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Silver conducting lines of dye-sensitized solar cells printed onto commercial building tiles

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Abstract

We report a novel design and experimental results of dye-sensitized solar cell (DSSC) modules using commercial building tiles as one bottom substrate. In the study, the low-cost tiles as being one common part of the present buildings were employed for solar energy conversion unit here. Silver conducting lines consisting of nano-size particles were directly inkjet-printed onto their non-uniform surfaces of the tiles, thereby forming a grid-type pattern of counter electrodes. After sintering at elevated temperatures, the silver-printed tile was bonded together with a TiO_2-coated ITO (indium tin oxide) glass substrate immersed in N719 dye solution. The bonded substrates were injected with electrolyte and sealed by thin Polydimethysiloxane (PDMS) film to generate a DSSC device. This DSSC built on the tile basis showed an electric voltage of 0.51 V in the experiment. It is expected to be further developed for the building application for solar energy in the future.

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Keywords: dye-sensitized solar cell (DSSC), power conversion, silver conductive line, inkjet printing, building tile, solar energy

1. Introduction

Solar energy that is one of clean and abundant resources on earth has attracted much attention of recent studies due to emerging global energy crisis. Many types of solar or photovoltaic cells based on silicon, polymer, and dye

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have therefore been explored and developed with various processes and materials [1-4]. Among them, recent development on dye-sensitized solar cell (DSSC) demonstrates one promising alternative to achieve low-cost and high-performance devices by using nanometer-size titanium dioxide (TiO2) particles as a semiconductor layer [1-2, 5]. In addition, the technology of screen-printing (SP) process is also employed to fabricate a parallel grid-type pattern of electrodes on DSSC, yielding higher efficiency of power conversion [6]. As compared to that of screen printing, drop-on-demand (DOD) inkjet printing (IJP) technique exhibits more precise capability of generating micrometer-scale patterns in polymer solar cells [7]. Thus this inkjet printing method can be expectedly employed with variety of materials on DSSC devices.

In the study, we aimed to directly fabricate solar cells onto wall tiles in building application [8]. Using the IJP processes, non-uniform surfaces of the wall tiles that generally inhabit screen printing can be precisely coated with grid lines of silver nanometer-size particles [9]. Thus silver conductive electrodes are formed after sintering at elevated temperature. The DSSC devices with such IJP electrodes are fabricated and examined for their performances. In this case, the feasibility of inkjet printing could be further extended for new dye solutions in the near future [10].

Nomenclature

V	electric voltage (mV)
I	electric current (mA)
P	energy power (mW)
FF	fill factor
R	electric resistance (Ω)
Greek symbols	
η	efficiency of power conversion
Subscripts	
m	maximum value
i	input value
sc	short-circuit
oc	open-circuit

2. Design and fabrication processes

2.1. Configuration of solar cells on a wall (SCOW)

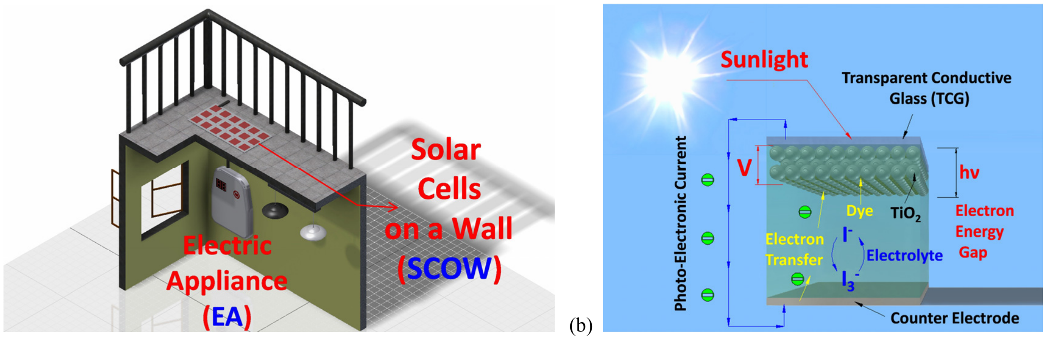
We first present a novel concept and configuration of solar cells on a wall (SCOW), as shown in Fig. 1(a). The power generated by the SCOW can provide an alternate of electricity for electric appliance inside a building. In this circumstance, the current dye-sensitized solar cell (DSSC) is very appropriate to be applied here for its large-scale active area available in manufacturing, as compared to conventional ones. As depicted in Fig. 1(b), this DSSC, composed of nano-porous TiO_2 (titanium dioxide) and photo-sensitizer of dye in a solution of electrolyte, directly converts photon power (*hv*) of sunlight into electric one by virtue of dye, thus generating electric voltage (*V*) together with photo-electronic current.

