PREGLED NESILICIJUMSKIH I NOVIH FOTONAPONSKIH TEHNOLOGIJA ZA GENERISANJE ELEKTRIČNE ENERGIJE

A REVIEW OF NON-SILICON AND NEW PHOTOVOLTAICS TECHNOLOGY FOR ELECTRICITY GENERATION

Danijela Nikolić[1], Milorad Bojić[1], Jasmina Skerlić[1], Jasna Radulović[1], Dragan Taranović[1]

[1]Faculty of Engineering, University at Kragujevac, Serbia
Seste Janjić 6, 34000 Kragujevac

Corresponding author: Danijela Nikolić
e-mail: danijelan@kg.ac.rs

Solarna energija je najzastupljeniji, neiscrpan i najčistiji resurs od svih obnovljivih izvora enegije. Fotonaponska (photovoltaic-PV) tehnologija je jedan od najboljih načina za iskorišćenje solarne energije. Proteklih godina, svetski razvoj fotonaponskh tehnologija raste veoma brzo, upravo zbog tehnološkog razvoja i podrške državnih vlada obovljivim izvorima energije. Silicijum je vodeći materijal u tehnologiji fotonaponskih solarnih ćelija, upravo zbog svoje visoke efikasnosti. Ovaj rad predstavlja pregled nesilicijumskih fotonaponskih tehnologija, zasnovanih na primeni kadmijum-telurida ((CdTe) i kadmijum-sulfida (CdS), bakar indijum galijum selenida/bakar indijum selenida (CIGS/CIS) i ćelija s fotoosetljivim pigmentima (DSSC). Takodje, u radu su prdstavljene i neke nove fotonaponske tehnologije za proizvodnju fotonaponskih ćelija – nanotehnologija ili ''fotonaponske ćelije treće generacije''.

***Ključne reči**: fotonaponski paneli; kadmijumske solarne ćelije; bakarne solarne ćelije; ćelije s fotoosetljivim pigmentima; fotonaponske ćelije treće generacije*

Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources. Photovoltaic (PV) technology is one of the finest ways to harness the solar power. In the recent years, the world's development of PV technology is growing very fast because of the technological development and government support for renewable energy. Silicon is a leading material in PV cells technology, due to its high efficiency. This paper reviews the non-silicon photovoltaic technology, based upon Cadmium telluride (CdTe) and Cadmium sulphide (CdS), Copper indium gallium selenide/copper indium selenide (CIGS/CIS) and Dye-sensitized solar cell (DSSC). Also, it is presented some new photovoltaic technology for PV cell production – Nanotechnology or ''third– generation PV''.

***Key words**: photovoltaic; cadmium solar cell; copper solar cell; dye-sensitized solar cell; third – generation PV*

1. INTRODUCTION

Photovoltaic (PV) is one of the most prominent renewable energy technologies. Solar photovoltaic technologies are an attractive option for clean and renewable electricity generation – it is the direct conversion of sunlight into electricity without any heat engine to interfere. The PV effect was discovered in 1839 by Becquerel while studying the effect of light on electrolytic cells [1]. Photovoltaic devices are rugged and simple in design requiring very little maintenance. Increasing number of countries is installing photovoltaic solar power plants. The main reason for this is that the use of solar energy contributes to more efficient use of the countries own potentials in generating electrical and thermal energy, reduction of the greenhouse emission, reduction of importing and use of the fossil fuels, development of the local industry and new job openings [2].

Starting from 1990 industry of photovoltaic conversion of solar irradiation shows constant annual economical growth of over 20%, and from 1997 over 33% annually. In 2000 total installed capacities worldwide have surpassed 1000 MW, and in developing countries have overreached more than million house-holds which are using electrical energy generated by means of the photovoltaic systems. It is predicted that PV will deliver about 345 GW by 2020 and 1081 GW by 2030 [3].

Overgrowing number of companies and organizations is taking active part in the promotion, development and the production of photovoltaic devices and systems - BP Amoco, Shell, Kyocera, Mitsubishi, Sanyo and Sharp.

Silicon is a leading technology in making solar cell [4, 5]. In this paper, it is analyzed the current status of the PV market and technology, non-silicon PV technologies based upon Cadmium telluride (CdTe) and Cadmium sulphide (CdS), and Copper indium gallium selenide/copper indium selenide (CIGS/CIS), dye-sensitized solar cells (DSSC) and the new photovoltaic technology for PV cells - nanotechnology or ‘‘third-generation PV cells’’.

