Journal of the Nigerian Association of Mathematical Physics
Volume26, (March, 2014), pp 501 – 527

Design and Construction of Dye-Sensitized Solar Cells (DSSCs) Incorporating Electrostatic Spray-Deposited Titanium Dioxide (TiO_2) Blocking Layers

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Abstract

The efficient performance of a Dye Sensitized Solar Cells (DSSC) is the blocking layer which among other things retards electron-hole recombination and improves the adhesion of the mesoporous Titanium Dioxide (TiO_2) layer to the fluorinated Tin oxide (FTO) substrate. Traditionally, blocking layers are deposited by spray pyrolysis, spin coating, sputtering or sol-gel among other methods. In this work, we explore electrostatic spray deposition subjected to a high voltage of 17kv with a constant distance of about 13.8cm between FTO and electrospray syringe orifice at a flow rate of 0.17ml/min with a constant temperature at 350^0C for the fabrication of dense TiO_2 blocking layers. TiO_2 nanoparticles were characterized by x-ray diffraction (XRD) pattern and the optical transmittance spectra in the ultraviolet and visible regions were determined using the UV-vis spectroscopy. By controlling different parameters including spray deposition times, the gap between two electrodes and sensitization times, Dye sensitized TiO_2-based solar cells with high efficiencies were achieved and compared. The results show that the increase in thickness of TiO_2 thin films via increasing the spray deposition times from 3 minutes to 5 minutes and then to 7 minutes with every other parameters kept constant, decreases the power conversion of efficiencies the solar cells, and the transmittance of the TiO_2 thin films. However, efficiency (%) of DSSC constructed with the 3 minutes deposited TiO_2 thin film electrodes is greater than those of DSSCs with either 5 or 7 minutes deposited TiO_2 thin films electrodes.

Keywords: Dye sensitized solar cells, electrostatic spray, Titanium dioxide TiO_2 blocking layers

1.0 Introduction

Dye sensitized solar cell (DSSC) is the only solar cell that can offer both the flexibility and transparency. Its efficiency is comparable to amorphous silicon solar cells but with a much lower cost. It is a photo-electrochemical solar cell that is generally composed of a photoactive mesoporous nanocrystalline semiconductors like TiO_2, ZnO and SnO_2 as a working electrode and counter electrode anchored with dye molecules.

Recently, Dye sensitized solar cells (DSSCs) have been the subject of intense study on account of their high conversion efficiency, low cost, less toxic manufacturing, easy scale up, light weight and use of flexible panels compared to conventional p-n junction devices.

Dye sensitized solar cells separates the two functions provided by silicon in a traditional cell design. Normally the silicon acts as both the source of photoelectrons, as well as providing the electric field to separate the charges and create a current. In the dye-sensitized solar cells the bulk of the semiconductor is used solely for charge transport, the photoelectrons are provided from a separate photosensitive dye. Charge separation occurs at the surface between the dye, semi conductor and electrolyte [1]

The dye molecules are quite small (nano meter sized), so in order to capture a reasonable amount of the incoming light the layer of dye molecules needs to be made fairly thick, much thicker than the molecules themselves. To address this problem, a nano-material is used as a scaffold to hold large number of the dye molecules in a 3-D matrix, increasing the number of molecules for any given surface area of cell. In existing designs, scaffolding is provided by the semiconductor material, which serves double-duty construction. In the case of the design and construction done in this work, the cell has 3 basic parts, on top is a transparent substrate glass made of fluorinated tin oxide (FTO) on the back of it.

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On the back of this conductive plate is a dense titanium dioxide (TiO_2) blocking layer which forms into a highly porous structure with an extremely high surface area. TiO_2 only absorbs a small fraction of the solar photons (those in the UV). The plate is then immersed in a mixture of a photosensitive chlorine-E6 dye (also called molecular sensitizers [2]) and a solvent. After soaking the film in the dye solution, a thin layer of the dye is left covalently bonded to the surface of the TiO_2. All components put together on top of the DSSC is called the photo-electrode (photo anode).

A separate plate is then made with a thin layer of the iodide electrolyte spread over a conductive sheet, typically platinum metal. The two plates are then joined and sealed together to prevent the electrolyte from leaking.

At the down is the transparent substrate glass, made of fluorinated tin oxide (FTO) on the back of it coupled with a platinum catalyst (pt), which is used for the re-generation of the electrolyte. This set of components is called the counter electrode (photo cathode).

2.0 Materials and Method

The nanoparticles TiO_2 layer were deposited by electrostatic spray deposition method (ESD) using 2ml Titanium tri-chloride added to 1ml acetic acid while stirring with additional 85%wt, 15ml ethanol. The prepared TiO_2 solution was electrosprayed onto a grounded fluorinated tin oxide substrate (FTO) at 17kv with a constant distance of approximately 13.8cm between FTO and the electrospray syringe at a flow rate of 0.17ml/min for 3 minutes, 5 minutes and 7 minutes. The resultant ESD TiO_2 blocking layer for 3 minutes was 100nm thick and was sintered at 350^0C for 30min in air.

In order to compare the effect of the blocking layer, three kinds of DSSCs were assembled:

i. DSSC fabricated from the ESD TiO2 blocking layer on the FTO substrate electrosprayed in 3 minutes at 17kv leaving other parameters constant.
ii. DSSC fabricated from the ESD TiO2 blocking layer on the FTO substrate electrosprayed in 5 minutes at 17kv.
iii. DSSC fabricated from the ESD TiO2 blocking layer on the FTO substrate electrosprayed in 7 minutes at 17kv.

(ii) and (iii) are the reference cells used to obtain the efficiency of the DSSC in (i).

Furthermore, mesoporous TiO_2 paste (SOLABONIX) were prepared on the dense TiO_2 blocking layer by a doctor blade technique and was heated at 100^0C for 1 hour.

A few drops of platinum solution (100g) (SOLARONIX) were dripped on the already made FTO substrate glass with dimensions of $2x2cm^2$ and in order to the stabilization of platinium on the FTO glass it was placed on electric furnace about 30 minutes in 500^0C.

Chlorin-E6 dye was used to sensitize the TiO_2 photo electrodes. The electrodes were immersed for 24 hours in a little quantity of the dye solution containing a mixture of acetonitrite and ethanol (1:1) and dried at room temperature. After the sensitization, UV-Vis spectrum was taken from electrode in both conditions, before and after sensitization. The dye-absorbed electrode was assemble into a sandwich-type cell with a counter electrode and spacer in the middle for ease of electrolyte solution injection. For the preparation of counter electrodes, a few drops of 5mM solution of H2PtCl6 in Isopropanol were allowed to spread on FTO. The plates were air dried for 5 minutes and heated at 3500C for 1 hour. The pt electrode was placed over the dye absorbed TiO_2 electrode, and the edges of the cell were sealed with a tiny thickness foil of polyethylene. The redox electrolyte used was 10-dolyte AN-50. A drop of the electrolyte solution was introduced into the cells.

3.0 Characterization of TIO_2 Thin Film

The XRD measurements were done with diffractometer system (XPERT-PRO) with generator settings of 40mA X 45KV to evaluate the crystal structure of the films, using Cu K∞ radiation with 0.5 ratio in the scanning angle range 10.093-100.033, and intensity range 5407.9 – 1063.4. Current- voltage characteristics of DSSCs were performed under 1 sun illuminator (Am 1.SG, $1000wm^{-2}$ with a Newport Solar Simulator. The photocurrent-voltage (I-V) measurements were used to calculate the short-circuit current (I_{sc}), open circuit voltage (Voc), fIll factor (a measurement of the “squareness” of the solar cell (FF)], and overall conversion efficiency (ŋ) of DSSC.

4.0 Results and Discussion

The X-Ray diffraction (XRD) analysis is conducted to determine the phases and the grain size. The XRD patterns for the investigated samples prepared at different deposition times at constant deposition temperature are shown in Fig (1.1a,b,c). It confirms that the product is titanium dioxide.

All diffraction peaks are indexed with the standard JCPDS (21-1272) and found to be corresponding to the pure anatase TiO_2 crystalline phase. The mean crystalline size diameter (D) of the TiO_2 nanoparticles has been obtained using equation (1.1)[3]

$$D=K\lambda/\beta\cos\theta) \text{ or } (D=0.9\lambda/\beta\cos\theta \qquad (1.1)$$

where k=0.9, β is full width at half maximum, or half-width (FWHM) in radians, θ_B is the brag angle at the position of the maximum of diffraction peak and λ is the x-ray wavelength (1.54060A for CU $K\alpha_3$). Crystallite minimum step size [^{0}2Th] has been found to be about 0.001m, with 10.00mm specimen length.

Also, XRD was used to investigate the changes of phase structures and crystalline sizes of the TiO_2 nanoparticles after spreading on the FTO and calcinated at 350^0C. Fig 1.2 shows the plot of identified phases structure;

Plot of identified phases structure and crystallite sizes of the TiO_2 nanoparticles investigated by XRD. It can be experimentally observed that the crystallinity of TiO_2 nanoparticles is quantitative evaluated via the relative intensity of the maximum diffraction peak of the anatase, corresponding to a score of 86 with a scale factor 0.972, but there are several small peaks and vibrations found in the spectrum, corresponding to glass substrate. In this case, the size of the sintered TiO_2 dense particles is calculated to be 15mm and it is appropriate for standard TiO_2 dense particles. Table 1.1 shows the XRD peak list used in calculating the mean crystalline size diameter for all three different deposition time samples.

Table 1.1 shows the XRD peak list used in calculating the mean crystalline size diameter (D) in meters for all three different deposition time samples.

