Research Inventy: International Journal of Engineering And Science
Vol.8, Issue 2 (May 2018), PP -01-04
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Comparison of Epbt of Solar Cells Produced By All-Electrode Position Method

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Abstract: Energy Payback Time (EPBT) of all electrodeposited (all-ED) solar cells are compared to various other solar cells made by leading solar module technologies. They are m:Si, p:Si, CIGS and CdTe solar modules. The EPBT of solar cells provides an alternative way to compare the environmental impact due to the production of the solar modules. Energy gone to produce all-ED solar cells at various stages are presented and the application of ISO50002 to reduce the energy consumption while maintaining the fabrication steps for the optimum efficiencies. Current leading EPBT solar modules are manufactured by using partial electrodeposition. The study of solar cells are produced by all-ED have an estimated EPBT of approximately 2.5 years. With the application of an energy audit and subsequent optimization of the process, the EPBT was lowered to 1.6 years.

Keywords: *Efficiency,electrodeposition, energy audit, energy consumption, EPBT, ISO50002*

DATE OF SUBMISSION: 31-05-2018 DATE OF ACCEPTANCE: 15-06-2018

I. Introduction

This paper reviews the energy consumption during the production of solar panels. Currently, solar panels are seen as means to unlimited energy with minor drawbacks. Even though solar power sets high standards in terms of energy production, the manufacturing process consumes a great amount of energy. The current leading solar panel with the lowest Energy Payback Time (EPBT) is produced by First Solar with a time period of six months [1] . EPBT refers to the time required for the solar panel to produce theenergy that was needed to fabricate it; the time after that, there will be a net energy production for the life of the panel. The investigation aims to identify areas in the manufacturing process that can be optimized through an energy audit. The International Organization for Standardization (ISO) defines an energy audit as the, “systematic analysis of energy use and energy consumption within a defined scope in order to identify, quantify, and report on the opportunities for improved energy performance” [2].

The high energy consumption processes is studied [3], the focus of this paper centers around the energy requirements to produce solar cells that are made solely by all-ED method. The steps to produce solar cells by all-ED are described in detail in section 2.1 alongside the energy consumption for each step. The energy requirements for this type of solar cells are then be compared to the leading thin-film and silicon based solar cells. The electricity requirement needed to manufacture the cells onsite are examined, however the energy requirements associated with the mounting system nor the material acquisition will be included.

1.1 Data and Literature Collection

The literature review primarily focused on the energy consumption during the manufacturing of solar cells; specifically monosilicon, polysilicon, CIGS, and CdTe with emphasis on their EPBT. The data for solar cell production by all-ED are from past and present work of the lead researcher of the project. This data is optimized for the most efficient solar cell, not for manufacturing efficiency.

1.2 Energy consumption data from market leading solar modules

One of the biggest criticisms of solar power is the cost; the panels are too expensive and the panels themselves take a long time to generate the power needed to produce the systems themselves [4]. Like in any technology, over time solar power systems became better understood, allowing leaner manufacturing processes and module efficiency. They have become a cost effective, viable option for individual residential energy production [4]. The solar power industry is also the safest out of all the different power generation methods [5], making the risk factor low.

To better illustrate the energy demand of solar cell manufacturing, four types of solar cells are examined: monosilicon, polysilicon, Copper Indium Gallium Selenide (CIGS), and Cadmium Telluride. These

four types of solar cells are then be compared to the solar cell produced solely by electrodeposition to evaluate the energy savings among different manufacturing methods.
Table 1 below tabulates the data taken from Bhandari [6] which gives an average value for these types of solar cells in the market. Also included is work taken from De-Scholten[7] that highlights some of the best results experienced by lab production.

Table 1: Comparison of current average EPBT to leading EPBT

Author	Type of Cell	EPBT (Years)	Efficiency	Lifetime in Years
Bhandari	**m:Si**	5	14	25-30
	p:Si	3.5	13	25-30
	CIGS	2.3	11	25-30
	CdTe	1.6	10	25-30
De-Scholten	**m:Si**	2.34	14.8	30
	p:Si	1.45	14.1	30
	CIGS	1.02	11.7	30
	CdTe	.68	11.9	30

The two silicon based solar cell techniques each have an EPBT that is much higher than their thin-film counterparts. This is mainly due to the high crucible temperature of 1414 ℃ during the synthesis of Si semiconductors [8]. Even though the reported efficiency for mono silicon and polysilicon base solar cells are higher than CIGS and CdTe, the EPBT is much lower for the CIGS and CdTe. Lower EPBT indicates lesser energy consumption in both the manufacturing process of thin-film solar cells and their mounting apparatus. To further lower the EPBT for solar modules, the efficiency of the modules must increase and the manufacturing process needs further optimization. Bhandari gives a great view of the market average since there are great variations from lab to manufacturing with respect to the efficiency being experienced as well as the electricity generation of the panels themselves.

In comparison to the data taken from Bhandari, the data taken from De-Scholten presents the lower values being produced around the world. The EPBT for CdTe comes from First Solar, as they are the leading thin-film solar cell manufacturers. It also follows the trend shown by the global average, the thin-film solar cells have the shortest EPBT, indicating the energy consumption in the manufacturing process is much lower than the other PV modules. The 6-7 month payback time for CdTe made by partial electrodeposition is a very short amount of time when considering the 30 year operation time; an energy audit can shorten that time even more.

