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RECENT ADVANCES IN DYE-SENSITIZED SOLAR CELLS USING PLANT PIGMENTS

Abstract: *The article discusses a number of plant-derived pigments, including titanium 2-oxide photoreceptors adsorbed with chlorophyll and anthocyanins. Various photoelectrochemical properties of dye-sensitized solar cells (DSSC) when copper thiocyanate and other substances are used as solid and liquid electrolytes have been studied.*

Key words: *chlorophyll, anthocyanin, photosensitivity, light coughing, dye sensitive solar cells, photovoltaics, efficiency, short circuit current, open circuit voltage, adsorption spectrum, copper thiocyanate.*

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Introduction

At present, the most efficient technologies for solar power generation are being implemented with the help of solar batteries based on semiconductors. If we look at the history of the development of photovoltaics, the conversion of light energy into electricity was first observed in March 1839 by the French scientist Edmond Becquerel and he created the world's first photovoltaic cell. Due to this phenomenon, the basis for practical photovoltaics, that is, the formation of electricity as a result of light absorption of certain substances. In 1817 Theodor Grotthuss first proposed the phenomenon called the Principle of Photochemical activation. This law states that only light which is absorbed by a system can bring about a photochemical change. Materials such as dyes and phosphors must be able to absorb "light" at optical frequencies. This law provides a basis for fluorescence and phosphorescence. The law was proposed in 1842, independently, by John William Draper. In 1865 Scottish scientist James Clerk Maxwell publishes “A Dynamical Theory of the Electromagnetic Field,” a mathematical description of light. This theory recognizes light as an electromagnetic wave. In 1905, A.Einstein publishes “On a Heuristic Viewpoint Concerning the Production and Transformation of Light,” a theory developing a hypothesis that light energy is carried in discrete quantized packets. In 1939 one of the most important discoveries was the invention of the American scientist Russell Ohl, and in 1946 he received a patent for the creation of a silicon solar cell [1]. From 1947 to 1967, a series of fundamental studies in the field of color photonics were carried out by the Russian academician A. Terenin [2]. In 1988, B. O’Regan and M. Gratzel invented the DSSC photocell at the University of California, Berkeley. In March 1991, they created titanium 2 oxides, color-sensitive complexes (ruthenium) and platinum cathode photovoltaic cells, namely Gratzel cells [3].

It is known from the 1st and 2nd laws of photonics that the efficiency of photovoltaic devices depends on the efficiency of the absorbed light beam. The efficiency of the DSSC photocell to generate electricity from light is determined by the ratio of the maximum value of the electric power generated in it to the total power of the incident light:

$$\eta = P_{max}/P_{lt} = I_m V_m / P_{lt} \quad (1)$$

here P_{lt} –the intensity of light adsorbing on the solar cell, I_m, V_m – maximum values of currents and voltages in the cell. To compare the current values generated in the surface units of different photocells, the current density J (mA / cm^2) is used instead of the current (mA). In engineering calculations, another parameter of the photocell, i.e. the filling factor (FF), is also used and is determined by the following formula:

$$FF = I_m U_m / I_{sc} U_{oc}, \quad (2)$$

here I_{sc} – short circuit current (the maximum current that can flow when the photocell clamps are connected), U_{oc} – open-circuit voltage (the value of the voltage at the terminals of the photocell not connected to the circuit when illuminated by light). Figure 1 shows the process of generating an electric current from light energy in the DSSC photocell (a) and the motion of electrons in the energy field (b). The processing of the dye-sensitive photocell is similar to the process of photosynthesis in plants. Chlorophyll takes the energy of light and generates an electron, which is then activated by other molecules. In the photocell, the excitation energy level of the dye molecule is located above the lower part of the conduction band of the semiconductor. The generated photoelectrons easily pass into the conduction band and move through the anode to the outer chain. In the electrolyte medium, the oxidized dye molecule is regenerated with iodide ion, and in the electrolyte medium, the cycle is repeated (Fig.1,a). The DSSC element differs sharply from silicon photocells in that titanium 2 oxide acts only as a medium for the diffusion (movement) of photoelectrons, while silicon acts as a medium for photoelectrons in its volume and acts as an environment for the electrons to move towards the conduction band. In the Gratzel cell, the dye plays a key role as a photoresist, with titanium 2 oxide anode, electrolyte and platinum cathode excipients. Initially, ruthenium complexes were used as dye sensitizers and platinum as cathodes in Gratzel cells [3].

