Nano Energy (2014) 5, 36–51

Available online at www.sciencedirect.com

ScienceDirect

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

REVIEW

Solution processed approaches for bulk-heterojunction solar cells based on Pb and Cd chalcogenide nanocrystals

Jayesh Patel[a], Frej Mighri[a,*], Abdellah Ajji[b], Tapas K. Chaudhuri[c]

[a]*CREPEC, Chemical Engineering Department, Laval University, Quebec, QC, Canada G1K 7P4*
[b]*CREPEC, Chemical Engineering Department, Ecole Polytechnique of Montreal, C.P. 6079, Succ. Center-Ville, Montreal, QC, Canada H3C 3A7*
[c]*Dr. K.C. Patel Research and Development Center, Charotar University of Science and Technology, Changa, Petlad, Anand, Gujarat 388421, India*

Received 27 October 2013; received in revised form 31 January 2014; accepted 4 February 2014
Available online 13 February 2014

KEYWORDS
Bulk-heterojunction;
Metal chalcogenide;
Conjugated polymers;
Blending;
Surface modification;
In situ growth

Abstract
The development of inorganic nanocrystals (NCs) based bulk-heterojunction (BHJ) solar cells provides an alternative way to harvest sunlight for energy conversion. BHJ solar cells attract significant interest due to their simple fabrication, low cost and high performance. Among all the inorganic NCs, Pb and Cd chalcogenide (PbX and CdX, X=S, Se or Te) NCs as electron acceptor materials theoretically improve the performance of BHJ solar cells due to their enhanced absorption and multiple exciton generation (MEG). However, their performance in BHJ solar cell devices still does not match with the BHJ solar cell devices made from phenyl-C61-butyric acid methyl ester (PCBM). The initial part of this review introduces the concept, materials, structure, device fabrication, working principles and characterization of BHJ solar cells. Then, the different solution processed approaches and details on reported BHJ solar cell devices based on Pb and Cd chalcogenide NCs are summarized. Finally, critical factors limiting the performance of BHJ solar cell devices are discussed and strategies for the improvement of the power conversion efficiency (PCE) are demonstrated by presenting recent examples from literature.

Contents

*Corresponding author. Tel.: +1 418 656 2241; fax: +1 418 656 5993.
E-mail address: Frej.Mighri@gch.ulaval.ca (F. Mighri).

http://dx.doi.org/10.1016/j.nanoen.2014.02.001
2211-2855

Introduction

The history of solar electricity since 1970s has shown that human use a limited portion of its electrical power without burning fossil fuels (coal, oil or natural gas) or creating nuclear fission reactions [1]. The Sun provides a tremendous amount of free, environmentally friendly, quiet and reliable energy. In comparison, Earth's ultimate recoverable resource of oil, estimated at 3 trillion barrels, contains 1.7×10^{22} joules of energy, which the Sun delivers to Earth in 1.5 days [2]. Since 120,000 TW of solar radiation strikes on the surface of Earth, solar conversion systems (10% efficient) covering 0.16% of the land would produce 20 TW of power, nearly twice the annual global energy consumption [3]. Photovoltaic (PV) energy conversion is the most direct way to convert solar radiation into electricity and is based on the PV effect. Edmond Becquerel discovered the PV effect in 1838, when he observed a small voltage and current when two silver halide coated platinum plates immersed in an acidic solution were exposed to light [4]. In 1877, Charles Fritts constructed the first true solar cells (at least, the first resembling modern cell made from only solid materials) by using junctions obtained by coating the semiconductor selenium with an ultrathin, nearly transparent layer of gold. Fritts's device was very inefficient, transforming less than 1% of the absorbed light into electrical energy [5]. Later (in 1946), Russell S.O patented the modern junction semiconductor solar cell [6]. The modern era of semiconductor PV started in 1954 when Chapin, Fuller and Pearson obtained a solar efficiency of 6% for a Si junction cell [7].

PV device can generate electricity for a wide range of applications, scales, and climates; it is a cost-effective way to provide power for remote areas and space applications. The enormous gap between the potential of solar energy and the current underuse of this energy is due to low power conversion efficiencies (PCEs) of PV devices and the cost of materials currently required. The cost effective improvement of PCE is a primarily scientific challenge: breakthroughs in fundamental understanding enable the development of materials and methods potentially leading to PV market progress. Consequently, it is not surprising that a lot of effort is still ongoing on the search for new materials. Requirements for the ideal solar cell material are:

- Band gap (E_g) between 1.1 and 1.7 eV to absorb along the maximum visible spectrum.
- Direct band structure.
- Consisting of readily available, non-toxic materials.
- Reproducible deposition technique, suitable for large area.
- Good photovoltaic PCE.
- Long-term stability.

Modern research in the area of PV technologies has led to the creation of a vast spectrum of solar cells, which are commonly classified in four generations, differing from each other based on the materials and the processing technologies used to fabricate them. The material used to make the solar cell determines its basic properties, including the typical range of efficiencies. The first generation of solar cells, also known as Si wafer-based PV device, is the dominant technology for terrestrial applications today, accounting for more than 85% of the solar cell market. Single-crystalline and multi-crystalline wafers, used in commercial production, allow PCEs up to 25% [8]. Most of the disadvantages with this first generation comes from the manufacturing process because it requires expensive manufacturing technologies and highly expensive crystalline Si wafers. The second generation of PV materials is based on the use of thin-film deposits of semiconductors, such as amorphous Si, CdTe, $CuInGaSe_2$ or $CuInS_2$ [9]. Thin-film technologies reduce the amount of material, consequently lowering the prices. However, it may also reduce the PCE. Indeed, the efficiencies of thin film solar cells tend to be lower compared to conventional solar cells (around 6 to 10%), but manufacturing costs are also lower. Third generation solar cells are potentially able to overcome the theoretical efficiency limit of 31–41% for single E_g solar cells [10]. This generation greatly differs from the previous semiconductor devices and does not rely on a traditional