Design and long-term monitoring of DSC/CIGS tandem solar module

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Abstract. This paper describes the design and development of tandem dye-sensitized/Cu(In, Ga)Se (DSC/CIGS) PV modules. The tandem PV module comprised of the top DSC module and a bottom commercial 0,8 m^2 CIGS module. The top DSC module was made of 10 DSC mini-modules with the field size of 20 × 20 cm^2 each. Tandem DSC/CIGS PV modules were used for providing the long-term monitoring of energy yield and electrical parameters in comparison with standalone CIGS modules under outdoor conditions. The outdoor test facility, containing solar modules of both types and a measurement unit, was located on the roof of the Institute of Biochemical Physics in Moscow. The data obtained during monitoring within the 2014 year period has shown the advantages of the designed tandem DSC/CIGS PV-modules over the conventional CIGS modules, especially for cloudy weather and low-intensity irradiation conditions.

1. Introduction

In last decade dye-sensitized solar cells (DSCs) have attracted a considerable attention as a next generation low cost photovoltaic technology, which promises a possibility of mass production in the near future. Previously it was shown that amorphous silicon, as well as some other types of thin film PV cells, provides better light absorption capability and performance under non-direct irradiation in comparison with PV cells based on crystalline solids [1]. For this reason, the next generation PV cells based on nanocrystalline mesoscopic layers should be more effective under both direct and low-intensity irradiation conditions, especially in northern European countries and in Russia with a limited amount of sunny days. Long-term outdoor monitoring of PV cells performance, being performed for different types of solar modules, was generally focused on assessing the annual yield of a particular module under specific climatic conditions [2-4]. The monitoring data for Si-based modules, that show relatively high performance, are widely reported so far [5, 6]. In our previous publications we have shown the advantages of the designed tandem dye-sensitized solar cells (TDSCs) for improving the energy conversion efficiency and light absorption characteristics by combining two stacked DSCs sensitized with different dyes, absorbing light in the overlapped wavelength ranges [7, 8]. Later M. Graetzel and co-workers developed a new type of TDSC, where DSC cell was combined with a conventional $Cu(Ga,In)Se_2$ (CIGS) solid state cell with a total conversion efficiency exceeding 15% [9]. However, the reasonable advantage of DSC/CIGS tandem cell may rise not only from the improved performance characteristics, but also from the above mentioned possibility to utilize both direct and diffuse light, taking into consideration that the average content of scattered light in total irradiance during the year in Central European Region is about 55%.

2. Experimental

We have fabricated and studied DSCs with the different field sizes. The designed middle-size samples were used for the construction of tandem PV modules.

2.1. DSCs fabrication

Following the conventional technology [9], TiO_2 based pastes were fabricated from commercially available P25 powder, mixed with a solution of terpineol and ethyl cellulose in ethanol. Solar cells were fabricated on a fluorine-doped tin oxide (FTO) coated glass substrates, which were cut into the appropriate pieces, cleaned in detergent, ethanol and acetone. The electrodes were prepared from the pastes obtained using screen-printing method and sintered at 500°C for 30 min. The electrodes fabricated were dipped in a 0.3 mM of N719 (Sigma Aldrich) dye solution in a mixture of acetonitrile and tert-butyl alcohol (1:1) for 24 h. After sensitizer uptake the TiO_2 layers were washed in acetonitrile. Platinum-coated FTO glass substrates were used as counter electrodes. The counter and working electrodes were assembled into the sandwich-type cell and sealed with an ionomer film (Surlyn 1702). Commercially available electrolyte AN-50 Iodolyte (Solaronix) was introduced into the construction. Thus DSCs with the field size of 0,7 × 0,7 $см^2$ were fabricated. The I-V characteristics and energy conversion efficiencies of DSCs were measured under AM1.5 incident light illumination (1000 W/m^2) using Abet Technologies Solar Simulator and Semiconductor Characterization System 4200-SCS (Keithley, USA). The measurements of incident photon to current conversion efficiency (IPCE) were provided using QEX10 Solar Cell Quantum Efficiency Measurement System (PV Measurements, USA) in the wavelength range 300 – 1100 nm.

