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Letter

Delaying the degradation caused by water of dye-sensitized solar cells

Omar Moudam [a], [*], Abdelaziz El Gamouz [b]

[a] *School of Chemistry, Imperial College London, South Kensington, SW7 2AZ, London, UK*
[b] *Department of Chemistry, College of Science, P.O. Box 27272, Sharjah, United Arab Emirates*

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ABSTRACT

A pure water electrolyte was fabricated and tested in printable flexible dye sensitized solar cells. The outdoor performance in highly humid condition shows significant degradation caused by water, which was rectified by introducing hydrophilic silica nanoparticles thus successfully delaying the degradation by three-fold.

1. Introduction

Water is not commonly used as a solvent in liquid electrolyte DSSCs, but there are many reasons to re-examine water, ranging from cost advantage to fundamental science. It is still considered poisonous for all types of solar cell panels. Sealing plastic materials are widely used to protect the cells from water permeation in the active materials causing degradation. This inevitably increases production costs as well as complicating and delaying the fabrication process. In the past, it has been proven in many reports that water was fatal for DSSCs and that the presence of even a slight trace of water in the electrolyte would be detrimental to the cell performance reducing cell stability either by dye detachment [1], by formation of iodate [2] or by a decrease in electron life-time [3]. Sumita et al. [4] demonstrated that by removing water from the liquid surface electrolyte is crucial to make DSSCs more durable and efficient. Recently, however, it has been thought that water-based DSSCs could be relevant to DSSC development since cells, properly optimized to work with water, can give reasonable efficiencies [5] and display other advantages. However, long-term stability in highly humid condition still remains an issue [6]. Current research is focused on solid-state DSSCs (ssDSSCs) to avoid sealing and leakage problems [7] with polymers widely employed to convert liquid electrolytes into solid state [8]. Alternatively, other studies have focused on the integration of hole transport layers (HTL) instead of solid electrolytes [9]. In this work, the pure water electrolyte, described by O'Regan et al. [10] with the following formulation: Guanidinium iodide (GuI) 8 M, I_2 20 mM, Chenodeoxycholic acid (Cheno) in 100% water, was used as the reference electrolyte. Guanidinium iodide has high solubility in water and the presence of the cheno is essential as it has proven to ameliorate the wettability of the TiO_2 and increase the efficiency to 4% in DSSC glass cells. Hydrophilic fumed silica nanoparticles were applied to this formulation. The water-silica electrolyte, which was tested in printable flexible DSSCs in highly humid weather conditions, showed visible improvement in stability performances compared with the water-based electrolyte cell.

2. Experimental

Fumed silica aerosil 300 with specific area of 300 m^2/g and pH (3.7–4.5), size of the nanoparticle 7 nm, was purchased from Evonik. Chenodeoxycholic acid (Cheno) and Iodine, were purchased from Sigma-Aldrich. De-ionized water was purchased from Re-Agent (conductivity <1 μS/cm). The ruthenium dye D149, Titanium foil, scattering TiO_2 nanoparticle paste, plastic counter-electrode platinum-sputtered ITO/PET (PET: Polyethylene terephthalate)/ 15 Ω/cm^2 were offered by G24i. Guanidinium iodide preparation: Guanidine carbonate (20 g, 156 mmol) was dissolved in water (100 mL), the Hydriodic acid HI (14 g, 156 mmol) was added drop by

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[*] Corresponding author.
E-mail address: omoudam@yahoo.co.uk (O. Moudam).

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drop to the solution and mixed together for 2 h (exothermic reaction), then water was evaporated into 20 mL and the solution was crystallized in Ethanol for 24 h. A white product was found with a very high yield (very soluble in water). Printable flexible cells were fabricated using standard procedures. The TiO_2 nanoparticles and Titanium foil were offered by G24i. Dyeing was done using 24 mM:24 mM: D149:GBA solutions in an alcohol-based solvent for 15 min. A platinum-sputtered ITO/PET was used as counter electrodes. Cell assemblies were formed by sealing the counter electrodes to the TiO_2 electrode with bynel at 150 °C for 10 s. The corresponding electrolyte was introduced through the edge of the cell by capillarity using a needle. Photocurrent versus voltage characteristics were measured with a Keithley 2602 sourcemeter and a LED solar simulator illuminated. The irradiated area of the cell was 8.1 cm^2. Symmetrical cells (Dummy Cells) were prepared by the following methods: Two rectangles from the counter electrode CE film approx. 25 mm × 35 mm were cut and stacked together by a thick square surlyn 25 mm × 25 mm in size and a 12 mm diameter hole was punched using syringes. Finally, the water and water-silica electrolytes were added into the holes using desecrator and vacuum pump and the holes were covered by silicone paste. Cell I–V characteristics were measured using illumination under AM 1.5 condition (100 mW/cm^2) from LED (Phillips LUXEON Rebel LXML-PWC2, Cool white). These LEDs cover the absorption spectra and mimic sun spectra for G24i technology. The I–V data was collected from the Keithley 2602. Life-time studies were carried out in outdoor humid condition for 1200 h.

