Fundamental Characteristics on Patterning TiO_2 of Dye-Sensitized Solar Cell Utilizing PELID (Patterning with Electrostatically-Injected Droplet) Method

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Abstract

Solar cell is one of the key technologies in this century because this has possibility to clear energy problems. In this paper, we tried to pattern titania layer of dye-sensitized solar cell (DSC) utilizing PELID method. The PELID method is an inkjet fabrication method. The PELID method has good merit; that is ability to eject highly viscous liquid. We applied the merit for patterning titania paste on FTO (Fluorine-doped Tin Oxide) glass. The thickness of titania layer was controlled by the time to print. DSC is composed of electrolyte that is sandwiched between FTO glass and Pt electrode. Titania and N3 are patterned on FTO glass. The efficiency is not so high. The main purpose of the study is to improve the efficiency. The fabrication process of the DSC was simple. Titania paste was patterned on FTO glass utilizing doctor blade. The patterned paste was dried and sintered. The thickness of the layer was controlled by the spacer between the doctor blade and the glass. In the former study, the thickness was not changed, however it is essential to determine the thickness to achieve the highest efficiency. Because best thickness will be changed by the chemical characteristics of titania, new fabrication method that can change the thickness easily should be developed. We developed the PELID method. When the strong electric field was applied to a nozzle, small droplets were ejected by the electrostatic force.

In this paper, we applied the PELID method to pattern titania on FTO glass. The thickness of patterned titania layer was investigated.

Introduction

Solar cell [1-3] is highly focused because this is able to generate energy without carbon. Many kinds of solar cell were suggested and produced. Silicon type and compound type are excellent in efficiency. However there are some difficulties in fabrication; those are high cost, complex process and high vacuum condition. Many researchers are engaged on dye-sensitised solar cell (DSC) to clear the problems. DSC is composed of electrolyte that is sandwiched between FTO glass and Pt electrode. Titania and N3 are patterned on the FTO glass. Light passes through the FTO electrode into the dye that is covered on the titania particles. Light excites electrons that flow into the titania. The electrons flow toward the FTO electrode. Through the external circuit, electrons are back to the Pt electrode of the cell. The electrolyte transports the electrons back to the dye. The mechanism of power generation of the DSC is similar to the photosynthesis of leaf. The efficiency of the DSC is not so high. The main purpose of the study on the DSC is to improve the efficiency. Former studies were focused on the shape and chemical characteristics of titania and pigments, the efficiency was relatively increased [4, 5].

The fabrication process was simple. Titania paste was patterned on FTO glass utilizing doctor blade. The patterned paste was dried and sintered. The thickness of the layer was controlled by the spacer between the doctor blade and the glass. In the former study, the thickness was not changed, however it is essential to determine the thickness to achieve the highest efficiency. Because best thickness will depend on kind of titania paste, fabrication method that can change the thickness easily should be developed.

We developed new inkjet technology that name was PELID method. When the strong electric field was applied to a nozzle, small droplets were ejected by the electrostatic force. Modes of droplet ejection were classified into several modes [6]. In this paper, we applied the spray mode to pattern titania layer on FTO glass. We investigated the thickness in case that the patterning time was changed because the efficiency depended on the thickness.

Experimental Set-up

Experimental set-up of PELID method was shown in Fig. 1 and 2. Small droplets were ejected by electrostatic force when high voltage was applied between nozzle that was filled with conductive liquid and plate electrode. The electrostatic field was controlled by the amplitude of applied voltage and the air gap between the electrodes. Print samples were patterned by the control of voltage application and xy linear stage. We already reported the fundamental characteristics of this inkjet technology. The merits of the inkjet technology were high resolution and ability to eject highly viscous liquid [6]. Inkjet technology is suitable to find best thickness of titania layer because the thickness is determined by the time to print. Titania paste in this experiment was made as follows. Titania particles (1.85 g) and water (1.0 g) was mixed. Acetylacetone (0.2 ml), Triton-X (1.0 ml) and polyethyleneglycol (0.185 g) were mixed into the paste. Titania was patterned on FTO electrode because FTO electrode was transmissive.

When high voltage was applied, titania paste was ejected like spray because of balance between charge and evaporation of the ejected droplet. In case that the mask was set on the FTO electrode shown in Fig. 1, titania on FTO electrode was patterned in a square shape.

The ejected droplet was separated into relatively small droplets because of balance between charge and evaporation of the ejected droplet when flight of the droplet was long. The experimental set-up shown in Fig. 2 was constructed to get uniform titania layer.

