



Bi-functional lithium doping in dye-sensitized solar cells

Chuen-Shii Chou^{a,b,*}, Yi-Ting Kuo^b, Jhih-Wei Jhang^b, Ping Wu^{c,*}

^a Research Center of Solar Photo-Electricity Applications, National Pingtung University of Science and Technology, Pingtung 912, Taiwan

^b Powder Technology R&D Laboratory, Department of Mechanical Engineering, National Pingtung University of Science and Technology, Pingtung 912, Taiwan

^c Entropic Interface Group, Engineering Product Development, Singapore University of Technology and Design, 20 Dover Drive, Singapore 138682, Singapore

Received 23 January 2014; received in revised form 24 May 2014; accepted 6 August 2014

Available online 7 September 2014

Communicated by: Associate Editor Hari Mohan Upadhyaya

Abstract

Despite intensive research into dye sensitized solar cells (DSSCs), simultaneously increasing both the short-circuit photocurrent density (J_{sc}) as well as open-circuit photovoltage (V_{oc}) of cells has thus far proven impossible. This paper reports the fabrication of Li-doped NiO electrodes to investigate a bi-functional mechanism in which Li enhances light absorption, suspends electron–hole recombination, and reduces the electrical resistivity of the electrode. We also outline the optimization of sol–gel synthesis and investigate the performance of the developed DSSCs. Our results reveal a 6.8% increase in V_{oc} as well as a 24.7% increase in J_{sc} , compared with a DSSC with TiO₂ electrode. The proposed mechanism, based on state-of-the-art electronic structure theory, provides a valuable guide for the further development of solar cells and electrochemical devices in general.

© 2014 Elsevier Ltd. All rights reserved.

Keywords: Dye-sensitized solar cell; Li-doped NiO; Sol–gel method; *p–n* Junction

1. Introduction

The dye-sensitized solar cell (DSSC) proposed by O'Regan and Grätzel (1991) has numerous advantages over other solar cell technologies, including low production costs, a variety of applicable substrates, and low environmental impact during fabrication (Lewis, 2007; Kim et al., 2008; Caramori et al., 2010). In principle, the power conversion efficiency (η) of a DSSC is determined by two

properties: short-circuit photocurrent density (J_{sc}) and open-circuit photovoltage (V_{oc}). The former is related to light absorption while the latter is related to electron–hole recombination within the DSSC (Wang et al., 2004).

High light absorption is desirable as it results in high J_{sc} . One promising approach to enhancing J_{sc} involves facilitating the capture of light through methods such as the creation of a light-scattering layer in the working electrode (Wang et al., 2004; Hore et al., 2006; Ito et al., 2008; Lee et al., 2009; Lan et al., 2011; Yang and Leung, 2011; Chou et al., 2012a; Guo et al., 2012; Liu et al., 2012; Tu et al., 2012; Jeng et al., 2013). To increase the V_{oc} , two types of energy barrier are commonly applied between the electrode and dye: a wide band semiconductor (such as ZnO) (Chou et al., 2012b,c; Guo et al., 2012; Wu et al., 2013) and a semiconductor *p–n* junction (such as TiO₂/NiO) (Bandara et al., 2005; Chou et al., 2011).

* Corresponding authors. Address: Powder Technology R&D Laboratory, Department of Mechanical Engineering, National Pingtung University of Science and Technology, Pingtung 912, Taiwan. Tel.: +886 8 7703202x7016; fax: +886 8 7740142 (C.-S. Chou). Engineering Product Development, Singapore University of Technology and Design, Singapore 138682, Singapore. Tel.: +65 64994576 (P. Wu).

E-mail addresses: cschou@mail.npust.edu.tw (C.-S. Chou), wuping@sutd.edu.sg (P. Wu).

Another approach involves synthesizing TiO₂ nanowires with embedded multi-walled carbon nanotubes to increase the transfer of electrons and suppress charge recombination in DSSCs (Ahn et al., 2013).

Nevertheless, increasing V_{oc} by introducing an energy barrier or p - n junction can decrease J_{sc} due to an increase in electrical resistivity. Few researchers succeeded in enhancing V_{oc} and J_{sc} simultaneously. For example, Chou et al. (2014) fabricated a DSSC with a light-scattering layer of Ni-doped TiO₂ particles, which can extend the retention period of light and reduce the recombination of excited electrons in a DSSC, to enhance V_{oc} and J_{sc} simultaneously. Although the p -type semiconductor NiO is commonly used to increase V_{oc} in DSSCs, it is a Mott–Hubbard insulator with very low electrical conductivity of less than $10^{-13} (\Omega \text{ cm})^{-1}$ at room temperature (Terakura et al., 1984). Wu et al. (2002) claimed that introducing of Ni²⁺ vacancies and/or doping with monovalent cations (such as Li⁺) could produce a considerable increase in conductivity.