Ruthenium has a high light absorption, but it is a rare metal and expensive. Therefore, researchers are currently conducting research to test natural dyes derived from ruthenium-replacing plants and to study their high photoelectrochemical performance. Various photoelectrochemical properties of chlorophyll extracted from spinach in water and ethyl alcohol were determined [4]. Band gap width of chlorophyll extracted in distilled water is 1.83 eV, light adsorption wavelength range is 400-700 nm, short-circuit current is 0.35 mA, open-circuit voltage is 440 mV, ethyl alcohol connection current and open-circuit voltage are respectively 0.32 mA was found to be equal to 384 mV. Table 1 shows the photoelectric parameters of solar cells prepared by adsorbing pigments (anthocyanins, chlorophylls) extracted from several plants to titanium oxide. It is known that corrosion is observed when liquids are used as electrolytes, and in most cases the service life of DSSC elements does not exceed 1 year. Therefore, the researchers used anthocyanins isolated from black grapes as a photosensitive, solid electrolyte - copper thiocyanate (CuSCN), and platinum as an injection electrode [5]. The efficiency of anthocyanin from black currant is 1.13, and the short-circuit current and open-circuit voltage are higher than those of black grape anthocyanin [6]. Photoelectrochemical parameters of DSSC elements based on titanium 2 oxide adsorbed with red cabbage, red onion peel, spinach-derived pigments (anthocyanins) and ruthenium complex (N719) were determined [7]. In this study, the ruthenium complex was observed to have adsorption peaks at 387 and 510 nm light wavelengths, red cabbage and onion peels at 544 and 486 nm, respectively, and chlorophyll from spinach with 2 adsorption peaks at 662 and 431 nm wavelengths, respectively. 4, 6, 8, 10% mesopore layers of oxide were prepared and their volt-ampere characteristics and light absorption spectra were obtained. From these characteristics, 10% layered titanium 2 oxide showed the highest current density, open-circuit voltage, filling coefficient, and efficiency. For the pigment obtained from the leaf of the red amaranth plant, the adsorption peak at the wavelength of light was 534 nm and the bandwidth of the band gap was 2.34 eV. Solar elements adsorbed on chlorophyll and betalene pigments derived from red amaranth and henna leaves were found to be 0.14% and 0.09% effective, respectively [8]. To determine the photoelectric parameters of DSSC elements, a solution of 6 pigments was prepared by dissolving and extracting amaranth and henna plants in distilled water, ethyl alcohol and acetone. Experiments have shown that the efficiency of naturally pigmented solar cells is 3-4 times smaller than that of synthetic pigmented elements. In addition, the high efficiency of liquid electrolyte solar cells compared to solid electrolyte used elements was also found. However, the existence of many types of natural pigments, the possibility of creating their compositions in the future and their wider use in DSSC elements, Hubert Hug and his colleagues studied the photoelectrochemical properties of chlorophyll, anthocyanins, betalene, lutein, beta-carotene, neoxanthin and other dyes derived from more than 25 plant species [9]. Recently, there has been a growing interest in the future use of pigments derived from seaweed as dyes in DSSC elements. Currently, 2 peaks with wavelengths of 404 nm and 666 nm have been identified in the adsorption spectrum of chlorophyll obtained from Scenedesmus obliquus micro algae, its current density, filling coefficient and efficiency are given in Table 1 [10].

From this table we can see that the solar element prepared on the basis of pomegranate pigment has the highest efficiency compared to other plants [11]. Areca catechu (Pinang) Adsorption spectra of pigment derived from Malaysian dates in ethyl and methyl alcohol, acetonitrile, hexane and chloroform have been determined and optical densities have reached 3 peaks at 442, 445 and 470 nm [12]. 0.2 accordingly for efficiency; 0.54; 72.5; Values of 0.077% were determined. For complete quantitative determination of anthocyanin content and molar mass of their components in plant pigments with relationship with spectral characteristics the fast chromatographic techniques such as HPLC (High Performance Liquid Chromatography) [13] and SEC (Size exclusion chromatography [14,15] can be used. Particularly, the identification was accomplished by the time of retention of anthocyanins signals in visible area, and by the comparison of chromatogram profiles for different species of fruits and berries [13]. The given method of the determination of anthocyanins content of colored by pigments fruit and berry stuff gives reliable data about qualitative content of the product.