The calculated values for the crystalline size is obtained by applying Equation (1.1)

Figure 1.3 shows the variation of optical transmittance of dense TiO_2 film on FTO surface using the optical transmittance spectra, the absorption coefficient and the band gap of TiO_2 film were evaluated. The absorption coefficient α was calculated using the equation (1.2).

$$\alpha = \ln(1/T)/t \qquad (1.2)$$

Where T is the transmittance and t the thickness of the film. The thickness of the film was evaluated from the UV-spectrum and the average value corresponds to 100nm for dense TiO_2 thin film. The band gap energy was obtained by plotting the optical absorption, $(\alpha hv)^2$ against the photon energy, (hv), and extrapolating the linear portion of the curve to $(\alpha hv)^2 = 0$

Titanium oxide film deposited on the FTO surface at 3 minutes absorbs appreciably at wavelengths of about 320nm, and confirms that accurate band gap energy of a 3.ev TiO_2 anatase film. The decrease transparency of the titanium oxide film deposited at either 5 or 7 minutes determines relatively high absorption once the TiO_2 layer increase in thickness. It can be observed vividly from Fig. 1.3 that there is higher transmittance in the ultraviolet region due to its transmittance from the 3 minutes deposited TiO_2 dense particles rather than the (5 and 7) minutes deposited TiO_2 dense particles.

The performance of fabricated solar cells has been tested under the same condition and some important parameters in the procedure have been studied which are discussed as follow:

By repeating the deposition procedure of the TiO_2 thin film and increasing the deposition time, the performance of the produced solar cells with different TiO2 thickness layers were examined critically.

As the thickness of the blocking layers were increased via increase in deposition time from 3 minutes to either 5 or 7 minutes the open-circuit voltage increases and decreases the power conversion efficiencies ŋ(%). This may likely result from the high transmittance produced by the 3 minutes deposited time resulting to a faint thickness of the films and probably also contributes to the improvement of solar cell performance. The increasing of the efficiency, (ŋ), was largely due to an increasing of short-circuit current, (I_{sc}) resulting from the prevention of the back transfer of electrons from the conducting layer on the FTO substrate to the electrolyte [4]

Figures 1.4a,b, 1.5a,b and 1.6a,b show the photocurrent-voltage (I-V) curve for DSSC with (3 minutes, 5 minutes and 7 minutes) deposition times of TiO_2-dense blocking layers. From the DSSC simulation curve, it can be observed that power conversion (mW) and efficiency (ŋ) increase with the decrease of the TiO_2 thin film thickness which constitutes the first dense blocking layers of the cells. Moreover, the I_{sc} and ŋ of DSSC fabricated with the electrosprayed electrodes having smaller thicknesses of TiO_2 blocking layers as a result of lesser deposition time, are higher than those electrosprayed at more deposition times resulting to bigger thicknesses of the thin film. However, the I_{sc} and ŋ of DSSC with 3 minutes deposition time of TiO_2 thin film at the first layer is greater than those of DSSC with 5 minutes and 7 minutes deposition times of the TiO_2 thin film blocking layers. This can be explained by the lower transmittance of the thicker TiO_2 thin film to reduce the incident light intensity on the chlorin-E6 dye [4]

Table 1.2 shows simulation results of the DSSC fabricated thin films showing voltage, current, time, resistance and current density.

By comparing these figures using figure 1.6 and Table 1.5, it can be observed vividly that, for solar cells with decreasing thin film thicknesses resulting from small deposition time, constitute higher I_{sc}, Fill Factor (F.F) (%) and efficiency (ŋ).

The solar cell with the smallest thickness of the TiO2 thin film, deposited in 3 minutes exhibited the highest overall conversion efficiency (0.12%), at a low light intensity. At a higher light intensity, the solar cell may exhibit approximately 0.68% efficiency which is very good for these kind of 0.283cm^2 cell size solar cells fabricated [5]

A requirement for the dye structure is that it must possess several O or –OH groups capable of anchoring to the Ti (iv) site on the TiO_2 surface. The molecular structure of chlorin-E6 dye exhibits the O and –OH groups, which are responsible for the transferring of excited electrons into TiO_2. The following processes may describe the dye sensitization into TiO_2:

i. Diffusion of dye into TiO_2 nanostrctured
ii. Adsorption of the dye to the TiO_2 surface, and
iii. Dissolution of Ti surface atoms from TiO_2 and formation of Ti2+/dye complex in the pores of the TiO_2 film.

Depending on the rate of these different processes, the outer part of the electrode form Ti2+/dye complexes in the pores, when dye molecules reach the interface between the bulk contact and the TiO_2 film. Therefore, the latter process increases the efficiency, whereas the former is responsible for the decrease in the efficiency. [6]. In this work a constant sensitization time of 24 hours in dye solution on the performance of DSSCs was studied by comparing the efficiencies of the cells fabricated according to the TiO_2 thin film deposition time. The efficiencies of the cells (3, 5 and 7) minutes deposition time are 0.12%, 0.09% and 0.07% respectively.

5.0 Conclusion

In Nigeria, solid state and printable DSSCs will have a promising future for the development of efficiency and flexible optoelectronics. Even though DSSCs have lower light to electricity conversion efficiency than the best thin film Si solar cells, they are considerably cheaper to be made and feasible to be printed on flexible substrate. Amorphous Si thin-film cells degrade in sunlight over time, and their efficiencies also go down if the sunlight hits them at some special incident angle. DSSCs are longer lasting and work at wide angles. In addition, DSSCs work more efficiency in indoor light, because the dye absorbs diffuse sunlight as well as fluorescent lighting. With improvements on nonvolatile electrolytes, organic dyes and nanoporous semiconducting electrode, cheaper but more robust DSSCs will definitely take their share in the solar cell markets competing with the traditional thin film solar technologies.

6.0 Acknowledgements

The authors are grateful to the Directorate of Sheda Science and Technology Complex (SHESTCO) for their tremendous assistance.

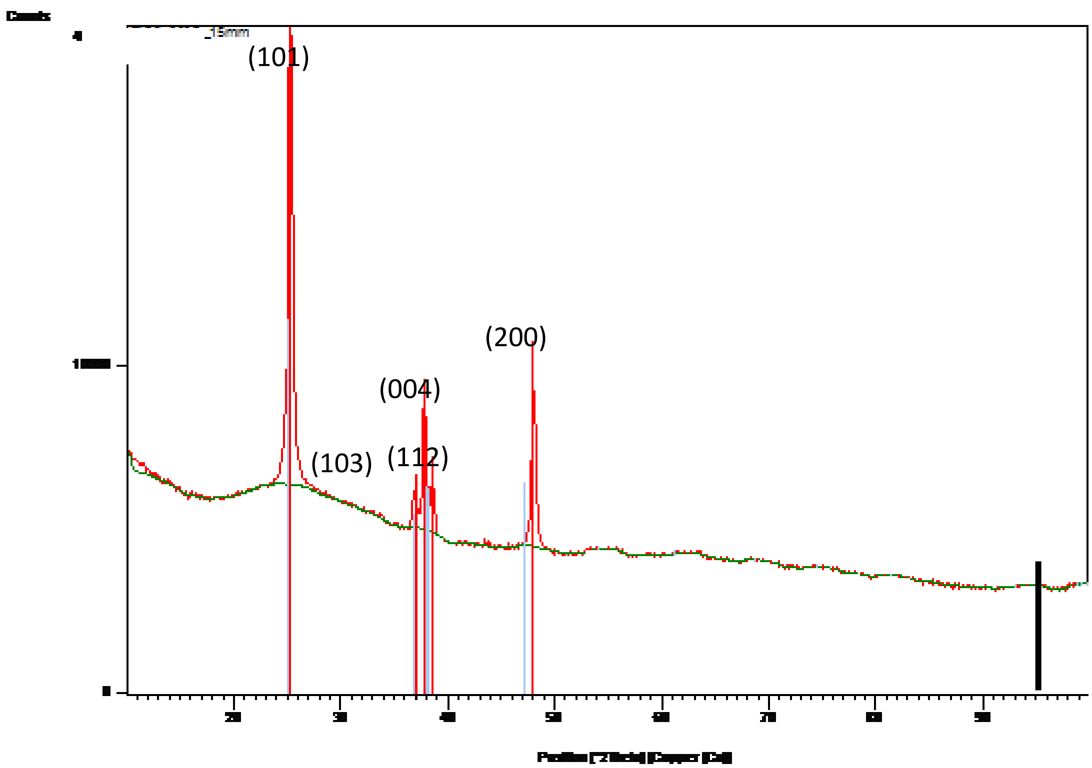

Fig. 1.1a: XRD patterns of TiO_2 thin films deposited at substrate temperature (350^0C) at 3 minutes deposition time. Standard peak position (TCPDS 21-1272) of the TiO_2 anatase phase is given in vertical lines.

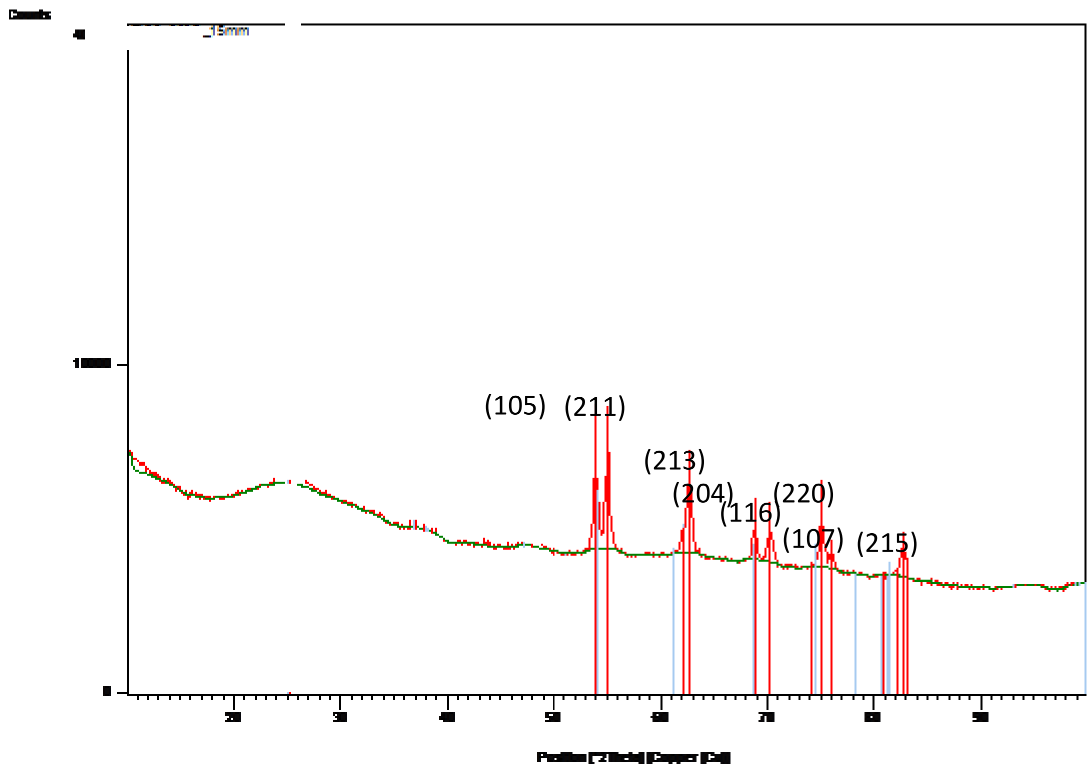

Fig. 1.1b: XRD patterns of TiO_2 thin films deposited at substrate temperature (350^0C) at 5 minutes deposition time. Standard peak position (TCPDS 21-1272) of the TiO_2 anatase phase is given in vertical lines.

