# DYE SENSITISED SOLAR CELL(DSSC) WITH TIO2 MULTILAYER FABRICATED BY NANO PARTICLE DEPOSITION SYSTEM

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## 1. Introduction

After developed by O'Reagan and Grätzel in 1991 [1], dye sensitized solar cell (DSSC) is one of highly attractive solar cells for many applications such as flexible solar cell, and building integrated photovoltaics (BIPV). Comparing DSSC with other solar cells, it has advantages such as low manufacturing cost, light weight, flexibility, transparency, and so on. DSSC consists of n-type semiconductor oxide, dye, electrolyte, and transparent electrodes. Conventional DSSC process is based on the glass substrate and it includes high temperature sintering process. This sintering process makes a strong bonding of oxide particles each other, but it limits the substrates materials of DSSC. Polymer substrates cannot be applied for the conventional DSSC fabrication process because of the process temperature. [2,3]

Nano particle deposition system (NPDS) is a novel method to deposit ceramic and metallic powders on substrates at room temperature by accelerating particles to subsonic speeds [4]. This new method adopts advantages of cold-gas dynamic spraying (CGDS) and aerosol deposition (AD). In NPDS, compressed air transports particles from a powder feeder to nozzle and particles are accelerated by nozzle. The main advantage of DSSC fabrication by using NPDS is that DSSC can be made on the polymer substrate and it needs no additional chemical processes. In addition, NPDS can create large oxide layer at once in atmospheric conditions.

Previous research shows the successful fabrication results on DSSC using NPDS [5]. But it shows the possibility of fabrication and the energy conversion efficiency should be improved. In order to increase efficiency, the bonding between transparent electrode and semiconductor oxide layer and the structure of semiconductor oxide layer are important. The multi-layer structure of semiconductor oxide showed improved energy conversion efficiency in conventional DSSC fabrication process. Arakawa et al fabricated multilayer film structure DSSC to increase the efficiency [6]. But the preparation of $TiO_2$ particles is complicated.

In this paper, DSSC with polymer substrate was fabricated using NPDS by taking advantage of the room temperature process and no additional chemical process. The semiconductor oxide multi-layer was fabricated using two different sizes of $TiO_2$ powders to increase the efficiency.

## 2. Experiment

Anatase phase $TiO_2$ powders of two different diameters (15 nm and 250 nm) were prepared for the fabrication of semiconductor oxide layer with multi-layer structure in DSSC. The sizes of each powder were observed by field emission scanning electron microscope (FE-SEM) image as shown in Figure 1.

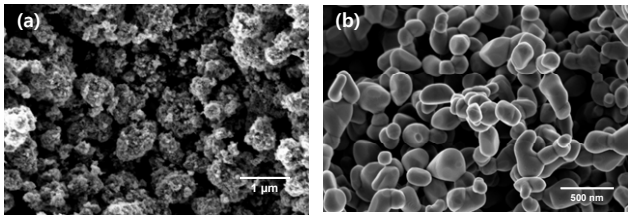


Figure 1. SEM images of $TiO_2$ particles with different diameters : (a) 15 nm and (b) 250 nm

All materials, including $TiO_2$ powder was used as commercially purchased. For working electrode and counter electrode, Indium tin oxide (ITO) coated PET (EMI-ito 15, Optical Filters, UK) which has high transparency and low surface resistance of 15 ohm per square was utilized. The ruthenium sensitizer (N719, Solaronix, Switzerland) solution was used as a dye and the iodide/tri-iodide

electrolyte (Iodolyte AN-50, Solaronix, Switzerland) was used as an electrolyte. The semiconductor oxide layer of $TiO_2$ nano powder was fabricated using NPDS.

