Solar Energy Materials & Solar Cells 108 (2013) 225–229

Contents lists available at SciVerse ScienceDirect

Solar Energy Materials & Solar Cells

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

Materials and devices design for efficient double junction polymer solar cells

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ARTICLE INFO

Available online 30 June 2012

Keywords:
Polymer solar cells
Single junction
Double junction
Interfacial layers

ABSTRACT

Organic solar cells exhibit potential to provide light-weight and low-cost solar energy on flexible substrates. However, current efficiency is still low for applications. New materials and device designs are needed to increase cell efficiency and make this technology available for large-scale applications. The dependence of double junction solar cell efficiency on polymer bandgaps in top and bottom subcells are presented, which provides guidance for engineering new conjugated polymers for efficient photovoltaic device development. The achievable cell efficiency can be beyond 16% with the bandgap of the bottom subcell at ~1.6 eV (~775 nm) and that of the top subcell at ~1 eV (~1240 nm). In addition, the LUMO and HOMO energy levels of the donor polymers are provided depending on various acceptor materials such as PCBM, TiO_2, ZnO and CdSe. The interfacial layers between the subcells in double junction organic devices are also discussed.

1. Introduction

Alternative energy has attracted increasing interest to mitigate dependence on conventional fossil fuels, with sunlight emerging as a particularly promising clean and readily available source. There are a number of reasons we have not yet effectively harnessed the power of the sun. Silicon (Si) solar cells usually require complex high-temperature and vacuum processing, and high purity silicon, making them cost prohibitive as an energy source [1–3]. These cells are further hampered by limited mechanical flexibility. Polymer solar cells exhibit potential as an inexpensive alternative to Si solar cells due to their solution-based processing [4,5]. Conjugated polymers also offer an attractive approach for increasing solar cell efficiencies because their bandgaps and energy levels can be engineered by modifying their chemical structure. However, efficiency of polymer solar cells does not yet approach that of inorganic solar cells. Low carrier mobilities and short carrier diffusion lengths in existing conjugated polymers make it impossible to arbitrarily increase active layer thickness in order to allow full spectrum light absorption in single junction solar cells. One promising path to increase cell efficiency is to use varied bandgaps in a serial structure in which two or more subcells with complementary absorption spectra are stacked [6–25]. In a two-terminal multijunction cell, open circuit voltage (V_{oc}) is the sum of V_{oc}'s of individual subcells, while current is determined by the minimum one in individual subcells [2,6,8,14–22,26].

Cell efficiencies have reached beyond 8% for single junction polymer solar cells, about 10% for double junction polymer cells. However, further significant increase in cell efficiency requires new design in materials and devices. Polymers currently lack appropriate bandgaps and HOMO/LUMO energy levels for optimal operation with highest efficiency in single and double junction polymer solar cells. There is a critical need for research in synthesizing and understanding a plethora of novel variable bandgap polymers with high carrier mobilities and controllable HOMO/LUMO energy levels to construct high efficiency polymer solar cells. Advances in efficiency in double junction cells also require greater fundamental understanding of interfacial layers between subcells. This work provides a guide for researchers to design and synthesize new polymers with a clear target in terms of polymer bandgaps, LUMO and HOMO energy levels, as well as selection of proper interfacial layers between subcells in a double junction device structure.

2. Results and discussion

Previous reports by Siddiki et al. [2] and Scharber et al. [27] showed that single junction polymer solar cells could achieve efficiencies up to 10–13%. Further increase in efficiency of single junction cells is challenging partly due to thermalization loss caused during the conversion from a large energy photon into an electron–hole pair in low bandgap polymers. Fortunately borrowed from the concept of inorganic solar cells [28], double

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http://dx.doi.org/10.1016/j.solmat.2012.04.028

junction solar cell structures appear to be a promising solution to achieve a higher efficiency in polymer solar cells.

In series connection double junction solar cells, the overall current is limited by the lowest current produced from individual subcells. To maximize current output from double junction cells, the currents need to be matched between individual junctions. Current matching can also help prevent the build-up of photo-generated charges in local regions in the cells [2,6,29]. The built-up charges can lead to formation of local potential and electrical field that affect performance of double junction solar cells by deviating from the optimal power output point, thereby reducing V_{oc}, short circuit current density (J_{sc}), or fill factor (FF)

