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Transparent Solar Cell Using Spin Coating and Screen Printing

A. A. F. Husain[1]* and W. Z.Wan Hasan[1,2]

[1]*Department of Electronic Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia*
[2]*Institute of Advance Technology, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia*

ABSTRACT

The development of Transparent Solar Cells (TSC) has become the main focus of solar energy research in recent years. The TSC has a number of applications and make use of unexploited space such as skyscraper windows. In this paper, TSC is fabricated using commercially available titanium dioxide (TiO_2) P25 to make a paste, which is deposited on FTO glass using screen printing and spin coating methods. The effects of the thickness of the TiO_2 film on transparency are examined. The paste is synthesised in the Cleanroom and used in both methods of deposition. The final cell fabrication is a Dye sensitised solar cell (DSSC). The obtained transparency of the FTO glass is 83%, and after the deposition of TiO_2 it is reduced to less than 80%. The overall transparency of the DSSC, which was made using the spin coating method, is 70% with an I_{sc} of 9.5 mA and V_{oc} 853mV.

Keywords: Transparent, Solar cell, TiO2, screen printing, spin coating

INTRODUCTION

In the last decades, solar energy has gained substantial attention from researchers due to its sustainability, environmental-friendly, and a great substitute to fossil fuel (Da, 2015) (Atul Tiwari (Editor), 2013) (M. Hosenuzzaman, 2015) (Bube, 1983). Various applications and technologies employ solar energy, such as cars, trains as well as organic and nonorganic solar cells respectively. This research is interested in photovoltaic solar cell, in particular dye syntsised solar cell (DSSC). This technology is the lowest in fabrication complexity and the solar cells. The DSSC converts photons from the sun to electricity through semiconductor materials such as Titanium Dioxide TiO_2. Titanium Dioxide has a photo catalytic property that helps convert solar energy into chemical energy to oxidise the material (Prochazka, Kavan, Zukalova, & Vlckova Zivcova, 2013). Additionally, TiO_2 has properties such as oxidisation, superhydrophilicity, chemical stability and it is also durable, non-toxic, cheap and transparent to visible light (Nakataa

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E-mail addresses:
alaa.a.f.husain@gmail.com (A. A. F. Husain),
wanzuha@upm.edu.my (W. Z. Wan Hasan)
*Corresponding Author

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& Fujishimaa, 2012). The photo catalytic properties of TiO_2 are due to the photogeneration of holes and electrons which occur after the absorption of the UV light that contains the equivalent energy to the band gap (Ikeda, Sakai, Baba, Hashimoto, & Fujishima, 1997). The holes diffused from the valence band to the surface of the TiO_2 react to the photons forming hydroxyl radicals (•OH). On the TiO_2 surface, organic molecules oxidise with the holes and the hydroxyl radicals, while electrons in the conducting band produce superoxide radical anions (O2 •−) (Fujishima, N. Rao, & A. Tryk, 2000).

In order to develop the properties of TiO_2, new structures have been created in nano and micro sizes. Many nano structured materials have been fabricated such as spheres, nanorods, fibers, tubes, sheets, and interconnected architectures. These structures have wide applications specially in DSSC. This research is focused on nano structure for achieving transparent TiO_2 without affecting the efficiency of light harvesting. The transparency is achieved through thin film technology. Thin film solar cell (TFSC) technology has semiconducting material deposited on the substrate with a thickness not more than few micrometers (Chopra, Paulson, & Dutta, 2004). Through this technology, cost can be lowered by reducing the amount of the active layer. Moreover, thin film technology is flexible, which increases its applications (Matsuno, Naomoto, & Arimoto, 1995) (Bjorkman, Kessler, & St, 2006). Through controlling the thickness of the film, the transparency will be controlled and eventually increased (Kim, Kim, & Seong, 2015). There are different methods of depositing thin film on the substrate such as chemical bath deposition (CBD) technique, physical vapour deposition (PVD) technique and sputtering (Reichelt, 1990), electro deposition (Deposition of transparent TiO_2 nanotube-films via electrophoretic technique for photovoltaic applications, 2015) (Bahramian & Vashaee, 2015) (T.Yuasa, 2012), screen-printing (Ramasamy, 2007; Nam, 2010; Lee, 2007; Fan, 2010), pulsed laser deposition (PLD) (Kumar, Ntwaeaborwa, & C, 2016; Liu, et al., 2016), Spray and Atomic layer deposition (ALD).

