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Classification and functional characterization of the basic types of photovoltaic elements

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Nowadays, the continuous rise of the Human population emerges diversification of the energetic sources, for reliable energy supply. Furthermore, the sustainable development of the modern communities relays to environmentally friendly energy production equipment. The apparent energy demand arisen during the last decades has promoted remarkable scientific efforts for elaboration of entire new generations of photovoltaic elements (cells). In that means, the present brief literature review is attempt to classify the basic types photovoltaic elements

Key words: Photovoltaics, Silicon Solar Cells (SSC), Copper Indium Gallium Selenide Cells (CIGS), Cadmium Telluride Solar Cells (CTSC); Dye Sensitized Solar Cells (DSSC), Organic Solar Cells (OSC).

INTRODUCTION

Each system, composed by electron conductors (electrodes), separated by ion conductor (electrolyte) can be considered as “electrochemical system” [1]. The basic processes that proceed inside the electrochemical systems are: electrochemical oxidation/reduction reactions on the electrode surfaces (that proceed by participation of electrons) and ionic transport between the electrodes, through the electrolyte. In order to work, all electrochemical systems require external electric chain for delivery of electrons for the respective electrochemical reactions. Additionally, all electrochemical systems could be divided into two general groups: (i) – electrochemical sources of electricity (they convert the chemical energy of spontaneous electrochemical reactions to120 electric power) and (ii) – electrolysers, and Galvanic baths (for conversion of electrical power to promote desirable electrochemical reactions). To the former kind of electrochemical systems belong all batteries from the most classical as the elements of Danielli [2], Weston [3], Volta, [4], through the widely used lead-acid accumulators (batteries) of Gaston Planté [5] to the nowadays elaborating lithium-ion batteries [6-10], and various kinds of fuel cells [11–16].

Alternative approach for elaboration of new generations of sources of energy is based on the employment of the solar energy for excitation of electrochemical reactions or metal/semiconductor’s charge transfers on the interface between the electrolyte and the electrodes. By that manner, the thermodynamic demand for excitation of an electrochemical reaction or alternatively electron-hole charge transition can be satisfied by involution of light energy via illumination. The response for the necessity for development of systems for elaboration of light induced energy sources is the solar cells, or otherwise called “photovoltaics”. The recent interest to these elements (devices) is predicted from their potential application as sensors for the industrial automation, as well [17].

In that means, the purpose of the present brief review is description and classification of the recently developed generations of photo-electrochemical cells.

CLASSIFICATION OF THE BASIC TYPES OF PHOTOVOLTAICS

As a result of the literature review, it was established that there is a large variety of photovoltaic elements (cells), but all they belong to five general groups: Silicon Solar Cells (SSC), Copper Indium Gallium Selenide Cells (CIGS); Cadmium Telluride solar cells (CTSC), Dye Sensitized Solar Cells (DSSC), and Organic Solar Cells (OSC). All of them are based either on conductor/semiconductor junction, or photo-activated electrochemical reactions. In the former case, the light energy promotes electron-hole transitions through the metal/semiconductor interface, whereas in the latter case, photoactivated oxidation/reduction reactions proceed on the interface between electrolyte and electrode. Bube [18] summarizes 6 kinds of semiconductor junctions, according to the interface between the

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respective semiconductors. Completely all electrochemical devices are based on oxidation/reduction reactions on the electrode/electrolyte interface, combined by ion transport across the electrolyte.

Silicon Solar Cells (SSC)

It is the most widely spread kind of solar cells, owing their origin since 1953 [19]. Cross-sectional schematic view of such kind of photovoltaic element is depicted in Fig. 1 [20].