The purpose of Li doping in NiO is to increase the hole concentration (major carrier for the p -type) and decrease the electron scattering (or resistance). The decrease in scattering of electrons can facilitate photo electrons to transport from dye to TiO₂ through tunneling in a DSSC with TiO₂/Li_{*x*}Ni_{1-*x*}O composite particles. Therefore, this study developed a novel hybrid working electrode with TiO₂/Li_{*x*}Ni_{1-*x*}O composite particles in order to enhance V_{oc} as well as J_{sc} in DSSCs. TiO₂/Li_{*x*}Ni_{1-*x*}O composite particles were prepared by dry mixing TiO₂ particles with Li-doped NiO (Li_{*x*}Ni_{1-*x*}O) powder, which was synthesized using the sol–gel method. We then investigated the effects of Li_{*x*}Ni_{1-*x*}O synthesis conditions and the mass ratio of TiO₂ to Li_{*x*}Ni_{1-*x*}O on the performance of DSSCs. Finally, we compared a DSSC equipped with the proposed TiO₂/Li_{*x*}Ni_{1-*x*}O hybrid electrode against a typical DSSC with TiO₂ electrode.

2. Experimental details

2.1. Preparation and characterization of Li_{*x*}Ni_{1-*x*}O and TiO₂/Li_{*x*}Ni_{1-*x*}O

The procedures involved in producing the various structures of Li_{*x*}Ni_{1-*x*}O powder via the sol–gel method are outlined as follows: (1) a solution of 0.5 M nickel (II) nitrate was prepared by mixing 3.635 g nickel (II) nitrate hexahydrate [Ni(NO₃)₆·6H₂O] (purity of 99.999%) with

25 mL ethanol (purity of 99.5%); (2) a preset mass of lithium nitrate (LiNO₃) was added to the 0.5 M nickel (II) nitrate solution and this mixture was used to synthesize the Li_{*x*}Ni_{1-*x*}O powder through the sol–gel method. Table 1 lists the test conditions of synthesizing the Li_{*x*}Ni_{1-*x*}O powder with x representing the ratio between the concentration of Li and that of Li + Ni. Photographic images of the Li_{*x*}Ni_{1-*x*}O powder were obtained using a digital camera (Panasonic DMC-LZ2) and micrographs were prepared using a scanning electron microscope (SEM) (HITACHI, S-4700).

TiO₂/Li_{*x*}Ni_{1-*x*}O composite particles were prepared using the Mechanofusion system (Hosokawa Micron Corp. AMS-mini). Titanium dioxide (TiO₂, Uniregion Biotech P-25) particles (average particle size of 21 nm) and the Li_{*x*}Ni_{1-*x*}O powder were loaded into the chamber of the Mechanofusion system with a rotor speed of 6000 rpm for 1 h. The centrifugal force created by the rotating rotor pushes the TiO₂ particles and the Li_{*x*}Ni_{1-*x*}O powder to the inner wall of the rotation chamber. When the TiO₂ particles and the Li_{*x*}Ni_{1-*x*}O powder pass through the space between the rounded press head and the inner wall of the rotating chamber, high shear-rate particle-to-particle and particle-to-wall collisions force the TiO₂ particles and the Li_{*x*}Ni_{1-*x*}O powder to adhere to each other and to the inner walls of the rotating chamber. The scraper blade is then used to scrape this powder mixture off and the product is subjected to continuous and repeated cycles of this procedure in the rotation chamber. The detailed mechanism involved in dry mixing was described in our previous works (Chou et al., 2009, 2011). Table 2 lists the test conditions under which the TiO₂/Li_{*x*}Ni_{1-*x*}O composite particles were prepared. X-ray diffraction (XRD) patterns of Li_{*x*}Ni_{1-*x*}O powder and TiO₂/Li_{*x*}Ni_{1-*x*}O composite particles were obtained using a powder X-ray diffractometer (Shimadzu, XRD-6000).

2.2. Preparation and characterization of DSSC with TiO₂/Li_{*x*}Ni_{1-*x*}O hybrid electrode

The procedure for fabricating DSSCs with a TiO₂/Li_{*x*}Ni_{1-*x*}O hybrid electrode is outlined in the following: (1) colloids of TiO₂/Li_{*x*}Ni_{1-*x*}O composite particles were prepared by mixing 2 g composite particles (Table 2) with 8 mL ethanol, 0.8 mL acetylacetone, and 0.1 mL Triton X-100. This mixture was then homogenized in an ultrasonic homogenizer for a given duration; (2) the homogenized colloids of TiO₂/Li_{*x*}Ni_{1-*x*}O were respectively

Table 1
Test conditions of preparing Li_{*x*}Ni_{1-*x*}O powder.

	Precursor solution			Polymerization and hydrolysis		Calcination		Li _{<i>x</i>} Ni _{1-<i>x</i>} O
	Ni(NO ₃) ₆ ·6H ₂ O (g)	Ethanol (mL)	LiNO ₃ (g)	Time (day)	Temp. (°C)	Time (h)	Temp. (°C)	
A1			0.0367					Li _{0.01} Ni _{0.99} O
A2	3.635	25	0.0742	1–3	80	1	730	Li _{0.02} Ni _{0.98} O
A3			0.1124					Li _{0.03} Ni _{0.97} O

Download English Version:

<https://daneshyari.com/en/article/1549843>

Download Persian Version:

<https://daneshyari.com/article/1549843>

[Daneshyari.com](https://daneshyari.com)