Fundamental Characteristics on Nano Porous Titania Layer of Dye-Sensitized Solar Cell (DSC) Utilizing Electrostatic 3D Printer

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Abstract

We are now developing a new electrostatic 3D printer. We are now applying the 3D printer for fabricating the 3D cell structure in biotechnology and the dye-sensitized solar cell (DSC). The 3D printer is based on electrostatic inkjet printer. In this case, the nozzle was filled with the titania paste. The plate electrode was set under the nozzle. When the high voltage was applied between the nozzle and the plate electrode, small droplets were ejected from the nozzle because of balance among the high electrostatic force, gravity force, and the surface tension and the titania layer was formed. The thickness of the titania layer was controlled by the printing time, the applied voltage, and the air gap. The titania layer had many cavities. In this paper, we investigated fundamental characteristics of the nano porous titania layer. With the nano porous titania layer, the surface of the titania layer was increased, and the efficiency was higher than the solid titania layer that was fabricated utilizing doctor blade method. SEM and another experiment was applied to investigate the nano porous titania layer.

Introduction

Dye-sensitized solar cell (DSC) [1] has been highly focused as a renewable energy source because of decoration and cheap production cost in spite of low conservation efficiency. DSC was composed of the fluorine-doped tin oxide (FTO) glass that was covered with titania and N3 dye, Pt electrode, and electrolyte. When light passed through the FTO electrode into the dye, light excited electrons. The electrons flowed through the titania to the FTO electrode, the external circuit, the Pt electrode, and the electrolyte. Finally, the electrons came back to the dye. While light was provided, the electrons were generated continuously. For improvement of conservation efficiency, most researchers focused on chemical and shape characteristics of the dye and titania[2]. However, few studies has been carried out to improve the efficiency by the development of fabrication method of the titania layer. Porous titania layer was formed by the chemical vapor deposition[3,4]. 3D printer was applied to control the titania layer. On the other hand, we are now developing electrostatic 3D printer to fabricate high-functional artificial organ[5-9], high-efficiency solar cell[10,11], and other devices. We already reported the fabrication of titania layer and Pt electrode by the electrostatic 3D printer. When the electrostatic 3D printer was applied to print titania layer, then the conservation efficiency was increased because porous titania layer was formed. In this paper, we investigate the fundamental characteristics on printed porous titania layer.

Experiment

Experimental set-up shown in Fig. 1 was constructed to print titania layer. Nozzle filled with titania paste was set above the plate electrode and ring electrode. FTO electrode with the mask was set on the plate electrode. High voltage was applied between the nozzle and the both electrodes. Gap 1 and gap2 were determined as the distance between the nozzle and the ring electrode, and the distance between the ring electrode and the plate electrode. The electric field around the tip of the nozzle depended on the applied voltage and the gap 1. So, when the gap 2 was changed in the condition that the gap 1 and applied voltage were fixed, the electric field around the tip of the nozzle, and the mode of the droplet formation were constant. Titania paste in this experiment was

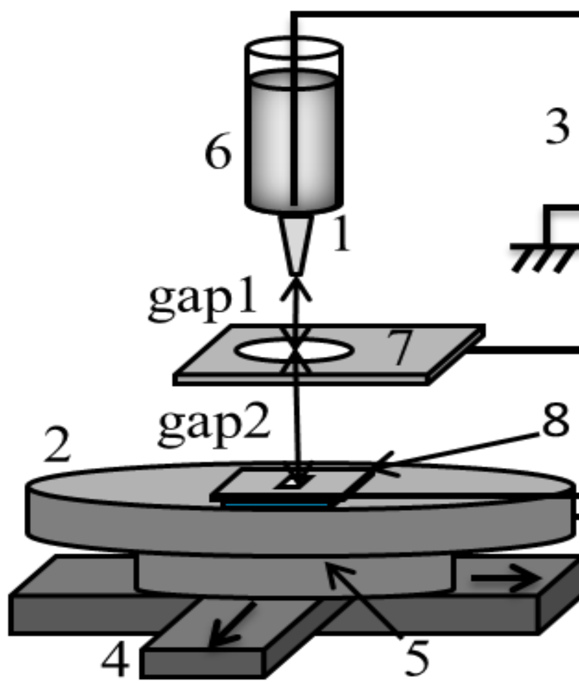
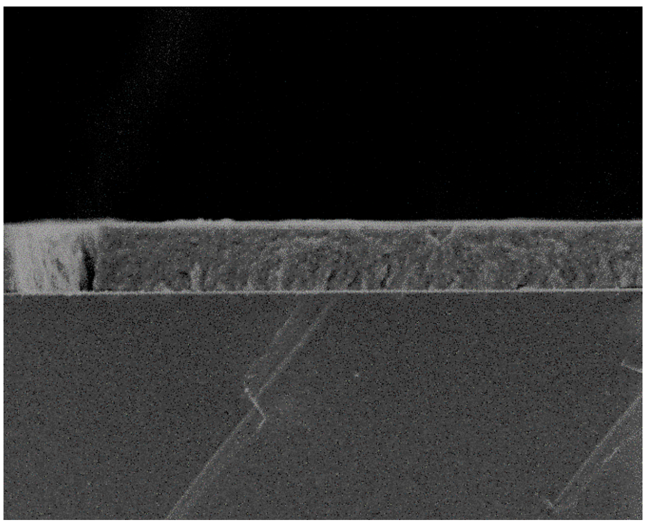