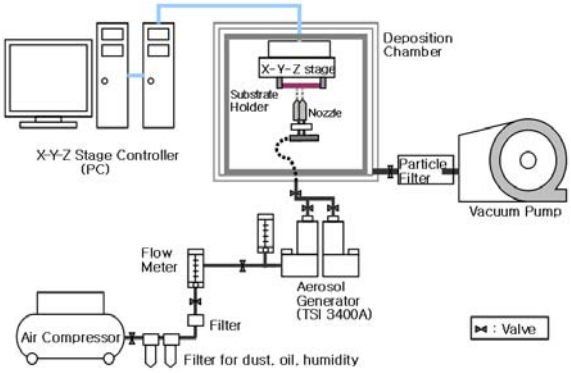


Figure 2. NPDS configuration

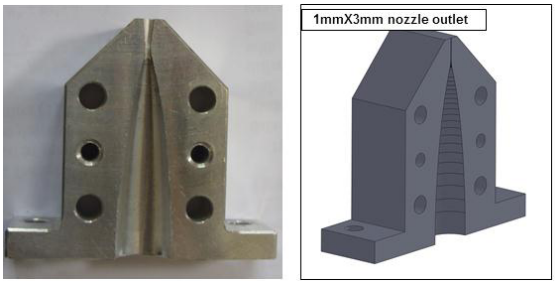


Figure 3. Shape of 1 × 3 $mm^2$ nozzle

As shown in Fig. 2, NPDS consists of controller, deposition chamber having substrate holder and nozzle, powder supplier, air compressor, and vacuum pump, etc.

The nozzle inside the chamber was a converging nozzle with outlet dimensions of 1 × 3 $mm^2$. The distance between nozzle outlet and substrate was 3 mm. Experimental parameters are listed in table 1. Chamber pressure was atmospheric condition and compressed air was 0.3 MPa.

$TiO_2$ powder was accelerated by compressed air and was sprayed with 1 × 3 $mm^2$ outlet dimensions. Since the chamber pressure was maintained at atmospheric pressure, vacuum condition required existing NPDS process wasn't necessary.

In the standard DSSC, a typical photoelectrode consists of about 10-15 μm layer of nanocrystalline $TiO_2$ particles (10-30 nm in diameter)[7]. But in this paper, 15 nm and 250 nm $TiO_2$ particles deposited to make multi-layer structure. First, 15 nm $TiO_2$ powder was deposited on ITO-coated PET. Then 250 nm $TiO_2$ was deposited on the first layer as shown in Figure 4.

Figure 4 shows schematic diagram of fabricated DSSC with multi-layer structure. And Figure 5 shows the fabricated semiconductor oxide $TiO_2$ multi-layer on ITO-coated PET substrate. This paper fabricated four kinds of structure, 15 nm mono-layer, 15 nm multi-layer, 250 nm mono-layer, and 15 nm 250 nm multi-layer. $TiO_2$ layered specimens as Figure 5.

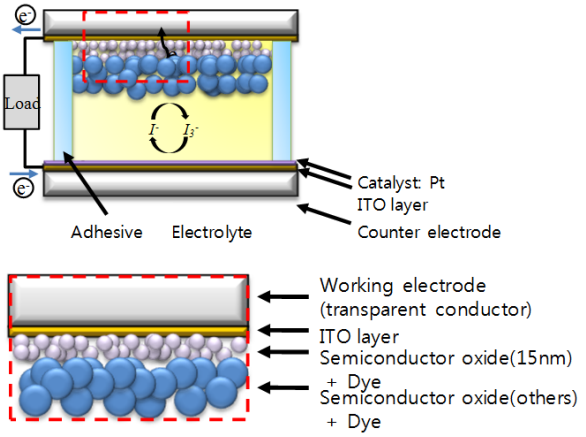


Figure 4. Schematic diagram of fabricated DSSC with multi-layer structure

Table 1. NPDS experimental parameters for TiO2 deposition of DSSC

| Chamber pressure | Atmospheric pressure |
|---|---|
| Compressor pressure (MPa) | 0.3 |
| Distance between nozzle and substrate (mm) | 3.0 |
| Number of scan | 1 or 2 |
| Scan speed (mm/sec) | 0.025 |

Through the dry-spray NPDS process, additional the semiconductor oxide printing method and high-temperature sintering processes is not be necessary.

After manufacturing the oxide multi-layer, $TiO_2$ photo-electrodes were dye sensitized by submerging the substrate with the deposited film in a dye bath for 12 hrs. in a dark room, and then cleaned with ethyl alcohol. The counter electrode also was prepared with ITO-coated PET. Platinum (Pt), as a catalyst, was coated onto the ITO-coated PET

substrate. Both electrodes were assembled with adhesive and electrolyte was injected.

