Renewable and Sustainable Energy Reviews 57 (2016) 550–561

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Review on recent advances in polythiophene based photovoltaic devices

Umer Mehmood [a], Amir Al-Ahmed [a,*], Ibnelwaleed A. Hussein [b]

[a] Center of Research Excellence in Renewable Energy, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia
[b] Gas Processing Center, College of Engineering, Qatar University, PO Box 2713, Doha, Qatar

ARTICLE INFO

Article history:
Received 24 January 2015
Received in revised form
21 October 2015
Accepted 17 December 2015

Keywords:
Organic solar cell
Polythiophene
Poly (3,4-ethylenedioxythiophene)
Poly(3-hexylthiophene)
Hybrid solar cell

ABSTRACT

Discovery of conducting polymer introduced us to the total polymeric solar cells (PSC). During the last decade, power conversion efficiency (PCE) of these solar cells has increased from 1% to 11.5% (with the bulk heterojunction concept). Though they are still behind their inorganic counterparts in terms of efficiency, these solar cells have several advantages, such as scalability, it is printable, we can get flexible solar panels and low cost, etc. This comparatively lower efficiency is the key driving force behind the ongoing research and development on organic photovoltaics. Functionalized polythiophenes are the most studied donors and hole transporting materials in this technology (total polymer and polymer based hybrid solar cells). Like all other conducting polymers, pure polythiophene (un-substituted) is difficult to process, but its processability can be improved through the addition of functional moieties, mostly alkyl side chains. These modified polyalkylthiophenes are relatively stable, processable and have excellent optical and electrical properties. For examples, poly (3,4-ethylenedioxythiophene) doped with poly (styrenesulfonate) (PEDOT:PSS) and poly (3-hexylthiophene) (P3HT) are the most investigated materials. Here, in this review article, we have summarized some of the important modification techniques of thiophene monomer to get the desired polymers, its features and recent uses in the polymer based solar cells.

Contents

* Corresponding author. Tel.: +966 13 8602533; fax: +966 13 8607312.
E-mail address: aalahmed@kfupme.edu.sa (A. Al-Ahmed).

http://dx.doi.org/10.1016/j.rser.2015.12.177
1364-0321/

1. Introduction

1.1. Conducting polymers

Efficiency and lifetime of the polymer solar cells (PSCs) have increased significantly during this decade. The most recent efficiencies of PSCs are reported as 10.8% (single junction cells) and 11.5% (multiple junction), with an estimated lifetime of 1000 h [1–3]. PSCs have several advantages over inorganic solar cells, such as light weight, ease in fabrication on flexible substrates and it can be colorful, which enhance their application areas. These cells can be manufactured by simple solution processing techniques such as printing and coating [4,5]; however, spin coating is the most commonly used technique. The widespread application of the photovoltaic (PV) cells is limited mainly due to its higher price to energy output ratio. Though the cost of the inorganic PV cells has dropped significantly in the last decades but still non-competitive to conventional electricity production sources. Presently, the efficiency of Si-based cell has reached 24% but the current cost is still around $4/W [6]. This relatively high cost is mainly due to the sophisticated and expensive production routes. It is estimated that in the near future the costs can go down to 1$/W to 1.5$/W, which is still considerably higher than the target cost of 0.33$/W [7]. The motive to achieve high cost/efficiency ratios derived the emergence of the third generation PV technologies. PSCs got popularity because of their low-cost and high-volume processing, which are the attractive properties for industrial point of view. PSCs also created a new class of solar cells that go by a variety of names, e.g. plastic solar cells, plastic photovoltaics organic solar cells, organic photovoltaics. During the last decades, many research articles have been published on PSCs and gave useful insides about the new topographies of PSCs [8–15]. However, it will be difficult to tag an exact starting point along the time curve, because, many invention and improvements took place simultaneously, but this field got the real push after the discovery of the conducting polymers. In an effort, Spanggaard et al. [10] discussed the brief history of polymer photovoltaics and presented the time axis of the important breakthroughs in this area, starting from Becquerel's studies of photochemical process in the 19th century [16] to the first studies on photoconductivity in polymers by Pochettino in 1906 [16]. Significant achievements in the recent decades were the fabrication of the first heterojunction photovoltaics (PVs) based on small organic molecules made by Tang in 1986 [17]; in 1991, Hiramoto [18] fabricated the first dye–dye bulk heterojunction PV and Sariciftci et al. [19] manufactured the first polymer–C60 heterojunction PV in 1993. Though PSCs have many advantages over the inorganic solar cells, but there are also some disadvantages, such as low power conversion efficiency (PEC), stability at higher temperature and short operational lifetime [20–26]. To improve its properties, researchers have tried many new and modified materials and cell fabrication techniques.

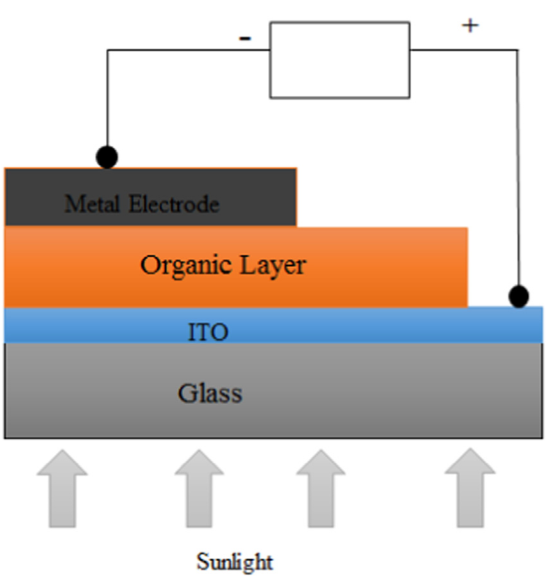

Fig. 1. Structure and working principle of typical PSC.

1.2. Assembly and operational principle

PSCs consist of superimposed structure as shown in Fig. 1, where the middle layer (active layer) can be built in three different manners: (1) a thin film of polymer materials inserted between the anode and cathode, (2) double-layer junction between donor and acceptor and (3) bulk heterojunction. The PSC generally consists of conductive glass substrate coated with indium tin oxide (ITO), an active layer and a top metal electrode. Usually the hole-conducting polymer acts as a donor material, while methanofullerene (PCBM) is considered as a best acceptor material. The optimum concentration ratio of donor and acceptor in the device should be 1:1 [27]. In order to improve the charge collection efficiency at the interface, in some cases an additional conducting layer is also applied between the conductive substrate and active layer [14]. Here, the mechanism of solar energy conversion into electrical energy consists of four fundamental steps.

As described in the literature [14,28–30]: (i) Photo-anode absorbs incident solar energy and the electrons in the active layer moves from ground state to the excited state, (ii) Due to the difference in energy levels of the electronic states, electrons from the exited state diffuse towards the interface between donor and acceptor; (iii) Charge separation occurs at the interface due to the dissociation of the excitons, (iv) Finally, charge transport and charge collection at opposite electrodes. In a PSC, open circuit voltage (V_{oc}), close circuit current (I_{sc}) and fill factor (FF) are dependent on the performance of the aforementioned steps. Experiments show that the performance of the first step is highly dependent on the type of the materials, while the performance of remaining steps depends on the designing of solar cell [31].

2. Thiophene based polymer materials

The discovery of the redox properties of conjugated polymers in 1976 [32] and the synthesis of thiophene based polymers are considered as the major breakthroughs for PSCs. Among the conducting polymers, polythiophene and its derivatives are the most investigated and successful conducting polymers in polymer based