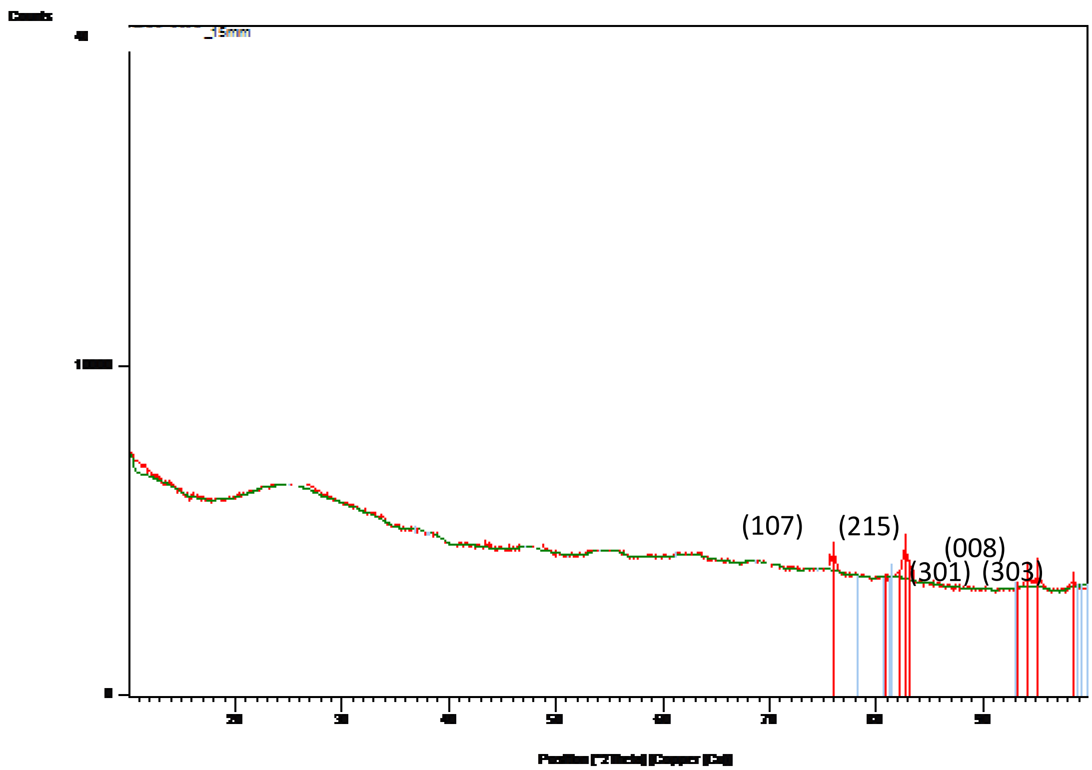

Fig. 1.1c: XRD patterns of TiO_2 thin films deposited at substrate temperature (350^0C) at 7 minutes deposition time. Standard peak position (TCPDS 21-1272) of the TiO_2 anatase phase is given in vertical lines.

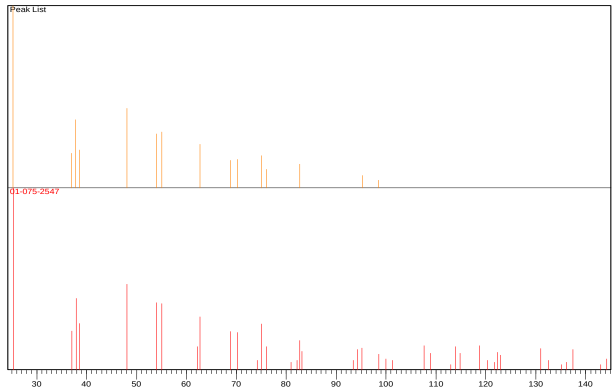

Fig. 1.2 shows a damping intensity dropping from anatase structure

Table 1.1 shows the XRD peak list used in calculating the mean crystallite size diameter (D) in meters for all three different deposition time samples.

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]	Tip width [°2Th.]	Crystalline size calculated values (nm)	Mean crystallite size (D) nm	Standard Miller index (hkl)
25.2765	38163.83	0.3936	3.52356	100.00	0.4723	8.9100	8.59nm For five values of the crystalline size	101
36.9347	1422.08	0.2952	2.43379	3.73	0.3542	9.2830		103
37.8232	5405.24	0.2952	2.37864	14.16	0.3542	9.1808		004
38.5766	1700.12	0.2952	2.33390	4.45	0.3542	9.1018		112
48.0323	7322.75	0.3936	1.89422	19.19	0.4723	6.4771		200
53.9400	3377.96	0.3936	1.69988	8.85	0.4723	6.6033	8.26nm For five values of the crystalline size	105
55.0664	3604.48	0.3936	1.66775	9.44	0.4723	6.6596		211
62.7355	2225.21	0.3936	1.48106	5.83	0.4723	7.3927		213
68.8444	899.49	0.3936	1.36380	2.36	0.4723	8.6407		204
70.2732	945.11	0.3936	1.33953	2.48	0.4723	9.0745		116
75.0863	1211.27	0.3936	1.26516	3.17	0.4723	11.2405	4.52nm For five values of the crystalline size	220
76.0839	403.52	0.2952	1.25104	1.06	0.3542	15.8592		107
82.7043	666.87	0.2952	1.16687	1.75	0.3542	28.0142		215
95.3120	192.68	0.5904	1.04306	0.50	0.7085	-17.1748		301
98.4837	73.35	0.7200	1.01693	0.19	0.8640	-8.6164		008

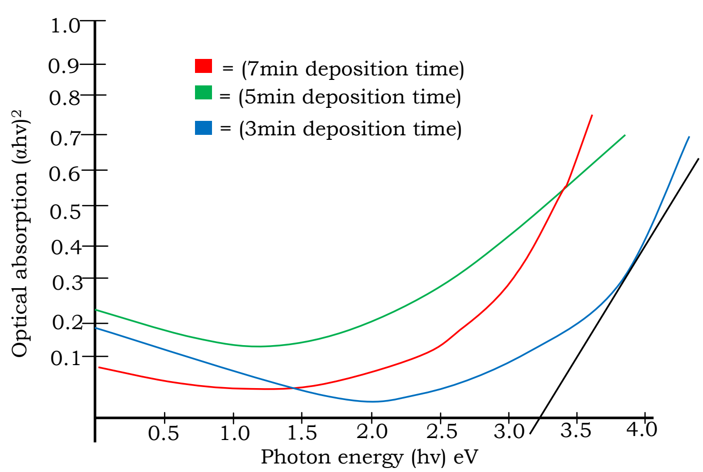

Fig. 1.3: Evaluated band gap energy of dense TiO_2 thin film

Table 1.2: simulation results of the DSSC fabricated thin films showing voltage, current, time, resistance and current density.

[0	CELL 2 (3MIN)	0]		
Voltage_1 (1)	**Current_1 (1)**	**Time Ch_1 (1)**	**Resistance**	**Current_Density**
-0.005628	0.000151598	1.030273	-37.12446134	0.000535683
-0.000549	0.000150138	1.235352	-3.656628368	0.000530524
0.00448	0.000148948	1.44043	30.07760481	0.000526318
0.009483	0.000147923	1.645508	64.107541	0.000522697
0.014545	0.000147031	1.849609	98.92485948	0.000519543
0.019624	0.000146264	2.053711	134.1678969	0.000516836
0.024653	0.000145618	2.256836	169.2991222	0.000514551
0.029656	0.000145072	2.460938	204.423035	0.000512621
0.034718	0.000144604	2.664063	240.0898496	0.000510969
0.039797	0.000144209	2.869141	275.9675536	0.000509572
0.044826	0.000143879	3.073242	311.5525879	0.000508408
0.049867	0.0001436	3.277344	347.2620275	0.000507422
0.054968	0.000143361	3.480469	383.4230497	0.000506577
0.060009	0.000143159	3.68457	419.1781457	0.000505861
0.065041	0.000142983	3.888672	454.8876869	0.000505239
0.070125	0.000142824	4.092773	490.9888547	0.000504679
0.075178	0.00014268	4.296875	526.9006648	0.000504168
0.080189	0.000142544	4.500977	562.5557791	0.000503689
0.08526	0.00014241	4.704102	598.6945855	0.000503215
0.09033	0.000142274	4.908203	634.8999653	0.000502736
0.095342	0.000142136	5.111328	670.7814281	0.000502246
0.1004	0.000141988	5.31543	707.1021689	0.000501724
0.105504	0.000141828	5.518555	743.8851364	0.00050116
0.110536	0.000141659	5.722656	780.2987332	0.00050056
0.115573	0.000141475	5.927734	816.9166761	0.00049991
0.120664	0.000141273	6.131836	854.1175015	0.000499199
0.125709	0.000141058	6.335938	891.18948	0.000498437
0.130693	0.000140828	6.540039	928.0330782	0.000497625
0.13574	0.000140578	6.744141	965.5815739	0.000496744
0.14077	0.000140313	6.948242	1003.258571	0.000495805
0.145753	0.000140033	7.152344	1040.848809	0.000494816
0.150795	0.000139733	7.356445	1079.166439	0.000493756
0.155857	0.000139415	7.558594	1117.934649	0.000492633
0.16088	0.000139084	7.763672	1156.712074	0.000491462
0.165932	0.000138735	7.966797	1196.034576	0.00049023
0.171036	0.000138367	8.170898	1236.100883	0.000488931
0.176059	0.000137991	8.374023	1275.876052	0.0004876
0.181095	0.000137599	8.578125	1316.110069	0.000486214
0.186182	0.000137188	8.783203	1357.127409	0.000484764