Fig. 1 Experimental set-up of electrostatic 3D printer of titania layer. (1: water pin electrode that is insulative capillary tube filled with titania paste, 2: plate electrode, 3: high voltage power supply, 4: x-y linear stages, 5: mechanical z-stage, 6: ink tank, 7: ring electrode, 8: mask on FTO electrode)

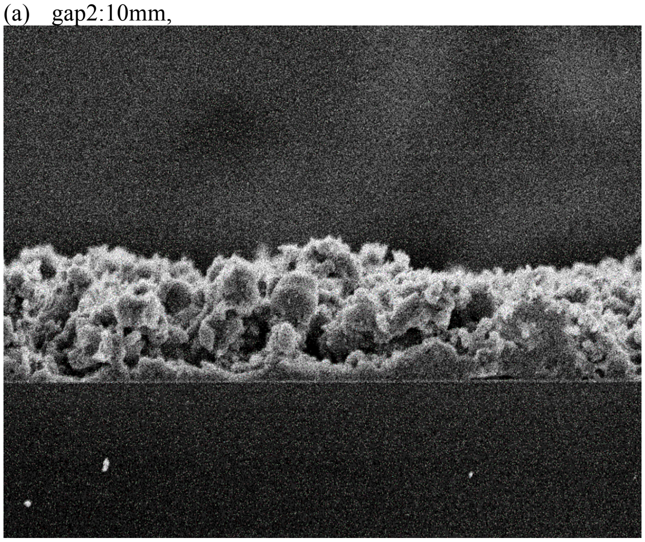
made as follows. Titania particles (1.85 g) and water (1.0 g) was mixed. Acetylacetone (0.2 ml), Triton-X (1.0 ml), and poly (ethylene glycol) (0.185 g) were mixed into the paste.

Results

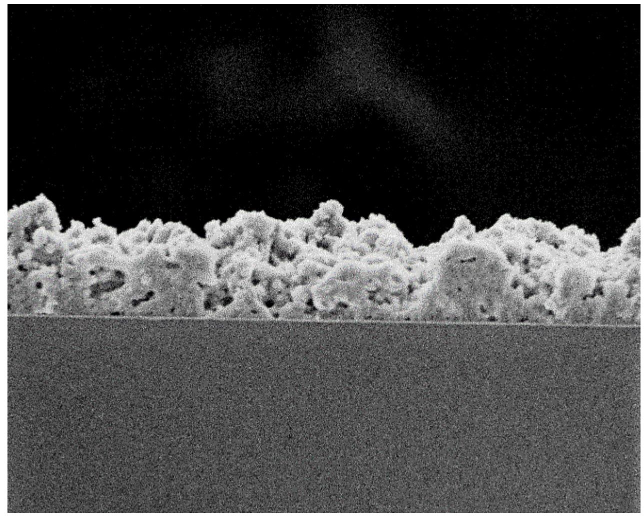
The titania layer was formed utilizing the electrostatic inkjet. Fig. 2 showed the SEM photographs of the cross section of the printed titania layers when the G2 was changed. When the G2 was 10 mm, solid titania layer was printed. When the G2 was 30 mm and 50 mm, porous titania layer was printed. The size of pores was increased in the condition that the G2 was wide because of the following evaporation process. The charged droplets were ejected by the electrostatic inkjet. During flying the moisture of the ejected droplets was decreased and the size of the droplets became small. The maximum charge of the droplet depended on the surface area of the droplet. So, the droplet charge exceeded the charge limit because of the reduction of the droplet size. Then, the droplets were divided into the further small droplets. The process continued before the droplet impact. In case that the gap was wide, the dried titania was printed on the target.