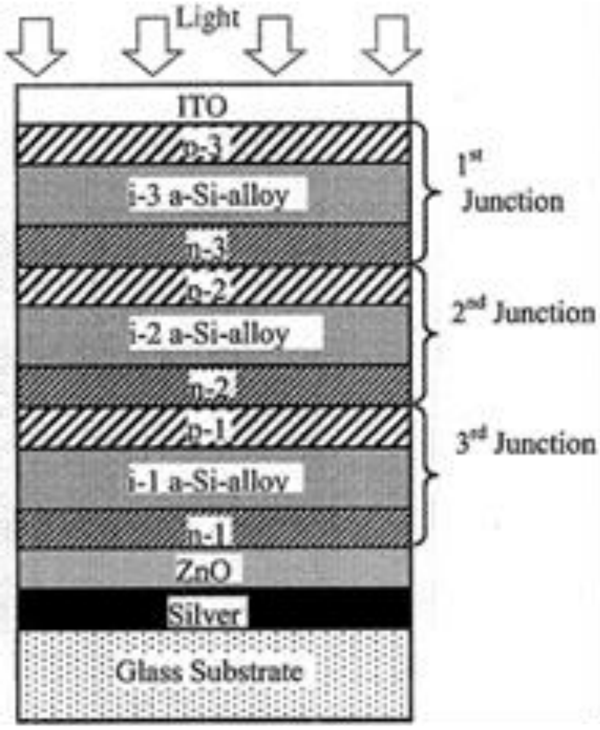

Fig. 1. Schematic cross-section of multilayered triple conjunction Si-solar cell [20].

Copper Indium Gallium Selenide solar cells (CIGS)

During the recent decades, large variety of semiconductor non-electrochemical photovoltaic elements (cells) have (has) been elaborated as an alternative to the silicon ones. Among the most favorite pretenders are the chalcopyrite CIGS and the kesterite $Cu_2ZnSn(S,Se)_4$ types of semi-conductive materials, as is mentioned elsewhere [21, 22]. As all the rest types of photovoltaics, these cells are with multilayer structure, as well. Example for this kind of solar elements is depicted in Fig. 2.

In the construction, shown in Fig. 2, the p-n transition proceeds on the Cu(InGa)Se2 – CdS. This transition is excitised by ZnO photoactive layer. The Indium Tin Oxide and the metallic molybdenum perform the function of electric contact layers for connection with the external electrical chain.

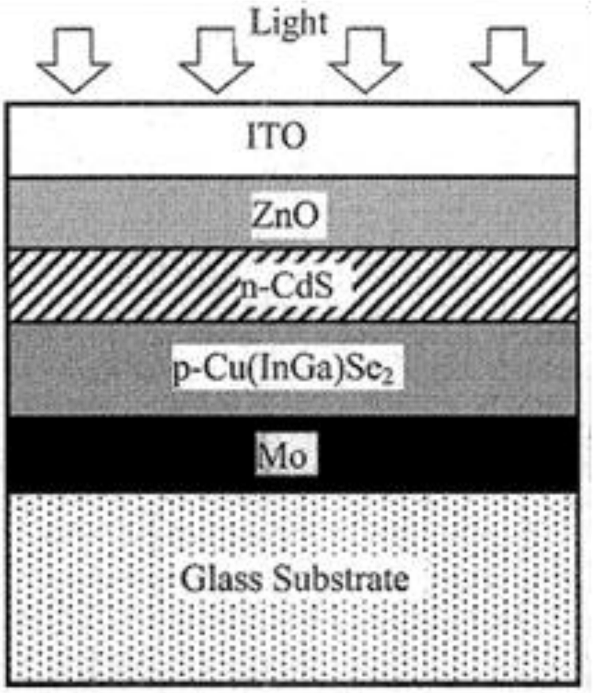

Fig. 2. Schematic illustration of CIGS –photovoltaic [20].

Cadmium Telluride solar cells (CTSC)

Besides CIGS, cadmium telluride also can be employed as adsorptive material. Nevertheless, Cd is considered to be highly toxic metal. Its use is limited by severe environmental restrictions [23].