0.191227	0.000136767	8.986328	1398.195039	0.000483276
0.196223	0.000136336	9.19043	1439.263522	0.000481752
0.201293	0.000135883	9.394531	1481.368626	0.000480152
0.206359	0.000135415	9.598633	1523.897585	0.000478499
0.21137	0.000134936	9.803711	1566.445226	0.000476806
0.216427	0.000134435	10.00586	1609.905397	0.000475034
0.221528	0.000133909	10.20996	1654.32109	0.000473176
0.226555	0.000133369	10.41406	1698.71436	0.000471267
0.231596	0.000132802	10.61719	1743.916314	0.000469266
0.236686	0.000132202	10.82227	1790.332549	0.000467146
0.241731	0.000131576	11.02637	1837.199786	0.000464932
0.246746	0.000130917	11.23047	1884.746625	0.000462605
0.251828	0.000130209	11.43457	1934.033337	0.000460101
0.256884	0.000129457	11.63867	1984.324139	0.000457444
0.261903	0.000128657	11.84375	2035.663041	0.00045462
0.266977	0.000127789	12.04883	2089.20842	0.00045155
0.272047	0.000126852	12.25098	2144.609132	0.000448239
0.277076	0.000125845	12.45605	2201.720785	0.000444683
0.282138	0.000124745	12.66113	2261.714056	0.000440796
0.287241	0.000123537	12.86523	2325.139289	0.000436527
0.292268	0.000122238	13.06934	2390.973798	0.000431937
0.297308	0.000120815	13.27344	2460.861604	0.000426907
0.302402	0.000119239	13.47656	2536.100628	0.000421339
0.307446	0.000117528	13.68066	2615.928566	0.000415295
0.312451	0.000115668	13.88477	2701.280728	0.00040872
0.317534	0.000113594	14.08789	2795.330972	0.000401394
0.322604	0.000111324	14.29199	2897.888222	0.00039337
0.327614	0.000108862	14.49609	3009.438037	0.000384672
0.332684	0.00010613	14.7002	3134.687063	0.000375017
0.337785	0.000103114	14.90234	3275.849392	0.000364359
0.342803	9.99E-05	15.10742	3432.77046	0.000352869
0.347852	9.63E-05	15.3125	3612.905172	0.000340213
0.352955	9.23E-05	15.5166	3823.230131	0.000326214
0.357985	8.80E-05	15.71973	4065.739058	0.000311128
0.363	8.34E-05	15.92383	4352.311534	0.000294714
0.378354	6.64E-05	16.12891	5694.112121	0.000234793
0.379335	6.52E-05	16.33301	5817.300579	0.000230417
0.381296	6.27E-05	16.53809	6084.012903	0.000221455
0.384303	5.86E-05	16.74121	6555.684902	0.000207143
0.388317	5.29E-05	16.94434	7340.913005	0.000186917
0.393314	4.52E-05	17.24414	8694.21396	0.000159854
0.398353	3.69E-05	17.44727	10801.8321	0.000130312

0.403463	2.77E-05	17.75195	14563.44811	9.79E-05
0.408491	1.79E-05	18.14355	22760.1033	6.34E-05
0.41353	7.40E-06	18.5293	55892.09589	2.61E-05
0.41864	-4.14E-06	18.7334	-101200.7229	-1.46E-05
0.423668	-1.64E-05	19.122075	-25895.21169	-5.78E-05
0.428707	-2.95E-05	19.455085	-14516.02829	-0.000104358
0.433817	-4.39E-05	19.788095	-9884.41929	-0.000155085
0.438845	-5.91E-05	20.121105	-7431.608597	-0.000208661
0.443884	-7.53E-05	20.454115	-5892.000296	-0.000266208

Table 1.3: A simulation result of the DSSC-fabricated thin film electrodes at 3 minutes deposition time.

Voltage_1 (1) (V)	**Current_Density mA/CM2**	**(mW) power (J*V)**
-0.0056	0.5356830000	-0.0030148239
-0.0005	0.5305240000	-0.0002912577
0.0045	0.5263180000	0.0023579046
0.0095	0.5226970000	0.0049567357
0.0145	0.5195430000	0.0075567529
0.0196	0.5168360000	0.0101423897
0.0247	0.5145510000	0.0126852258
0.0297	0.5126210000	0.0152022884
0.0347	0.5109690000	0.0177398217
0.0398	0.5095720000	0.0202794369
0.0448	0.5084080000	0.0227898970
0.0499	0.5074220000	0.0253036129
0.0550	0.5065770000	0.0278455245
0.0600	0.5058610000	0.0303562127
0.0650	0.5052390000	0.0328612498
0.0701	0.5046790000	0.0353906149
0.0752	0.5041680000	0.0379023419
0.0802	0.5036890000	0.0403903172
0.0853	0.5032150000	0.0429041109
0.0903	0.5027360000	0.0454121429
0.0953	0.5022460000	0.0478851381
0.1004	0.5017240000	0.0503730896
0.1055	0.5011600000	0.0528743846
0.1105	0.5005600000	0.0553299002
0.1156	0.4999100000	0.0577760984
0.1207	0.4991990000	0.0602353481

0.1257	0.4984370000	0.0626580168
0.1307	0.4976250000	0.0650361041
0.1357	0.4967440000	0.0674280306
0.1408	0.4958050000	0.0697944699
0.1458	0.4948160000	0.0721209164
0.1508	0.4937560000	0.0744559360
0.1559	0.4926330000	0.0767803015
0.1609	0.4914620000	0.0790664066
0.1659	0.4902300000	0.0813448444
0.1710	0.4889310000	0.0836248025
0.1761	0.4876000000	0.0858463684
0.1811	0.4862140000	0.0880509243
0.1862	0.4847640000	0.0902543310
0.1912	0.4832760000	0.0924154197
0.1962	0.4817520000	0.0945308227
0.2013	0.4801520000	0.0966512365
0.2064	0.4784990000	0.0987425751
0.2114	0.4768060000	0.1007824842
0.2164	0.4750340000	0.1028101835
0.2215	0.4731760000	0.1048217329
0.2266	0.4712670000	0.1067678952
0.2316	0.4692660000	0.1086801285
0.2367	0.4671460000	0.1105669182
0.2417	0.4649320000	0.1123884773
0.2467	0.4626050000	0.1141459333
0.2518	0.4601010000	0.1158663146
0.2569	0.4574440000	0.1175100445
0.2619	0.4546200000	0.1190663419
0.2670	0.4515500000	0.1205534644
0.2720	0.4482390000	0.1219420752
0.2771	0.4446830000	0.1232109869
0.2821	0.4407960000	0.1243653018
0.2872	0.4365270000	0.1253884520
0.2923	0.4319370000	0.1262413631
0.2973	0.4269070000	0.1269228664
0.3024	0.4213390000	0.1274137563
0.3074	0.4152950000	0.1276807866
0.3125	0.4087200000	0.1277049727
0.3175	0.4013940000	0.1274562424
0.3226	0.3933700000	0.1269027355

0.3276	0.3846720000	0.1260239326
0.3327	0.3750170000	0.1247621556
0.3378	0.3643590000	0.1230750048
0.3428	0.3528690000	0.1209645518
0.3479	0.3402130000	0.1183437725
0.3530	0.3262140000	0.1151388624
0.3580	0.3111280000	0.1113791571
0.3630	0.2947140000	0.1069811820
0.3784	0.2347930000	0.0888348707
0.3793	0.2304170000	0.0874052327
0.3813	0.2214550000	0.0844399057
0.3843	0.2071430000	0.0796056763
0.3883	0.1869170000	0.0725830487
0.3933	0.1598540000	0.0628728162
0.3984	0.1303120000	0.0519101761
0.4035	0.0978933000	0.0394963245
0.4085	0.0634194000	0.0259062541
0.4135	0.0261439000	0.0108112870
0.4186	-0.0146174000	-0.0061194283
0.4237	-0.0578122000	-0.0244931791
0.4287	-0.1043580000	-0.0447390051
0.4338	-0.1550850000	-0.0672785094
0.4388	-0.2086610000	-0.0915698365
0.4439	-0.2662080000	-0.1181654719

fill factor	efficiency (%)	Voc	Isc	cell size in cm2
0.586749	0.127705	0.4135	0.5263180	0.283

