Electrophoresis Temperature Effect on the TiO_2 Thickness of Dye-Sensitized Solar Cell

N. E. Lydia M. Safri, Kanta Sugii, and Kozo Taguchi
Department of Electrical and Electronic Engineering, Ritsumeikan University, Shiga, Japan
Email: {ro0027ef, ro0022ik}@ed.ritsumei.ac.jp, taguchi@se.ritsumei.ac.jp

***Abstract*—Dye-Sensitized solar cell is one of the newest ways to exploit the solar energy to convert it into electricity. It is composed of a few structures to function such as the electrodes, conducting layer, dye and electrolyte. Titanium dioxide is one of the most used substances to make conducting layer in dye-sensitized solar cell. There are many methods employed to create titanium dioxide coating such as spin-coating and electrophoresis. In this paper, we investigate the effect of electrophoresis temperature on the formation of the thickness of titanium dioxide layer thus linking the temperature effect to the solar cell energy conversion rate. The result is higher temperature resulted in more even titanium dioxide layer, with the solution boiling point as the temperature limit. From the experiments that we have conducted, it can be said that electrophoresis temperature affect the stability of titanium dioxide thin film thickness.**

***Index Terms*—electrophoresis, temperature, titanium dioxide, dye-sensitized solar cell**

I. Introduction

Titanium dioxide has three types of mineral form namely rutile, brookite and anatase. Anatase titanium dioxide one of the rarest type of titanium dioxide and is widely used as cathode material for dye-sensitized solar cell. In dye-sensitized solar cell, the titanium dioxide film quality has a huge effect on the solar cell's characteristic.

There are many methods used to deposit titanium dioxide on the conducting glass slide. One of the most inexpensive and easiest methods is by using electrophoretic deposition.By using this method, we can control the thickness of the titanium dioxide film by electrophoresis time and current density while the surface density (g/m^2) can be controlled by the concentration of the colloid itself [1]. In this paper, we use electrophoretic deposition method as described by Kawakami *et al.*in their paper [2]. The titanium dioxide used is P25 in nanoparticle size with diameter around 20nm.

There were also attempts to fabricate the titanium dioxide layer without sintering process but treating it with chemicaltreatment which is done by Miyasaka *et al.* in their paper [3].

A. Dye-Sensitized Solar Cell

Dye-Sensitized solar cells have gained a lot of attention in the solar energy conversion field with their advantageswhich include low fabrication cost and easy manufacturing. The highest efficiency rate for this solar cell is reported by Grätzel team to be about 13% [4] in early 2014.

When sunlight hit the dye molecules, energy is absorbed by the dye thus releasing electrons into the conducting layer. The electrons then reach the electrode and flow into counter electrode through external circuit thus creating current flow. The electrolyte helps prevent the degradation of dye molecules by supplying back the lost electrons to the dye. These processes are then repeated as long as there are excited electrons and this creates a continuous current flow. The rough structure of this solar cell is shown in Fig. 1 below.

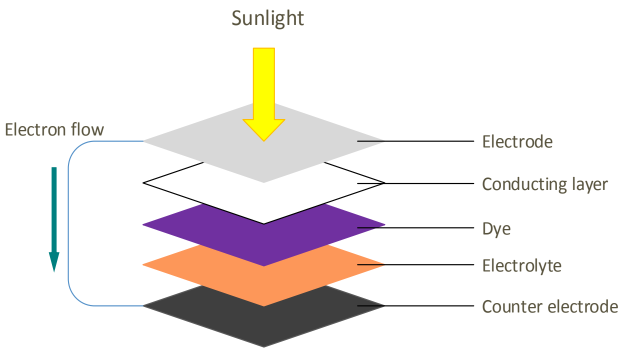

Figure 1. Basic structure of DSSC

B. Electrophoretic Deposition

Electrophoretic deposition, according to Van Tassel and Randall [5], is a particulate forming process where it begins with a dispersed powder in a solvent. Electric field generated by the direct current is used to move the dispersed powder particle across the solution onto electrode surface.

In this experiment, when powdered titanium dioxide is dispersed into ethanol, the titanium dioxide particles get positively charged. When direct current is supplied to the electrodes immersed in titanium dioxide colloid, these positively charged particle move towards the FTO (Fluorine doped Tin Oxide)glass slide which acts as the anode thus creating an even thin film.

II. Discussed Problems

As the quality of titanium dioxide film can affect the efficiency of the dye-sensitized solar cell itself [2], [6], various variables such asthe film thickness must be

Manuscript received January 6, 2015; revised July 28, 2015.

doi: 10.18178/ijeee.4.2.130-133

reproducible under the same experimental condition to ensure the credibility of the experiments and stable energy conversion. To create a stable dye-sensitized solar cell, apart from manipulated variable, othervariables in experiments mustbe almost identicalin every attempt to get a reliable data.