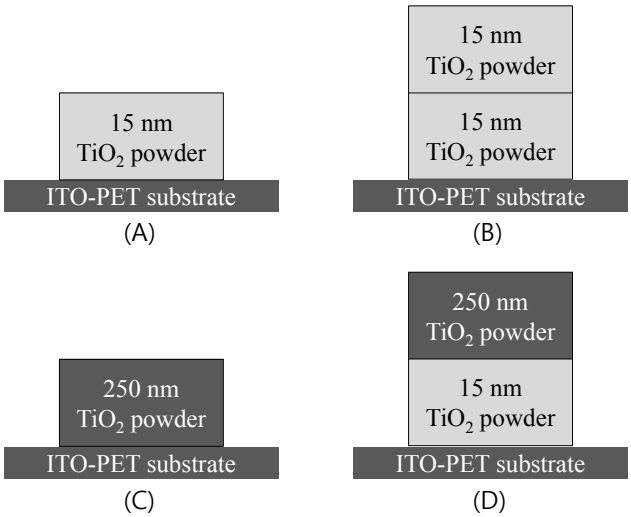


Figure 5. Schematic diagram of prepared TiO2 layers. (A) is 15 nm $TiO_2$ monolayer, (B) is multi-layer by same particle size 15 nm, (C) is 250 nm $TiO_2$ monolayer, and (D) is multi-layer using 15 nm and 250 nm $TiO_2$ particles.

After all the fabrication process DSSC was simulated by solar simulator (Polaronix, K201-LAB 50); it had a xenon lamp and the light illumination intensity was 100 $mWcm^{-2}$ (AM 1.5).

## 3. Results

Figure 6. (a) is result of optical image and (b) shows FE-SEM image of deposited $TiO_2$ particles on ITO PET substrates in a $10\times3$ $mm^2$ rectangular area(specimen (D) in table 2.). FE-SEM image shows 250 nm particles were deposited on the 15 nm particles.

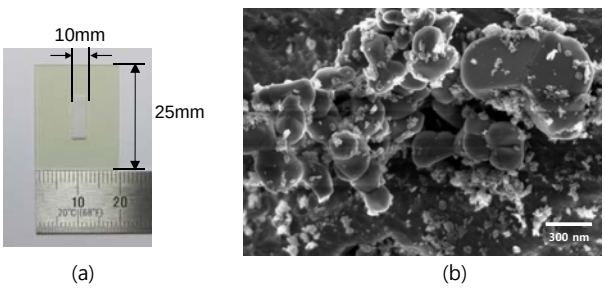


Figure 6. (a) Fabricated semiconductor oxide TiO2 multi-layer on ITO-coated PET substrate. (b) FE-SEM observation (top view)

Figure 7. shows x-ray diffraction (XRD) result of deposited $TiO_2$ particle. In this paper, anatase phase $TiO_2$ was used. The XRD results are consistent with anatase properties. There is no chemical reaction during the deposition process using NPDS.

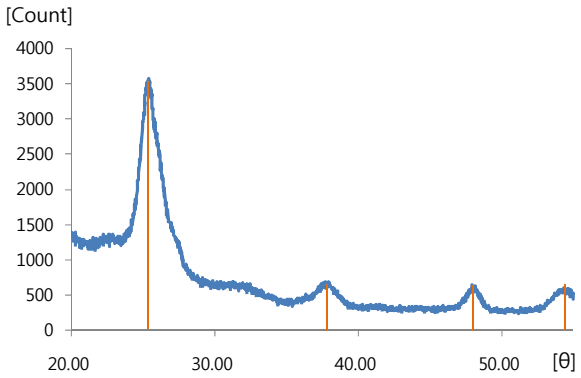


Figure 7. XRD result of deposited $TiO_2$ particle

The current density-voltage (I-V) curve of the fabricated DSSC cell was obtained by solar simulator. Figure 8 shows the I-V curve of the fabricated $TiO_2$ DSSC. And Table 3. shows the performance of fabricated $TiO_2$ DSSC cells.

