well as high specific surface area [18] has become to an exclusive material, which can be used in the manufacture of electronic devices, especially solar cells to increase cell efficiency. Thus, in experiments that will be conducted in this project, Graphene as composite with platinum as the counter electrode will be used to understand solar cell efficiency. Also, in this study, in section related to light-absorbing dyes, we will use natural plant pigments, Terminalia chebula rather than commercial pigments to absorb photons.

II. Experimental

In this project, we will manufacture several different solar cell. In experiment A, we manufacture a conventional dye-sensitized solar cell without the use of graphene, and in other experiments, graphene will be used with in solar cells. For the manufacture of dye solar cell in experiment A, first two transparent conductive oxide glasses FTO with dimensions of 2.5 × 2.5 mm, the resistance of 15 ohms on the square, and a thickness of 2.2 mm (Fig. 2) were washed with distilled water and ethanol to thoroughly clean, and they put in the open air to dry up (These glasses have been purchased from Iran's Sharif University of Technology).

Fig. 2: The Glasses of Conductive Oxide FTO

We put one of them on a desk and the conductor side has identified, then its three sides are marked by tag with adhesive tape with the size of 3 mm from the edge of the glass. For making paste of titanium dioxide, 0.5 g of anatase titanium dioxide nano powder with particle size of 10-15 nm(purchased from Tecnologia Navarra de Nanoproductos of Spain) has poured into a mortar, then 9 ml of acetic acid and two drops of Triton X-100 has added to it, and it has mixed for half the time to forma mass of titanium dioxidepaste. We pour a little of this paste on glass, and by using doctor blade method, create a uniform layer of Tio_2on glass (Fig.3), and heat glass for 30 minutes at 400 degrees Celsius, and then we put it in the open air.

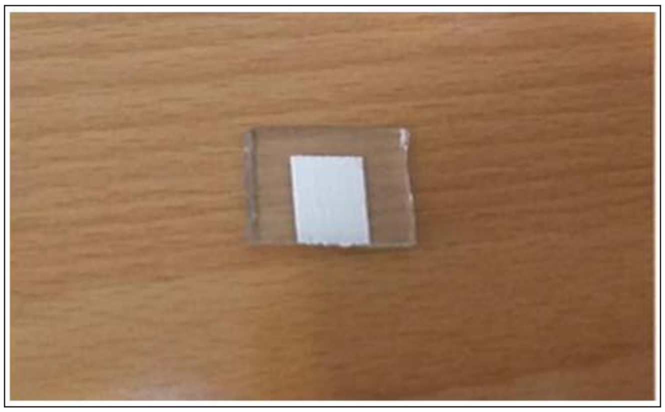

Fig. 3: Formation of Tio_2 Layer on a Conductive Glass

We will use the Soxhlet to extract the Terminalia chebula plant extract,in this apparatus, 40g of Terminalia chebulais milled, and 400 ml of methanol is also used in this apparatus. For the formation of pigment on Tio_2, we immerse the glass for 3 hours inside extracts of Terminalia chebula, and then, for the removal of additional molecules, glasses are washed with distilled water and ethanol, and we put glass in the open air to dry (Fig. 4).

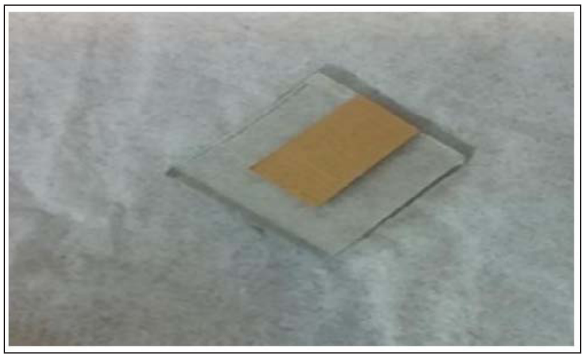

Fig. 4: The Formation of the Pigment Layer on Tio_2

Now, we determine the conductive side of the second glass, and substrate the platinum paste (purchased from Sharif University Iran) similar to Tio_2 deposition by using doctor blade method evenly on the glass, and heat it for 20 minutes at 450 ° C, and finally, the glass is out of the furnace, and cooled to room temperature, and then use it as a counter electrode (Fig. 5).