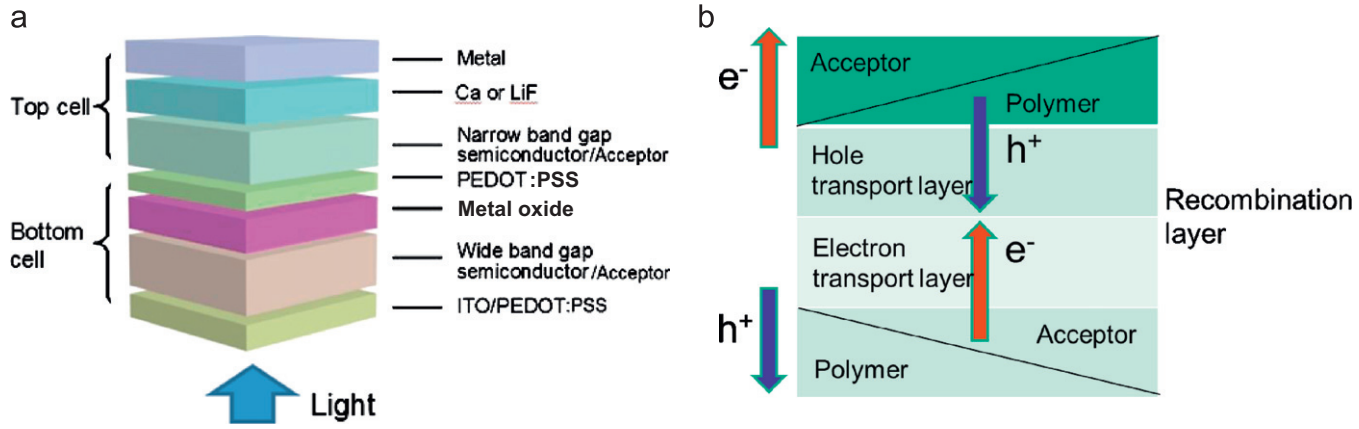

Fig. 1. (a) Device configuration of a typical double junction polymer solar cell and (b) the mechanism of the interfacial layers consisting of HTL and ETL. The HTL is typically PEDOT:PSS, while ETL is TiO_2, ZnO or Nb_2O_5.

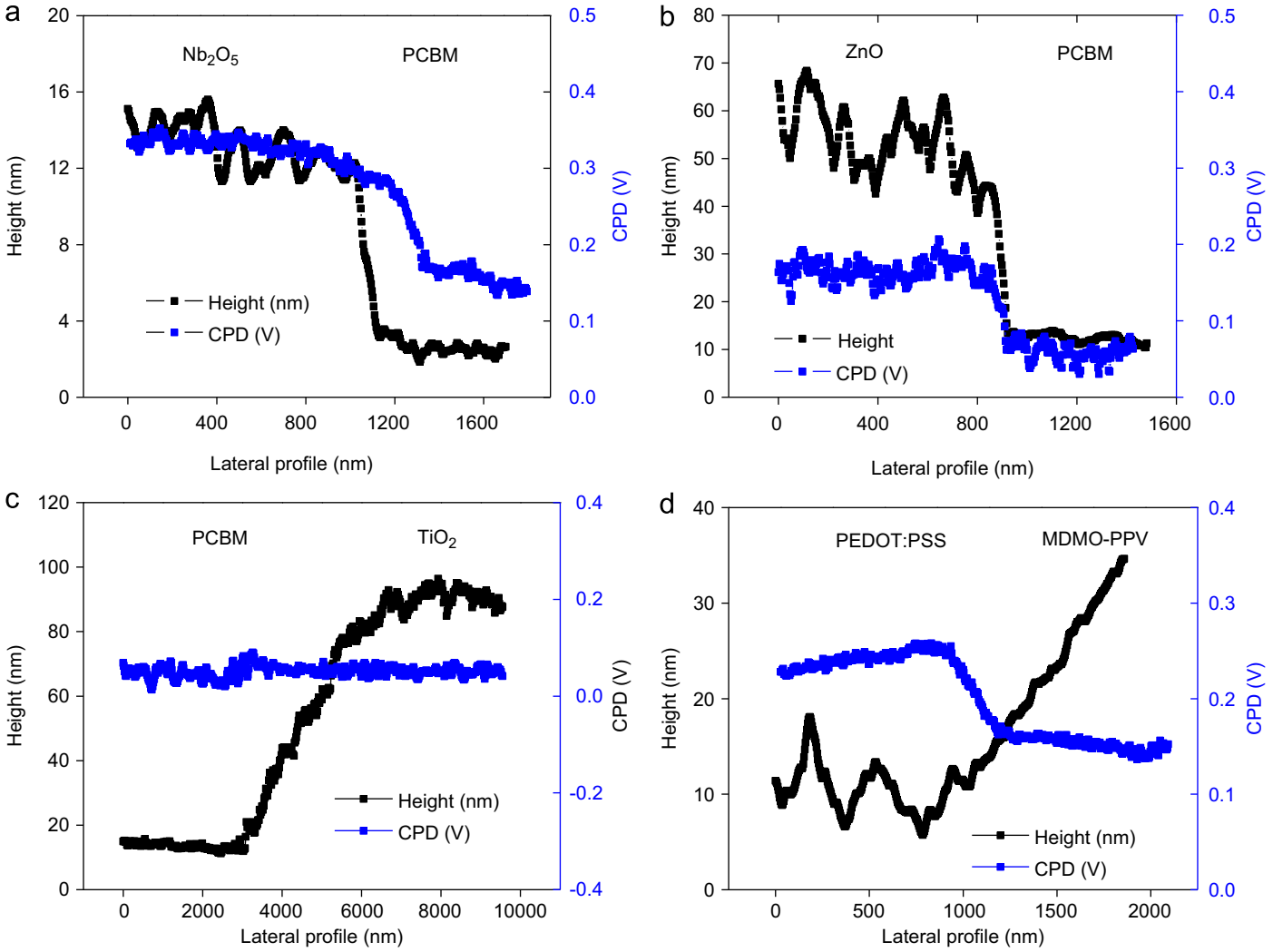

Fig. 2. Height and surface potential across a surface interface measured by scanning probe microscope (SPM) of (a) Nb_2O_5 on top of PCBM, (b) ZnO on top of PCBM, (c) TiO_2 on top of PCBM, and (d) MDMO-PPV on top of PEDOT:PSS.