Screen printing is one of the most popular methods in depositing thin film due to ease of controlling the thickness by managing fabric thickness. In addition to that, quality of the paste, mesh opening size and fabric thickness are other factors to be controlled for improving the performance of the thin film and its transparency (Ito, Chen, Comte, & Khaj, 2007) (Park, 2008). Spin coating is also used to apply thin film onto substrate in many applications. The advantages of spin coating are that it requires less time and effort to make a thin film. The solvent is cast on the glass in an uniformed way because of the centripetal force and the tension of the solution on the surface. In order to make a thin film using spin coating, the rotation speed must be more than 1000 rpm. In this study, the methods of screen printing and spin coating are employed.

METHODOLOGY

In this section, the experiment is discussed and illustrated in Figure 3. The experiment is divided into two stages: the first is spin coating and the second is screen printing. Before the experiment begins, the paste is prepared in the clean room. Below describes the materials used in the experiment.

Materials

For making the paste, the following materials were used: titanium dioxide TiO2 (P25) (Aldrich, USA), Acetic acid, Water, Ethyl alcohol, α Terpineol and Ethyl cellulose. FTO glass (100mm × 100mm × 1.6mm), transmission ≥ 83%, resistance sheet 15Ω/sq (Kivo, China) was used as a base, and for cleaning the glass Isopropyl alcohol (IPA), Acetone AR Grade were used. Scotch tape was used for framing. Hydrogen Hexachloroplatinate (IV) Hexahydrate was used for coating the counter electrode. The materials for preparing the dye are: acetonitrile (solvent), Iodine (I2) (QRëC, New Zealand), Lithium iodide crystalline powder 99.9% trace metals basis (Lil) (Aldrich, USA), 4-tert-Butylpyridine 96% (Aldrich, USA), Ethyl-methyl-Imidazolium iodide (Aldrich, USA), Di-tetrabutylammoniumcis-bis (isothiocyanato)bis(2,2′-bipyridyl-4,4′-dicarboxylato) ruthenium(II) 95% (NMR) Synonym: N-719 dye (Aldrich, USA).

Experiment

TiO_2 paste was fabricated using the method reported by (Ito S. C., 2007). Three replicas of the solution were prepared. Each of the replicas was evaporated to form a paste with different concentration. The volume of each paste was 166.6ml. After evaporating to P1 (5/10), P2 (3/10), and P3 (1/10), the paste volumes in orders were 80ml, 50ml, and 16.6ml. The deposition was carried out directly to experiment the effect of temperature during deposition. The experiment is divided into two stages. The first, spin coating, and the second, screen printing.

Spin coating. The paste which was prepared in the previous section was used for spin coating using Polos spin coater. Three variables were controlled to of the film; speed, concentration, and temperature. The paste amount was fixed to less than 0.5ml per drop. The solution temperature and concentration were 42-65 C and 5/10 and 3/10 respectively, The speed in spin coating was fixed to 10000 rpm for 120 s while the acceleration was 100 rpm /s. The acceleration remained the same when the solution was 5/10 at room temperature. In addition, the speed was 10000, the time 300 s, and the acceleration 1000, when the concentration was 1/10 and the temperature 40-42 C. The same speed and acceleration remained for the rest of samples, 3/10 and 1/10, at room temperature.

Screen printing. For the screen printing experiment, a special board was designed for preparing nine samples with three controlled variables (i.e. concentration, temperature, and numbers of layers). The characteristics of the board are 90 T-mesh/cm (230T mesh/inch), 60 µm mesh opening, 50 µm thread diameter, 29.8% open surface, 20 µm fabric thickness, 24.5 (cm^3)(m^-2) theoretical paste volume, (17cm^3)(m^-2) k/k volume, 48gm^-2 weight.