Spin coating method was used in previous experiments and the obtained efficiency percentages were very uneven. We think one of the reasons is that the thickness of the titanium dioxide thin film differs greatly with each sampleeven with fixed procedures thus affecting the efficiency of dye-sensitized solar cell.

It is well known that the thickness and quality of the titanium dioxide film is one of the important factors that can have big effect on the efficiency of dye sensitized solar cell. Therefore in this paper, we will use electrophoretic deposition to fabricate titanium dioxide layer which has high possibility of duplication.

During electrophoretic deposition, a lot of parameters have to be taken into account. Examples are solution used, current density, electrode used and distance between electrodes. Another parameter that is seldom taken into account is temperature of the colloid itself [7]. Therefore in this paper, we will investigate the effect of temperature of colloid during electrophoretic deposition on the thickness of the titanium dioxide layer.

III. Experimental Set-Up

A. Materials and Methods

Titanium dioxide particle used in this paper is P25 in powder form and used as received. The solvent used is ethanol because it has a high zeta potential which is needed to improve dispersibility of titanium dioxide nanoparticle in the solution [2].

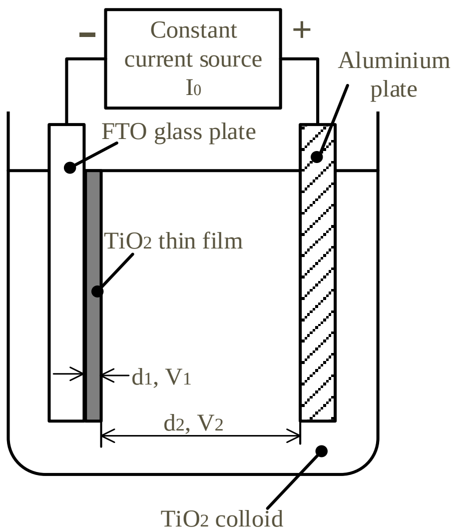

Figure 2. Experimental set-up for electrophoresis

FTO glass slide and aluminium plate were used as cathode and anode respectively. 0.1g of titanium dioxide powder was mixed with 20ml of 95.1% ethanol and magnetic stirrer was used to stir the colloid with the speed of 700rpm for one hour. The colloid temperature was then changed and electrophoretic deposition was carried out when colloid temperature reached desired temperature.

The temperature before electrophoresis and after electrophoresis was noted to ensure that it is within the range of T±5 ℃, where T is the electrophoresis temperature. However, the higher the desired electrophoresis temperature, the harder it was to keep the temperature within the range. To overcome this, the initial temperature of the titanium dioxide colloid before moving it to electrophoresis beaker must be high enough to ensure that the temperature during electrophoresis fall within the desired temperature range.

Ethanol has a boiling temperature of 78 ℃. Therefore, the colloid was tested for temperature starting from 10 ℃ to 60 ℃. Electrophoresis temperature of 70 ℃ cannot be tested as it is too near the boiling point, making it impossible to control the temperature to make it fall within the range when using our method.

For electrophoresis, current density suppliedwas of 0.0375mA/cm^2. The distance between electrodeswas set to 0.3cm(Refer Fig. 2 [2]). The electrophoretic deposition time was set to 60 seconds. Two specimens were made with as little time gap as possible. This is to limit the effect of stirring time which becomes longer with each consecutive specimen made.

$$V_0(t) = \frac{\rho_1}{S_0} d_1(t) I_0 + \frac{\rho_2}{S_0} d_2(t) I_0 \quad (1)$$

$$V_0(0)=d_2E \quad (2)$$

V_0 is the voltage across two electrophoresis electrodes. S_0 is the electrode area, ρ_1 is the resistivity of the TiO_2 thin film, ρ_2 is the resistivity of the colloid, d_1 is the thickness of titanium dioxide thin film, d_2 is the distance between positive electrode and the surface of the thin film on the negative electrode ($d_2 >> d_1$). I_0 is electrophoresis current. E is the electric field strength [2].

The specimens were then sintered at 450 ℃ for 1 hour. The thickness of the titanium dioxide thin film was then measured with contact type step profiler and the surface crack was observed by using optical microscope.

IV. Results and Discussion

Table I below shows the data for the graph in Fig. 3. A graph (Fig. 3) was the plotted according to the data and error bars were placed for easy comparison. The graph shows the relationship between titanium dioxide thin film thickness and electrophoresis temperature.