2. PV MARKET TODAY

The rapid growth of the PV market began in the 1980s. Today, the present PV market grows at very high rates, 30 – 40 %, like the telecommunication and computer sectors. World PV production in 2009 increased to 10.66 GW (Fig. 1) [1].

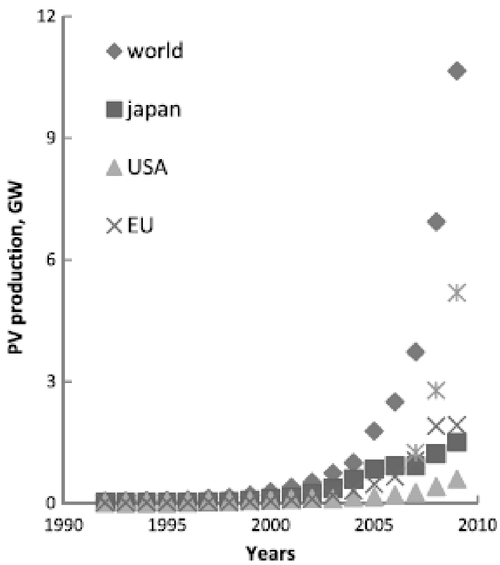

Fig 1 - Evolution of world PV cell/module production

PV applications are progressively finding their markets mainly in the United States, Japan, and the European Union (mostly Germany) and China/Taiwan. The annual production of PV cells and modules in the United States, Japan, European Union, and China/Taiwan in 2009 was 595 MW, 1.5 GW, 1.93 GW, and 5.19 GW, respectively [1]. Recently, China/Taiwan became the leading PV country, and PV production has almost doubled. Another 6.9 GW of cell and 6.7 GW of module capacity are being added—most of it in China, Taiwan, and Japan - bringing total global cell and module capacity to 25.1 GW and 22.7 GW, respectively. Indian government is serious for solar electricity production and other renewable energy sources with the set up of a national solar mission to make India a sale leader in solar energy and have targeted for 500 GW power productions through solar energy by 2030 [6] .

3. NEW MATERIALS FOR SOLAR CELLS

Silicon is a leading technology in making solar cell due to its high efficiency (Fig 2). However, due to its high cost, most researchers are trying to find new technology to reduce the material cost to produce solar cell and to till date, thin film technology can be seen as a suitable substitute [4]. Three materials that have been given much attention under thin film technology are amorphous silicon, CdS/CdTe and CIS, but researchers are continuously putting in more effort to enhance the efficiency. However, all of these materials have some bad impact on the environment [7]. Another solution for thin film technology has been carried out by researchers by using polymer organic as a solar cell material. Polymer materials have many advantages like low cost, light weight and environmental friendly, but they have very low efficiency compared to other materials with just 4–5%.

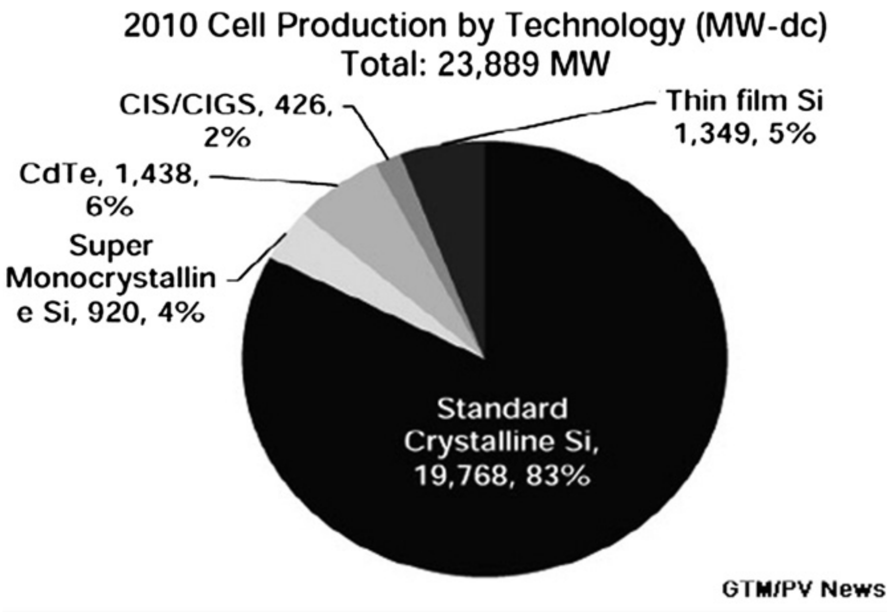

Fig 2 - Solar cell materials markets in 2010.