2.2. Fabrication processes of DSSC on a tile

Fig. 2 presents a typical scheme of fabrication processes for a DSSC. Here the whole processes can be divided into two parts: one cover ITO (indium tin oxide) glass substrate and one bottom tile substrate. As demonstrated in Fig. 2(a), an ITO glass substrate has been processed through a series of steps consisting of cleaning, TiO_2 spin-coating (for semiconductor layer), TiO_2 curing, TiO_2 dyeing (for photo-sensitizer film) and drying. After undergoing through the first part of fabrication processes, one transparent conductive glass (TCG) with active dyed-TiO_2 area is yielded, as being a cover substrate of a DSSC to receive the solar power of sunlight in Fig. 1(b).

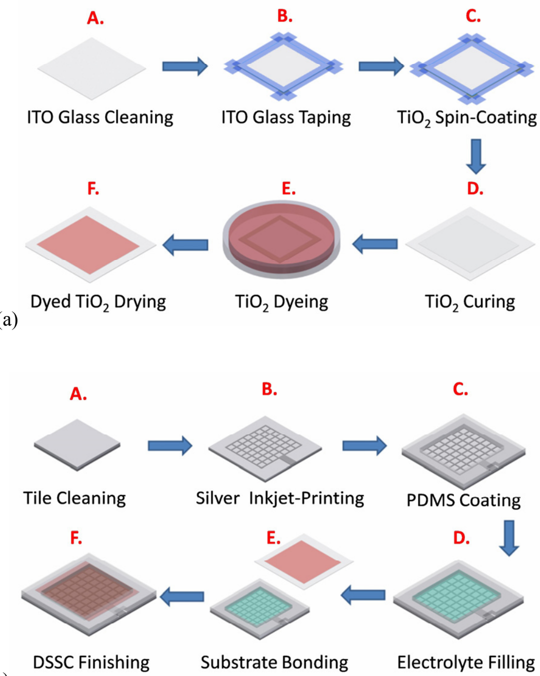
In the second part of fabrication processes, as illustrated in Fig. 2(b), another wall tile substrate is separately processed by virtue of silver inkjet-printing (for conductive grid lines of electrode), PDMS (Polydimethysiloxane)-coating (for patterning spacer), electrolyte filling (for redox solution), substrate bonding (with the cover substrate) and final finishing to be a completed DSSC.

Meanwhile, it is known in the first part that intensive care should be taken in steps of curing, dyeing and drying for resulting in nano-sized porous structures of TiO_2 [1-2]. However, in the second part, it is still unknown about the inkjet printing of a wall tile with silver nanoparticle ink, thereby forming a conductive layer of counter electrode. Hence, much attention should be paid for design here to find its feasibility in the study as below.



(a) (b)

Fig. 1. Fundamental concept of the present application studied for solar cells: (a) solar cells on a wall (SCOW) electrically connected with electric appliance (EA) for power supply and (b) photo-electronic current generated between a transparent conductive glass (TCG) and a counter electrode.



(a)

(b)

Fig. 2. Illustration of fabrication scheme for (a) cover ITO glass substrate processed successively through cleaning, taping, spin-coating, curing dyeing, drying and (b) bottom tile substrate processed with following steps of inkjet-printing, coating, filling, bonding and finishing for a DSSC.

2.3. Silver grid lines of inkjet printing

A conceptual design of silver grid lines of inkjet printing on a wall tile is shown in Fig. 3. It is noted that this non-contact inkjet printing is suitable for patterning the non-uniform surface here. To yield a fine conductive layer, the 7×7 grid-type pattern is adopted with outlined dimensions of 71.5× 85 mm^2, substantially covering ~61% of a tile area with 100× 100 mm^2. Its effect of the electric conductivity on efficiency of power conversion can be found in experiments.

