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Dye-sensitised solar cells: Development, structure, operation principles, electron kinetics, characterisation, synthesis materials and natural photosensitisers

Mahmoud A.M. Al-Alwani [a,d,*], Abu Bakar Mohamad [a,c], Norasikin A. Ludin [b], Abd. Amir H. Kadhum [a,b,c,d], Kamaruzzaman Sopian [b]

[a] Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[b] Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia, Bangi, 43600 Selangor, Malaysia
[c] Fuel Cell Institute, Universiti Kebangsaan Malaysia, Bangi, 43600 Selangor, Malaysia
[d] Department of Biology, College of Education for Pure Sciences/Ibn Al-Haitham, University of Baghdad, Baghdad, Iraq

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ABSTRACT

The energy economy is highly dependent on oil, coal and natural gas, which constitute 37%, 27% and 20% of energy usage, respectively. However, the reserves of fossil fuels (e.g., crude oil) are limited and could run out in approximately 40 years based on a daily consumption of 82.5 million barrels and the current reserves to production (R/P) ratio. Solar energy is the source of nearly all energy on Earth. Of all renewable power sources, solar energy is the most easily exploitable, inexhaustible, quiet, and adaptable to different applications. Photovoltaic cells (PVCs) are devices that directly convert sunlight into electricity without pollution, sound, or moving parts, which makes them long-lasting and dependable. PVCs use an elegant method to take advantage of sunlight. Solar cells offer one of the most promising and environmentally friendly methods for producing electricity. This paper reviews the emergence, principles, electron kinetics and components of PVCs with a focus on the molecular engineering of several metal complexes, organic dyes and natural dyes that are used as photosensitisers in dye-sensitised solar cells (DSSCs).

Contents

* Corresponding author at: Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
E-mail address: mamash73@yahoo.com (M.A.M. Al-Alwani).

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1. Introduction

Solar energy is the main source of energy for all forms of life. It is one of very few sources of energy that are completely clean and free. The assessment of economical renewable energy sources is essential for the development of a sustainable global society. The global energy consumption is expected to reach 28 TW by the year 2050 [1]. Solar energy has the characteristics and greatest potential to meet the growing global need for future renewable energy.

The total solar radiation is approximately 3×10 24 J per year. Of the 1.7×105 TW of solar energy that reaches the Earth's surface, approximately 600 TW is of practical value, and 60 TW of power could be generated by using solar farms that are only 10% efficient [2]. These figures provide a clear vision of the possibility of using solar energy technology to meet the global demand for energy [3]. Population growth and increased global manufacturing, which is accompanied by dwindling energy resources, has caused global concern and has led to increased searches for alternative sources of energy [4,5]. At the current rate of energy consumption, especially regarding fossil fuels, available fuel sources will be depleted by the next century. The sun is the greatest source of inexhaustible energy, and twice the current global energy consumption could be provided by covering an area equivalent to approximately 1% of the Earth's surface by solar cells with a 10% collection efficiency (Sun, 2010). Photovoltaic cells (PVCs) are the most important renewable energy source because solar energy is very abundant [6]. The development of high-efficiency and low-cost solar cells is essential for the large-scale adoption of solar energy as an alternative to non-renewable energy.

2. Rapid growth in the electricity sector

According to the U.S. Energy Information Administration, the worldwide electricity consumption was estimated to be 19.1 trillion KWh in 2008 and is expected to increase to 35.2 trillion KWh in 2035 (Fig. 1), which includes an increase of 85% in Organization for Economic Co-operation and Development (OECD) countries. Electricity consumption is projected to increase by an average of 1.7% per year from 2008 to 2035 in OECD countries (46% overall). In non-OECD countries, the electrical system must expand to meet the demand for energy, and electricity consumption is expected to increase by 4.7% per year during this period (total increase of 127%). Electricity consumption will increase faster in India and China (5% per year; total increase of 154%) than the average for non-OECD countries during this period. Improvements in technology and the large growth in demand for electricity will provide an opportunity for new energy generation technologies to be deployed at a large scale across the world [7].

3. Background

The history of PV cells began in the 19th century, when Charles Fritts fabricated a primitive photovoltaic cell that was composed of selenium and a thin layer of gold. After 1873, the development of the first panchromatic film, which rendered realistic images into black and white, was followed by the work of Hermann Wilhelm Vogel, who discovered a method for increasing the photographic emulsion sensitivity and associated silver halide emulsions with dyes to produce black and white photographic films. Silver halides are insensitive to most visible light because they have band gaps at 2.7–3.2 eV. This achievement can be considered the first significant study of the dye sensitisation of semiconductors [8]. The first sensitisation of a photo-electron occurred only four years later using similar chemistry. Max Planck described the spectral distribution of the solar spectrum in 1901 through Planck's law [9].

Albert Einstein described how photon absorption causes the photoelectric effect in 1905 and was awarded the Nobel Prize in 1921 [10]. This work formed the theoretical basis for all photovoltaic devices and semiconductors, in which photons excite electrons out of the valence band and into the higher energy conduction band, where they are collected and transported to the outer circuit. In 1904, Wilhelm Hallwachs developed a semiconductor junction solar cell from copper and copper oxide. In 1914, Goldmann and Brodsky confirmed the barrier layer at the semiconductor metal interface, which was then studied in detail by many researchers, such as Neville Mott and Walter Schottky, in the 1930s. Russell Ohl fabricated a silicon solar cell in 1941. With the development of silicon in the 1950s, Fuller made near-surface *p-n* junctions using a boron trichloride treatment of *n*-type silicon, which caused charge separation in the device. In 1954, Bell Laboratories announced the production of silicon solar cells with efficiencies exceeding 6% [11].

However, the possibilities of sensitisation were not fully recognised until the early 1960s. Many new findings were reported at the International Conference on Photosensitization of Solids in Chicago in 1964, such as the sensitisation of ZnO with cyanine dyes and the necessity for an adsorbed dye monolayer to reach maximum efficiency [12]. Many types of *p-n* junctions were developed using gallium arsenide (GaAs), cadmium sulphide (CdS),

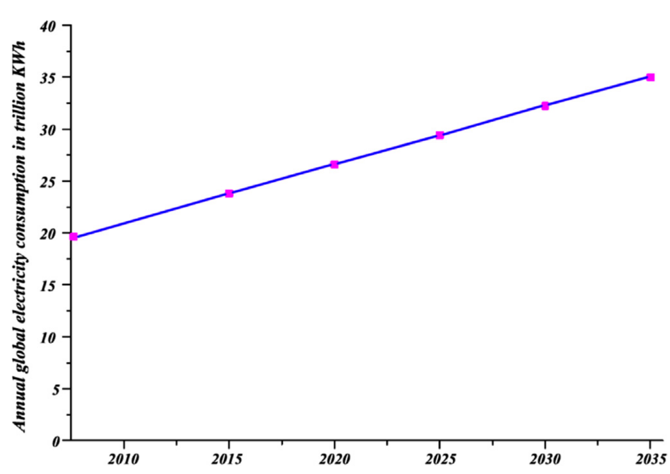

Fig. 1. Projected annual global electricity consumption in trillion KWh [7].