3.1 Cadmium telluride (CdTe) and cadmium sulphide (CdS) solar cells

This material can produce high efficiency, more than 15 % and is also known to give an ideal band-gap (1.45 eV) since the direct absorption coefficient is very high. A layer of cadmium sulphide is deposited from solution onto a glass sheet coated with a transparent conducting layer of thin oxide. This is followed by the deposition of the main cadmium telluride cell by variety of techniques including close-spaced sublimation, vapor transport, chemical spraying or electroplating [2]. CdTe solar cells have been used as low cost, high efficiency, thin-film photovoltaic applications since 1970. With the forbidden zone width of 1.5 eV and the coefficient of absorption 10^5 cm^{-1}, which means that a layer thickness of a few micrometers is sufficient to absorb 90 % of the incident photons, CdTe is almost an ideal material for solar cells manufacturing. CdTe solar cell is sensitive in the wave length of 0.3–0.95 mm and maximum of its sensitivity is in the wave length range of 0.7– 0.8 mm. Laboratory CdTe cells have the efficiency of 16 %, and commercial ones around 8 %. Great toxicity of tellure and its limited natural reserves diminish the prospective development and application of these cells. In order to improve CdTe solar cell characteristic, Soliman et al. [8] have conducted an experiment that prove the chemical heat treatment is needed to produce better cells.

3.2 Gallium arsenide (GaAs) solar cells

GaAs is a compound semiconductor form by gallium (Ga) and arsenic (As) that has similar structure as silicon. Compared to silicon based solar cells, GaAs has high efficiency and thickness is also less. Band gap energy for GaAs is 1.43 eV. Efficiency of GaAs solar cell can be increased by alloying it with certain materials such as aluminum, indium, phosphor and lead. Alloying process will result in formation of multi-junction devices and band gap values will also be increased [9]. GaAs is normally used for concentrator PV module and for space application since it has high heat resistance. In addition, GaAs is lighter compared to poly-and monocrystalline silicon. However, GaAs material and manufacturing can be costly [8].

3.3 Copper indium gallium selenide/copper indium selenide (CIGS/CIS) solar cells

This material is still in its developing phase since it is a new technology and is set to compete with other silicon solar cell. An efficiency of 13 % for modules and 20 % for cell has been recorded [8]. Its direct band gap can be as high as 1.68 eV with slight modification with Sulphur (S). Radue et al. [10] had conducted an experiment to asses CIGS solar cell performance and life time. The experiment had been conducted indoor (under STC) and outdoor for 4 months. It has been observed that the defects on the module will lead to a decrement in current collection. Meyer and van Dyk [11] also conducted an experiment to investigate the performance of CIS and other thin film material. The result from the experiment conducted is CIS only degrades by 10 % compared to other thin film material after an outdoor exposure of 130 kWh/m^2. Absorption coefficient of $CuInSe_2$ is greater than 10^5 cm^{-1}.

3.4. Dye-sensitized solar cell (DSSC)

Due to some problems with efficiency, production cost and environmental related issues of some solar cell materials, researchers have come up with ideas to produce new material technology call dye-sensitized solar cell. Generally, this type of material has five working principles which are (1) a mechanical support coated with transparent conductive oxides; (2) the semiconductor film, usually TiO_2; (3) a sensitizer adsorbed onto the surface of the semi conductor; (4) an electrolyte containing a redox mediator; (5) a counter electro de capable of regenerating the redox mediator like platinum [12]. Dye-sensitized solar cell will be a good competitor to the existing material technology in producing of solar cell.

3.5. New technology for PV solar cell

Other than searching for new material to improve solar cell output, new technology in processing PV solar cell has been ascertained. Nanotechnology or sometimes referred as ‘‘third-generation PV’’ is used in order to help increase conversion efficiency of solar cell since energy band-gap can be controlled by nanoscale components [13]. Nanotubes (CNT), quantum dots (QDs) and ‘‘hot carrier’’ (HC) solar cell are three devices used in nanotechnology for PV cell production. The advantages of using this technology are: (I) Enhance material mechanical characteristic, (II) Low cost, (III) Lightweight and (IV) Good electrical performances.

3.5.1. Carbon nanotubes (CNT)

Carbon nanotubes (CNT) are formed by hexagonal lattice carbon. One research team has invented photo diode solar cell from CNT and successfully improves efficiency and current output from that solar cell. Although the efficiency for solar cell is still low (3 – 4 %), many research will be carried out in this technology to improve the electrical output [14].

