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Electroanalytical investigation of the losses during interfacial charge transport in dye-sensitized solar cell

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Abstract

In the present article, the direct current and alternating current characterization techniques are employed to investigate the losses during interfacial charge transport in dye-sensitized solar cell (area: 3.78 cm^2) having a power conversion efficiency of 4.32%. The analysis of current–voltage characteristics depicts that the loss in photocurrent density is about 1–1.5% at low forward bias, ∼8% at knee voltage and ∼79% at open circuit voltage. The electrochemical impedance spectroscopy measurement leads to the direct determination of recombination resistance, chemical capacitance, charge transport resistance and double layer capacitance. The current–voltage characteristics obtained from the impedance parameters allows separating the contributions of different resistive processes on the overall conversion efficiency. The experimental results along with the analytical model provide an insight into the electric power loss mechanism, which is useful for analyzing performance of other upcoming devices with a similar working mechanism like perovskite sensitized solar cells.

Keywords: Dye-sensitized solar cell; Electrochemical impedance spectroscopy; Current–voltage characteristics; Recombination kinetics

1. Introduction

Dye-sensitized solar cells (DSCs) have gained a significant attention as an alternative to Silicon based solar cell due to the low cost material, cheap fabrication process and efficient working under diffuse light (Fabregat-Santiago et al., 2005; Wang et al., 2006; Sarker et al., 2014). Unlike the conventional p–n junction solar cells, DSC consists of a dye-sensitized photo anode of mesoporous oxide semiconductor (typically TiO_2), an electrolyte solution containing iodide/tri-iodide (I^-/I_3^-) for hole transportation and a platinized counter electrode (Fabregat-Santiago et al., 2007). In DSCs, several simultaneous processes occur at different junctions, such as: (i) recombination of electrons with oxidized dye and tri-iodide, (ii) radiation less relaxation of the excited state of the dye, and (iii) interfacial mismatch between energy levels of different interlayers may hinder the achievable efficiency (Sarker et al., 2013; Zhu et al., 2011; Tripathi et al., 2014). Moreover, the influence of free carrier density, electron mobility and trap states in TiO_2 also hinders the transport of electron in TiO_2. In the view of resolving the above mentioned losses in DSC, the current–voltage (J–V) characteristics and electrochemical impedance spectra of solar

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cell in a theoretical framework with standard equivalent circuit is demonstrated (Garland et al., 2014; Rock et al., 2014). The implication of electrochemical impedance spectroscopy (EIS) analysis for DSCs under different conditions of applied potential, different TiO_2 synthesis routes, different counter electrodes and electrolyte compositions have been discussed in detail in the recent articles (Hoshikawa et al., 2005; Liu et al., 2011; Xu et al., 2012; Ondersma and Hamann, 2011; Barea et al., 2010). EIS is a frequency domain technique that can resolve the charge transfer/transport kinetics of DSC in terms of capacitive and resistive elements. The AC response of the solar cell under proper limiting conditions, one can easily deconvolute the electron transport and recombination in TiO_2 and TiO_2–electrolyte interface (Sarker et al., 2013, 2014). Also, the phenomenon of charge transfer at the counter electrode and diffusion of redox species can be distinguished by the response to AC perturbation signal.

In the present article, the EIS studies of DSC (active area = 3.78 cm^2) are extended by elucidating the recombination and resistive loss in relation with the analytical diode equation of a solar cell. The article mainly focuses on: (i) the determination of the resistive and recombination losses in a DSC, and (ii) the use of direct current (DC) and alternating current (AC) techniques to explore the voltage dependent dynamic trend of impedance at different interfaces in terms of the established mechanisms. Moreover, the experimental results along with the analytical model will provide an insight into the energy loss mechanism and also lay the basis to improve the performance of a solar cell and the other optoelectronic devices.