TABLE I. TiO_2 Thin Film Thickness and Colloid Temperature

Colloid temperature [℃]	Titanium dioxide thin film thickness		
	Minimum thickness [μm]	Maximum thickness [μm]	Mean [μm]
10	9.404	10.879	10.184
20	9.799	10.630	10.097
25	9.992	10.752	10.264
30	8.000	9.591	8.871
40	8.322	11.407	9.867
50	6.262	8.381	7.063
60	5.512	10.879	8.077

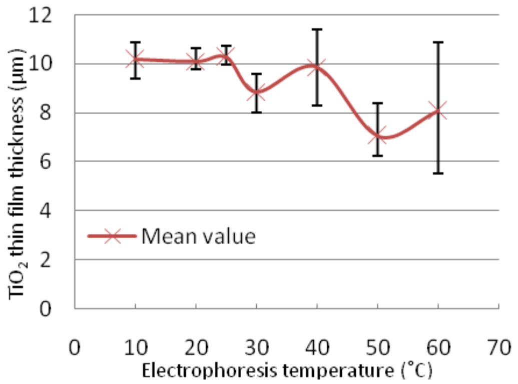

Figure 3. Relationship between thin film thickness and electrophoresis temperature

From calculating the average and plotting the graph, we can see a rough trend that shows titanium dioxide thin film thickness decreases with increasing electrophoresis temperature.

The difference between minimum value and maximum value is the lowest at temperature around 25 ℃ and the highest at temperature around 60 ℃. From the graph, we can conclude that the best temperature with the lowest variation of thin film thickness is around 20 ℃ to 30 ℃.

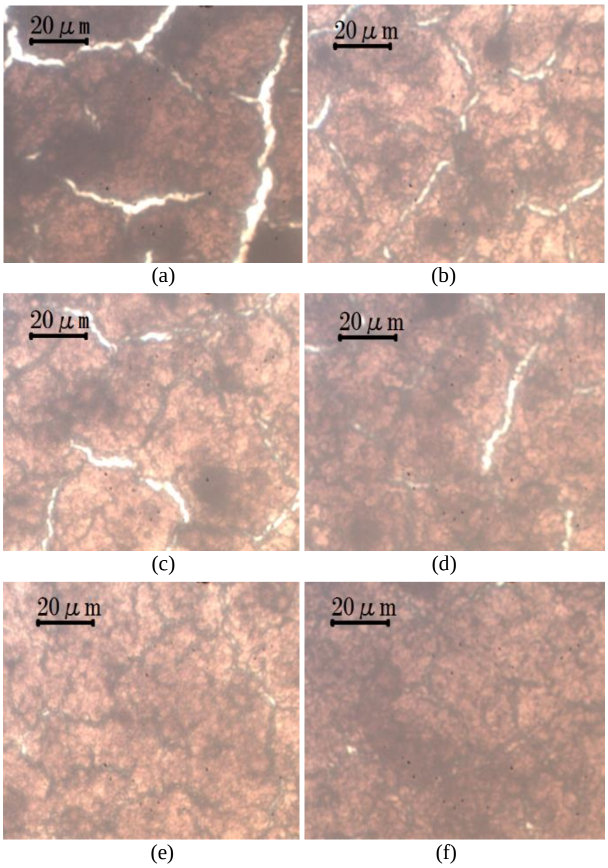

Figure 4. The surface images of titanium dioxide thin film seen under 40x optical microscope. (a) 10 ℃ (b) 20 ℃ (c) 30 ℃ (d) 40 ℃ (e) 50 ℃ (f) 60 ℃

Fig. 4 above shows the surface image of titanium dioxide thin film when take using a light microscope. The cracks become smaller as electrophoresis temperature increases.

During high temperature electrophoresis, it was observed that the area of titanium dioxide nanoparticles adsorbed onto the FTO conducting glass was smaller and at random.

This can be observed in the Fig. 5 below. Thin film in Fig. 5(b) which was fabricated at 30 ℃ has less area adsorbed with titanium dioxide compared to Fig. 5(a) which was fabricated at 20 ℃. This is thought to be due to the effect of fluid current flow throughout the titanium dioxide colloid during electrophoresis. This phenomenon poses difficult problem because high temperature electrophoresis yielded less cracks in the thin film surface as shown in Fig. 4.

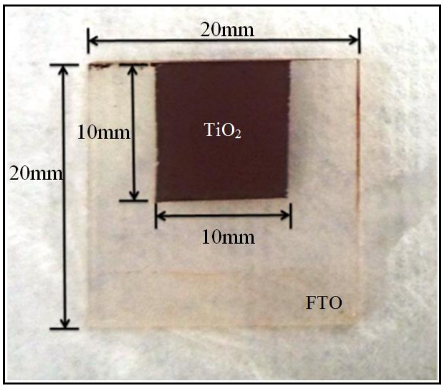

Figure 5(a). Dyed titanium dioxide thin film. Electrophoresis temperature at 20 ℃.

