Solar Energy Materials & Solar Cells 128 (2014) 335–342

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Outdoor testing and degradation of dye-sensitized solar cells in Abu Dhabi

A. Asghar [a], M. Emziane [b,*], H.K. Pak [c], S.Y. Oh [d]

[a] Renewables Department, Saudi Aramco, P.O. Box 11638, Dhahran, Saudi Arabia
[b] Solar Energy Materials and Devices Laboratory, Masdar Institute of Science and Technology, Masdar City, P.O. Box 54224, Abu Dhabi, UAE
[c] Electronics and Telecommunication Research Institute, 138 Gajeongno, Yuseong-gu, Daejeon 305-700, South Korea
[d] Department of Chemical Engineering, Yeungnam University, South Korea

ARTICLE INFO

Article history:
Received 26 February 2014
Received in revised form
15 May 2014
Accepted 24 May 2014
Available online 20 June 2014

Keywords:
DSSC
Field testing
Degradation
Lifetime

ABSTRACT

This paper reports on the long-term testing of Dye-Sensitized Solar Cells (DSSCs) compared with a polycrystalline Si solar cell under the outdoor conditions of Abu Dhabi, UAE. A comparison of the temperature and irradiance dependence of both types of solar cells shows that DSSCs has relatively better performance than the polycrystalline Si solar cell under low irradiance levels and high temperatures. The monthly energy yields reveal that DSSCs produce about 20% higher energy during the spring months and about 30% higher energy during the summer months. The long-term stability of different DSSCs has been monitored under real outdoor conditions for over six months and degradation mechanisms have been proposed. Ionic liquid based DSSCs were significantly more stable when compared to devices based on other electrolyte solvents. However, the efficiency of all the experimental DSSCs degraded over time due to several factors outlined in the paper. This paper further outlines the advantages of DSSCs for their potential use in buildings in warm regions such as the Middle East and North Africa.

1. Introduction

Solar energy is the most sustainable renewable energy on earth and it is present in abundance in the Middle East and North Africa (MENA) region [1]. As governments in MENA try to move towards a more environment friendly energy mix, solar energy comes as the main renewable energy resource and it is attracting attention indeed. Building integrated photovoltaics (BIPV) is one way to harness the abundant solar energy and schemes like 500 MW Abu Dhabi Solar Rooftop Plan (SRP) are being approved to meet the target of 7% renewable energy in the overall energy mix of the United Arab Emirates (UAE) by 2020 [2].

DSSC technology has potential use in BIPV due to its low cost and relatively good efficiency under low light intensity conditions [3]. The current challenge that is restricting DSSCs from entering the BIPV market is their long-term stability. This problem is often attributed to either the instability of the dye in the presence of additives in the electrolyte [4,5], volatility of the electrolyte [6,7] or improper sealing [8]. Limited information on outdoor testing of DSSCs is available and this is one area that is considered to be of great importance for the commercialization of DSSCs [7,9].

Due to the current lower efficiency of DSSCs, they obviously require a larger area to generate the same amount of energy as other conventional solar cells. Therefore, DSSCs are not very feasible for PV power plants as a larger area and more supporting structures would have to be built, thus yielding higher balance of system's costs. However, for BIPV applications, where the built structure already exists and no significant capital investment is needed for the infrastructure, DSSCs seem to be an attractive option due to their potential low cost and flexibility.

Reports of efficiencies and power outputs of solar cells are widely available in the literature. However, the efficiency and power output of such cells are measured under a standard temperature of 25 °C and an irradiance of 1000 W/m^2 which rarely match the real operating conditions. It has been previously shown that the operating parameters such as the cell temperature and the irradiance level can affect the power output of different solar cell technologies in different locations around the world [10–14]. It was found that due to the changes in temperature and irradiance levels, the overall energy output of solar cells is often much lower than expected. For the implementation of DSSCs as BIPVs in the MENA region, a technical study is required to assess the performance parameters of DSSCs in order to understand how they perform in hot climates. This technical study consists of a long-term outdoor testing of DSSCs together with a polycrystalline Si (pc-Si) commercial cell to assess the real outdoor performance of

* Corresponding author. Tel.: +971 28109140; fax: +971 26988121.
E-mail address: memziane@masdar.ac.ae (M. Emziane).

http://dx.doi.org/10.1016/j.solmat.2014.05.048
0927-0248/

Table 1
Materials and device characteristics of the different DSSCs tested.

Deviceid	Dye	Electrolyte solvent	Sealing	Type	Size (cm^2)	Initial efficiency (%)
1	N719	3-methoxy propionitrile	Epoxy	Z-connected module	645	2.388
4	N719	3-methoxy propionitrile	Epoxy	Z-connected module	645	2.441
9	N719	Ionic liquid	Epoxy	Z-connected module	645	1.346
A3	N719	Ionic liquid	Epoxy	Z-connected module	66	0.954
B3	N719	3-methoxy propionitrile	Epoxy	Z-connected module	66	2.548
C3	N719	3-methoxy propionitrile	Epoxy	Z-connected module	66	3.033
D3	N719	3-methoxy propionitrile	Epoxy	Z-connected module	66	1.306
F3	TG6	3-methoxy propionitrile	Epoxy	Z-connected module	66	0.563
G2	TG6	3-methoxy propionitrile	Epoxy	Z-connected module	66	1.438
H2	TG6	Ionic liquid	Epoxy	Z-connected module	66	3.849
G24i				Z-connected module	262	2.507

solar cells in the hot climate of Abu Dhabi. Due to the hot and sometimes arid climate of the MENA region, most cities are located on the coast. Therefore, Abu Dhabi, which is also a coastal city, serves as a good model for most of the cities in the MENA region, and the Gulf Cooperation Council (GCC) region in particular.