The amount of paste to be deposited was fixed to less than 0.3ml; the first three samples were prepared using high temperature for the three concentrations of pastes (P1, P2, and P3). The same pastes were used to prepare another three samples at 28°C. After that, 10 samples were prepared using P1 at room temperature by increasing numbers of layers in each sample. In each layer, a drop of paste with a volume of less than 0.2 ml was deposited on the FTO glass. After preparing the samples, the counter electrode of the solar cell was prepared using spin coating by dropping 50µ, 1500 rpm for 20s of H_2+Pt+Cl_6 solution on the FTO glass. All the samples were annealed in furnace at 450°C for 30 minutes and then left in the oven overnight to cool down.

DSSC fabrication

The DSSC assembling was done following the conventional method reported in (Ito, Chen, Comte, & Khaj, 2007). After testing the effects of using screen printing and spin coating on transparency, the assembling was carried out to test the efficiency. The electrode TiO_2 was immersed in N791 dye solution at room temperature for 36 hours. After taking the TiO_2 sample glass out of the dye solution, it was cleaned with some ethanol and air-dried for 10 minutes. The electrolyte was prepared out of Acetonitrile solvent 10ml, I_2 0.05M, LiI 0.1M, 4-tert-Butylpyridine 0.5M, and Ethyl-methyl-Imidazolium iodide 0.6M. The electrode covered with dye and the counter electrode covered with Pt were assembled in a sandwich form using polymer sheets with a 25µm thickness on a hotplate. For depositing the electrolyte, a small space was left open as shown in Figure 1. In this experiment, no hole was made in the counter electrode. Finally, between one and two drops of the electrolyte were added from the open corner of DSSC and the cell was sealed using Epoxy resin to finish the assembling of the cell.

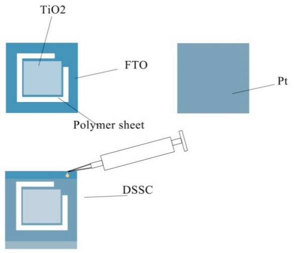


Figure 1. DSSC assembling

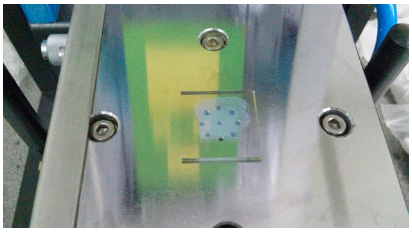


Figure 2. TiO_2 spilled while depositing using screen printing

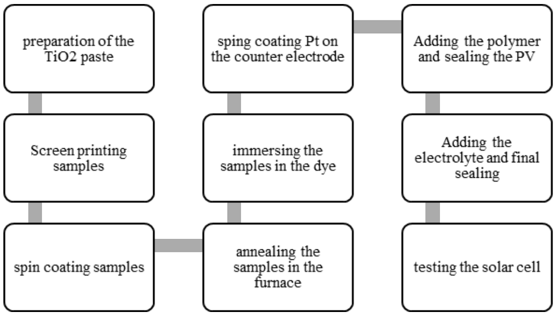


Figure 3. Methodology flow chart

RESULTS AND DISCUSSION

Paste fabrication and deposition

Three replicas of TiO_2 Paste were fabricated in the clean room based on the method explained in (Ito, Chen, Comte, & Khaj, 2007). The first variable in the experiment was the paste concentration of the titanium dioxide. The solution was evaporated alcohol to form a different percentage of pastes, P1 (0.1), P2 (0.3), and P3 (0.5).

During the spin coating deposition of the paste, it is noticed that when the paste is highly concentrated, it was harder to deposit on the FTO glass than the less concentrated paste ending up with a thicker layer. Moreover, at high temperature, the viscosity of the paste was reduced which made the deposition easier. On the other hand, when P3 is used, it is recommended to reduce the acceleration while for P3 and P1, it is better to increase the acceleration to 1000/s. when P1 was used for preparing the samples, after annealing it in the furnace dried and peeled off the FTO. As for screen printing, when P1 was used it is hard to deposit unless the temperature is high, while P2 deposited easily. As for P3, its viscosity is very high for screen printing and much of it is spilled outside the active area (Figure 2).

Transparency and efficiency measurement

The tables below show the measurements of the highest transparency, the voltage open circuit (V_{oc}) and the current short circuit (I_{sc}) achieved by each sample in spin coating (Table1) and screen printing methods (Table 2). The transmittance was measured using UV- Vis spectrometer (Perkin Elmer Lambda 35, USA). The V_{oc} and the I_{sc} were measured using digitalmultimeter and light source with a power of *100mW/cm*^{2}.