Fig. 5: The formation of Platinum Layer on a Conductive Glass

Both the glass are connected together using two clamps, and stuck together, and finally, we pour 0.08 mL of electrolyte on the free edges of the glass, the electrolyte layer will be formed on the layer of Terminalia chebula pigment. Thus, solar cell is manufactured and is ready to characterization (Fig. 6).

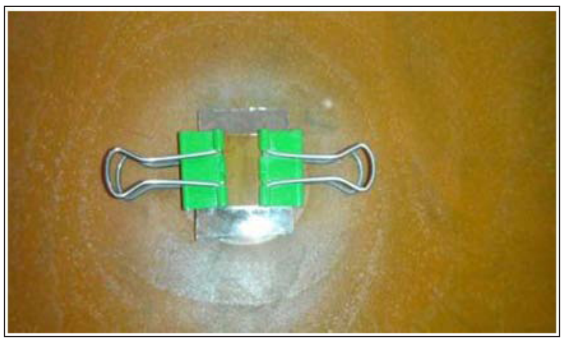

Fig. 6: Dye Solar Cell Made Without the Presence of Graphene

In second experiment, the platinum and graphene composite is used as the counter electrode, and the experiment is done three times and with varying amounts of graphene, so that, first time (experiment B) 0.03 mL, second time (experiment C) 0.06 ml and third time (experiment D) 0.1 ml of solution of graphene (Fig. 7) at a concentration of 0.5 milligrams per milliliter (purchased from Amir Kabir University in Tehran), and each time is added to 0.25 g platinum paste, and mixed , then, using doctor blade method, as in experiment A, we create a layer on the glass. The rest of the steps are similar to the experiment A (Fig. 8).

Fig. 7: Graphene Solution at Concentration of 0.5 Milligrams Per Milliliter of (Graphene in the Water Solvent as Stable)

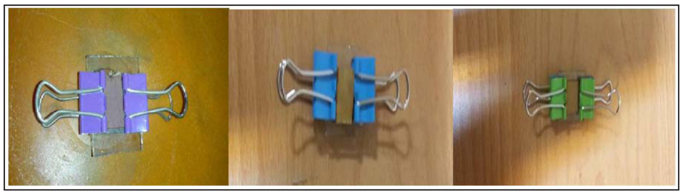

Fig. 8: Dye Solar Cells Made Based on Graphene

III. Results and Discussion

We use natural sunlight for the analysis of solar cells, and measuring the current - voltagewhich its light intensity in accordance with international standards for analysis of cells is obtained as follows:

The air mass (AM) should be 1.5 (air mass is a length of the pathwhich light moves through the atmosphere can to the nearest possible length of the path (which is when the sun is overhead)). According to the standard air mass to obtain a standard beam angle, we use the following formula(Eq. 1):

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

Where, is the angle compared to the perpendicular (zenith angle) and can be obtained as follows:

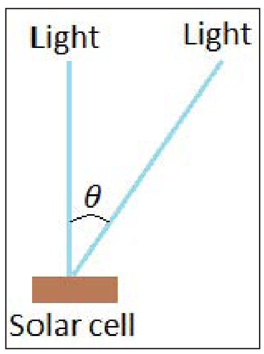

Fig. 9: Schematic of Light Radiation on the Solar Cell

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

Angle = and AM = 1.5 can be obtained as follows using the shadow of a stationary object: We consider a fixed rod, and by using the figure below (Fig. 10) and the Pythagorean theorem, we calculate the standard air masses (Eq. 2):

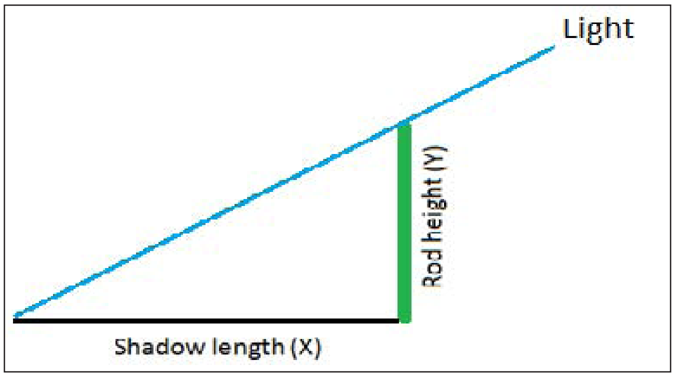

Fig. 10: Schematic of Obtain Air Mas(AM) by Using the Fixed Rod

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

To get the intensity of solar radiation, we use the following formula(Eq. 3),(Eq. 4):