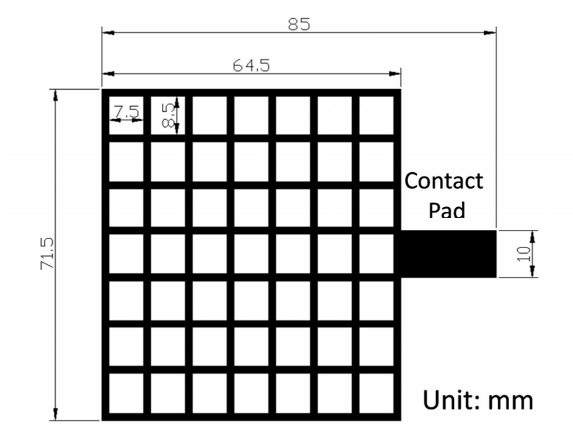


Fig. 3. Design of silver grid lines of 7×7 for counter electrode (each opening with 7.5× 8.5 mm^2) on the wall tile with dimensions: covering a width of 58 mm and a length of 71.5 mm together with a connected contact pad of 10 mm.

2.4. Efficiency of solar cells

The electric current (*I*)-voltage (*V*) relationship (i.e., *I-V* curve) plays a significant role in determination of performance for a DSSC. Based on the measurement of current and voltage, a fill factor (*FF*) presents the ratio of an actual maximum DSSC power (i.e., $P_m = I_m \times V_m$) to a virtual power of short-circuit current (I_{sc}) and open-circuit voltage (V_{oc}), as expressed in Equation (1). In addition, the efficiency of conversion from solar energy to electric energy can be, therefore, calculated with this value of *FF* and the input power of sunlight, as shown in Equation (2). Thus the values of the printed DSSC in the study will be given in experiments below.

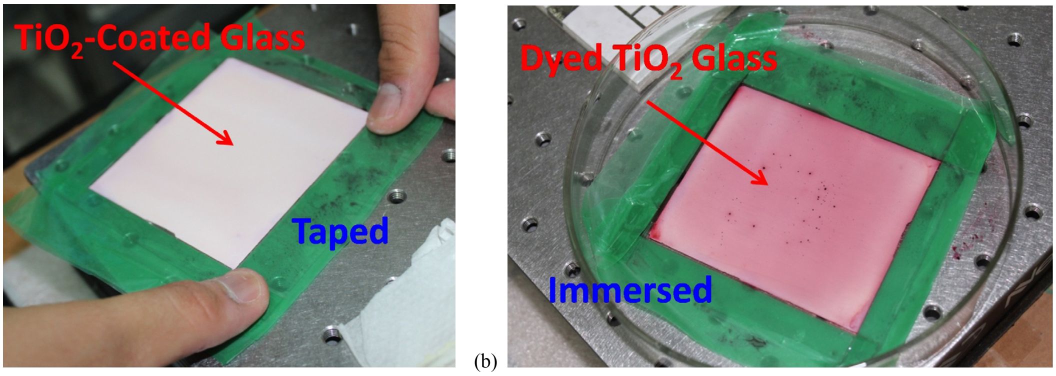
$$FF = \frac{I_m \times V_m}{I_{sc} \times V_{oc}} \tag{1}$$

$$\eta = FF \times \left(\frac{I_{sc} \times V_{oc}}{P_{in}} \right) \tag{2}$$

3. Results and discussions

3.1. TiO_2 coating and dyeing of a wall tile

First of all, as demonstrated in Fig.4(a), a TiO_2 dispersion solution (FW 79.90 with 0.2 ml Triton X-100) is coated onto taped ITO glass substrate with an area of 70×80 mm^2. Then the TiO_2-coated substrate is thermally cured at an elevated temperature of 450°C for 30 minutes. As shown in Fig. 4(b), this cured substrate is further immersed in dye solution (N719, 1188 g/mole) for 24 hours to yield a cover glass substrate.

