Ultra-high speed fabrication of TiO_2 photoanode by flash light for dye-sensitized solar cell

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Abstract

In this work, a new way to fabricate nanoporous TiO_2 photoanode by flash light is demonstrated. TiO_2 nanoparticles are sintered on FTO glass by flash light irradiation at room temperature in ambient condition, which is dramatically simplified, ultrahigh speed and one-shot large area fabrication process compared to a conventional high temperature (450~500 °C) thermal sintering process. The effect of the flash light conditions (flash light energy and pulse numbers) on the nanostructures of sintered TiO_2 layer, was studied and discussed using several microscopic and spectroscopic characterization techniques such as XRD, SEM, AFM and UV-vis. The sintered TiO_2 photo anodes by flash light were used in DSSC and its performance were compared with that of DSSC fabricated by conventional thermal sintering process. It was found that a flash light sintered TiO_2 photoanode has efficiency which is similar to that of the thermal sintered photoanode. It is expected that the newly developed flash light sintering technique of TiO_2 nanoparticles would be a strong alternative to realize the room temperature and in-situ sintering of photoanode fabrication for outdoor solar cell fabrication.

Keywords: *Dye-sensitized solar cell (DSSC), Flash light (IPL), TiO_2*

1. Introduction

Recently, dye-sensitized solar cells (DSSC) has received increased attention as they are a low-cost alternative to conventional silicon based solar cells owing to potentially high efficiency(~10%) and low cost fabrication processes. Furthermore, DSSCs are applicable to windows or wearable electronic products due to their transparency and flexibility.

Conventionally, nanoporous TiO_2 photoanode is fabricated through blading or screen printing of TiO_2 slurry followed by high temperature (450~500 ℃) thermal sintering. However, high temperature processes include fatal problem. Lowering the processing temperature is required for cell fabrication on flexible substrates.

Recently, laser sintering process of TiO_2 have been widely studied to alleviate this problem. However its application to mass production is difficult as a laser sintering process can cover only a small sintering area and it requires a sophisticated 3D-gantry system to cover a large area. Therefore, new low temperature and large area sintering technique has been required. In this letter, we report a room temperature, ambient condition and ultra-high speed process to fabricate TiO2 photoanode for dye-sensitized solar cell (DSSC) applicable to mass- producion.

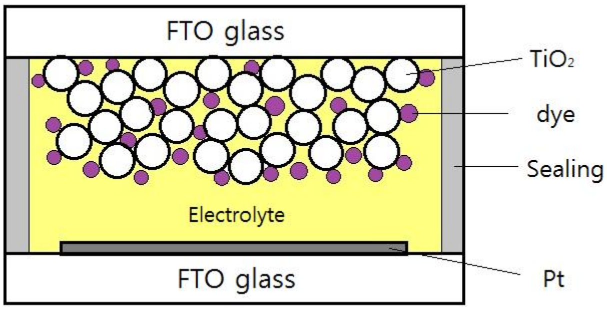


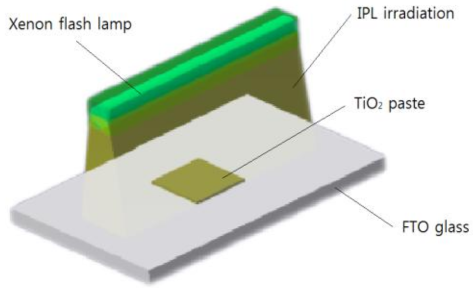
Fig.1. Schematic of DSSC

2. Experimental procedure

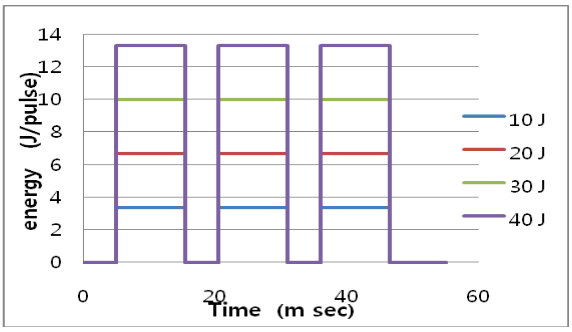
The TiO_2 thin-film electrode was designed and fabricated for use in the dye-sensitized solar cell. This TiO_2 thin-film was deposited on the surface of a FTO glass(Fluorine doped tin oxide, SnO_2:F) substrate, of dimensions 50 x 50 x 2.2 mm and a sheet resistance of 7 Ω/sq. And then the working electrode with the layer of TiO_2 nanoparticles was sintered at 500℃ for 30 min in a high-temperature furnace. And a FTO glass substrate with a layer of TiO_2 nanoparticles was then kept immersed for 24 h at room temperature in a mixture containing a solution of N-719 dye (Ruthenium 535-bis TBA) and distilled water. Using these procedures a conventional working electrode with a layer of thermal sintered TiO_2 nanocrystalline was compared with the working electrodes with the layer of TiO_2 nanoparticles sintered by flash light (IPL : Intense Pulsed Light) with different IPL conditions (Table 1) for the aim of demonstrating the feasibility and advantages of the DSSC by IPL sintering. Having prepared the working electrode, the counter electrode was prepared by depositing a thin film of platinum on the FTO glass substrate. The two electrodes were fitted together and sealed by melting sheet(SX 1170-60, 60 microns thick), such that there was a space between the two electrodes which was adjusted to approximately 50μm for insertion the liquid electrolyte. After sealing, the liquid electrolyte, Iodide based redox electrolyte (Iodolyte AN-50), was injected into the cell through a hole ohn the cell that was prepared in advace.