3.5.2. Quantum dots (QD)

Quantum dots (QD) can be described as a material that is built with many forms of material thus makes it a special semiconductor system with an ability to control band-gap of energy. Voltage output can be increased as band-gap energy size increases but on the other hand, smaller band-gap can also increase current output. As a solution, QDs are used since they can vary light absorption and emission spectra of light [15]. Efficiency of solar cells based on QD are easily influence by the defects on them.

3.5.3. Hot carrier solar cell (HC)

Hot carrier (HC) is a challenging method compared to CNT and QD because it needs selective energy contacts to convert light into electrical energy without producing heat. Its efficiency reaches 66% which is three times higher than existing cell made from silicon. But to this date, due to lack of suitable material that can decrease carrier cooling rates, HC has never been commercialized but remain an experimented technology [16, 17].

4. EFFICIENCY OF SOLAR CELLS

The efficiency of solar cell is one of the important parameter in order to establish this technology in the market. Presently, extensive research work is going for efficiency improvement of solar cells for commercial use. It is known that efficiency is a main parameter for establishment of PV technology in the market but some factors are affecting the PV efficiency. The main factors are (1) temperature of solar cell, (2) effect of dust on solar cells, (3) effect of humidity on solar cells [8].

GaAs has the highest efficiency among all other solar cell materials with 40.7 % efficiency achieved in 2010. The new materials for solar cells i.e., dye-sensitized and organic base cells are still rated at low efficiency with only 5.4% until 2010. The mono-crystalline solar cell has 24.7% efficiency, polycrystalline cells with 20.3% and thin film technology with 19.9% in 2010, respectively [8].

Highly efficient plastic-substrate dye-sensitized solar cells (DSCs) by the press method were developed by Yamaguchi et al. [18]. The conversion efficiency of cell was improved by optimizing the press conditions, the thickness of the TiO2 layer and the surface treatment of the plastic-substrate. They achieved 8 % efficiency of such cells. Yamaguchi et al. also improved the efficiency of dye-sensitized solar cell to more than 10 % with the help of Series-connected tandem method. They optimized the dye combination, TiO_2 layer (structure and thickness), and electrolyte (TBP concentration) and successfully obtained an efficiency of 10.4 %, which was slightly higher than that of the black-dye single cell.

5. ENVIRONMENTAL ASPECTS

In order to get the raw materials for PV production, mining operation needs to be done and this may cause danger to miners. In addition, mining machine involves usage of petrol and diesel so it may cause air pollution. Solar cells for PV emit high volume of sulfur oxide, nitrogen oxide and carbon dioxide. Sulfur and nitrogen oxide can combined with water thus producing acidic rain that harms living beings and deteriorate many other materials, while carbon dioxide constitutes the main reason to global warming [8].

Several researchers [8] conducted the research work on environmental aspects of four major solar cell technologies i.e., multi-crystalline silicon (mc-Si), amorphous silicon (a-Si), cadmium telluride (CdTe) and $CuInSe_2$ (CIS). For the consideration of emission estimation and risks from cadmium or selenium use in CdTe and CIS modules, respectively, it is acceptable in comparison with some existing products or services like NiCad batteries or coal-fired electricity production. The conclusion of this study is that no single technology score good or excellent on all considered aspects, although future a-Si technology, seems to be the most ‘‘environmental friendly’’ technology. In reality, when PV replaces coal burning for electricity generation, it will prevent Cd emissions as well as large quantities of CO_2, NO_x, and particulate emissions.

6. CONCLUSION

The worldwide energy consumption is increasing every year and different technologies are using to produce electricity to compete the energy demand. The environmental pollution is also a serious problem nowadays due to the more use of fossil fuel for energy production. Solar PV technology is growing rapidly in past decades and can play an important role to achieve the high energy demand worldwide. This paper illustrated about the worldwide status of PV technology, research in new materials for solar cell and their environmental impact. The main conclusions of this study are:

- Nowadays, the non-silicon photovoltaic technology, based upon Cadmium telluride (CdTe) and Cadmium sulphide (CdS), Copper indium gallium selenide/copper indium selenide (CIGS/CIS), Dye-sensitized solar cell (DSSC) and ‘‘third- generation PV’’ solar cells are also in development stage and extensive research work is going for efficiency improvement for commercial use,
- The efficiency of solar cell is one of the important parameter in order to establish this technology in the market,
- The electricity production through PV system is clean and safe for environment with comparison to coal and fossil fuel. Electricity production through PV module reduces the carbon dioxide emission in environment and safe for global warming problem. The solar cell production has some disadvantages on environment during manufacturing and process time but it gives much more advantages during use.

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