It is clear from the results shown in the table below that number of layers have a slight effect on transparency. The transparency drops slightly from 79% to 76% when the number of layers increases (Figure 4). On the other hand, the voltage open circuit decreases by increasing the number of layers while it is the opposite for the current short circuit - it increases by increasing the number of layers until 5 layers after which it drops again (Figure 6). As for the concentration of the paste, the best one is P2, which has the highest transparency (Figure 6) and the best V_{oc} and I_{sc} when it is deposited in room temperature (Figure 7). Furthermore, when the temperature of the paste was more than 40 C, the transparency dropped for P1 & P3 bur remained the same for P2 (Figure 8) and V_{oc} and I_{sc} decreased as shown in Figure 9.

Table 1
Spin coating testing measurements

Sample	Temperature *C*°	Paste	Transparency peak %	Voc	Isc
S15	42	P3	73.9	126	2.2
S16	28	P3	70	743	4.5
S17	63	P2	70	191	2
S18	28	P2	71	295	2.3
S19	40	P1	69	620	2.3
S20	28	P1	27	-	-

Table 2
Screen printing testing and measurements

Sample	Layers	Temperature $C°$	Paste	Transparency peak %	Voc(mV)	Isc(mA)
S1	1	28	P3	80	509	1.5
S2	1	28	P2	82	720	8.6
S3	1	28	P1	79	644	1.7
S4	2	28	P1	78	621	3
S5	3	28	P1	77.5	628	2.7
S6	4	28	P1	77	629	6.6
S7	5	28	P1	76	340	4.8
S8	6	28	P1	78.4	319	2.9
S9	7	28	P1	76.7	625	5
S10	8	28	P1	77.4	212	2.3
S11	9	28	P1	77	296	2.9
S12	10	28	P1	76.2	393	1.6
S12	1	46	P3	78	300	1.6
S13	1	63	P2	81	127	.9
S14	1	61	P1	78	580	1.3

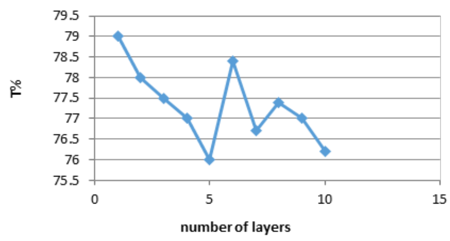


Figure 4. The transmittance spectra of TiO2 on FTO glass using Screen printing In Room temperature

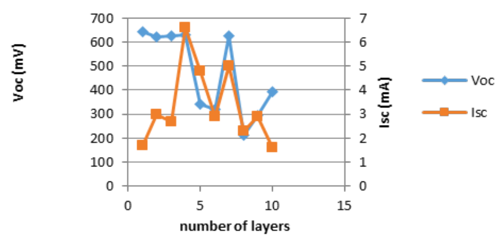


Figure 5. Voltage open circuit and current short circuit of DSSC made using screen printing

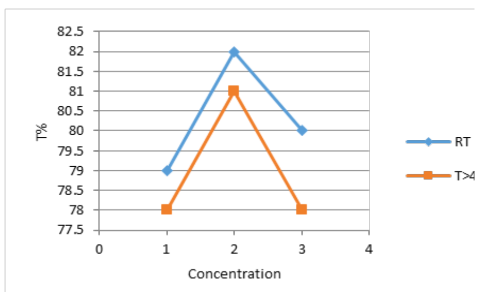


Figure 6. The transmittance spectra of TiO_2 on FTO glass using screen printing

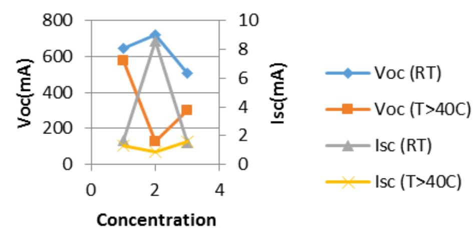


Figure 7. Voltage open circuit and current short circuit of DSSC made using screen printing