Table 2. Performance of DSSC

| Notation | Voc [V] | Jsc [mA/cm2] | Fill Factor [%] | Efficiency [%] |
|---|---|---|---|---|
| (A) | 0.653 | 1.042 | 48.563 | 0.330 |
| (B) | 0.539 | 1.390 | 47.698 | 0.357 |
| (C ) | 0.448 | 0.673 | 28.210 | 0.085 |
| (D) | 0.614 | 2.566 | 44.928 | 0.635 |

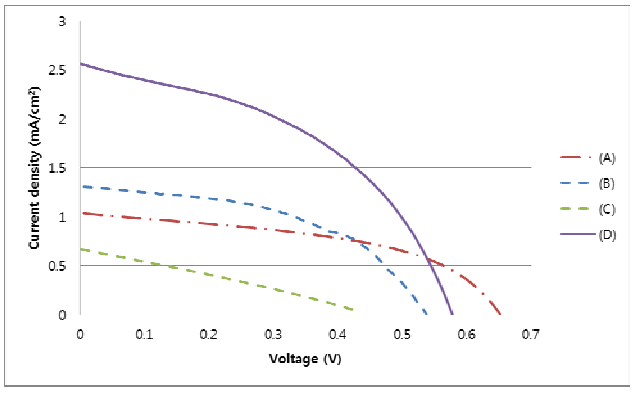


Figure 8. J-V curves of cells on ITO PET with various $TiO_2$ layers. (A) 15nm monolayer, (B) 15 nm multi-layer, (C) 250 nm monolayer, (D) 15 nm and 250 nm multi-layer

The performance of 15nm monolayer had highest open circuit voltage ($V_{oc}$) 0.653V but short circuit current density ($J_{sc}$) was poor. Efficiency is 0.33%. It because of the efficiency is combination of $V_{oc}$ and $J_{sc}$. To fabricate semiconductor oxide layer in multi-structure was increase the $J_{sc}$ and efficiency.

Specimen (B) is multi-layer of 15 nm particle. The result shows slightly decrease of $V_{oc}$ but increase the $j_{sc}$ from 1.042 mA/cm$^2$ to 1.39 mA/cm$^2$. And (D), multi-layer structure of 15 nm and 250 nm, had similar levels of $V_{oc}$ (0.614V) and more than twice value of $J_{sc}$ (2.566 mA/cm$^2$).

Although the (D) was not good in all parameters, $V_{oc}$ and fill factor (F.F), the multi-layer structure DSSC generated a highest $J_{sc}$. As a result of increased $J_{sc}$, efficiency increased from 0.33 to 0.635 %. This result shows multi-layer structure is a suitable mixture of semiconductor oxide layer for DSSC to improve the cell performance.

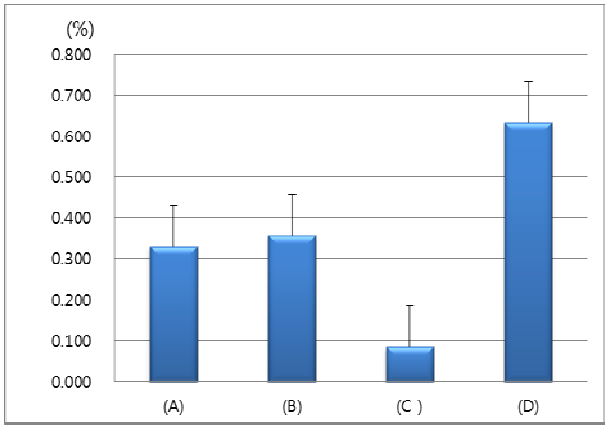


Figure 9. Result of DSSC efficiency. (A) 15nm monolayer, (B) 15 nm multi-layer, (C) 250 nm monolayer, (D) 15 nm and 250 nm multi-layer

## 4. Conclusions

Nanocrystalline semiconductor oxide powders with different diameters were deposited on ITO PET substrate using NPDS. In this paper fabricated multi-layer structure using 15 and 250 nm particles. The $TiO_2$ powders were deposited with a subsonic nozzle at room temperature. Without sintering process enables to fabricate $TiO_2$ layer on the flexible polymer substrate.

The multi-layer structure of semiconductor oxide can proved the bonding between electrode and semiconductor oxide layer and the interaction between semiconductor oxide and electrolyte. With these improvements, $J_{sc}$ was increased and energy conversion efficiency of fabricated DSSC was increased 0.33 to 0.635%.

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