2.2. Design of DSC mini-modules and tandem DSC/CIGS modules

Following the technology, described in the previous paragraph, we have prepared DSC mini-modules with a field size of 20 × 20 cm^2, consisting of two electrically connected middle-size DSCs in aluminum frame. These devices were used for the construction of tandem DSC/CIGS PV-modules, in which 10 DSC-based top mini-modules were used for fabrication the top DSC module, combined with a bottom commercial 0,8 m^2 CIGS module (SunPower model AD-CIS-80, China). Two 0,8 m^2 tandem DSC/CIGS PV modules with optimized configuration of the top mini-modules, as well as two 0,8 m^2 conventional CIGS modules, were installed on a fixed rack facing South-East in a tilt angle of 40°.

2.3. The outdoor test facility

The outdoor test facility located on the roof of the Institute of Biochemical Physics in Moscow was equipped with two types of solar modules (tandem DSC/CIGS and conventional CIGS) and was connected to a measuring unit providing long-term monitoring of energy yield and electrical parameters of solar modules under study. The picture of installed PV test facility is given in figure 1.

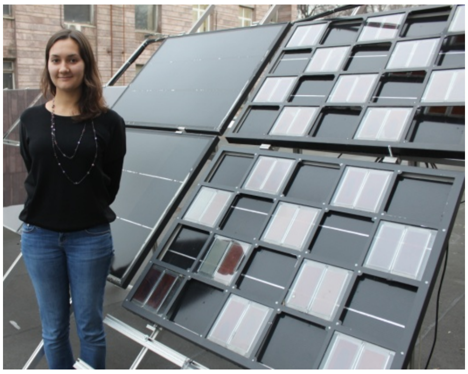

Figure 1. Tandem CIGS/DSC (right) and CIGS (left) modules installed on the roof of the Institute of Biochemical Physics, Russian Academy of Sciences, Moscow, Russia.

3. Results and discussion

3.1. DSCs performance characteristics

First we have fabricated and investigated small laboratory DSC samples with the field size of 0.7 × 0.7 cm^2. IPCE spectrum for a DSC sample, given in figure 2(a), shows that the spectral area of light energy conversion for this type of PV cell ranges from 350 to 700 nm. Note that the appropriate spectral region for CIGS PV cell ranges to 1100 nm that opens a possibility for constructing efficient tandem DSC/CIGS PV-modules [9, 10].

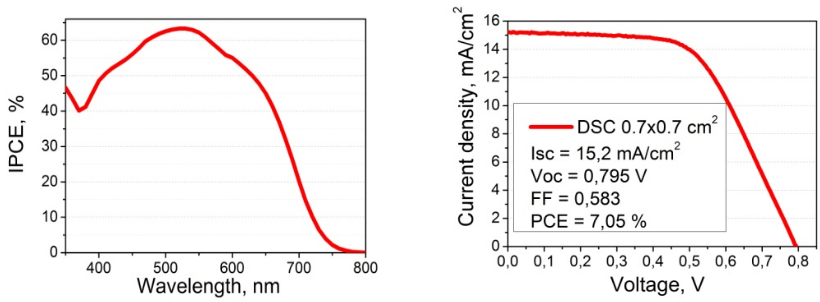

Figure 2. IPCE spectrum (a) and the I-V characteristic (b) of DSC PV cell (I_{SC} - short-circuit photocurrent, V_{OC} - open-circuit voltage, FF - fill factor, PCE – power conversion efficiency).

The photovoltaic performance and other characteristics of DSC PV cell are listed in figure 2(b). DSC with the field size of 0.7 × 0.7 cm^2 have demonstrated relatively high efficiency of 7,05%. The value of the Fill Factor is in a good agreement with that available in the literature [9].

At the following step we have fabricated DSCs with the field size of 20 × 20 cm^2, which were assembled in mini-modules. Ten DSC-based top mini-modules were arranged like a chessboard pattern for constructing 0,8 m^2 tandem DSC/CIGS PV module.