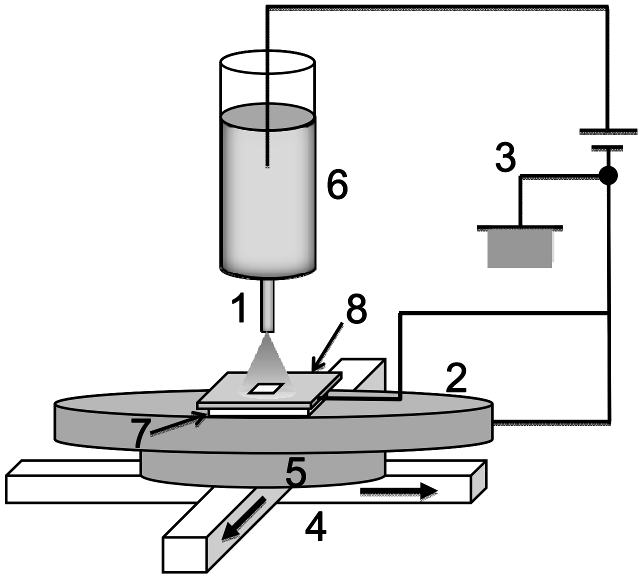

Fig. 1 Experimental set-up to pattern titania utilizing mask on FTO electrode. (1: water pin electrode, insulative capillary tube filled with TiO2 paste, 2:plate electrode, 3: high voltage power supply, 4: x-y linear stages, 5: mechanical z-stage, 6: tank, 7: FTO substrate，8: stainless mask)

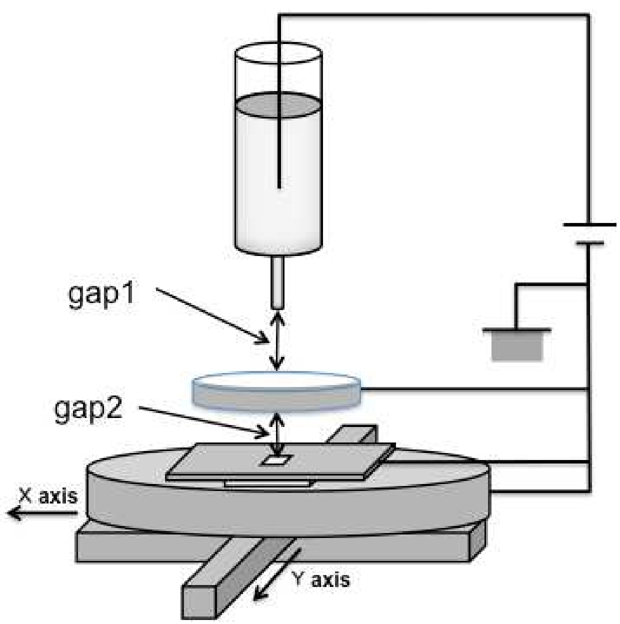

Fig. 2 Experimental set-up to pattern titania utilizing circle electrode and mask on FTO electrode.

Results

Titania was patterned utilizing the PELID method. The pattened samples were shown in Fig. 3 and 4. Because of the mask, titania on FTO electrode was patterned in a square shape. These pictures indicated that when the patterning time was increased, the titania layer was thick. Figure 5 shows the thickness of titania right after the patterning when the patterning time was changed. In spite that three types of experimental set-up were used, the thickness was almost the same. The thickness was linearly increased, whick depended on the patterning time. This figure indicated that we can control the thickness easily and precisely.

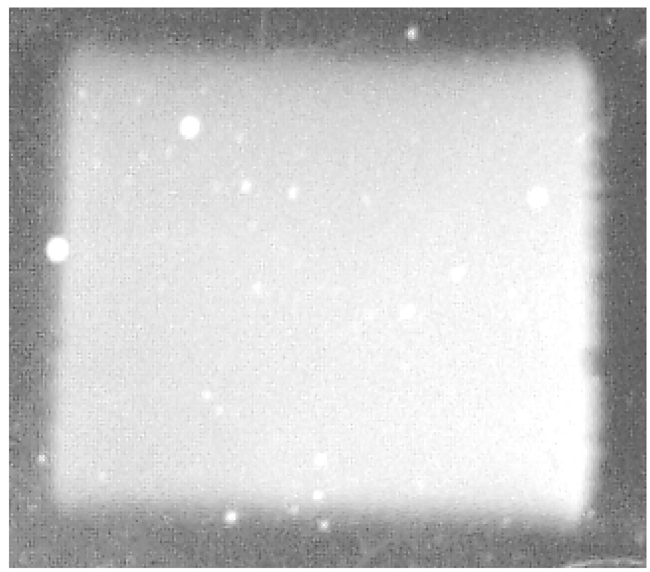

Fig. 3 Picture of patterned titania. (patterning time: 1 min)