(a) gap2:10mm,

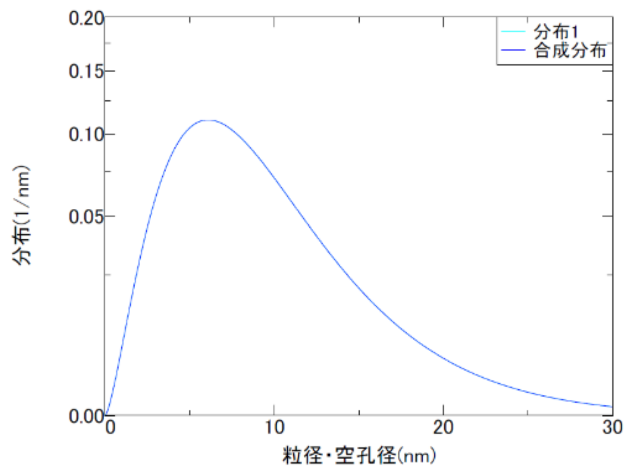


(b) gap2:30mm

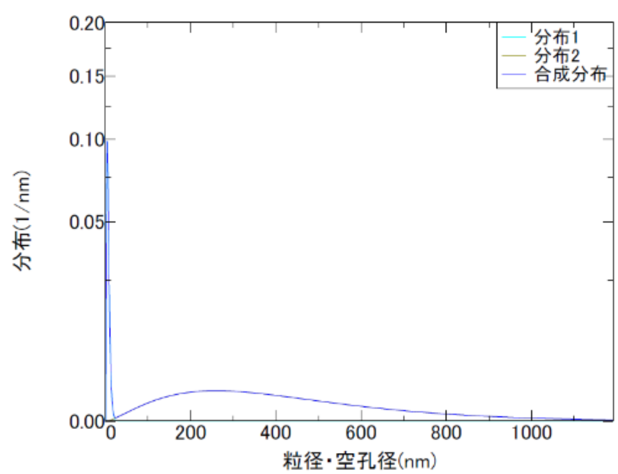


(c) gap2:50mm

Fig.2 SEM photograph of the printed titania layer when the G2 was changed.



(a) Gap2: 10 mm



(a) Gap2: 50 mm

Fig. 3 Pore size profile in the printed titania layer when the gap2 was changed. The profile was measured by XRR.

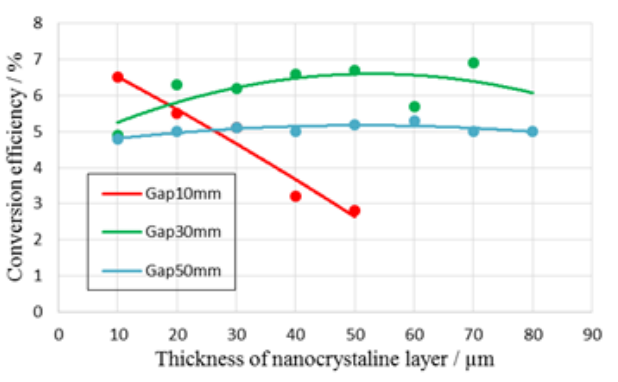


Fig. 4 Conversion efficiency when the gap 2 was changed.

We investigated the size and ratio of the pore utilizing XRR. Fig. 3 showed the profiles in the condition that the gap2 was 10 mm and 50 mm. In the case that the gap2 was 10 mm, the profile had single peak and the peak of pore size was around 7 nm. On the other hand, in the case that the gap2 was 50 mm, the profile had twin peaks. One peak was around 7nm and the other peak was around 220 nm. The later peak indicated the pores that we detected in the titania layer of the SEM photograph shown in Fig. 2 (c).

Fig. 3 showed the conversion efficiency when the titania thickness and the gap 2 were changed. In the case that the gap2 was 10 mm, the solid titania layer was formed. The optimized thickness of the titania layer was around 15~20 nm. So, the conversion efficiency was lineally decreased when the thickness of the titania layer exceeded 20 nm. When the gap2 was 30mm or 50 mm, porous titania layer was formed. So, the optimized thickness of the porous titania layer was around 40~50 nm. The conversion efficiency was not drastically decreased when the thickness was increased.

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