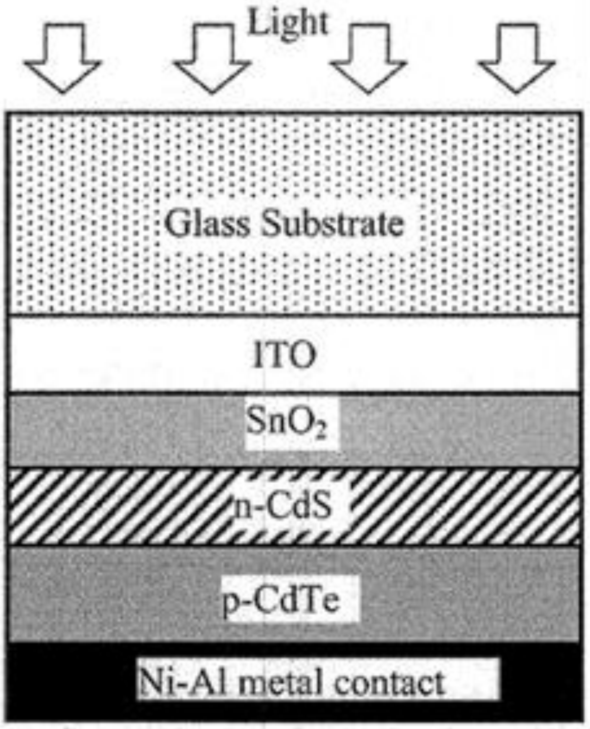

Fig. 3. Cross-section of CdTe –solar cell [20].

The organic chemical synthesis provides a great variety of organic conductive materials as an alternative to the application of heavy and toxic metals. In that means, various materials as organic dyes for Dye Sensitized Solar Cells, and even entirely organic solar cells are object of intensive research activities.

Dye Sensitized Solar Cells

These elements are based on photoactivited (activated) electrochemical processes, unlike all the rest photovoltaics. The interest to these elements (cells) has been raised remarkably, after the publications of O'Regan and Grätzel [24]. Its construction is depicted in Fig. 4.

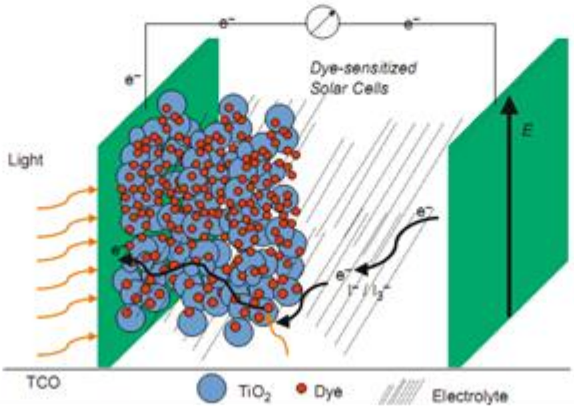

Fig. 4. Scheme of Dye Sensitized Solar cell [25]

The principle of function of these cells is based on reversible electrochemical oxidation of iodine ions ($I_3^- \rightarrow I^-$) from (in) the electrolyte and their diffusion through the electrolyte. This process proceeds being promoted by photoactivation by dye sensitized mesoporous titania [24 – 27]. This oxide is considered to be non-toxic and biocompatible and even appropriate for fabrication of implants [28 - 30], or drug delivers [31 – 33]. At last, this oxide is described as a versatile material for large variety of applications [34].

According to Stacow et al. [35], the photosensitizers are substances, generally with organic origin, able to transmit the light energy, absorbed by them, to neighboring molecules. Nevertheless, TiO_2 decomposes many organic substances when is illuminated by UV light. This fact means that titania is able to deactivate the photosensitizer by its decomposition. In addition, the presence of a liquid phase together with the photosensitizer decreases the life time of these elements. Furthermore, the simultaneous presence of oxidized and reduced iodine ions in the bulk of the electrolyte results in the recombination of the former by their "quenching" by the reduced form. As a result, difficulties related to the reaching of high efficiency exist.

Among the most durable and reliable photosensitizers are the tetrapyrole derivatives, such as: porphyrines, chlorines, phatlocyanines and naphtalocyanines. These compounds enable formation of metal complexes, where the metallic moiety could predetermine the optical properties of the respective metal-organic complex [36]. The properties of the respective metal-organic photosensitizer could be rather easily modified by involvement of different metal ions. Another advantage of these substances is their tremendous thermal and chemical durability, resulting in their compatibility to TiO_2-composed solids. Additionally, in the same book, these compounds are described as generally non-toxic and environmentally friendly substances. Indeed, the most famous presenters of these classes of compounds are the chlorophyll [37] in the algae and plants and the haemoglobin in the human and animal's blood [38]. Generally, the tetrapyrrole-based dyes have various applications, for instance: photodynamic therapy of cancer diseases, bleaching of textile and paper, purification of air, or water disinfection, as is mentioned elsewhere [39].

