Renewable and Sustainable Energy Reviews 59 (2016) 726–737

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Advances in nanostructured thin film materials for solar cell applications

N. Ali [a,f,*], A. Hussain [a,b], R. Ahmed [a,*], M.K. Wang [c], C. Zhao [d], B. Ul Haq [a,e], Y.Q. Fu [d,*]

[a] Department of Physics, Faculty of Science, University Teknologi Malaysia, Skudai UTM Skudai, 81310 Johor, Malaysia
[b] Department of Computer Science & IT, Sarhad University of Science & IT, Ring Road (Hayatabad Link), Peshawar, 25000 KPK, Pakistan
[c] Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan, PR China
[d] Department of Physics and Electrical Engineering, Faculty of Engineering and Environment, University of Northumbria, Newcastle Upon Tyne, NE1 8ST, UK
[e] Department of Physics, Sungkyunkwan University, Suwon 440-746, Korea
[f] Department of Physics, GPG Jehanzeb College Swat, Pakistan

ARTICLE INFO

Article history:
Received 13 November 2014
Received in revised form
12 December 2015
Accepted 27 December 2015

Keywords:
Nanostructured
Thin films
Solar cell
Dye sensitized
Perovskite materials

ABSTRACT

This paper reviews recent advances in photovoltaic devices based on nanostructured materials and film designs, focusing on cadmium telluride (CdTe), copper zinc tin sulfide (CZTS), dye-sensitized solar cells (DSSCs) and perovskite solar cells. The current major challenges associated with the development of thin film solar cells are the reduction in manufacturing cost and increase in efficiency and performance. The CdTe and CZTS films have been investigated extensively due to its cheap and abundant elemental constituents and better physical properties. Solar cells based on the nanostructured technology including the DSSCs have also made wide impact into the solar cell industry in terms of manufacturing cost and improved efficiency. Perovskite solar cells have received significant interest recently due to its potential high efficiency.

Contents

1. Introduction

Due to the rapid growth of population and extensive usage of newly developed electricity-consuming devices, the energy consumption throughout the world is predicted to be increased at the

* Corresponding authors.
E-mail addresses: nisaraliswati@hotmail.com (N. Ali), rashidahmed@utm.my (R. Ahmed), richard.fu@northumbria.ac.uk (Y.Q. Fu).

http://dx.doi.org/10.1016/j.rser.2015.12.268
1364-0321/

rate of 1.5% per annum from 2010 to 2040 as shown in Fig. 1 [1–4], and it is estimated that 30 TW of energy is needed globally by the year 2050. This need will lead to a significantly increased energy demand from 16,999 to 42,655 Terawatt-hours (TWh) in the year 2007–2050, with an annual increase rate of 2.0% [5]. The electricity demand in the non-Organization for Economic Co-operation and Development (non-OECD) countries grows by 3.1% a year, which is almost three times faster than that in the OECD countries [5]. More than ten million people from the developing countries will need to get access to electricity up to year 2050, and large amount of energy up to 36,948 TWh will be needed [6]. Renewable energy resources play a critical role in coping with this huge demand of energy consumption. Among these, solar cell energy is regarded as one of the best solutions, and the decrease in the manufacturing cost of the solar cell devices is boosting the solar energy market, which will be comparable with the other available renewable energy resources. The annual market share of the photovoltaic technologies from year 2000 to 2015 is shown in Fig. 2 and the growth rate for the photovoltaics (PV) industry is ~30% per annum in the last decade and is increasing consistently [7]. The PV modules have contributed considerable power to the market annually which is 61400 GW by the end of 2015 [8].

Today 80–90% of the solar cell technology is dominated by silicon-based materials [9], and silicon technology is the mainstream and proven to be a robust technology in the PV modules. The reason behind this is that silicon is the leading material used in bulk (1st generation), thin film (2nd generation) and some of the nano-structured (3rd generation) solar cells for photovoltaics. However, the highest efficiency for non-concentrated silicon solar cell design reported so far is 25% only [10]. It is difficult to further increase the efficiency, although the following methods have been employed:

- Use of hydrogenated silicon [11].
- Use of nanoparticles as the back electrodes [12].
- Use of textured back surface reflector [13].
- Use of ZnO based back reflector in triple junction thin film solar cell [14].
- Use of concentrators on different substrates [15].
- Use of double and triple junctions [16].
- Incorporation of oxygen in Si, etc. [17].
- Nanostructured designs, such as p–n junction Si micro/nano-wire arrays and quantum dots [18], or nano-scale honeycomb structures [19].

