Renewable and Sustainable Energy Reviews 59 (2016) 662–691

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Photogalvanics: A sustainable and promising device for solar energy conversion and storage

Amulyacharya Malviya, Prem Prakash Solanki *

Department of Chemistry, Centre of Advanced Study, Faculty of Science, Banaras Hindu University, Varanasi 221005, Uttar Pradesh, India

ARTICLE INFO

Article history:
Received 11 March 2015
Received in revised form
4 December 2015
Accepted 27 December 2015

Keywords:
Photogalvanic cells
Photopotential
Photocurrent
Mechanism
Fill factor
Conversion efficiency
Storage capacity

ABSTRACT

Photogalvanic cells are based on the photogalvanic effect; provide an additional method on acquiring energy, converting sunlight into electricity and its storage. Production of potential between two electrodes separated by suitable substances in which the influence of light on the electrode potential is due to a photochemical process in the body of the electrolyte is termed as the Becquerel effect so called photogalvanic effect. In this review we have proposed suitable classification of solar cell based on the excitation (direct or indirect) of electron and semiconductor used, in which the photogalvanic cell has potential to revolutionize the existing solar cells due to its low cost and inherent storage capacity. Various type of photogalvanic effect has been discussed as linear photogalvanic, circular photogalvanic and photogalvanomagnetic effect. The main purpose of the paper is to review the results of research published related to this phenomenon and to propose the mechanism for the photocurrent generation in detail. Here, we have reviewed around 400 research articles/patents/reports/proceedings in the development of photogalvanic cells, from early stage to recently more efficient; considering electrolyte, electrode material and assembly set up. The results of electrical parameters (open circuit potential, short circuit current, power at power point, fill factor, conversion efficiency and storage capacity) of the photogalvanic cells containing dye, reductant and surfactants have given in a tabular form with comparison of more than 150 systems. A vast collection of photogalvanic systems and their electrical parameters have been scrutinized for further research work to enhance the electrical output and to make it commercially viable. In this paper, the primitive photogalvanic systems with iron–thionine to recent dye–reductant–surfactant system with specific reference to chronological and technological development in the cell have been discussed. We have also focused on the challenges and limitations in the field of photochemical conversion of solar energy and its storage.

Contents

* Corresponding author. Tel.: +91 542 6702469 (Office)/+91 9453361476; fax: +91 542 2368127.
E-mail addresses: ppsolanki@bhu.ac.in, ppsolankibhu@gmail.com (P.P. Solanki).

http://dx.doi.org/10.1016/j.rser.2015.12.295
1364-0321/

1. Introduction

Energy was a great discovery of human being which made our life more and more comfortable. The vital source of energy is the sun and life on earth is heliocentric as most of its energy is derived from the sun. The sun rays shower the surface of earth and humans have been using them to meet their energy needs. Although, earth receives only small fraction of sun total energy, yet one year's worth of solar energy reaching the surface of the earth is twice the amount of all non-renewable resources, including fossil fuels and nuclear uranium. Mankind has been harnessing the energy from the sun since the 17th century B.C. The ancient civilizations (Rome and Greece) has demonstrated their first documented use of sunlight by burning mirrors to light torches for religious purposes and ancient architecture has utilized passive solar design i.e. the use of sunlight to heat and light indoor spaces. 19th century saw the incommensurable and revolutionary discovery of the A. E. Becquerel, known as Becquerel effect in 1839. The 20th century witnessed the discovery of the photoelectric effect by Einstein and others. This led to research in the field of materials whose chemical properties were desirable to convert solar energy into electrical energy.

There are three approach of solar energy harnessing [1] – (i) direct photo-induced and endothermic chemical reaction (photosynthesis), (ii) direct production of electrical power (solar cells) and (iii) combined solar energy driven thermal conversions (solar heaters and cookers). The aim of this paper is to review the development and contribution of various researchers towards photogalvanic cell; hence production of electrical power from the solar energy.

The photogalvanic cells are dilute solution based dye sensitized solar power and storage devices, which is based on "photogalvanic effect". The photogalvanic effect was first discovered by Rideal and Williams [2] but it was systematically investigated and term was first used by Rabinowitch [3,4] to denote a special case of the so called Becquerel effect, in which the influence of light on the electrode potential is due to a photochemical processes in the body of electrolyte, which is the basis of the original Becquerel effect. Hence photogalvanic effect is quite different from other solar cells in which the photochemical and photoelectrical process occurs at the surface of electrode. Later on this kind of work was followed by various notable workers all over the world as Waber and Matijevic [5], Sancier [6], Potter and Thaller [7], Gomer [8], Clarck and Eckert [9], Kaneko and Yamada [10], Osif et al. [11], Wildes and Lichtin [12], Kamat and Lichtin [13,14], Kamat et al. [15–17], Albery and Archer [18–21], Albery and Foulds [22], Albery et al. [23,24], Archer et al. [25], Murthy and Reddy [26,27], Murthy et al. [28,29], Roy and Aditya [30], Shigehara and Tshuchida [31], Witzke [32], Tamilarasan and Natarajan [33], Bhattacharya et al. [34,35], Rohatgi Mukhrjee et al. [36], Rohatgi Mukhrjee and Bagchi [37], Ameta et al. [38–45], Jain et al. [46,47], Dubey et al. [48], Gangotri et al. [49–54].

These cells exploit photosensitizer (dye), reductant, alkali/acid and with or without surfactant for solar energy conversion and storage. Although, initial research work of photogalvanic cell was based on dye and reversible reductant systems, especially thionine–iron system [3,8,9,11,18], but later on various intense color dyes and irreversible reductant were used for the same. Hence, there are two main components of electrolyte of photogalvanic cells; photosensitizer and reductant. On our best knowledge so far 155 various systems have used in the photogalvanic cells for solar power generation and storage. In these systems, 36 types of different dyes from 8 different classes have used as a photosensitizer in photogalvanic cells as given in Table 4. Among these dyes, which are frequently used in photogalvanic cells as: bismark brown [55–59], methyl orange [60–62] (azo dye); brilliant cresyl blue [50,63,64] (oxazine); safranine [57,65–70], safranine-O [71–73] (phenazine); azur-A [74–82], azur-B [83–88], azur-C [81,82,89,90] methylene blue [42,49,91-98], toluidine blue [40,51–53,64,99–102], thionine [103–105] (thiazine).

First, Hendrich [106] has used ascorbic acid as an irreversible reductant in place of iron. Later on, so far 18 different irreversible reductant, have been used in the cells. Mostly EDTA [107], ascorbic acid [108], oxalic acid [58], mannitol [69] etc. reductants have been used.

At the outset, Srivastva et al. [109] have used systematically polyvinyl methyl ether as a surfactant to enhance conversion efficiency of photogalvanic cells and onward various anionic (as DSS, [68,72] SLS [83,84,110]), cationic (as CTAB, [71,105] TTAB [77]) and neutral (as triton-100, [90] brij-35 [57]) surfactants have been used. But out of 155 systems of photogalvanic cells, 47 times only SLS [61,64,75,79,111] surfactant has been used. For enhancement of electrical output various workers have been used mixed dye [81,82,112–119], mixed reductant [81,120] and mixed surfactants [97,98] in photogalvanic cells.

The results of first 100 years development of photogalvanic cells have been reviewed by Copeland et al. [121]. Then, till 1958 the work on photogalvanic cells have been reviewed by Sancier [6]. Later on, time to time results and developments on photogalvanic cells have been revieved by Daniel [122], Stein [123], Archer [124], Natarajan