A digital sourcemeter (Keithley 2611A) was utilized to measure the open-circuit photovoltage and short-circuit photocurrent of the DSSC. A solar simulator (Abet technologies, LS150) with 150W xenon arc lamp source was employed to illuminate the DSSC on the condition of 1.5 AM.

To obtain high performances comparable to conventional DSSC by thermal sintering, we performed experiments for optimizing IPL sintering DSSC in different conditions in this study as shown in Table 1. The parameters of IPL sintering are irradiation energy per unit area, pulse number, on time/off time and shot number.



(a)



(b)

Fig.2. (a) Schematic of IPL sintering
(b) Pulse management of IPL

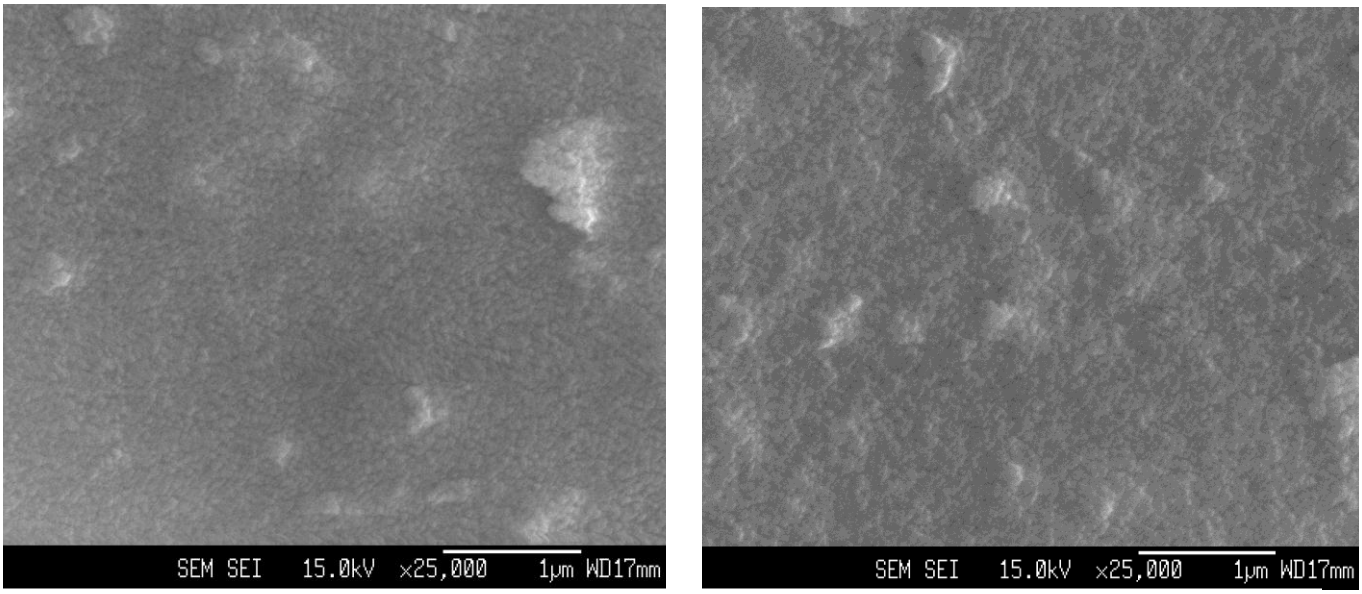
Pulse number	**3**	10	50
10 J (4 shot)	2ms/10 ms	4.3ms/10ms	6.8ms/10ms
20 J (4 shot)	**2ms / 30ms**	2 ms / 30ms	2 ms/ 30 ms
30 J (4 shot)	1.5ms/30ms	1.5ms/30ms	1.5ms/30ms

Table 1. Test conditions of IPL sintering

From the study, we found out that IPL sintering is possible with certain conditions (20 J/cm^2, 3 pulse, on/off time 2 ms / 30 ms, 4 shot). The effect of the flash light conditions (flash light energy and pulse numbers) on the nanostructures of sintered TiO_2 layer, was studied and discussed using several microscopic and spectroscopic characterization techniques such as SEM, AFM, XRD and UV-vis. And we compared performance of DSSC fabricated by IPL sintering with that of DSSC fabricated by conventional thermal sintering process through I-V curve.