There is also another concern about the high price of silicon wafers due to its extraction from the raw materials [20]. In order to reduce the cost and achieve high potential efficiency in the solar cells, it is critical to apply new materials with accompanying advantages such as abundant availability, less-toxicity, stability and growth with easy deposition techniques [21]. Generally, the recently extensively investigated solar cell materials include; thin films of CdTe, CZTS, SnSbS, CIGS, etc.; dye-sensitized TiO_2 and ZnO and their nanostructures; composite material CuO/ZnO, CIS/TiO_2, etc., homojunction materials, such as Cu_2O; and perovskite based solar cells, etc.

Fig. 3 shows the efficiencies plot for the key materials published in the current review from 2010 onward. It can be inferred from the figure that quantum dot and pervoskite solar cell efficiency increases significantly.

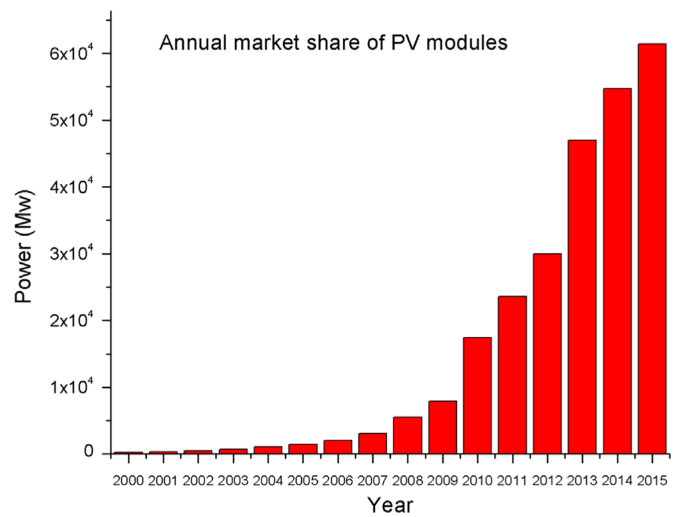

Fig. 2. Annual market share of PV modules.

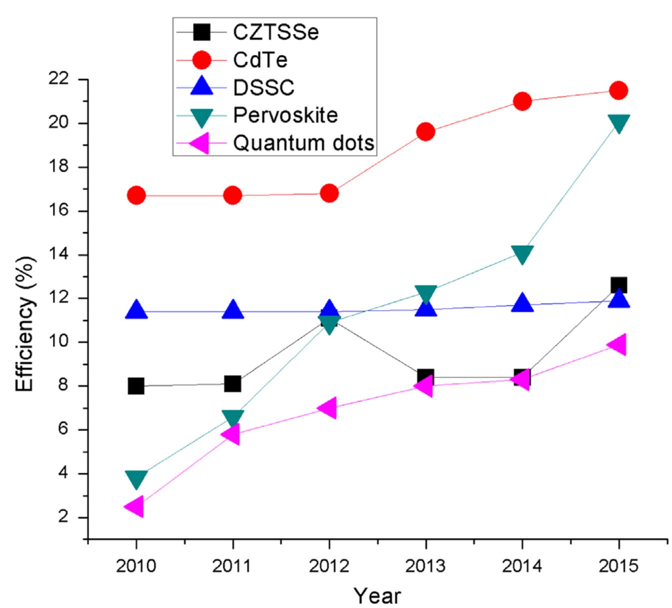

Fig. 3. Solar cell efficiency chart (2010–2015) [22–26].

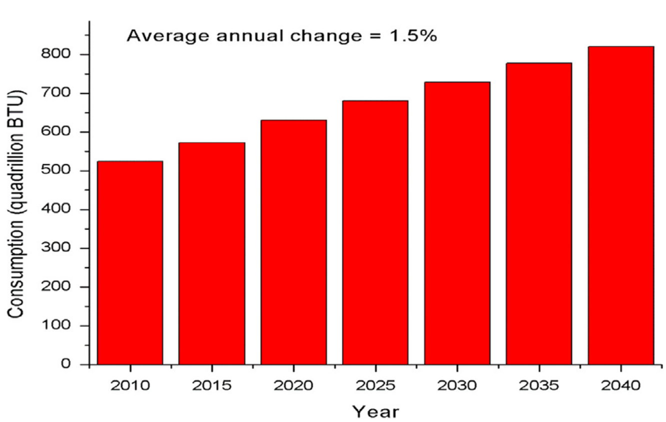

Fig. 1. World energy consumption, 2010–2040 (quadrillion BTU).