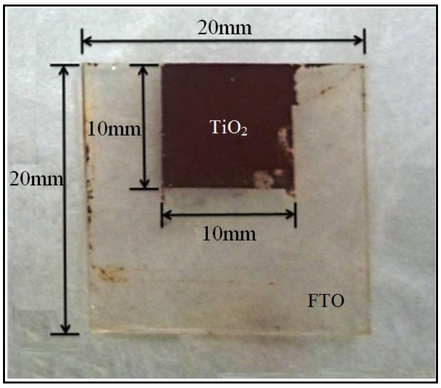

Figure 5(b). Dyed titanium dioxide thin film. Electrophoresis temperature at 30 ℃

In dye sensitized solar cell, the presence of cracks can interfere with the electrons movement. As such, lesser or no cracks are preferable for this type of solar cell.

The huge thickness difference obtained at high electrophoresis temperature may be due to the increasing kinetic energy of titanium dioxide nanoparticles causing bigger resistance to electric field force. This in turn makes the particles move slower in uneven fashion thus creating film with varying thicknesses.From the images, we can also infer that titanium dioxide nanoparticles were more dispersed i.e. less accumulated at higher temperature as there were less cracks in the thin film.

V. Conclusions

From the results and discussions, we can conclude that while higher temperature showed less and smaller cracks, the thickness of the thin films were relatively very unstable.

At high temperature, the particles were more dispersed than at lower temperature but the fluid movement caused the absorption area to be smaller as temperature increased.

Lower area of adsorption at higher temperature makes the fabricated thin film not suitable for dye-sensitized solar cell use. This problem of must be addressed first before further research involving efficiency is conducted.

VI. Future Work

High temperature during electrophoresis will cause fluid movement in the titanium dioxide colloid. Therefore to improve adsorption rate, a solvent with higher boiling point than ethanol will be used to make titanium dioxide colloid to avoid the fluid movement from interfering with the electrophoresis process.

However, the zeta-potential of the solvent must be taken into account to ensure that electrophoresis can take place. A solvent with similar zeta-potential to ethanol is preferable as it makes the comparison between the new solvent and ethanol easier. Most likely, the solvent will be a type of alcohol such as methanol and propanol.

Future research will be done to test these thin films in power generation efficiency. If the high temperature electrophoresis thin film is proven to have better efficiency than other temperatures, a way must be found to further stabilize the thickness of the thin film.

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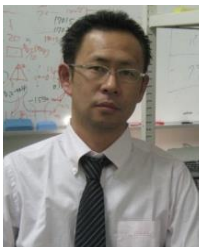
N. E. Lydia M. Safriwas born in Malaysia in 1991. Her first tertiary education was in Malaysia where she joined Japanese Associate Degree twinning program in a local university. This program included a 3-year Diploma's degree in Malaysia before entering a university in Japan as a third-year student. She completed the Bachelor's degree in photonics engineering from Ritsumeikan University, Japan in 2014. She is currently pursuing Master degree in electric, electrical and computer systems in the Ritsumeikan University as a second year student. Her current research interests include power electronics and materials.

Kanta Sugiiwas born in Osaka, Japan, in 1991. He received Bachelor's degree in photonics engineering from Department of Science and Engineering of Ritsumeikan University in Shiga, Japan.He graduated from his bachelor study in 2015. He is currently researchingabout fabricating DSSC by using electrophoresis.



Kozo Taguchi was born in Kyoto, Japan, on December 18, 1968. He received the B.E., M.E., and Dr. Eng. Degrees in electrical engineering from Ritsumeikan University, Kyoto, Japan, in 1991, 1993, and 1996, respectively. In 1996, he joined Fukuyama University, Hiroshima, Japan, where he had been engaged in research and development on the optical fiber trapping system, semiconductor ring lasers and their application for optoelectronics devices, and polymeric optical waveguides for optical interconnection. In 1996-2003, he worked as an assistant and lecturer in Fukuyama University. In 2003, he moved to Ritsumeikan University, Shiga, Japan, and currently he is a professor of Department of Electric and Electronic Engineering. From 2006 to 2007, he was a visiting professor at University of St Andrews (Scotland, United Kingdom). From 2014 to 2015, he was a visiting professor at Nanyang Technological University (Singapore). His current research interests include cells trap,microfluidic cell based devices, dye sensitized solar cell, biofuel cells. Dr. Taguchi is a member of the SPIE.