Various approaches for improvement of the Dye Sensitized Solar Cells are available. The chemical modification of TiO_2, as DSSC layer enables covalent binding with the organic photosensitizes, in order to obtain a robust hybrid material (formed by covalent bonded dye sensitizer on chemically modified TiO_2 with maximal porosity and specific surface area). Its activity could be supplementary enhanced by its modification with by involvement of transition metal ions, [40 - 43], noble metals [44, 45], or by other supplements [46 - 48] prior to dye deposition.

Other approach for optimization of the DSSC elements (cells) is the substitution of the liquid electrolyte by solid state ones [49, 50]. However, the solid state electrolytes supply unsatisfying contact, as is established by Gong et al. [51]. In the same article, they propose application of quasi-solid (gel) electrolyte, remarking its advantages as: (i) relatively high ambient ionic conductivity (6–8 $mS.cm^{-1}$), (ii) intimate interfacial contact with TiO_2, and (iii) remarkable electrolyte stability. At the initial step, the solvent with a low viscosity penetrates the TiO_2. The gels are considered as "quasi-solid" state, because they are composed by equally distributed liquid in the bulk of a solid matrix [52].

In quasi-solid electrolytes, framework materials play an important role for providing of a liquid channel for the I_3^-/I^- diffusion [53]. Examples for such "quasi-solid" electrolytes by involvement of nanoparticles [54 - 57], or organic gelator [58 - 63] could be found in the literature. In [51] is mentioned that an alternative direction for optimization of the DSSC-elements (cells) is the substitution of the iodine compounds by other electrochemical mediators (electrolytes). Different works are dedicated in this field [64 - 66].

Alternative direction for enhancing of DSSC efficiency is via employment of carbon nanotubes [67, 68]. They can be produced extremely easy by simple spray pyrolysis of saccharose [69, 70].

Besides implementation of organic dyes, fabrication of almost entire organic solar cells is available, as well.

Organic solar cells

The organic chemical synthesis provides a great variety of compounds composed by only several elements: C, H, N, S, and O. In that means, the Organic Solar Cells could be fabricated without of any heavy metal (such as Cd), and rather less amounts of semiconductors or novel elements. Other advantage of OSC is that their industrial fabrication could proceed at moderate temperatures, without of remarkable energetic expense.

The functional principle of a typical organic solar cell is described to be opposite to this of the light emitting diodes [71]. When light is absorbed an electron is promoted from the highest occupied molecular orbital (HOMO) to the lowest unoccupied molecular orbital (LUMO) forming an exciton (see Fig. 5). In a PV device, this process is followed by exciton dissociation. The electron reaches one electrode while the hole must reach the other electrode.

Sn-oxides could be SnO or SnO_2, according to the oxidation state of tin, whereas the most typical oxidation state of Indium is +3. In that means, the difference the doping of Sn(IV)-oxide by In(III) promotes depletion of electrons (vacancies), while the In(III) added Sn(II)-oxide should possess excess of electrons. When the element in Fig. 5-b is illuminated, the organic substance becomes electric conductor, and the more active metals from the counter-electrode render their electrons to compensate the electron vacancies in the $In_xSn_{1-x}O_4{}^{\delta+}$.

The conductivity of the organic substances could appear only when they possess a "conjugated" structure. This class of organic substances has cyclic structures with subsequent repetition of double bonds. They enable the presence of delocalized π-molecule orbitals enabling transmission of electrons through the entire organic molecules [72]. All organic substances with: (i) aromatic structures, (such as benzene, naphthalene, the antraquinones, phenantrenes); (ii) pyrrole (iii) aniline derivatives, etc. possess electric conductivity. Among the most appropriated organic conductors are the mentioned in the previous section porphyrines and phtallocyanines.

Regardless the apparent similarity between the Dye Sensitized Solar Cells and the Organic Solar Cells, the latter (e.g. OSC) are not electrochemical devices, because any ionic transport is not involved in their function. Consequently, the Organic Solar Cells do not relay to the definition for an "electrochemical device" [1].