3. Results and discussion

Figure 3 shows scanning electron microscopy (SEM) micrographs of IPL sintered TiO_2 nanoparticles on glass under different IPL condition : (a) pure TiO_2 , (b) IPL irradiated TiO_2 with 20J -3pulse. In 20J -3pulse condition, we can confirm that fine grains were formed comparing pure TiO_2. That means there are some changes in TiO_2 nanoparticles as irradiated by flash light. As the results of manufacturing solar cells and measuring efficiency, IPL sintering of TiO_2 is possible in 20J -3pulse condition. Thus we could think the SEM image (Fig. 3(b)) means the result of IPL sintering. However we couldn't logically prove IPL sintering of TiO_2 is possible in 20J -3pulse condition. So we also take AFM (Atomic Force Microscope) images to compare pure TiO_2, thermal sintered TiO_2 and IPL sintered TiO_2 with different irradiation energy conditions. Figure 4 shows pure TiO_2 changes similar to thermal sintered one as IPL irradiation energy increases. That means IPL sintering of TiO_2 is possible and sintering-degree of TiO_2 grow up as IPL irradiation energy increases. However, through manufacturing solar cells and measuring efficiency, we confirmed that IPL sintering of TiO_2 isn't efficiently accomplished as irradiation energy simply increases.



(a) (b)

Fig.3. The SEM (scanning electron microscopy) image of TiO_2 ; (a) pure TiO_2 , (b) 20J -3pulse

