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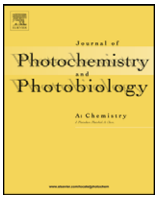

A module of a TiO_2 nanocrystalline dye-sensitized solar cell with effective dimensions

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ABSTRACT

As dye-sensitized solar cells (DSSCs) have advanced to large-scale applications from lab-level research, the large-scale performance has attracted much attention. Modules of DSSCs with size up to 10 cm × 15 cm have been investigated to optimize the efficiency for effective application. Essentially, these modules have an extended structure with lab-scale works with the exception of the dimensions and methods for the series connection. The 10 cm × 10 cm modules have shown an efficiency of 6.3% without a scattering layer and over 6.6% with a scattering layer. While the fill factors of modules depend on the width of each TiO_2 unit cell, they are much less dependent on the lengths of the unit cells.

1. Introduction

Since the first successful demonstration of TiO_2 nanocrystalline dye-sensitized solar cells (DSSCs) [1], they have attracted much attention due to their low cost, steady efficiency, and relatively transparent characteristics compared to conventional inorganic thin-film solar cells [2]. In addition, they are available in a variety of bright colors whereas conventional solar cells are typically black or blue. Based on these advantages, they have a broad range of applications, including as functional windows. Although there are drawbacks associated with the use of DSSCs, such as leakage with the liquid electrolyte system at high temperatures, there continues to be intensive study towards solving these issues; thus, DSSCs can be introduced into the market. For instance, much research has involved trials to replace the liquid electrolyte with other materials such as inorganic or organic hole conductors, ionic liquids, or polymers for a better sealing of the system [3–7]. In addition, other research has focused on replacing the current solvent to a solvent with a higher boiling point. This will reduce the vapor pressure at high outdoor temperatures. Wang et al. introduced stable DSSCs that showed a high efficiency of 8% with low volatility [8]. They applied an electrolyte based on 3-methoxypropionitrile, and showed long-term stability with this electrolyte for up to 1000 h.

Although laboratory studies are well demonstrated and understood, studies of larger scale devices are limited. Many obstacles remain to be solved at the manufacturing level, including factors related to reliability, an efficient structural design for assembly, and stability-related issues. These issues are gradually being addressed. Toyoda et al. investigated possible challenges for practical outdoor uses of DSSCs with a large-scale DSSC module composed of 64 DSSC cells in a series [9]. They successfully operated the modules for nearly six months.

In the present paper, the effective dimension and structure necessary to commercialize DSSCs are demonstrated. These efforts aim at obtaining maximized efficiency from the DSSCs, which are prepared by effectively connecting individual TiO_2 unit cells in series. In essence, conditions identical to those of small lab-scale cells are utilized to fabricate a module. However, the length and width were changed in order to realize these effects.

A small number of researches have addressed optimization of a large-area DSSC array [9–11]. Krebs et al. addressed the optimum condition through a combination of three major factors: transparency control, quasi-solid-state construction, and a low-cost realization of modules [3].

2. Materials and preparation [12,13]

Anatase TiO_2 colloids were made from a sol–gel hydrolysis and autoclaving of titanium isopropoxide at 230 °C for 12 h in an acetic acid aqueous solution, as described elsewhere. The

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autoclaved colloidal solution (containing 18–25 nm size particles) was condensed into a TiO_2 concentration of 12 wt%. To control the viscosity of the solution and prevent TiO_2 film from cracking, 20 wt% polyethylene glycol (Fluka, MW 20,000) and 20 wt% polyethylene oxide (Aldrich, MW 100,000), with respect to the amount of TiO_2, were added. For scattering layer, 400 nm TiO_2 (CCIC) particles were used. The doctor blade technique with the solution was used to produce a TiO_2 film on conducting F-doped tin oxide (FTO) coated glass. For screen printing, the colloidal solution from the autoclave was treated with terpineol, lauric acid, and ethyl cellulose for a proper viscosity. The film (10 μm) was annealed at 500 °C for 30 min in air.

Silver lines were prepared as the same method for TiO_2 preparation. Silver paste was purchased from Metek, and thickness of the silver line was controlled by screen pattern thickness.

Etching was patterned by Nd:YAG pulse laser scriber (Wondar Laser). The laser wavelength, maximum output, and pulse energy are 1064 nm, 15 W, and 1 J, respectively. The resistance between two places divided by etching is over 15 MΩ.

To coat sensitizing dye on a TiO_2 nanocrystalline film, the samples were immersed in 3×10^{-4} M Ru(II)LL′(NCS)2 (L = 2,2′-bipyridyl-4,4′-dicarboxylic acid, L′ = 2,2′-bipyridyl-4,4′-ditetrabutylammonium carboxylate, Solaronix) ethanol solution overnight.

Pt coated FTO glass was prepared by spreading a few drops of 5 mM hydrogen hexachloroplatinate (IV) hydrate (Aldrich, 99.9%) 2-propanol solution on FTO glass (Pilkington, TEC 8), followed by heating at 450 °C for 30 min. After preparing two electrodes as described above, they were superposed by facing each electrode. We used surlyn film (30–40 μm) to seal the gap between electrodes for holding electrolyte.