3. Results and discussion

The pure water electrolyte formulation was prepared by using Guanidinium iodide (GuI) 8 M, I_2 20 mM and Chenodeoxycholic acid (Cheno) and water, 5% (w/w) of hydrophilic silica aerosil was optimized and added to the water electrolyte. Fig. 1a shows an image of the printable flexible DSSC fabricated during this work. In Fig. 1b, a microscopy image of a printable flexible TiO_2 electrode with a water-based electrolyte shows a homogenous surface contact in the presence of cheno as opposed to the water-silica electrolyte (Fig. 1c). This is due to an increase in the viscosity in the latter by using silica aerosil. To further comprehend this process, the wettability of the water-silica based electrolyte was subjected to a 15 min test in which a drop of water-silica electrolyte was added at the top of the TiO_2-coated titanium foil electrode, as indicated in the drop view image displayed in Fig. 1. Fig. 1b illustrates total permeation by the water-based electrolyte in the printed TiO_2. Conversely, the contact angle of a drop of water-silica electrolyte with TiO_2 was determined to be 51° after 2 s (Fig. 1c) as a result of increased viscosity passing from water to water-silica whereas the angle decreases to 33° after 15 min (Fig. 1j). The contact angle is still below 90°, suggesting the feasibility for the

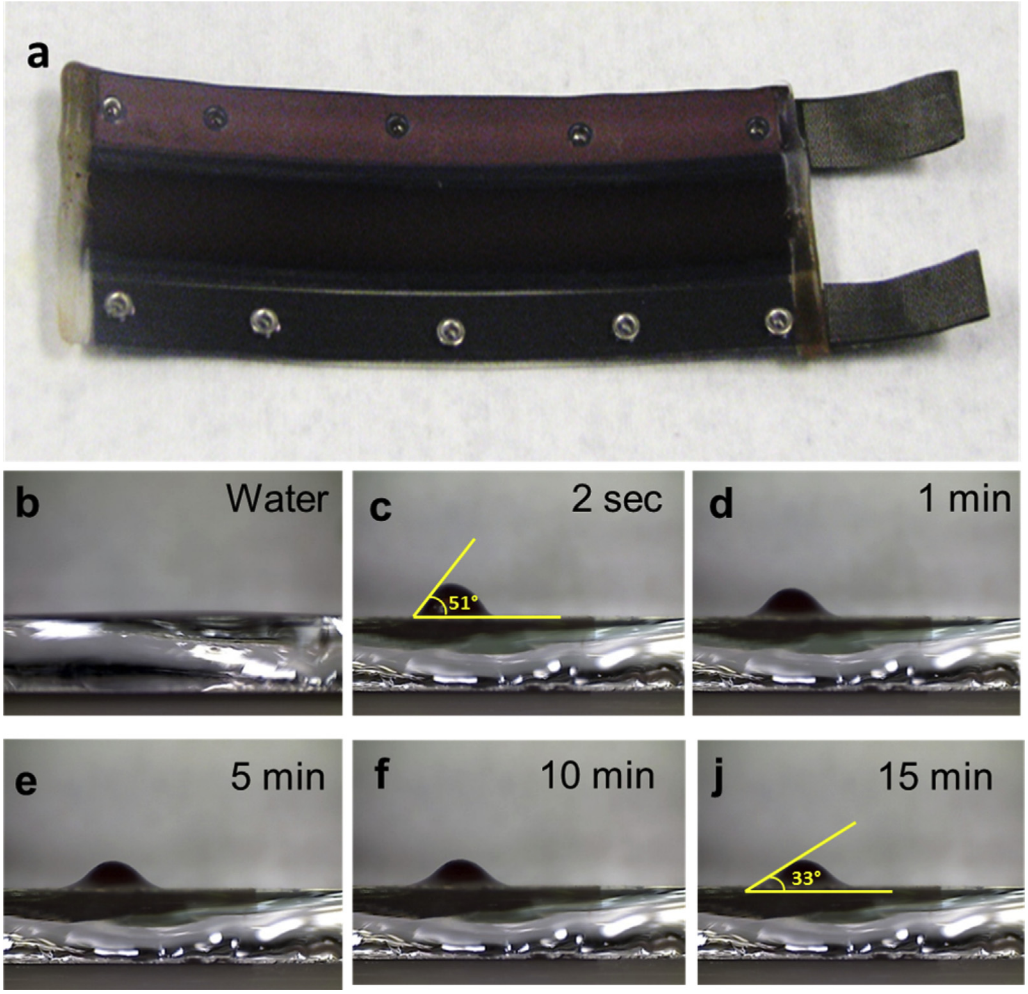

Fig. 1. a) Printable flexible DSSC b) view image of a printable flexible cell with water electrolyte and c) with water-silica electrolyte; d) drop view image with water-silica electrolyte and TiO_2-coated titanium foil electrode; from e) to j) contact angles of water-silica electrolyte formulation with TiO_2- coated titanium foil substrates.