$$I_D = 1.353 \times 0.7^{AM0.678} \tag{3}$$

$$I_G = 1.1 \times I_D \tag{4}$$

Where, I_D is direct beam intensity, and I_G is meeting the global radiation. So, if 1.5 = AM, I_D is 0.846 kW per square meter, and I_G is equal to 0.9306 kW per square meter. So, for this experiment, the light intensity equal to 0.9306 kW per square meter is used [19].

To obtain the current - voltage of solar cell, and charting it, we use a circuit similar to the following circuit:

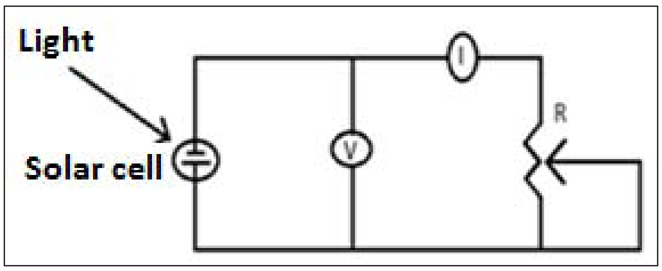

Fig. 11: Schematic of the Circuit Used to Record Results of the Electric Cell

We calculate cell efficiency using the following equation (Eq. 5):

$$\eta = \frac{V_m I_m}{P_{in}} = \frac{J_{sc} V_{oc}\, FF}{P_{in}} \tag{5}$$

Where, J_{sc} is short-circuit current density, V_{oc} is open circuit voltage, *FF* is fill factor, V_m and $I_m$is maximum output voltage and current and P_{in} is the input power [20].

Thus, we calculate current, voltage and efficiency of solar cells:

Table 1: Specifications of Solar Cells Made in the Project

%η	FF%	JSC(mA/cm2)	VOC(v)	experi-ment
2.09	56.7	5.86	0.585	A
3.01	58	6.22	0.769	B
3.46	59.5	6.90	0.785	C
2.36	55	6.30	0.635	D

Current-voltage diagrams of solar cells made in the project are as follows:

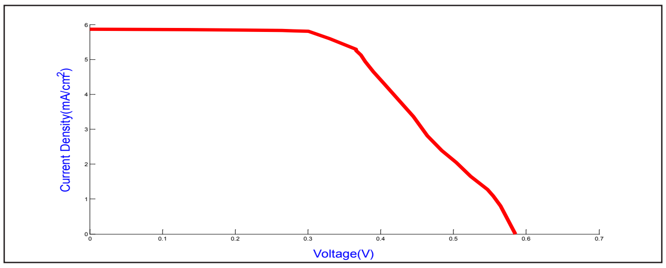

Fig. 12: Current-Voltage Diagram of Solar Cell Made in the Project Without the Use of Graphene (Experiment A)

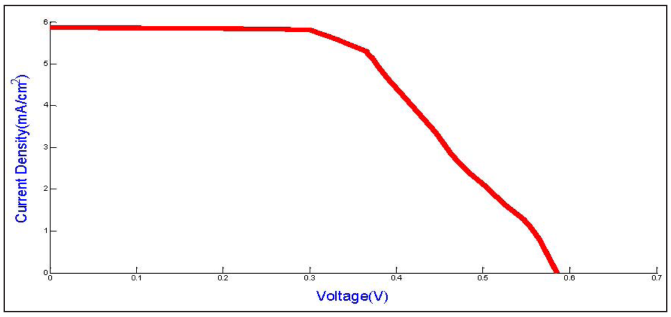

Fig. 13: Current-Voltage Diagram of Solar Cell Made in the Project using Platinum-Graphene Composite (Experiment B)