CONCLUSIONS

The advantages of DSSC over silicon elements are their lightness, flexibility, simplicity and ease of manufacture, their ability to be used even in low light, low cost, and the ability to install them on various products and devices. At present, the main focus of researchers is the development of new solid and solid substances that can replace the liquid electrolyte for DSSC elements, cheap and safe electrodes instead of platinum cathode, high-sensitivity elements with high photoelectrochemical parameters. aimed at increasing the service life and efficiency.

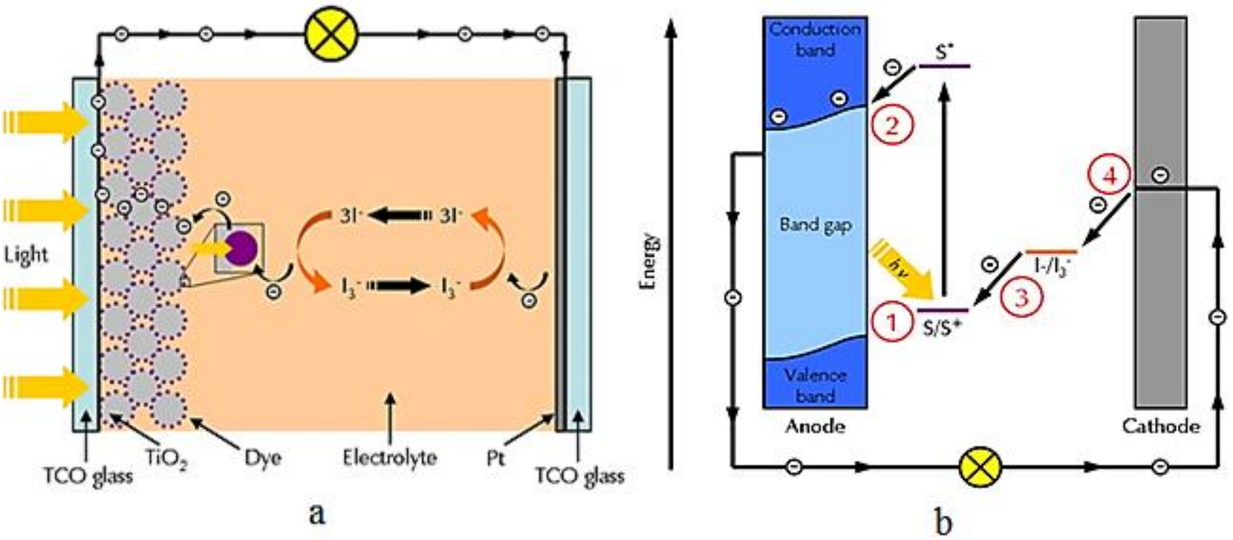

Figure 1. Schematic representation of the DSSC element (a) and the scheme of movement of electrons in the energy zones (b).

Table 1. Photoelectric properties of DSSC elements based on plant pigments

№	Pigmented plant	J_{sc}, mA cm^{-2}	V_{oc}, мВ	FF	Efficiency	Source
1	Black grapes	1,91	449	0,50	0,43	[5]
2	Black currant	2.08	770	0.49	1,13	[6]
3	Red cabbage	0,21	510	0,46	0,06	[7]
4	Spinach (chlorophyll)	0,35	440	0,49	-	[4]
		0,41	590	0,58	0,17	[7]
5	Peel a red onion	0,24	480	0,46	0,06	[7]
6	Red amaranth	1,00	350	0,38	0,14	[8]
7	Henna leaves	0.42	548	0,38	0,09	[8]
8	Micro water weed	0,18	502	0,69	0,06	[10]
9	Pomegranate	12,20	390	0,41	2	[11]

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