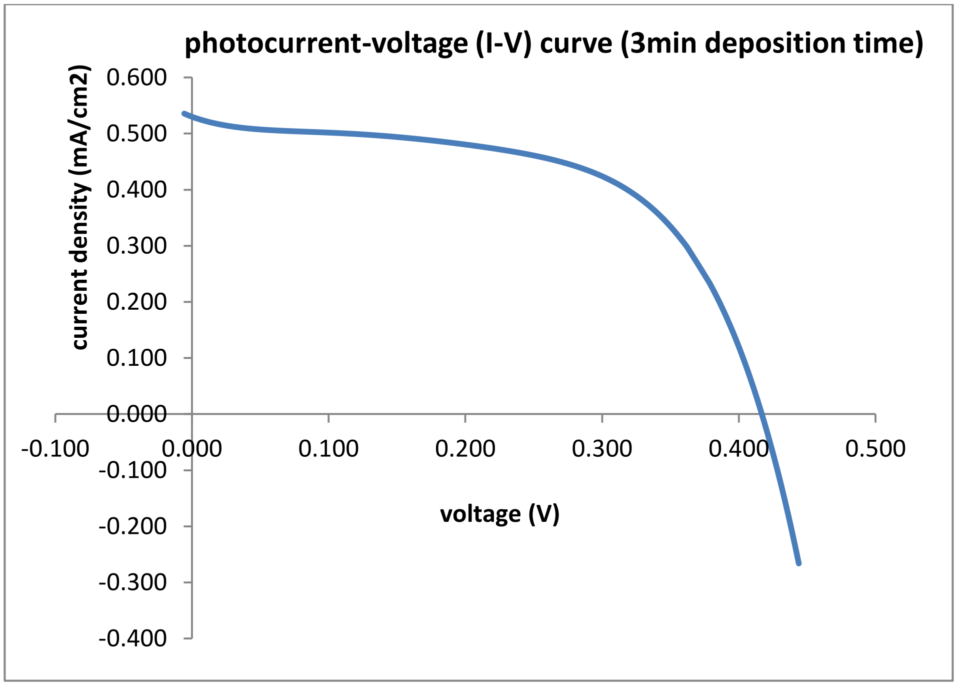

Fig. 1.4a: A simulation graph showing the I-V Curve for DSSC with 3 minutes deposition time of TiO_2 thin film blocking layers

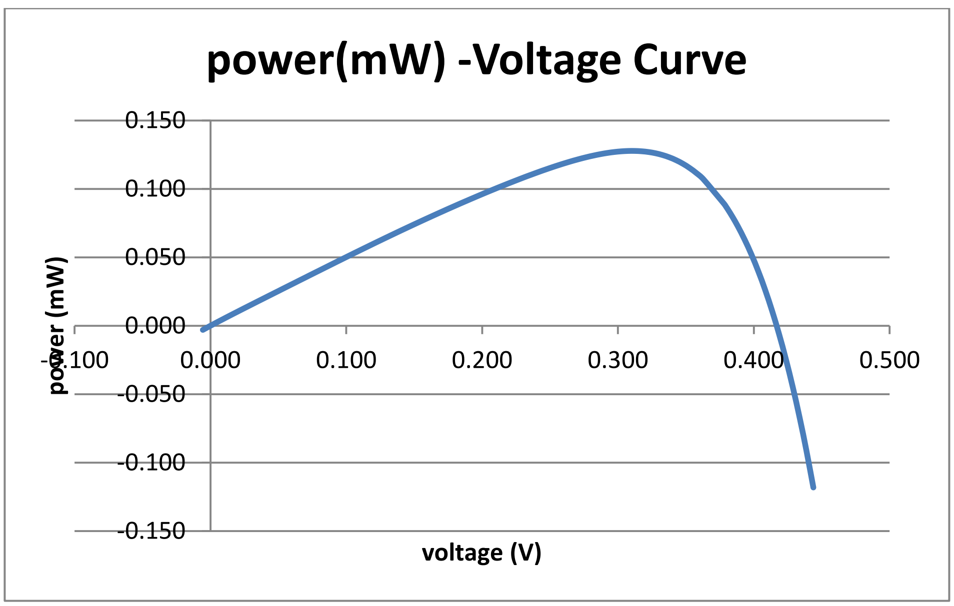

Fig. 1.4b: A simulation graph showing the power (mW) – voltage curve for DSSC with 3 minutes deposition time of TiO_2 thin film blocking layers

Table 1.4a: A simulation result of the DSSC-fabricated thin film electrodes at 5 minutes deposition time.

[0	**CELL 3 (5MIN)**	**0]**		
Voltage_1 (1)	**Current_1 (1)**	**Time Ch_1 (1)**	**Resistance**	**Current_Density**
-0.005628	0.000100225	1.030273	-56.15355155	0.000354153
-0.000549	0.000100022	1.235352	-5.488794058	0.000353435
0.00448	9.98E-05	1.44043	44.879817	0.000352728
0.009483	9.96E-05	1.645508	95.18288717	0.000352047
0.014545	9.94E-05	1.849609	146.2636119	0.000351391
0.019624	9.93E-05	2.053711	197.6825394	0.000350778
0.024653	9.91E-05	2.256836	248.7358443	0.000350223
0.029656	9.90E-05	2.460938	299.6378411	0.000349727
0.034718	9.88E-05	2.664063	351.2267673	0.000349286
0.039797	9.87E-05	2.869141	403.0486084	0.000348904
0.044826	9.87E-05	3.073242	454.3928836	0.000348588
0.049867	9.86E-05	3.277344	505.8683285	0.000348329
0.054968	9.85E-05	3.480469	557.9441188	0.000348123
0.060009	9.85E-05	3.68457	609.3781212	0.000347971
0.065041	9.84E-05	3.888672	660.6787244	0.000347865
0.070125	9.84E-05	4.092773	712.4593039	0.000347797
0.075178	9.84E-05	4.296875	763.8711924	0.000347764
0.080189	9.84E-05	4.500977	814.805603	0.000347756
0.08526	9.84E-05	4.704102	866.3060394	0.000347766
0.09033	9.84E-05	4.908203	917.764134	0.000347788
0.095342	9.84E-05	5.111328	968.6181737	0.000347813
0.1004	9.84E-05	5.31543	1019.944097	0.000347833
0.105504	9.84E-05	5.518555	1071.767125	0.000347842
0.110536	9.84E-05	5.722656	1122.917141	0.000347832
0.115573	9.84E-05	5.927734	1174.206752	0.000347797
0.120664	9.84E-05	6.131836	1226.170631	0.000347729
0.125709	9.84E-05	6.335938	1277.824361	0.000347623
0.130693	9.83E-05	6.540039	1329.045908	0.000347477
0.13574	9.83E-05	6.744141	1381.147759	0.000347281
0.14077	9.82E-05	6.948242	1433.345794	0.000347035
0.145753	9.81E-05	7.152344	1485.361557	0.000346736
0.150795	9.80E-05	7.356445	1538.340785	0.000346376
0.155857	9.79E-05	7.558594	1591.919726	0.000345954
0.16088	9.78E-05	7.763672	1645.508056	0.000345474
0.165932	9.76E-05	7.966797	1699.86492	0.000344929
0.171036	9.74E-05	8.170898	1755.282567	0.000344314
0.176059	9.73E-05	8.374023	1810.343492	0.000343646
0.181095	9.70E-05	8.578125	1866.095727	0.000342915

0.186182	9.68E-05	8.783203	1922.996476	0.000342116
0.191227	9.66E-05	8.986328	1980.03021	0.000341264
0.196223	9.63E-05	9.19043	2037.121647	0.000340366
0.201293	9.61E-05	9.394531	2095.698874	0.000339401
0.206359	9.58E-05	9.598633	2154.889773	0.000338386
0.21137	9.55E-05	9.803711	2214.100706	0.000337334
0.216427	9.52E-05	10.00586	2274.535893	0.000336227
0.221528	9.48E-05	10.20996	2336.202006	0.000335067
0.226555	9.45E-05	10.41406	2397.678948	0.000333884
0.231596	9.41E-05	10.61719	2460.04454	0.000332661
0.236686	9.38E-05	10.82227	2523.762984	0.000331389
0.241731	9.34E-05	11.02637	2587.680986	0.000330092
0.246746	9.30E-05	11.23047	2652.000834	0.000328768
0.251828	9.27E-05	11.43457	2718.014564	0.00032739
0.256884	9.23E-05	11.63867	2784.575979	0.00032598
0.261903	9.18E-05	11.84375	2851.590406	0.000324539
0.266977	9.14E-05	12.04883	2920.378438	0.000323034
0.272047	9.10E-05	12.25098	2990.267719	0.000321475
0.277076	9.05E-05	12.45605	3060.872343	0.000319865
0.282138	9.00E-05	12.66113	3133.403436	0.00031817
0.287241	8.95E-05	12.86523	3208.228958	0.00031637
0.292268	8.90E-05	13.06934	3283.882767	0.00031449
0.297308	8.84E-05	13.27344	3361.992384	0.000312481
0.302402	8.78E-05	13.47656	3443.639967	0.000310299
0.307446	8.72E-05	13.68066	3527.644084	0.000307962
0.312451	8.64E-05	13.88477	3614.676578	0.00030544
0.317534	8.56E-05	14.08789	3707.518711	0.000302636
0.322604	8.48E-05	14.29199	3805.448536	0.000299556
0.327614	8.38E-05	14.49609	3908.458311	0.00029619
0.332684	8.28E-05	14.7002	4020.26122	0.000292409
0.337785	8.16E-05	14.90234	4141.969202	0.000288169
0.342803	8.02E-05	15.10742	4272.582137	0.00028351
0.347852	7.87E-05	15.3125	4417.201194	0.000278266
0.352955	7.71E-05	15.5166	4579.757765	0.000272327
0.357985	7.52E-05	15.71973	4759.775363	0.000265761
0.363	7.31E-05	15.92383	4963.443916	0.000258427
0.378354	6.51E-05	16.12891	5811.621266	0.000230046
0.379335	6.45E-05	16.33301	5882.06824	0.00022788
0.381296	6.32E-05	16.53809	6030.851825	0.000223407
0.384303	6.12E-05	16.74121	6282.147206	0.000216162
0.388317	5.82E-05	16.94434	6670.066311	0.000205717

0.393314	5.42E-05	17.24414	7262.077702	0.000191378
0.398353	4.96E-05	17.44727	8030.654008	0.000175279
0.403463	4.45E-05	17.75195	9074.400785	0.000157108
0.408491	3.88E-05	18.14355	10517.41068	0.000137242
0.41353	3.26E-05	18.5293	12687.53592	0.000115171
0.41864	2.56E-05	18.7334	16367.67405	9.04E-05
0.423668	1.79E-05	19.122075	23610.70244	6.34E-05
0.428707	9.50E-06	19.455085	45104.47822	3.36E-05
0.433817	7.17E-08	19.788095	6047255.913	2.53E-07
0.438845	-1.01E-05	20.121105	-43274.23103	-3.58E-05
0.443884	-2.14E-05	20.454115	-20763.86575	-7.55E-05

Table 1.4b: A simulation report of the DSSC-fabricated thin film electrodes at 5 minutes deposition time.