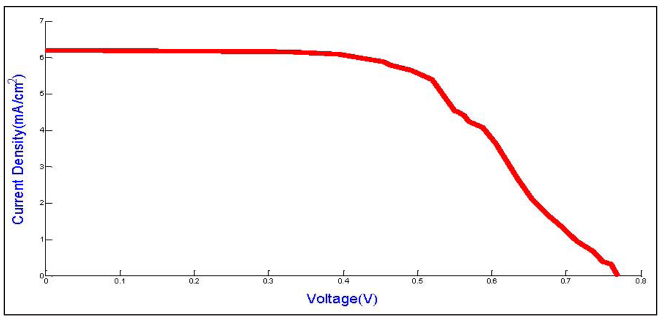

Fig. 14: Current-Voltage Diagram of Solar Cell Made in the Project Using Platinum-Graphene Composite (Experiment C)

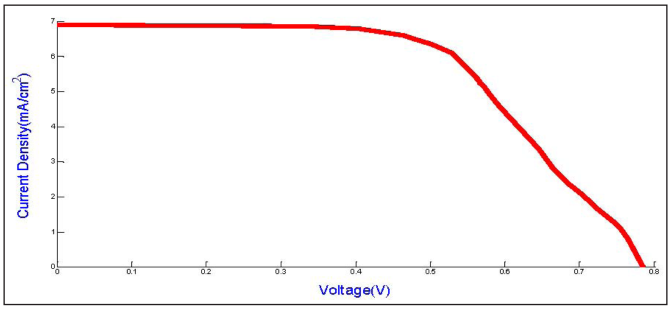

Fig. 15: Current-Voltage Diagram of Solar Cell Made in the Project Using Platinum-Graphene Composite (Experiment D)

Dye solar cell efficiency without the presence of grapheme was 2.09 percent resuled, but using graphene in solution form, and composite form, with platinum as the cathode, cell efficiency increased, and with increase in the amount of material inside the cell, efficiency is also increased. But with more than 0.06 ml of solution grapheme, solar cell efficiency was reduced. In fact, maximum solar cell efficiency, equal to 3.46,was achieved using 0.06 mL of the graphene solution. So, initially, with increasing graphene, efficiency is also increased, but with increasing the amount of graphene from a certain extent, current, voltage and output was reduced. In general, increasing the efficiency of solar cells by graphene and platinum composite can be for these reasons that the larger surface area of the counter electrode of the graphene / Platinum composite creates a positive effect by increasing the contact area of the electrode / electrolyte and provides more electrocatalytic sites to reduce in the counter electrode, the electrode of graphene / Platinum composite shows a higher electrocatalytic activity, has lower carrier transport resistance, generates more current which results in fast reaction kinetics in reduced in the counter electrode, which leads to lower carrier recombination. Also, graphene is stable, and corrosion doesn't occur by electrolyte. In this study, in addition to the counter electrode, we focused on photon absorption layers, and we used a natural pigment. The use of Terminalia chebula in solar cells, rather than commercial pigments, has faster titanium dioxide absorption. in fact, the pigment of N719, that has the highest efficiency among commercial pigments, It takes at least 24 hours to complete Tio_2 absorption, and the reason for this is that the titanium dioxide absorbs the ligands of N 719 slowly. However, Terminalia chebula has less photon absorption, which is why the efficiency of solar cells made by it is less.

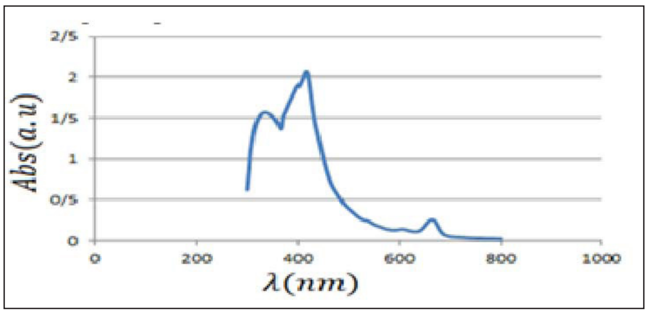

Fig. 16: Absorption Spectrum of the Extract of Terminalia Chebula

Due to the absorption spectrum of the extract of Terminalia chebula(Fig.16), this plant at wavelengths of 370-423nm and 322-352nm has absorption greater than 1.5, and at a wavelength of 416 nm, it has maximum absorption (absorbion: 2.068).