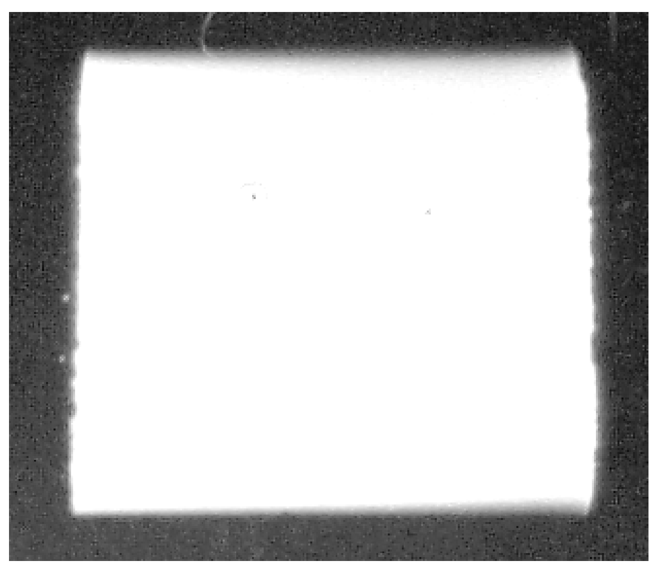

Fig. 4 Picture of patterned titania. (patterning time: 4 mins)

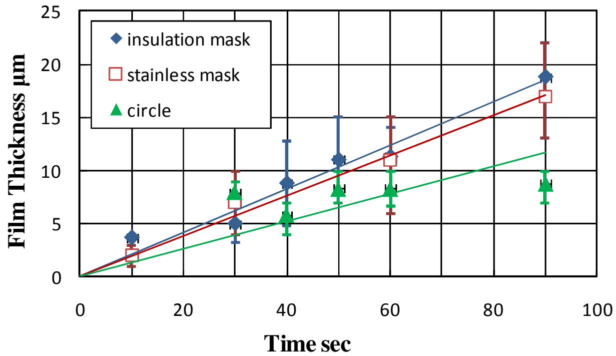

Fig. 5 Thickness of patterned titania when the patterning time was changed. (insulation mask: lower side of stainless steel mask was coated with insulator, stainless mask: shown in Fig. 1, circle: circle electrode was installed that was shown in Fig. 2)

Table1 Relationship between thickness and efficiency.

sample	Thick-ness /µm	J_{sc} /mA cm^{-2}	V_{oc}/V	f f	η/%
A	66	3.43	0.605	0.69	1.4
B	116	3.6	0.644	0.69	1.6
C	220	0.29	0.699	-	-

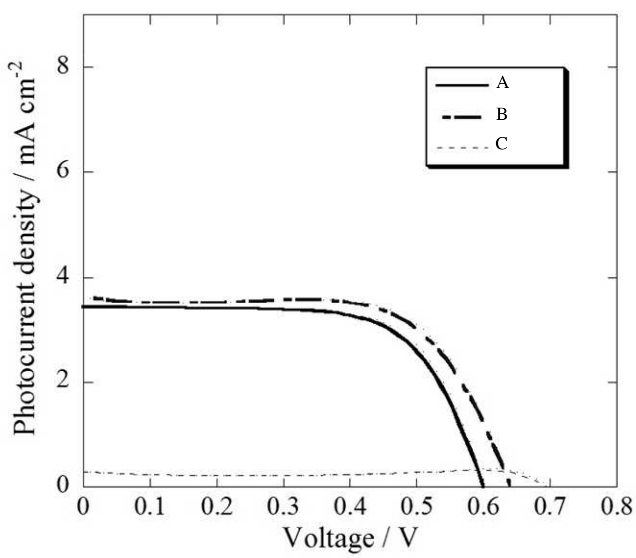

Fig. 6 *J-V* curve of fabricated DSC in case that the patterning time was changed.

Table 1 and Figure 6 show the fundamental characteristics of the fabricated DSC when the thickness of titania layer was changed. The thickness of the fabricated DSC was too thick because the former study indicated that the best thickness was about 20 micron meters. The efficiency was not so high.

Conclusions

Our inkjet technology, PELID method, was applied to pattern titania paste on FTO electrode. In spite that the viscosity of the paste was high, the paste was ejected by the PELID method. The patterned area was controlled utilizing the mask on FTO glass. It was possible to control the thickness of TiO2 layer when the time to pattern was changed. The efficiency of the preliminary fabricated DSC was about 1.5 %.

Acknowledgement

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References

[1] B. O Regan, M. Grätzel, Nature, 353, 737(1991).
[2] A. Hagfeldt and M. Grätzel, Acc. Chem. Res., 33, 269(2000).
[3] H.Arakawa, J. Surface Finish. Soc. Jpn., 59, 167 (2008) (in Japanese)
[4] S.Ferrere, B. A. Gregg, J. Phys. Chem. B 105, 7602-7605(2001)
[5] J. Spivack, Solar Energy Materials & Solar Cells 90, 1296-1307 (2006)
[6] H. Kawamoto, etal., J. Imaging Sci. Technol, 49, 1 (2005) pp.19-27.
[7] S. Umezu, etal., Proc. of EUSPEN 2008.
[8] S.Umezu, etal., SNA A, 166, 2 (2011) pp. 251-255.

Author Biography

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