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Short Communication

Functional Materials for Dye-sensitized Solar Cells

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A review on the analysis of characteristics of dye-sensitized solar cells (DSSC) is provided. DSSC design, materials that are used for the manufacture of functional layers and the characteristics of elements depending on their properties are analyzed. The basic disadvantages DSSC, the factors leading to their appearance, as well as solutions to eliminate or reduce the impact of these factors are revealed.

Keywords: Solar cell, Photoconversion, Efficiency, Transparent conductive oxide, Metal-oxide semiconductor, Dye, Electrolyte, Catalyst.

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1. INTRODUCTION

Problems of solar energy can be solved by improving the efficiency of photoconversion and as results reduce the production cost of solar cells (SC). Organic solar cells outperform silicon analogues in economic efficiency, however inferior to them in photoconversion efficiency. As a result, dye-sensitized solar cells (DSSC) cause an increased interest today.

The maximum value of the efficiency of DSSC $\eta = 15.0$ % [1] and received on a cell area of 1 cm^2. The cost of such elements is less than 60 % of cells based on other materials such as silicon. In addition, no expensive equipment and materials that do not require a high level of purification, is used in the DSSC production.

Thanks to these advantages, DSSC may be installed in places where the angle of light incidence is not optimal and others solar cells are not suitable, for example, glass buildings, outer panels of cars, housings of mobile phones. For this reason DSSC are among the most promising types of photovoltaic cells today. The largest companies that produce and sell them around the world are "Solaronix" and "Dyesol".

2. FUNCTIONAL MATERIALS

The typical structure of DSSC is shown schematically in Figure 1. From the list of functional materials forming this structure, the DSSC characteristics (coefficient of photoelectric conversion, open circuit voltage, short circuit current, fill factor, external quantum efficiency) depends on morphological properties of semiconductors, spectroscopic properties of dyes and electrical properties of electrolyte.

2.1 Transparent Conductive Substrate

Two glass substrates, on which are deposited thin films of a transparent conductive oxide (TCO), are used as electrodes in DSSC. Transparency of such electrodes must be high (> 80 %) in the visible region of the spectrum, to facilitate the passage of solar light maximum amount into the active area of cell. The electrical conductivity of substrates must be large for efficient charge transport and minimize energy losses. These two parameters greatly influence on the DSSC efficiency.

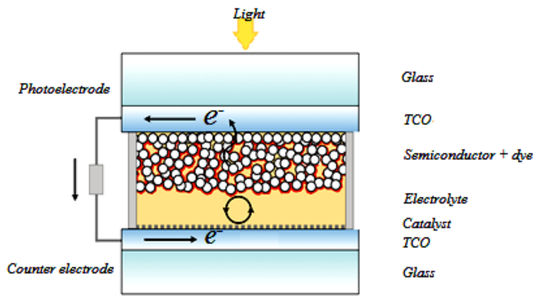

Fig. 1 – DSSC structure

Indium oxide doped with tin (ITO) is often used as the TCO. ITO thin films are usually deposited on the surface of a soda-lime-silicate glass by magnetron sputtering in the DSSC production. An alternative method of deposition is used in the department of "Nano and microelectronics" Penza State University. This method is called spray pyrolysis. Today deposition conditions are selected so that transparency of the TCO thin films is $T \geq 80$ %, and surface resistance $Rs \sim 30$ Ohm/□ [2].

2.2 Metal-oxide Semiconductor

Semiconductor absorbing dye accepts electrons from it and transfers into the external circuit DSSC. The rate of electron transfer greatly depends on the crystal structure, morphology and surface area of semiconductor. The following metal oxides are used: titanium dioxide (TiO_2), zinc oxide (ZnO) and tin dioxide (SnO_2). Today, however, titanium dioxide is considered to be an ideal semiconductor material for DSSC, due to the best morphological and photovoltaic properties.

Semiconductor layer should consist of TiO_2 nanoparticles and have a porous structure that provides high surface area (at least 200 m^2/g) of photoelectrode. This in turn improves concentration of a sensitizing

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dye and efficiency of light collection with photoconversion. The diameter of TiO_2 particles should be 10-30 nm at layer thickness 10 microns for the 50 % porosity formation [3].

The main cause of losses in DSSC is the recombination of injected electrons with electrolyte. Dark current is the result of this phenomenon. It leads to decrease the DSSC efficiency. Dark current may be minimized by means structural changes, such as using a TiO_2 surface treatment or special insulating layer (Nb_2O_5, SiO_2 and Al_2O_3) deposited on the semiconductor [4].

2.3 Dye

The function of dye is the light absorption and electrons transfer into the conduction band of semiconductor. Dye should intensively absorb radiation in the visible region of the spectrum, should be adsorbed on the semiconductor surface, is stable in an oxidized form and should recover via electrolyte. The molecular structure of dye affects the DSSC efficiency.

