Solar Energy Materials & Solar Cells 98 (2012) 208–211

Contents lists available at SciVerse ScienceDirect

Solar Energy Materials & Solar Cells

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

New series connection method for bulk-heterojunction polymer solar cell modules

Jongjin Lee [a,*,1], Hyungcheol Back [b,1], Jaemin Kong [b], Dong-Won Park [a], Kwanghee Lee [a,b,*]

[a] Heeger Center for Advanced Materials (HCAM) & Research Institute for Solar and Sustainable Energies (RISE), Gwangju Institute of Science and Technology, Gwangju 500-712, South Korea

[b] Department of Materials Science and Engineering, Gwangju Institute of Science and Technology 500-712, South Korea

ARTICLE INFO

Article history:
Received 6 September 2011
Received in revised form
1 November 2011
Accepted 6 November 2011
Available online 18 November 2011

Keywords:
Bulk-heterojunction
Polymer solar cell
Module
Series connection

ABSTRACT

We propose and demonstrate a new series connection method that employs alternating conventional and inverted bulk-heterojunction (BHJ) solar cells. The two adjacent cells in each submodule are connected through top or bottom 'continuous terminals' made of aluminum or indium tin oxide (ITO), which are shared by cells with different polarities in either a top-to-top or a bottom-to-bottom manner. In comparison with the conventional series-interconnection method, our new structure offers unique advantages in that both printing methods and efficient coating methods can be applied in the manufacturing of series-connected BHJ photovoltaic modules.

1. Introduction

Over the last decade, much attention has been focused on the development of organic photovoltaics (OPVs) because of their simple structure and their potential for low-cost manufacturing [1,2]. The current state-of-the-art devices are known as bulk-heterojunction (BHJ) devices in which an OPV active layer is formed from a blend of donor polymer and acceptor fullerene-derivative materials. The power conversion efficiencies (PCEs) of BHJ polymer solar cells are close to commercialization; through optimization of the materials and processing parameters, PCEs exceeding 8% have recently been achieved [3–5]. In recent years, researchers have also attempted to enlarge these solar cells (modules) for practical use. However, the conductivity of transparent conducting oxides (TCOs), e.g., the widely used indium tin oxide (ITO), on a glass substrate is approximately 6×10^3 S/cm, which is at least one order of magnitude smaller than that of thin metal films. Thus, a simple scaling up of the active area results in ohmic losses of the photogenerated charge carriers in the TCO substrate [6,7]. Two different methods are commonly adopted to circumvent the limited conductivity of TCO films. One approach for large-area cells is the use of current-collecting metal grids. Depending on the positions of the transparent metal grids, front- and back-side illuminated structures have been employed [8–12]. Many groups have successfully demonstrated large-area OPV cells with the same PCEs as small-scale laboratory cells [8–10]. Large-area roll-to-roll production with ITO-free structures has also been demonstrated [11,12]. However, the fabricated cells should be interconnected in series or parallel to be used in more large-scale modules, as this monolithic approach is well established in crystalline silicon solar module manufacturing.

Another approach is to connect arrays of parallel single cells in series to enlarge a single module. This technique is widely used in thin film solar cells, including OPVs, to boost the voltage of the module. Voltage boosting is favored over current boosting because voltage boosting produces lower ohmic losses in low-conductivity substrates. However, excessively increasing the number of connections per unit area causes aperture losses in the photoactive area because a substantial area is required to connect the adjacent cells. Tipnis et al. demonstrated the fabrication of a series-interconnected module using spin coating and laser ablation [13]. However, although the PCE of the active area was 2.4%, the PCE of the total area was only 1.1% because approximately 54% of the aperture of the photoactive area was lost for connections. Krebs et al. demonstrated the elaboration of an all-printed module using the slot-die method. This module also suffered a 40% aperture loss because each printed layer of a BHJ solar cell must be shifted relative to the underlying layers to avoid undesirable fill-over and to ensure series interconnections [14,15]. Thus, a series-interconnection method that is able to avoid or at least suppress substantial aperture loss would be highly desired.

* Corresponding authors at: Heeger Center for Advanced Materials (HCAM) & Research Institute for Solar and Sustainable Energies (RISE), Gwangju Institute of Science and Technology, Gwangju 500-712, South Korea.
E-mail addresses: bandy1@gist.ac.kr (J. Lee), klee@gist.ac.kr (K. Lee).
[1] These authors contributed equally to this work.

0927-0248/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.solmat.2011.11.008