This study assesses the power output of DSSCs over a period of almost seven months in Abu Dhabi and compares it with a commercial pc-Si solar cell. Sixteen different DSSCs that contained different electrolytes and dyes were tested. Several degradation trends were identified and correlated to the materials used for the fabrication of the cells.

2. Experimental procedure

2.1. Device fabrication

Different DSSC devices were made using several combinations of dyes and electrolytes as shown in Table 1. TiO_2 (ENB Korea) was deposited on Fluorine doped Tin Oxide (FTO) coated glass using screen printing. The counter electrode was made by thermal reduction of H_2PtCl_6 solution (in isopropanol) at 450 °C. The devices were fabricated in the form of z-connected cells to form a small module. A silver grid (InkTech) was screen printed on each side of the glass and the glass frit passivation barrier acted as spacers in the device. The small module is made first and then the dye solution is circulated through a small pin-hole for dye adsorption. The dyes that were used were N719 (*cis*-bis(thiocyanato)bis(2,2′-bipyridine-4,4′-dicarboxylato)ruthenium(II) bis(tetrabutylammonium) salt) dye which is hydrophilic and TG6 (*cis*-bis(thiocyanato)(2,2′-bipyridyl-4,4′-dicarboxylato){4,4′-bis[2-(4-hexylsulfanylphenyl)vinyl]-2,2′-bipyridine}ruthenium(II) mono (tetrabutylammonium) salt) dye which is hydrophobic in nature. Once the dye is adsorbed and subsequently drained, the electrolyte solution is added through a pin-hole. Two different electrolyte solvents were used: 3-methoxy propionitrile (MPN) and ionic liquid provided by TG energy. The device is then sealed using glass frit. A layer of polymer was placed on top of all the devices to protect them from UV radiation during outdoor testing. Fig. 1 shows the schematic of the complete z-connected module. All the devices were handmade and a commercial DSSC made by G24i [1] was also tested for comparison purposes. The handmade DSSC devices were fabricated by ETRI in South Korea and were transported and set up for testing in Abu Dhabi, UAE.

2.2. Device testing

These devices were mounted on a rigid stand (Fig. 2) and tested under outdoor conditions for over six months in Abu Dhabi, UAE. An I–V measurement system (Ontest Co. Ltd.) was used to measure

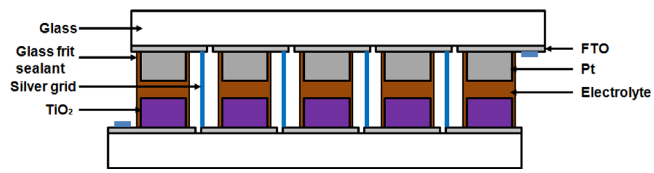

Fig. 1. Schematic of the z-connected DSSC devices that were tested.

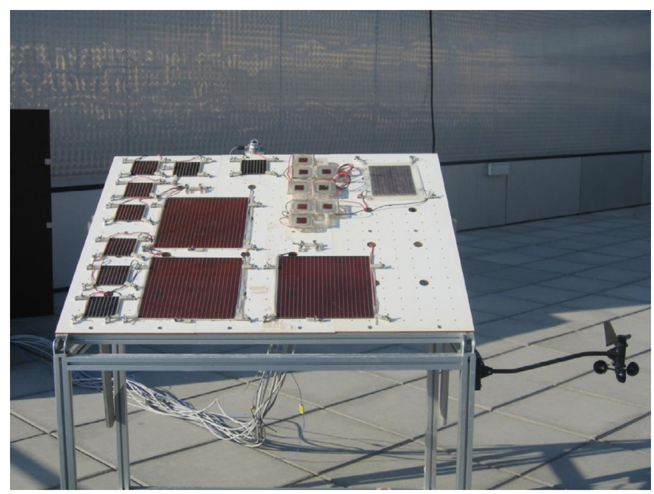

Fig. 2. Outdoor setup used to test DSSCs and pc-Si cell.

the I–V characteristics of the devices every 30 min. Several thermocouples were connected to measure the ambient temperature and the temperature of some of the devices. Similarly, a pyranometer (EKO) was connected to measure the irradiance levels, an anemometer was connected to measure the wind speed and direction and a humidity sensor was connected to measure the humidity level in the air.

In this study, the temperature dependence of the solar cell is measured using an established procedure reported in the literature [15]. The devices were kept covered and cooled with ice so that their temperature is much lower than the ambient temperature. The cover was then removed and the devices were exposed to direct sunlight due to which their temperature increased. Simultaneously, I–V measurements were taken as a function of the device temperature. In order to isolate the temperature effect on the device performance, it was necessary to keep all other parameters constant. Also, to ensure that the irradiance was constant, the measurements were taken on a clear day at noon over 10 min.

The energy yield of the devices was calculated by summing up the product of the instantaneous power and the time interval between subsequent power recordings over one month. The