Metal complex, non-metallic organic and natural dyes used. Ruthenium compounds (N-719) have the highest efficiency ($\eta = 11.2$ %) among metal complex dyes. However, they are rarely used because of the high cost. To date, the efficiency of organic dyes (e.g., indoline, $\eta = 9$ %) is less than that of metal complex dyes, but they are cheaper and have better electronic properties.

The advantages of natural dyes are easy extraction, lack of toxicity and low cost. However, the minimum coefficient of photoelectric conversion is generated when they are used in DSSC. Dyes based on red turnip pigment have the highest efficiency ($\eta = 1.7$ %) among this type [5].

2.4 Electrolyte

The DSSC operability also depends on the properties of electrolyte. Its function is to regenerate dye and transfer of positive charge to counter electrode. Therefore electrolyte should have a high conductivity and low viscosity for rapid diffusion of electrons, a good interfacial contact with semiconductor and counter electrode, should not induce the desorption of dye with oxidized surface and its degradation. Electrolytes used in DSSC are three types: liquid, solid and quasi-solid electrolytes.

Liquid electrolytes are classified into organic and ionic, depending on the type of solvent. Couple I^{3-}/I is considered the ideal option because of good solubility, rapid regeneration of dye, low light absorption in the visible region of the spectrum, compatible redox potential and slow kinetics of recombination between injected electrons in semiconductors and triiodide.

Leakage is a major problem for DSSC based on liquid electrolytes, because it greatly reduces long-term stability elements. Therefore solid electrolytes are designed to improve its [6]. Here, the liquid phase is replaced by p-type semiconductor or material p-type conductivity. Compounds based on copper (CuI, CuBr and CuSCN) are used as inorganic materials with p-type conductivity. However, organic materials (e.g. Spiro-OMeTAD) are more profitable due to the low cost and ease of deposition. DSSC based on solid electrolytes have a very low efficiency ($\eta = 3.8$ % for CuI) because of poor contact with photoelectrode and high rate of recombination of charges.

Almost all of the above problems are solved by using quasi solid electrolytes. They have better long-term stability, high conductivity and good interfacial contact compared to liquid materials [7]. Such properties appear due to the formation of unique polymers network structure. DSSC based on trimethylolpropane with ethylene carbonate as a solvent has a maximum coefficient of photoelectric conversion ($\eta = 8.1$ %) among this type.

2.5 Counter Electrode

Counter electrode is used in the process of electrolyte regeneration. The layer of catalyst is required to accelerate the reduction reaction. The counter electrode efficiency depends on several factors: type of catalyst, process of its formation on TCO, compatibility with electrolyte. It is preferable to use platinum because of the high exchange current density, good catalytic activity and transparency. However, the activity of platinum catalyst decreases with time in presence the redox couple iodide/triiodide. Also the cost of platinum or its compounds is high [8]. Graphene and conductive polymers used as alternative materials for the production of counter electrode [1]. However, their efficiency is very low compared with the platinum catalyst.

3. CONCLUSIONS

The following decisions need to be taken to improve the efficiency and stability of DSSC:

1) Optimizing the morphology of semiconductor (to reduce the dark current).

2) The development of low volatile and less viscous electrolytes (to increase the rate of charge transport).

3) To improve mechanical contact between two electrodes.

4) Selection of specific additives (to improve the properties of electrolytes and dyes).

REFERENCES

1. L. Andrade, H.A. Ribeiro, A. Mendes, *In Encyclopedia of Inorganic and Bioinorganic Chemistry* 11 (2010).
2. V.I. Kondrashin, E.A. Pecherskaya, R.M. Pecherskaya, S.V. Raksha, *FM&NT* (2015).
3. J. Gong, J. Liang, K. Sumathy, *Renewable Sustainable Energ. Rev.* **16**, 5848 (2012).
4. E. Palomares, J.N. Clifford, S.A. Haque, T. Lutz, J.R. Durrant, *J. Am. Chem. Soc.* **125** No 2, 475 (2003).
5. H.S. El-Ghamr, S.A. Taya, T.M. El-Agez, A.M. Al-Kahlout, N.Al Dahoudi, M.S. Abdel-Latif, *J. Nano- Electron. Phys.* **7** No 3, 03001 (2015).
6. B. Li, L. Wang, B. Kang, P. Wang, Y. Qiu, *Sol. Energ. Mater. Sol. C* **90** No 5, 549 (2006).
7. N. Mohmeyer, P. Wang, H.-W. Schmidt, S.M. Zakeeruddin, M. Gratzel, *J. Mater. Chem.* **14** No 12, 1905 (2004).
8. G. Syrrokostas, *Sol. Energ. Mater. Sol. C* **103**, 119 (2012).