3.2. Monitoring of DSC/CIGS tandem module

The long-term monitoring of energy yield and electrical parameters of tandem DSC/CIGS PV modules in comparison with standalone CIGS modules was provided under outdoor conditions. The comparison of PCE for PV modules is given in figure 3.

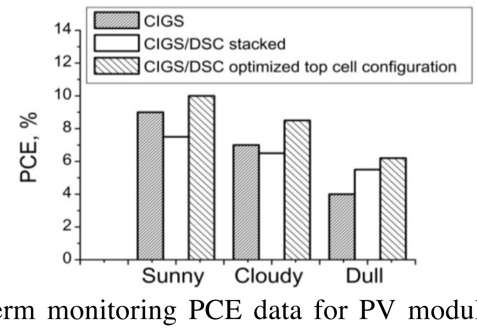

Figure 3. The average long-term monitoring PCE data for PV modules (conventional CIGS, CIGS stacked with DSCs and tandem CIGS/DSC modules with optimized top cell configuration).

CIGS module shows good performance at a sunny weather with PCE reaching 9%, however the efficiency sufficiently decreased under cloudy weather conditions. At the same time tandem DSC/CIGS module with optimized top cell configuration (a chess board pattern) have shown much higher potential abilities over the conventional CIGS modules, especially for cloudy weather and low-intensity irradiation conditions.

Figure 4 shows the daily energy yield of CIGS and tandem CIGS/DSC modules for the days with different weather conditions. Note that output power of CIGS module decreases to zero in the early morning and in late evening while tandem DSCs provided ~ 60% of power obtained at 12 a.m.

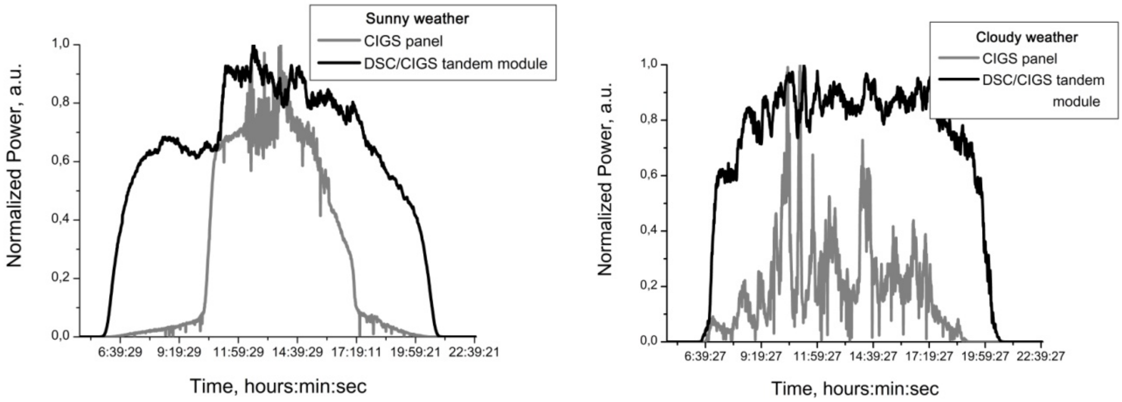

Figure 4. Power output for conventional CIGS and tandem CIGS/DSC modules under different weather conditions (left – sunny day, right - cloudy weather).

4. Conclusions

We have developed and fabricated tandem DSC/CIGS PV modules with optimized top cell configuration, in which the top DSC solar module covered about 50% area of the bottom CIGS solar module. To assemble the tandem PV module we have prepared DSC mini-modules with the field size of 20 × 20 cm^2 which were used for fabrication the top DSC module, combined with a bottom commercial 0,8 m^2 CIGS module. Tandem DSC/CIGS PV modules were used for providing the long-term monitoring of energy yield and electrical parameters in comparison with standalone CIGS modules under outdoor conditions. It was found that the developed tandem solar modules have shown a better photovoltaic performance in comparison with CIGS modules under cloudy weather and low-intensity irradiation conditions.

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