(V)	mA/CM2	power (J*V)
-0.0056	0.3541530000	-0.0019931731
-0.0005	0.3534350000	-0.0001940358
0.0045	0.3527280000	0.0015802214
0.0095	0.3520470000	0.0033384617
0.0145	0.3513910000	0.0051109821
0.0196	0.3507780000	0.0068836675
0.0247	0.3502230000	0.0086340476
0.0297	0.3497270000	0.0103715039
0.0347	0.3492860000	0.0121265113
0.0398	0.3489040000	0.0138853325
0.0448	0.3485880000	0.0156258057
0.0499	0.3483290000	0.0173701222
0.0550	0.3481230000	0.0191356251
0.0600	0.3479710000	0.0208813917
0.0650	0.3478650000	0.0226254875
0.0701	0.3477970000	0.0243892646
0.0752	0.3477640000	0.0261442020
0.0802	0.3477560000	0.0278862059
0.0853	0.3477660000	0.0296505292
0.0903	0.3477880000	0.0314156900
0.0953	0.3478130000	0.0331611870
0.1004	0.3478330000	0.0349224332
0.1055	0.3478420000	0.0366987224
0.1105	0.3478320000	0.0384479580
0.1156	0.3477970000	0.0401959427
0.1207	0.3477290000	0.0419583721
0.1257	0.3476230000	0.0436993397
0.1307	0.3474770000	0.0454128116
0.1357	0.3472810000	0.0471399229
0.1408	0.3470350000	0.0488521170
0.1458	0.3467360000	0.0505378122
0.1508	0.3463760000	0.0522317689
0.1559	0.3459540000	0.0539193526
0.1609	0.3454740000	0.0555798571
0.1659	0.3449290000	0.0572347588
0.1710	0.3443140000	0.0588900893
0.1761	0.3436460000	0.0605019711
0.1811	0.3429150000	0.0621001919
0.1862	0.3421160000	0.0636958411
0.1912	0.3412640000	0.0652588909
0.1962	0.3403660000	0.0667876376
0.2013	0.3394010000	0.0683190455
0.2064	0.3383860000	0.0698289966
0.2114	0.3373340000	0.0713022876

0.2164	0.3362270000	0.0727686009
0.2215	0.3350670000	0.0742267224
0.2266	0.3338840000	0.0756430896
0.2316	0.3326610000	0.0770429570
0.2367	0.3313890000	0.0784351369
0.2417	0.3300920000	0.0797934693
0.2467	0.3287680000	0.0811221889
0.2518	0.3273900000	0.0824459689
0.2569	0.3259800000	0.0837390463
0.2619	0.3245390000	0.0849977377
0.2670	0.3230340000	0.0862426482
0.2720	0.3214750000	0.0874563093
0.2771	0.3198650000	0.0886269147
0.2821	0.3181700000	0.0897678475
0.2872	0.3163700000	0.0908744352
0.2923	0.3144900000	0.0919153633
0.2973	0.3124810000	0.0929031011
0.3024	0.3102990000	0.0938350382
0.3074	0.3079620000	0.0946816851
0.3125	0.3054400000	0.0954350334
0.3175	0.3026360000	0.0960972196
0.3226	0.2995560000	0.0966379638
0.3276	0.2961900000	0.0970359907
0.3327	0.2924090000	0.0972797958
0.3378	0.2881690000	0.0973391657
0.3428	0.2835100000	0.0971880785
0.3479	0.2782660000	0.0967953846
0.3530	0.2723270000	0.0961191763
0.3580	0.2657610000	0.0951384516
0.3630	0.2584270000	0.0938090010
0.3784	0.2300460000	0.0870388243
0.3793	0.2278800000	0.0864428598
0.3813	0.2234070000	0.0851841955
0.3843	0.2161620000	0.0830717051
0.3883	0.2057170000	0.0798834083
0.3933	0.1913780000	0.0752716467
0.3984	0.1752790000	0.0698229155
0.4035	0.1571080000	0.0633872650
0.4085	0.1372420000	0.0560621218
0.4135	0.1151710000	0.0476266636
0.4186	0.0903790000	0.0378362646
0.4237	0.0634060000	0.0268630932
0.4287	0.0335857000	0.0143984247
0.4338	0.0002534910	0.0001099687
0.4388	-0.0358340000	-0.0157255717
0.4439	-0.0755396000	-0.0335308198

fill factor	efficiency (%)	Voc	Isc		cell size in cm^2
0.66733	0.097339	0.4135	0.3527280000	0.097339	0.283

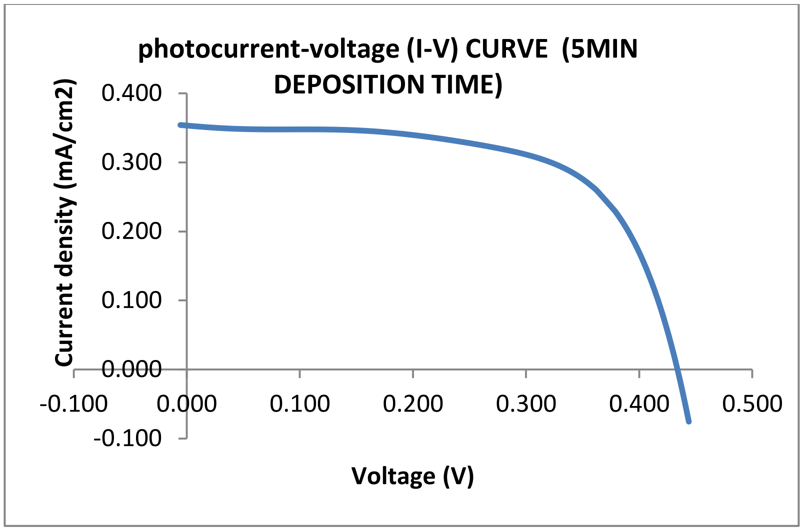

Fig. 1.5a: A simulation graph showing the I-V Curve for DSSC with 5 minutes deposition time of TiO_2 thin film blocking layers

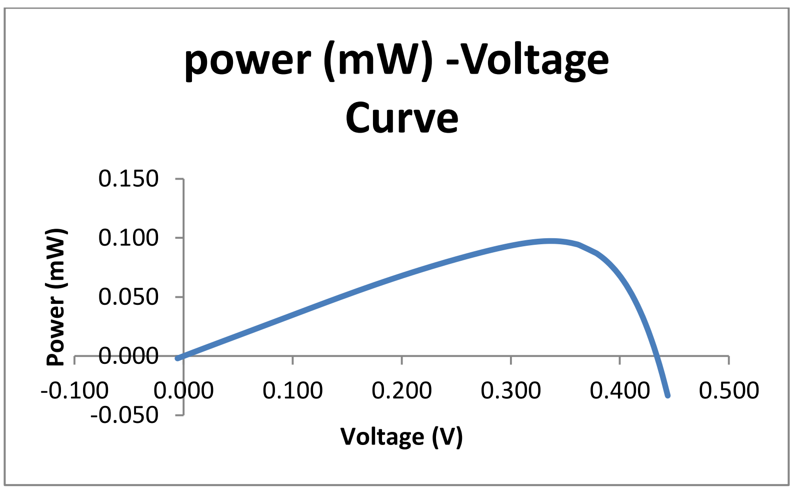

Fig. 1.5b: A simulation graph showing the power (mW) – voltage curve for DSSC with 5 minutes deposition time of TiO_2 thin film blocking layers

Table 1.5a: A simulation result of the DSSC-fabricated thin film electrodes at 7 minutes deposition time.

[0	CELL 1 (7MIN)	0]		[0
Voltage_1 (1)	Current_1 (1)	Time Ch_1 (1)	Resistance	Current_Density
-0.0056	0.0000807933	1.0302730000	-69.6592033900	0.0002854890
-0.0005	0.0000809847	1.2353520000	-6.7790594660	0.0002861650
0.0045	0.0000810901	1.4404300000	55.2472109200	0.0002865370
0.0095	0.0000811253	1.6455080000	116.8932094000	0.0002866620
0.0145	0.0000811026	1.8496090000	179.3407659000	0.0002865820
0.0196	0.0000810317	2.0537110000	242.1767165000	0.0002863310
0.0247	0.0000809238	2.2568360000	304.6445091000	0.0002859500
0.0297	0.0000807875	2.4609380000	367.0863355000	0.0002854680
0.0347	0.0000806276	2.6640630000	430.5968903000	0.0002849030
0.0398	0.0000804513	2.8691410000	494.6717050000	0.0002842800
0.0448	0.0000802666	3.0732420000	558.4638763000	0.0002836280
0.0499	0.0000800758	3.2773440000	622.7474409000	0.0002829530
0.0550	0.0000798808	3.4804690000	688.1253082000	0.0002822640
0.0600	0.0000796892	3.6845700000	753.0377995000	0.0002815870
0.0650	0.0000795015	3.8886720000	818.1107548000	0.0002809240
0.0701	0.0000793170	4.0927730000	884.1102987000	0.0002802720
0.0752	0.0000791402	4.2968750000	949.9348101000	0.0002796470
0.0802	0.0000789718	4.5009770000	1015.4127900000	0.0002790520
0.0853	0.0000788089	4.7041020000	1081.8578730000	0.0002784770
0.0903	0.0000786533	4.9082030000	1148.4580490000	0.0002779270
0.0953	0.0000785062	5.1113280000	1214.4512640000	0.0002774070
0.1004	0.0000783639	5.3154300000	1281.2019320000	0.0002769040
0.1055	0.0000782255	5.5185550000	1348.7164360000	0.0002764150
0.1105	0.0000780929	5.7226560000	1415.4418340000	0.0002759470
0.1156	0.0000779628	5.9277340000	1482.4120500000	0.0002754870
0.1207	0.0000778324	6.1318360000	1550.3053440000	0.0002750260
0.1257	0.0000777028	6.3359380000	1617.8190940000	0.0002745680
0.1307	0.0000775727	6.5400390000	1684.7814930000	0.0002741080
0.1357	0.0000774373	6.7441410000	1752.9017620000	0.0002736300
0.1408	0.0000772972	6.9482420000	1821.1534270000	0.0002731350
0.1458	0.0000771516	7.1523440000	1889.1762290000	0.0002726210
0.1508	0.0000769960	7.3564450000	1958.4779940000	0.0002720710
0.1559	0.0000768299	7.5585940000	2028.5985230000	0.0002714840
0.1609	0.0000766539	7.7636720000	2098.7856290000	0.0002708620
0.1659	0.0000764643	7.9667970000	2170.0595800000	0.0002701920
0.1710	0.0000762588	8.1708980000	2242.8376300000	0.0002694660
0.1761	0.0000760417	8.3740230000	2315.2939110000	0.0002686990
0.1811	0.0000758086	8.5781250000	2388.8458930000	0.0002678750
0.1862	0.0000755564	8.7832030000	2464.1467840000	0.0002669840