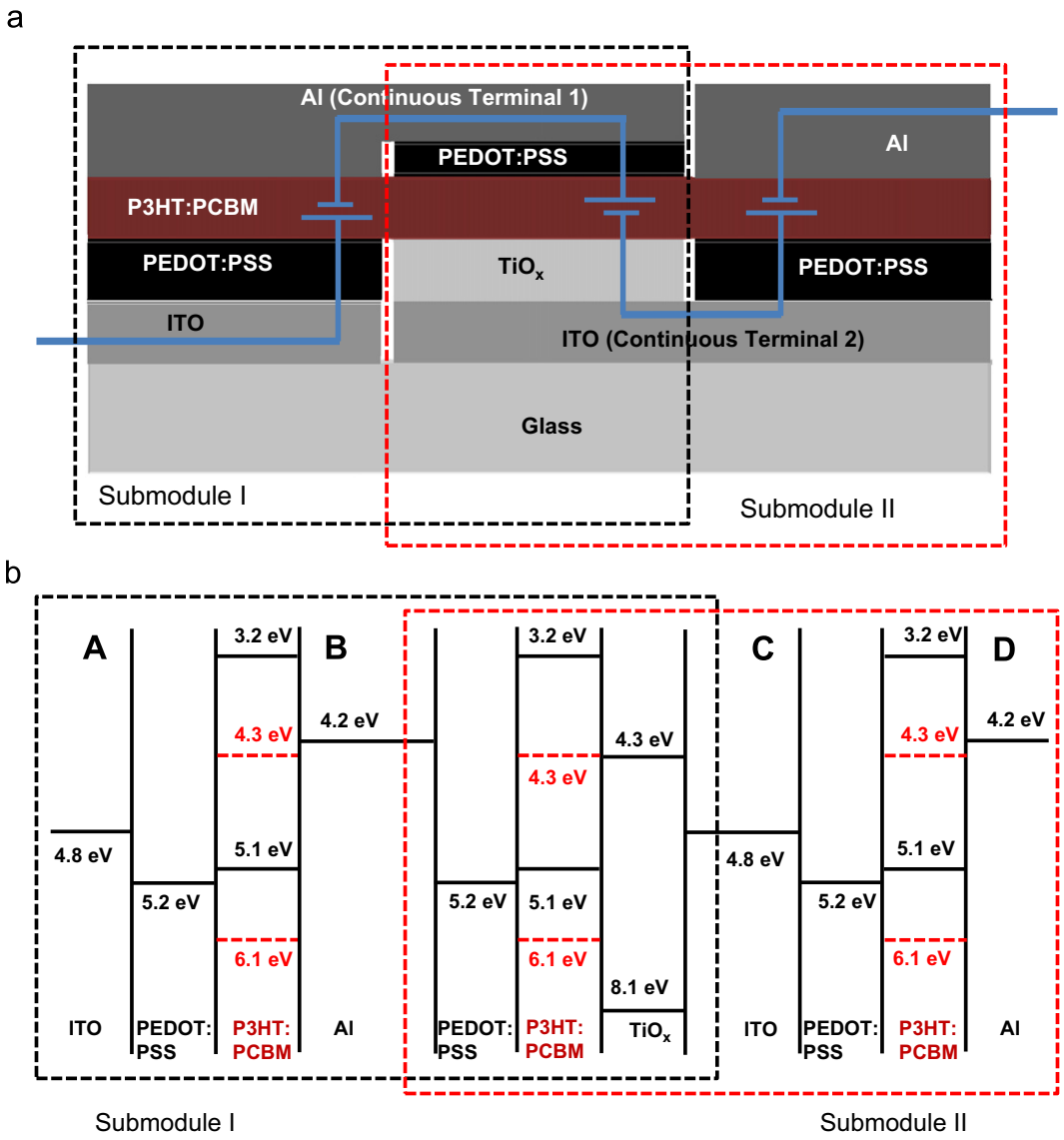

Fig. 1. (a) Schematic diagram of a new series-connected structure showing submodules I and II. (b) The corresponding energy level diagrams of the structures.

In this study, we propose a new series connection method for future large-scale modules, which is achieved by alternating conventional and inverted BHJ solar cells. Fig. 1(a) shows a schematic cross-section of the proposed module structure that is composed of two components: submodules I and II. The operation of this device is illustrated by the corresponding energy level diagram in Fig. 1(b). The structure provides neighboring cells with alternate biases. Two different continuous terminals, B (an aluminum electrode) and C (an ITO electrode), spontaneously connect neighboring cells in series. Another advantage of this structure is that the BHJ layer, which is the most sensitive to the PCE, does not have to be patterned or scribed for the series connections.

2. Experimental

In this work, submodules I and II, which were connected by shared 'continuous terminals' made of aluminum or ITO electrodes, respectively, were demonstrated using a printing method. For the fabrication of the BHJ solar cells, (patterned) ITO substrates were first cleaned with detergent, ultrasonicated in distilled water, acetone and isopropyl alcohol, subsequently dried in an oven and treated with a 10 min UV ozone exposure. Poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS, Clevios P VP AI 4083, H. C. Starck) was coated on the left half of the ITO substrate as a hole transport layer (HTL) using a doctor blade. The films were annealed at 120 °C for 10 min in air. A sol–gel processed titanium oxide (TiO_x) precursor solution diluted in methanol to a concentration of 1:200 was coated on the remaining right half of the ITO substrate as an electron transport layer (ETL) by the same method and heated at 80 °C for 10 min in air [16]. A 1 wt% solution of poly(3-hexylthiophene) (P3HT) and [6] 6-phenyl-C_{61}-butyric acid methyl ester (PCBM) dissolved in chlorobenzene at a weight ratio of 1:0.8 was spin cast on top of the underlying PEDOT:PSS and TiO_x layers, followed by annealing at 80 °C for 10 min under N_2 to form a thin film with the thickness about 80 nm . Afterwards, on top of the right half region where absorber layer and bottom TiO_x layer were deposited previously, PEDOT:PSS diluted in isopropyl-alcohol was coated by doctor blade, followed by annealing at 120 °C for 10 min. The solar cells were completed by evaporating aluminum (Al) electrodes through a shadow mask in high vacuum (10^{-6} mbar). Unit cell area defined by patterned ITO or aluminum was 4.64 mm^2. Current density–voltage (J–V) characteristics of the