Nowadays, there are various approaches for optimization of the organic solar cells in both directions of increasing of their efficiency, and extending of their durability [73]. One of the basic trends in the elaboration of new OSC is the employment of junctions of more than one polymer.

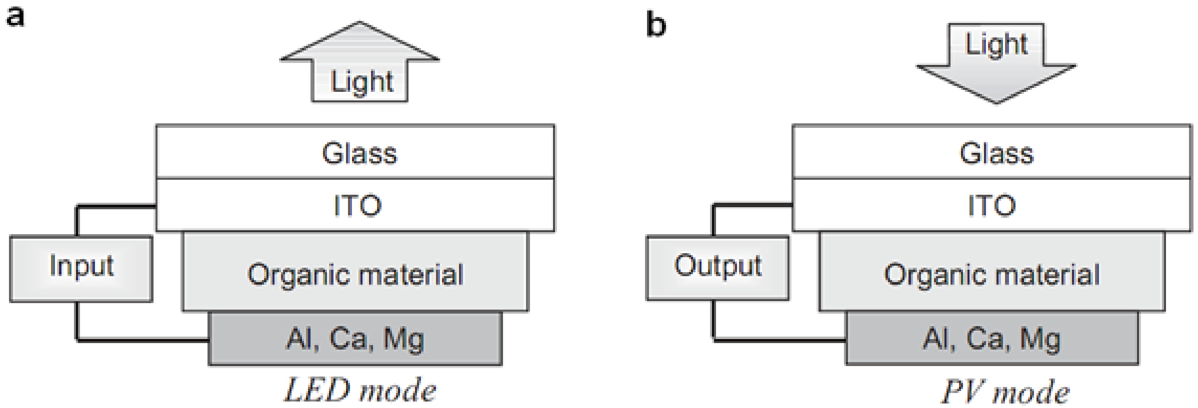

Fig. 5. Illustrations of light emitting diode (a) and organic photovoltaic element (b) [71], ITO - Indium Tin Oxide

Here should be mentioned that when elements as O, S, or N are included in the organic compound, it could reveal semiconductors properties. The reason for these properties is the aptitude of these elements to change their oxidation state (for example N(III) → N(V); S(II) → S(VI), etc.). In that means various polymers of organic substitution derivatives are investigated [74 – 80]. Involvement of carbon nano-particles is also described in the literature [73, 81]. Besides, there are technologies for their easy production [69, 70].

The main disadvantages of the organic solar cells are their relatively low efficiency [73], and low durability. The main processes of deterioration of these elements are: water and O2 uptake that lead to corrosion of the metallic electrodes, decomposition oxidation and hydration of the organic stuff as is describe in detail, elsewhere [82].

CONCLUSION

As a result of the literature review done, several important conclusions were reached:

The photovoltaics can be divided into five main groups: (i) - Silicon Solar Cells (SSC), (ii) - Copper Indium Gallium Selenide Cells (CIGS), (iii) - Cadmium Telluride solar cells (CTSC); (iv) - Dye Sensitized Solar Cells (DSSC), (v) - Organic Solar Cells (OSC). The former three groups are completely composed by inorganic materials, whereas the latter two contain organic compounds in their structures.

The latter two groups of PV are more perspective for R & D, then the former, because they are relatively newer classes, and do not require toxic or environmentally incompatible elements, such as cadmium.

From all five groups of PV, only DSSC can be considered as photoelectrochemical devices, because of presence of purely electrochemical processes of oxidation/reduction and ion transport between the electrodes.

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КЛАСИФИКАЦИЯ И ФУНКЦИОНАЛНА ХАРАКТЕРИСТИКА НА ОСНОВНИТЕ ВИДОВЕ ФОТОВОЛТАИЧНИ ЕЛЕМЕНТИ

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(Резюме)

В днешно време, поради непрекъснатото увеличаване на населението възниква диверсификация на енергийните източници. Освен това, устойчивото развитие на съвременното общество се променя към производство на екологично чиста енергия. Високото потребление на енергия през последните десетилетия е насърчило забележително научните изследвания за разработване на цели нови поколения фотоволтаични елементи (клетки). В този смисъл ще бъде представен кратък литературен обзор на основните видове фотоволтаични елементи.