IV. Conclusion

As shown, the presence of graphene in dye-sensitized solar cells helped better performance of the cells and thus increased its efficiency. In fact, according to the electrical properties of graphene, and its high stability, such an outcome was not unexpected. Use of graphene solution in form of composite with platinum as catalyst has increased efficiency of solar cells by as much as 1.37 percent. Of course, by adding different amounts of graphene solution to the cell, different yields are achieved first, by increasing the amount of graphene, efficiency increased, but by increasing the amount of graphene solution from a certain level (more than 0.06 ml in this experiment), the efficiency reduced. However, according to test results, the presence of graphene in solar cells can be a good option to increase its efficiency. Also, in this study, a natural plant, Terminalia chebula, has been used in the area of photon absorption, as pigment layer that despite the lower efficiency than commercial and expensive pigments, has the advantages including it is cheap, accessible, environmentally friendly and its stability is good, and is absorbed easily by oxide semiconductor titanium dioxide.

References

[1] C. H. Tsai, "Investigation of Graphene Nanosheets as counter electrodes for efficient dye-sensitized solar cells," *Organic Electronics*, vol. 17, pp. 57-65, 2015.

[2] C. Conti, J. Lino, and P. Nunes, "*International Energy Outlook*," U.S. Energy Administration, 2011.

[3] C. H. Yang, "Spectroscopic evidences of synergistic co-sensitization in dye-sensitized solar cells via experimentation of mixture design," *Electrochimica Acta*, vol. 107, pp. 170-177, 2013.

[4] F. Bella, "Aqueous dye-sensitized solar cells," *Chemical Society Reviews*, vol. 44, no. 11, pp. 3349-3862, 2015.

[5] H. Imahori, T. Umeyama, and S. Ito, "Large π-aromatic molecules as potential sensitizers for highly efficient dye-sensitized solar cells," *Accounts of Chemical Research,* vol. 42, no. 11, 1809-1818, 2009.

[6] http://dc344.4shared.com/doc/ULh-YoeP/preview.html.2.

[7] http://edu.nano.ir/index.php?actn=papers_view&id=67.

[8] T. Toyoda, "Outdoor performance of large scale DSC modules," *Photochemistry and Photobiology A: Chemistry*, vol. 164, no. 1-3, pp. 203-207, 2004.

[9] P. Rostami, "One-pot synthesis of zno nanoparticles and submicron-aggregates for dye-sensitized solar cells," *Materials Letters*, vol. 139, no. 2, pp. 433-436, 2015.

[10] P. C. Yao, and S. T. Hang, "Enhancing photovoltaic performances of dye-sensitized solar cells by multi-layered nano-structured titanium oxide photo-electrode," *Solar Energy*, vol. 108, no. 8, pp. 322-330, 2014.

[11] H. Ellis, "PEDOT counter electrodes for dye-sensitized-solar cells prepared by aqueous micellar electrode-position," *Electrochimica Acta*, vol. 107, pp. 45-51, 2013.

[12] M. S. Alvar, "Enhancing the electron lifetime and diffusion coefficient in dye-sensitized solar cells by patterning the layer of TiO2 Nano-particles," *Journal of Applied Physics*, vol. 119, no. 11, 2016.

[13] J. Halme, "*Dye-sensitized Nano-structured and Organic Photovoltaic Cells: Technical Review and Preliminary Tests*," Master's Thesis at Helsinki University of Technology, 2002.

[14] A. Sacco, "Toward quasi-solid state dye-sensitized solarcells: Effect of c-al2o3 Nano-particle dispersion into liquid electrolyte," *Solar Energy*, vol. 111, no. 5, pp. 125-134, 2015.

[15] J. Nelson, "*The Physics of Solar Cells (Properties of Semiconductor Materials)*," Imperial College Press, 2003.

[16] R. R. Nair, P. Blake, and A. N. Grigorenko, "Fine structure constant defines visual transparency of grapheme," *Science*, vol. 320, no. 5881, pp. 1308, 2008.

[17] A. K. Geim, and P. Kim, "Carbon wonderland," *Scientific American*, vol. 298, no. 4, pp. 90-97, 2008.

[18] X. Fang, "Graphene quantum dots optimization of dye-sensitized solar cells," *Electrochimica Acta*, vol. 137, pp. 634-638, 2014.

[19] http://pveducation.org/.

[20] K. Maabong, "Natural pigments as photo-sensitizers for dye- sensitized solar cells with TiO2 thin films," *International Journal of Renewable Energy Research*, 5, 2015.