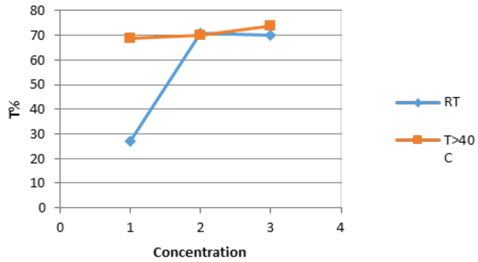


Figure 8. The transmittance spectra of TiO2 on FTO using spin coating

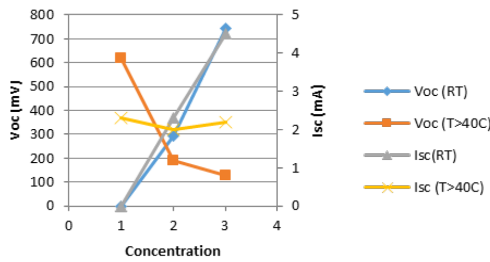
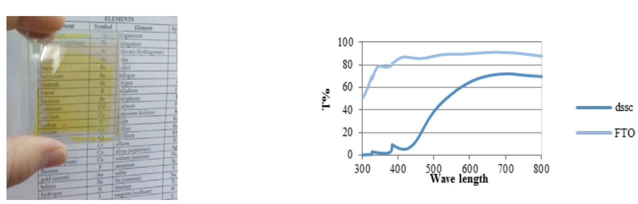


Figure 9. Voltage open circuit and current short circuit of DSSC made using spin coating

Spin coating performed better when the paste was deposited in temperature higher than 40 C. The three pastes had almost the same transparency. It dropped when the paste was deposited on RT for P1 due to its low viscosity. This means, increasing the temperature of the paste during the deposition will increase its viscosity. However, V_{oc} and I_{sc} were better with the low concentration than high concentration paste at room temperature. As for high temperature, V_{oc} was better with higher concentration and I_{sc} was almost the same for the three concentrations.

The transparency ranges from 75-80% and from 27-73% in screen printing and spin coating respectively. During deposition, screen printing was much better in terms of homogeneity and transparency than spin coating. For spin coating when the solution had low concentration it was easier to deposit and the resulted transparency was high.

Finally, a model sample was prepared with 5cm* 5cm measurement from FTO glass. The active area was 4cm*4cm. The TiO2 was deposited on the glass using screen printing with the same characteristic as the previous samples and using the paste with a concentration of 3/10 at RT. A final DSSC was fabricated using this sample and the transmittance was measured using UV-Vis spectrometer (Perkin Elmer Lambda 35, USA) as shown in Figure 10. It can be concluded that the peak transmittance obtained in this sample was 70%. The V_{oc} of this sample was 853mV and the I_{sc} was 9.4mA.



(a) (b)

Figure 10. (a) Transparent DSSC, (b) The transmittance spectra of DSSC and FTO glass

CONCLUSION

Transparent DSSC is hard to achieve fully as transparency is the total opposite of the concept of solar cell. However, this research tested two methods and their effects on transparency: spin coating and screen printing. When the results of both methods were compared, screen printing was better for making the thin film of titanium dioxide. Spin coating is not recommended because of the high viscosity of titanium dioxide which makes it dry faster and restricts its uniform coating on the surface of the substrate. In screen printing, three variables were considered to observe their effects on transparency, temperature, concentration, and number of layers. We inferred from our experiment that the best number of layers is 4 or 5, the best concentration is 3/10, and the best temperature is room temperature. Additionally, the variables in the spin coating were temperature and concentration. In using spin coating, the best concentration is P2, and the best temperature is above 40°C. It is noticed that P1 has a low viscosity which makes it dry and peels off after annealing. Spin coating is more suited for research purposes rather than manufacturing because it requires single sample each time which results in material wastage which is not feasible for manufacturing purposes. On the other hand, screen printing is faster, more economical in terms of the amount of materials consumed in deposition and the thickness is easily controlled using this method. The best Paste to use in screen printing is P2 due to its suitable viscosity compared with P3 which is not advisable. In this study, the transparent solar cell was successfully fabricated with more than 70% transmittance peak using screen printing method.

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