0.1912	0.0000752891	8.9863280000	2539.9036800000	0.0002660390
0.1962	0.0000750070	9.1904300000	2616.0621000000	0.0002650420
0.2013	0.0000747027	9.3945310000	2694.5865060000	0.0002639670
0.2064	0.0000743803	9.5986330000	2774.3757100000	0.0002628280
0.2114	0.0000740433	9.8037110000	2854.6827930000	0.0002616370
0.2164	0.0000736847	10.0058600000	2937.2020920000	0.0002603700
0.2215	0.0000733046	10.2099600000	3022.0210160000	0.0002590270
0.2266	0.0000729119	10.4140600000	3107.2424370000	0.0002576390
0.2316	0.0000725005	10.6171900000	3194.4076410000	0.0002561850
0.2367	0.0000720673	10.8222700000	3284.2344970000	0.0002546550
0.2417	0.0000716209	11.0263700000	3375.1478520000	0.0002530770
0.2467	0.0000711605	11.2304700000	3467.4593530000	0.0002514500
0.2518	0.0000706774	11.4345700000	3563.0649020000	0.0002497430
0.2569	0.0000701805	11.6386700000	3660.3350860000	0.0002479870
0.2619	0.0000696713	11.8437500000	3759.1208040000	0.0002461880
0.2670	0.0000691407	12.0488300000	3861.3606460000	0.0002443130
0.2720	0.0000685942	12.2509800000	3966.0337020000	0.0002423820
0.2771	0.0000680360	12.4560500000	4072.4932710000	0.0002404100
0.2821	0.0000674572	12.6611300000	4182.4764920000	0.0002383650
0.2872	0.0000668557	12.8652300000	4296.4322060000	0.0002362390
0.2923	0.0000662444	13.0693400000	4411.9649760000	0.0002340790
0.2973	0.0000656113	13.2734400000	4531.3555460000	0.0002318420
0.3024	0.0000649487	13.4765600000	4656.0096150000	0.0002295010
0.3074	0.0000642679	13.6806600000	4783.8214420000	0.0002270950
0.3125	0.0000635648	13.8847700000	4915.4695330000	0.0002246110
0.3175	0.0000628193	14.0878900000	5054.7234460000	0.0002219760
0.3226	0.0000620396	14.2919900000	5199.9713030000	0.0002192210
0.3276	0.0000612288	14.4960900000	5350.6521590000	0.0002163560
0.3327	0.0000603617	14.7002000000	5511.5090560000	0.0002132920
0.3378	0.0000594351	14.9023400000	5683.2549620000	0.0002100180
0.3428	0.0000584630	15.1074200000	5863.5854640000	0.0002065830
0.3479	0.0000574156	15.3125000000	6058.4897890000	0.0002028820
0.3530	0.0000562765	15.5166000000	6271.8044480000	0.0001988570
0.3580	0.0000550634	15.7197300000	6501.3225800000	0.0001945700
0.3630	0.0000537528	15.9238300000	6753.1362330000	0.0001899390
0.3784	0.0000489655	16.1289100000	7726.9432870000	0.0001730230
0.3793	0.0000486128	16.3330100000	7803.1899230000	0.0001717770
0.3813	0.0000478884	16.5380900000	7962.1847380000	0.0001692170
0.3843	0.0000467251	16.7412100000	8224.7577760000	0.0001651070
0.3883	0.0000450668	16.9443400000	8616.4679490000	0.0001592470
0.3933	0.0000428184	17.2441400000	9185.6259650000	0.0001513020

0.3984	0.0000403227	17.4472700000	9879.1144090000	0.0001424830
0.4035	0.0000375318	17.7519500000	10749.8970200000	0.0001326210
0.4085	0.0000345024	18.1435500000	11839.5087700000	0.0001219160
0.4135	0.0000311547	18.5293000000	13273.4533700000	0.0001100870
0.4186	0.0000274085	18.7334000000	15274.1180600000	0.0000968497
0.4237	0.0000233424	19.1220750000	18150.1498300000	0.0000824820
0.4287	0.0000188523	19.4550850000	22740.3024100000	0.0000666159
0.4338	0.0000138339	19.7880950000	31358.8741300000	0.0000488832
0.4388	0.0000083964	20.1211050000	52265.7156600000	0.0000296693
0.4439	0.0000024044	20.4541150000	184617.2231000000	0.0000084959

Table 1.5b: A simulation result of the DSSC-fabricated thin film electrodes at 7 minutes deposition time.

Voltage_1 (1) (V)	**Current_Density mA/CM2**	**(mW) power (J*V)**
-0.0056	0.2854890000	-0.0016067321
-0.0005	0.2861650000	-0.0001571046
0.0045	0.2865370000	0.0012836858
0.0095	0.2866620000	0.0027184157
0.0145	0.2865820000	0.0041683352
0.0196	0.2863310000	0.0056189595
0.0247	0.2859500000	0.0070495254
0.0297	0.2854680000	0.0084658390
0.0347	0.2849030000	0.0098912624
0.0398	0.2842800000	0.0113134912
0.0448	0.2836280000	0.0127139087
0.0499	0.2829530000	0.0141100173
0.0550	0.2822640000	0.0155154876
0.0600	0.2815870000	0.0168977543
0.0650	0.2809240000	0.0182715779
0.0701	0.2802720000	0.0196540740
0.0752	0.2796470000	0.0210233022
0.0802	0.2790520000	0.0223769008
0.0853	0.2784770000	0.0237429490
0.0903	0.2779270000	0.0251051459
0.0953	0.2774070000	0.0264485382
0.1004	0.2769040000	0.0278011616
0.1055	0.2764150000	0.0291628882
0.1105	0.2759470000	0.0305020776
0.1156	0.2754870000	0.0318388591
0.1207	0.2750260000	0.0331857373

0.1257	0.2745680000	0.0345156687
0.1307	0.2741080000	0.0358239968
0.1357	0.2736300000	0.0371425362
0.1408	0.2731350000	0.0384492140
0.1458	0.2726210000	0.0397353286
0.1508	0.2720710000	0.0410269464
0.1559	0.2714840000	0.0423126818
0.1609	0.2708620000	0.0435762786
0.1659	0.2701920000	0.0448334989
0.1710	0.2694660000	0.0460883868
0.1761	0.2686990000	0.0473068772
0.1811	0.2678750000	0.0485108231
0.1862	0.2669840000	0.0497076151
0.1912	0.2660390000	0.0508738399
0.1962	0.2650420000	0.0520073364
0.2013	0.2639670000	0.0531347093
0.2064	0.2628280000	0.0542369233
0.2114	0.2616370000	0.0553022127
0.2164	0.2603700000	0.0563510980
0.2215	0.2590270000	0.0573817333
0.2266	0.2576390000	0.0583694036
0.2316	0.2561850000	0.0593314213
0.2367	0.2546550000	0.0602732733
0.2417	0.2530770000	0.0611765563
0.2467	0.2514500000	0.0620442817
0.2518	0.2497430000	0.0628922802
0.2569	0.2479870000	0.0637038925
0.2619	0.2461880000	0.0644773758
0.2670	0.2443130000	0.0652259518
0.2720	0.2423820000	0.0659392960
0.2771	0.2404100000	0.0666118412
0.2821	0.2383650000	0.0672518244
0.2872	0.2362390000	0.0678575266
0.2923	0.2340790000	0.0684138012
0.2973	0.2318420000	0.0689284813
0.3024	0.2295010000	0.0694015614
0.3074	0.2270950000	0.0698194494
0.3125	0.2246110000	0.0701799316
0.3175	0.2219760000	0.0704849272
0.3226	0.2192210000	0.0707215715
0.3276	0.2163560000	0.0708812546
0.3327	0.2132920000	0.0709588357
0.3378	0.2100180000	0.0709409301
0.3428	0.2065830000	0.0708172721
0.3479	0.2028820000	0.0705729095

0.3530	0.1988570000	0.0701875724
0.3580	0.1945700000	0.0696531415
0.3630	0.1899390000	0.0689478570
0.3784	0.1730230000	0.0654639441
0.3793	0.1717770000	0.0651610283
0.3813	0.1692170000	0.0645217652
0.3843	0.1651070000	0.0634511154
0.3883	0.1592470000	0.0618383173
0.3933	0.1513020000	0.0595091948
0.3984	0.1424830000	0.0567585305
0.4035	0.1326210000	0.0535076665
0.4085	0.1219160000	0.0498015888
0.4135	0.1100870000	0.0455242771
0.4186	0.0968497000	0.0405451584
0.4237	0.0824820000	0.0349449840
0.4287	0.0666159000	0.0285587026
0.4338	0.0488832000	0.0212063632
0.4388	0.0296693000	0.0130202240
0.4439	0.0084959300	0.0037712074

fill factor	efficiency (%)	Voc	Isc	cell size in cm2
0.557657	0.070959	0.4439	0.2866620000	0.283