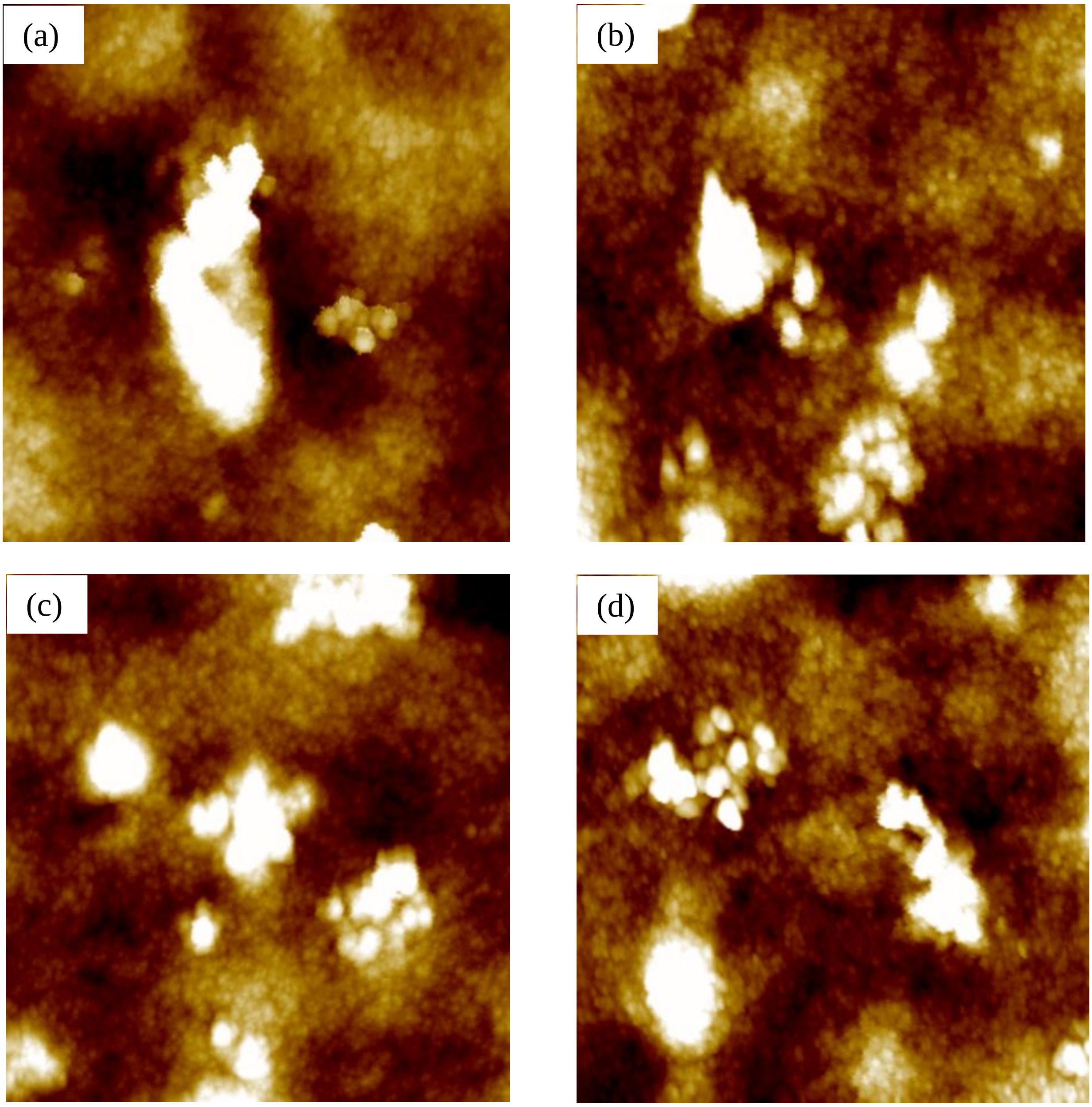


Fig.4. The AFM image of TiO_2 (a) pure TiO_2, (b) 20J -3pulse, (c) 30J -3 pulse,

(d) Thermal sintering

Figure 5 shows the J-V characteristics for several DSSCs containing the results of measuring efficiency of the DSSCs. As the results, DSSC with flash light sintering process (20 J/cm^2, 3 pulse, on/off time 2 ms / 30 ms, 4 shot) has almost half of efficiency of DSSC with thermal sintering process. So we sintered the whole area of TiO_2 layer through twice irradiation of flash light. And then DSSC with two-step flash light sintering process in same condition has efficiency similar to that of DSSC with thermal sintering process. In IPL sintered DSSC, the short circuit current density (J_{SC}) is 0.786mA/cm^2 nearly same to thermal sintered one, 0.839mA/cm[2]. Also, the open circuit voltage (V_{OC}) doesn't largely different between IPL and thermal sintered DSSCs. In conclusion, the IPL sintered DSSC has almost same efficiency with conventionally thermal sintered DSSC. It is expected that DSSC with flash light process would have high performance by changing flash light condition; irradiation energy per unit area, pulse number, on time/off time and shot number. Varying these parameters, we will be able to achieve higher efficiency of IPL sintered DSSC and epoch-making in solar cell study field.

4. Conclusion

In some IPL condition, IPL sintering of TiO_2 is possible and IPL sintered DSSC has almost same efficiency with thermal sintered one. Therefore, it is expected that IPL sintering process would be used efficiently to commercial dye-sensitized solar cells and would be a solution for the low-cost and mass production of high performance DSSC is possible. Based on the flash light sintering process proposed in this study, high performance DSSC working electrode can be fabricated in short time (msec) at room temperature and in ambient condition. Therefore, it would realize the solar painting process where the solar cell can be directly fabricated on the window and wall in real time. Through the solar painting process, low cost installation of the DSSC can be realized.

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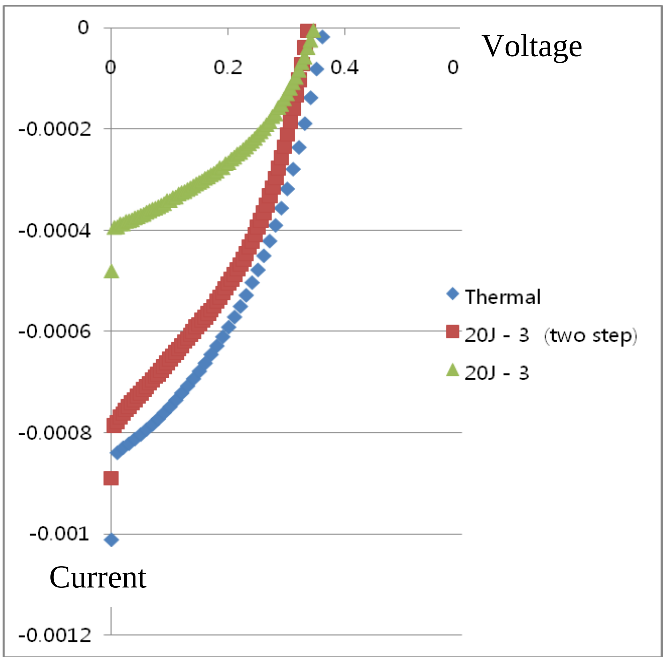

Sample	J_{SC} (mA)	V_{OC} (V)	FF (%)	η (%)
20 J - 3	0.394	0.347	39.8	0.054
20 J – 3 (two step)	0.786	0.340	38.8	**0.104**
Thermal	0.839	0.362	40.2	**0.12**

Fig.5. A comparison I-V curve of DSSC by IPL sintering with that of DSSC by thermal sintering