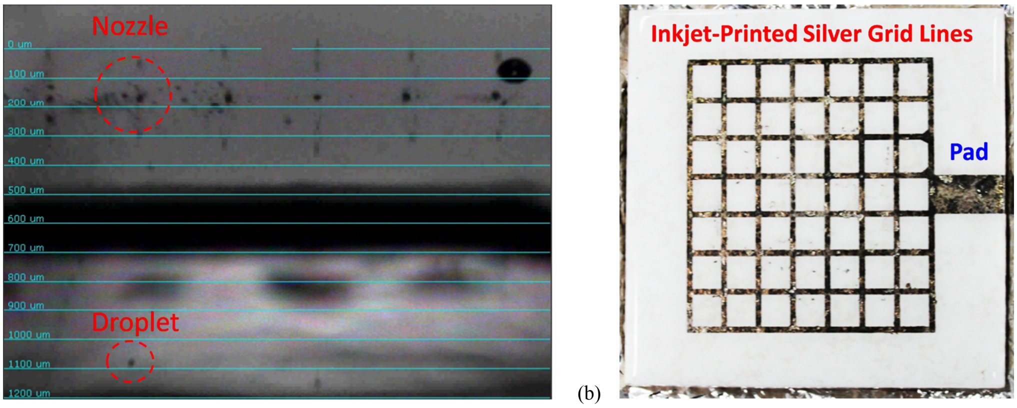


(a) (b)

Fig. 4. Photographs of experimental results for (a) TiO_2 spin-coating and taping of a 70× 80 mm^2 glass substrate and (b) dyeing of the TiO2-coated glass substrate in a solution N719.

3.2. Inkjet printing of counter electrodes

Using a commercial inkjet printer (Dimatix 2800, USA), the silver nanoparticle droplets (volume of 10 pl) can be generated from a nozzle under a driving voltage of 25 V and frequency of 3 kHz, as shown in Fig. 5(a). With a number of the generated droplets, the grid-line patterning is performed under a normal condition of room temperature. After thermally cured at 200^{o}C for 6 hours, a low electric resistance (R) square of 7 Ω-cm^{-2} is obtained with the printed silver grid, as depicted in Fig. 5(b).

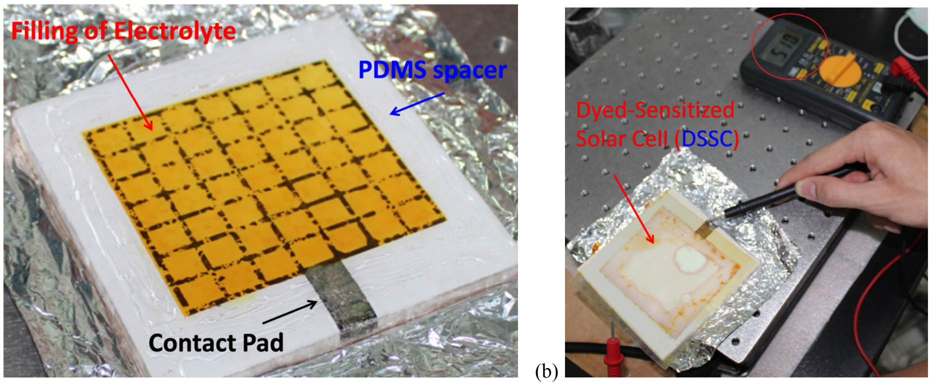


(a) (b)

Fig. 5. Demonstration of inkjet printing processes: (a) small droplets of silver nanoparticle generated from nozzles under a normal condition of room temperature (b) printed grid lines formed by silver-droplet deposition after thermally curing.

3.3. Package and tests

Finally, the electrolyte (0.6M-KI and 0.05M-I_2 with Acetonitrile) is filled into the region surrounded by PDMS film, as illustrated in Fig. 6(a). Then the cover and bottom substrates are eventually bonded and packaged together to form a DSSC as previously shown in Fig. 2. Thus this DSSC is found with a generation of electric voltage of 0.51 V under illumination, as demonstrated in Fig. 6(b). In addition, the V_{oc} of 0.41 V and I_{sc} of 0.1 mA are preliminarily obtained under simulated solar power of 1000 W-m^{-2}, corresponding to the V_m of 0.21 V and I_m of 0.1 mA with FF of 41%. Still, it requires more detailed measurement of conversion efficiency in the future.



(a) (b)

Fig. 6. The final package and test for a printed DSSC: (a) filling of electrolyte with PDMS spacer and (b) measurement of an electric voltage directly generated under illumination.

4. Conclusion

In the study, a novel design of dye-sensitized solar cell (DSSC) modules built on a TiO_2 glass and a low-cost building tile is proposed and explored here. In particular, inkjet printing technology is employed to directly form a grid-type of silver counter electrodes on a wall tile. The DSSC created here is measured with an electric voltage of 0.51 V under illumination. In the near future, following the concept of solar cells on a wall (SCOW), it is expected to be further investigated in the potential building application for solar energy.

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