2. Experimental

The preparation of working electrode consists of the fabrication of FTO, current collecting Ag grids, TiO_2 film and dye coating whereas the preparation of platinized counter electrode consists of sputtering of Pt on titanium, hole drilling for electrolyte filling. The details of fabrication steps, chemicals and processing temperature were discussed in our previous work (Kumara et al., 2012; Jayaweera and Kaneko, 2012). The as prepared working and counter electrodes were sealed using a three bond UV sealant along the silver grid. The active area of the fabricated cell is 3.78 cm^2. The cells are fabricated in SPD laboratory, Japan with standardized parameters and negligible performance deviation.

The photovoltaic measurements were carried out using a solar simulator (Photoemission Tec SS80AAA with 1.5AM-G filter) and a source measuring unit (U2722A, Agilent). A constant temperature was maintained by mounting the fabricated cell over a heat sink and the temperature was measured using a digital thermometer (Mini-Temp, Raytek) with an accuracy of ±2 °C. A three electrode potentiostat (CHI 660D) equipped with a general purpose software was used for the EIS measurements. The working electrode was connected to the positive terminal of the cell whereas the counter electrode and reference electrode were shorted and connected to the negative terminal of the DSC. An AC perturbation signal of 10 mV (root-mean-square voltage) was applied in the frequency range of 1 Hz–100 kHz during the EIS measurements. The inductive effect between the connecting leads and the potentiostat were taken care of during the experiments. The EIS data were collected in the form of Nyquist impedance spectra.

3. Results and discussion

3.1. *J–V* characteristics

Fig. 1A depicts the *J–V* characteristics of a DSC with a power conversion efficiency (η) of 4.2%, short circuit current density (J_{SC}) of 10.5 mA/cm^2, open circuit voltage (V_{OC}) of 0.68 V and fill factor (*FF*) of 60%. The dashed curve in Fig. 1(A) represents the difference between dark

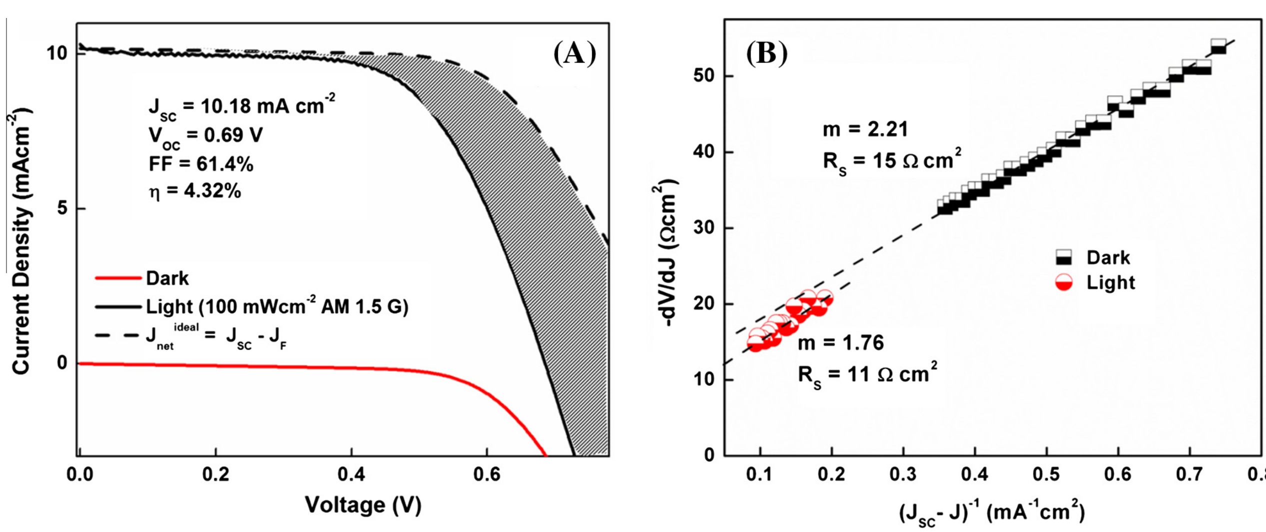

Fig. 1. (A) Current–voltage characteristics of DSC and (B) plot of $-dV/dJ$ vs. $(J_{SC}–J)^{-1}$ and the linear fitting curves.