The liquid electrolyte was composed of 0.70 M 1-vinyl-3-methyl-immidazolium iodide, 0.10 M LiI (Aldrich), 40 mM iodine (Aldrich) and 0.125 M 4-*tert*-butylpyridine (Aldrich) in 3-methoxypropionitrile (Aldrich).

The *J–V* curves were measured with a Keithley 2400 source meter. A 1000 W Xenon lamp (Oriel, 91193) served as a light source. The light intensity was adjusted with a reference Si cell (Fraunhofer Institute for Solar Energy System) for 1 sunlight intensity of 100 mW/cm^2.

3. Results and discussion

Fig. 1 shows the internal structure of a module of dye-sensitized solar cells prepared by connecting unit cells in a series. The series connection of each unit cells was prepared on an FTO-conducting substrate by screen printing method. As the bottom substrate is conductive through the FTO layer, it is necessary to isolate each cell by etching the FTO layer. The etching was placed directly next to silver lines that connect each isolated cell in series. If the etching for the top substrate occurs on the right side of the silver line, the etching for the bottom substrate is made on the left side of the silver line. This completes the series connection for each unit cell when they are sandwiched. The top substrate with the Pt coating, silver lines, and etching lines are assembled to complete a module. The far left line is the silver line. This silver line was completed by assembling the two silver lines of the bottom and top substrates. Fig. 2 shows the top view of the module before assembly. The thin black lines represent silver lines. The etching lines are not clear, but located right next to the silver lines. To assemble and fix two substrates, a UV-hardening polymer was applied around the silver lines on the Pt-coated substrate. Sealing was then achieved by shining UV light for 15 min after attaching the two substrates.

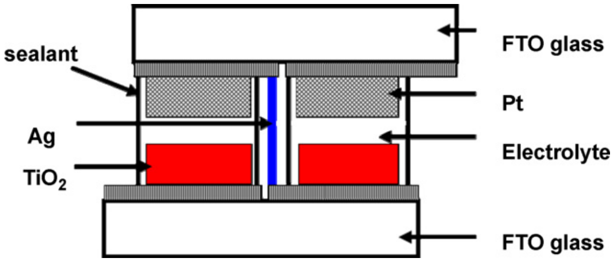

Fig. 1. The internal structure of a module of dye-sensitized solar cells prepared by connecting unit cells in a series. Connection was completed up to 10 unit cells.

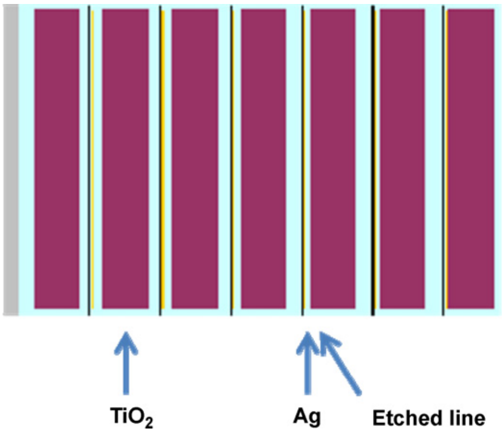

Fig. 2. The top view of the module before assembly. The thin black lines represent silver lines. The etching lines are not clear, but located right next to the silver lines.

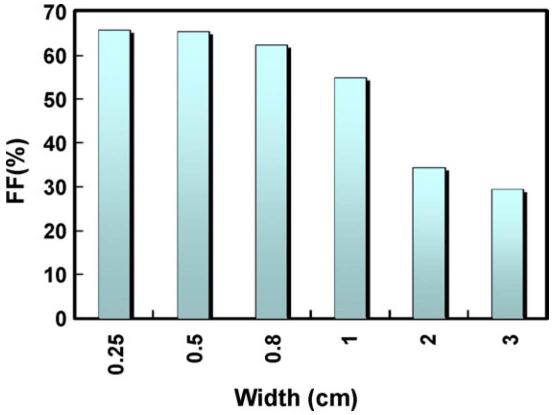

Fig. 3. The fill factor changes depending on the width of the TiO_2 individual film. The increase in the film width results in a decrease of the fill factor. The ff change is negligible until the width increases to 0.8 cm. For the experiment, the length was fixed at 10 cm. The width was changed from 0.25 cm to 3 cm.

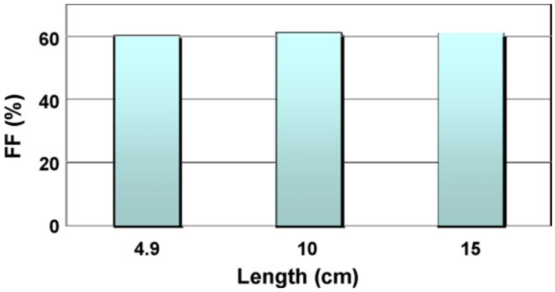

Fig. 4. The fill factor changes depending on the length of the TiO_2 individual film. The increase in the film width does not dramatically change the fill factor. The width was constant at 0.8 mm.