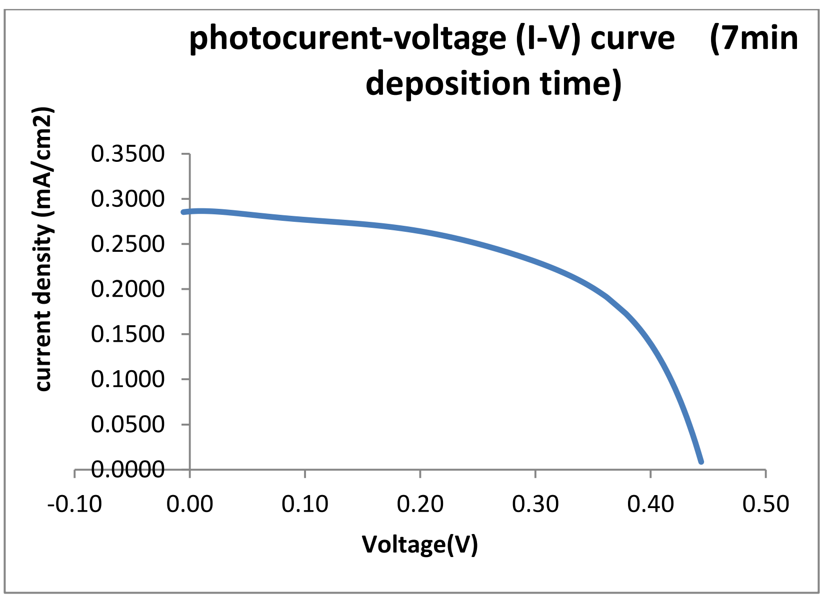

Fig. 1.6a: A simulation graph showing the I-V Curve for DSSC with 7 minutes deposition time of TiO_2 thin film blocking layers

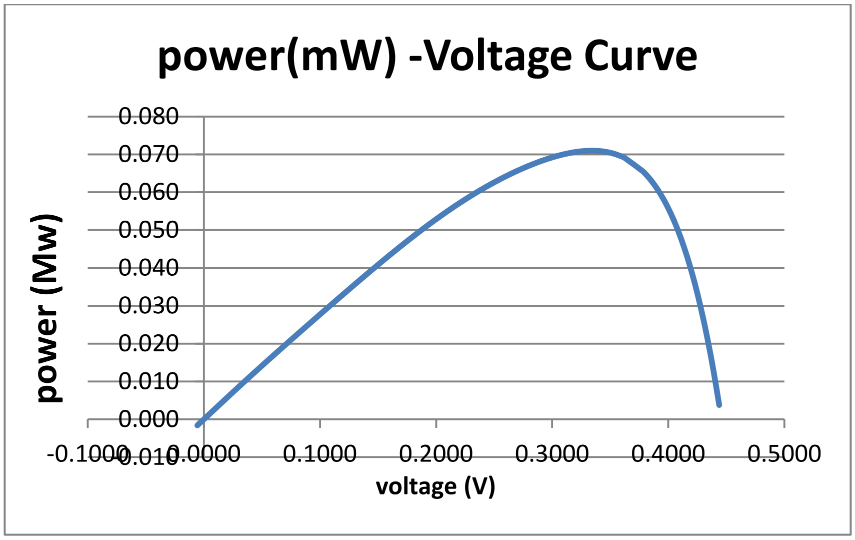

Fig. 1.6b: A simulation graph showing the power (mW) – voltage curve for DSSC with 7 minutes deposition time of TiO_2 thin film blocking layers

Table 1.6: Evaluated Result of the (I-V) simulation scales, for 3 minutes, 5 minutes and 7 minutes deposition times.

Voltage_1 (1)	CELL 2 (3MIN)	CELL 3 (5MIN)	CELL 1 (7MIN)
-0.00563	0.151598	0.100225	0.080793
-0.00055	0.150138	0.100022	0.080985
0.00448	0.148948	0.099822	0.08109
0.009483	0.147923	0.099629	0.081125
0.014545	0.147031	0.099444	0.081103
0.019624	0.146264	0.09927	0.081032
0.024653	0.145618	0.099113	0.080924
0.029656	0.145072	0.098973	0.080788
0.034718	0.144604	0.098848	0.080628
0.039797	0.144209	0.09874	0.080451
0.044826	0.143879	0.09865	0.080267
0.049867	0.1436	0.098577	0.080076
0.054968	0.143361	0.098519	0.079881
0.060009	0.143159	0.098476	0.079689
0.065041	0.142983	0.098446	0.079502
0.070125	0.142824	0.098427	0.079317
0.075178	0.14268	0.098417	0.07914
0.080189	0.142544	0.098415	0.078972
0.08526	0.14241	0.098418	0.078809
0.09033	0.142274	0.098424	0.078653
0.095342	0.142136	0.098431	0.078506
0.1004	0.141988	0.098437	0.078364
0.105504	0.141828	0.098439	0.078226

0.110536	0.141659	0.098437	0.078093
0.115573	0.141475	0.098426	0.077963
0.120664	0.141273	0.098407	0.077832
0.125709	0.141058	0.098377	0.077703
0.130693	0.140828	0.098336	0.077573
0.13574	0.140578	0.098281	0.077437
0.14077	0.140313	0.098211	0.077297
0.145753	0.140033	0.098126	0.077152
0.150795	0.139733	0.098024	0.076996
0.155857	0.139415	0.097905	0.07683
0.16088	0.139084	0.097769	0.076654
0.165932	0.138735	0.097615	0.076464
0.171036	0.138367	0.097441	0.076259
0.176059	0.137991	0.097252	0.076042
0.181095	0.137599	0.097045	0.075809
0.186182	0.137188	0.096819	0.075556
0.191227	0.136767	0.096578	0.075289
0.196223	0.136336	0.096324	0.075007
0.201293	0.135883	0.096051	0.074703
0.206359	0.135415	0.095763	0.07438
0.21137	0.134936	0.095465	0.074043
0.216427	0.134435	0.095152	0.073685
0.221528	0.133909	0.094824	0.073305
0.226555	0.133369	0.094489	0.072912
0.231596	0.132802	0.094143	0.072501
0.236686	0.132202	0.093783	0.072067
0.241731	0.131576	0.093416	0.071621
0.246746	0.130917	0.093041	0.071161
0.251828	0.130209	0.092652	0.070677
0.256884	0.129457	0.092253	0.070181
0.261903	0.128657	0.091845	0.069671
0.266977	0.127789	0.091419	0.069141
0.272047	0.126852	0.090978	0.068594
0.277076	0.125845	0.090522	0.068036
0.282138	0.124745	0.090042	0.067457
0.287241	0.123537	0.089533	0.066856
0.292268	0.122238	0.089001	0.066244
0.297308	0.120815	0.088432	0.065611
0.302402	0.119239	0.087815	0.064949
0.307446	0.117528	0.087153	0.064268
0.312451	0.115668	0.08644	0.063565
0.317534	0.113594	0.085646	0.062819
0.322604	0.111324	0.084774	0.06204

0.327614	0.108862	0.083822	0.061229
0.332684	0.10613	0.082752	0.060362
0.337785	0.103114	0.081552	0.059435
0.342803	0.099862	0.080233	0.058463
0.347852	0.09628	0.078749	0.057416
0.352955	0.092319	0.077069	0.056277
0.357985	0.088049	0.075211	0.055063
0.363	0.083404	0.073135	0.053753
0.378354	0.066447	0.065103	0.048966
0.379335	0.065208	0.06449	0.048613
0.381296	0.062672	0.063224	0.047888
0.384303	0.058621	0.061174	0.046725
0.388317	0.052898	0.058218	0.045067
0.393314	0.045239	0.05416	0.042818
0.398353	0.036878	0.049604	0.040323
0.403463	0.027704	0.044462	0.037532
0.408491	0.017948	0.03884	0.034502
0.41353	0.007399	0.032593	0.031155
0.41864	-0.00414	0.025577	0.027409
0.423668	-0.01636	0.017944	0.023342
0.428707	-0.02953	0.009505	0.018852
0.433817	-0.04389	7.17E-05	0.013834
0.438845	-0.05905	-0.01014	0.008396
0.443884	-0.07534	-0.02138	0.002404

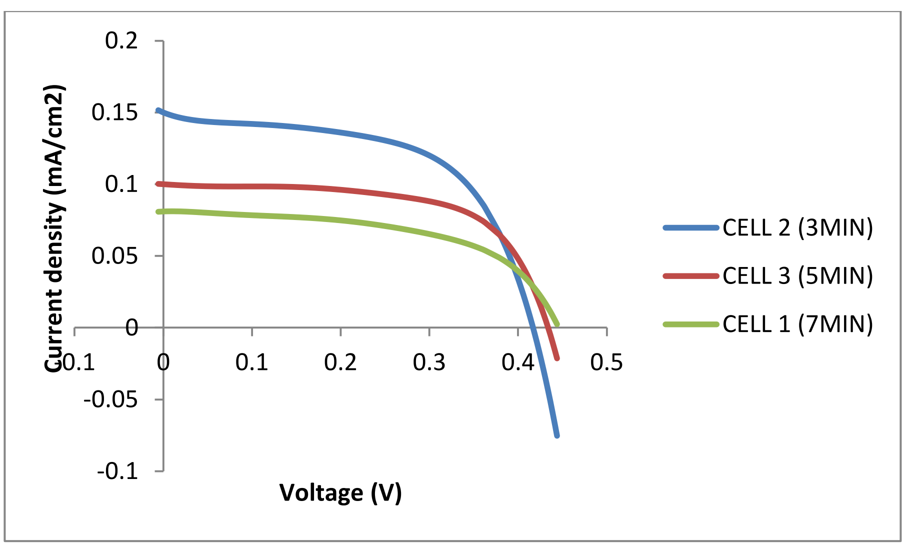

Fig. 1.7: Evaluated simulation graph comprising the I-V Curve for DSSCS for 3 minutes, 5 minutes and 7 minutes deposition times.

Table 1.7 Influence of TiO_2 Dense thin films blocking layer thicknesses, due to increase in deposition times on photo voltaic parameters of DSSCS.

Samples	V_{oc} (V)	I_{sc} ($mAcm^{-2}$)	F.F (%)	Efficiency (%)
3 min deposition time	0.41	0.52	0.68	0.12
5 min deposition time	0.41	0.35	0.66	0.09
7 min deposition time	0.40	0.28	0.55	0.07

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