II. Experimental procedure for all-ED solar cells

Fabrication of all-ED solar cells involves several steps. They included electrodeposition of semiconductors, heat treatment, and back contact deposition under a vacuum. The long term future directions of projects which are promising to reduce energy consumption are excluded from this study. The energy consumption for electrodeposition of solar cells are elaborated the section 3.1 below.

2.1 Summary of energy consumption of ED solar cells

Examining the energy consumption per step in the process, there is a wide gap between how much energy is consumed during the ED process and the heat treatment process. Heat treatment accounts for 60.3% of the total energy consumption for the process, this is an extremely large margin. The heat treatment is an essential step to optimize surface modification of semiconductors [8].

2.2 Predicted energy consumption and generation of all-ED solar module

To estimate the energy generation of a solar module by using the energy consumed to fabricate a solar cell, a linear extrapolation is used. In actuality, there will not be a linear relationship when scaling up from the lab to mainstream production of the solar modules. There will be degradation over time that causes the solar module to no longer generate as much energy as the beginning the products life. Even there is extremely little variation in the energy consumption of the solar cells, variations in how many individual cells work properly will exist. This study made the assumptions that there will be no defects in the cells, nor any reason to discard them after manufacturing, leading to 100% yield. Taking that into account, the energy consumption for a plant making solar cells by all electrodeposition will have a lower energy consumption per module than was reported here. The predicted energy consumption is tabulated in Table 2.

III. Results

The process was optimized for the solar cell efficiency rather than the energy consumption during the fabrication. To ensure the efficiency was not harmed, the study sought to reduce energy in areas that do not have an effect on the overall efficiency of the solar cells.

3.1 ED energy usage in fabrication steps

Table 2: Energy consumption for fabrication steps before and after optimization[10]

Steps to produce a 100 cm^2 solar cell	Power (W) Pre-Audit	kWh	Optimized Power(W)	kWh
Cleaning of the glass/FTO substrates	1.0E2	3.4E-3	1.0E2	3.4E-3
Electrodeposition of buffer layer	1.0E2	3.4E-2	1.0E2	3.4E-2
Heat treatment of buffer layer	3.0E3	1	3.0E3	1
Electrodeposition of window layer	1.0E2	3.4E-2	1.0E2	3.4E-2
Heat treatment of window layer with chemical treatment	3.0E3	1	3.0E3	1
Electrodeposition of absorber layer	1.0E2	4.0E-1	1.0E2	4.0E-1
Heat treatment of absorber layer with chemical treatment	3.0E3	1	3.0E3	1
Metallization with 2 mm or 3 mm diameter back contacts	5.0E3	5	3.0E3	2
Total energy consumption and time for the PV cells		8.5		5.5

The sum of the heat treatment process and metallization account for approximately 60% and 30% of the energy consumption, respectively. The energy consumption remaining steps are minute when compared to these figures. The predicted energy consumption is tabulated below in Table 3:

3.2 The energy analysis of all-ED solar modules

Table 3: Estimated Electricity Generation of 2m^2all-ED Solar Panel

	Pre-Audit	Optimized	Units
Annual Electricity Generation	669.3	669.3	kWh/yr
Lifetime Electricity Generation	125,487	125,487	kWh (30years)
Energy Payback Time	2.5	1.6	Years

Table 3 tabulates the estimated annual electricity generation as well as lifetime electricity generation of the solar cells produced by all-ED. With the known efficiency of the prototype, the electricity generation was calculated using the typical solar insolation of California's San Joaquin Valley per year [11].

IV. Discussion

Correlating with the lower temperature fabrication methods, all-ED of semiconductors have a lower consumption of energy. When both the semiconductors are fabricated by all-ED method, it contributed to lowering EPBT of solar cells. The new research direction to electrodeposition the back electrode contact will drastically reduce the energy consumption.

The heat addition during the process is often one of the prominent areas of focus in industrial energy audits [12]. During an audit, it is vital to find a way to either repurpose the heat or use equipment that is better suited to handle the temperatures needed without consuming as much energy [13]. As process become more refined, the areas of improvement become more specific, requiring the auditor to have a solid understanding of each individual process [13]. To properly apply energy audit, proper study of the chemistry and engineering behind electrodeposited solar cells are vital in ensuring that the fabrication energy consumption can be reduced. In the case of photovoltaics, the heat treatment cannot be reduced without reducing the efficiency of the panel [9]. With this restriction, the second largest energy consumption step was addressed, the metallization of back contacts. Through experiment, the metallizationwas reduced from a 5 kW process to a 2 kW process. The reduction in power consumption resulted in lowering the EPBT nearly a full year, making this method a more viable option. This was accomplished by utilizing the framework for energy auditing given by ISO50002 [2], to be applied to a study being conducted by the lead researcher. The defined scope was to identify and implement ways in which the energy consumption of the process can be reduced to lower the EPBT and save energy cost. To lower the energy consumption of the heat treatment process without lowering the efficiency of the solar modules, solar thermal furnaces can be used to achieve the desired temperatures [14]. This change in equipment will eliminate the electrical power consumption for the heat treatment steps.

V. Conclusion

Currently First Solar produces the best PV module in terms of energy payback time with a time around six months. That time frame is just a third the EPBT of the solar cell produced by all electrodeposition. However, the method done by First Solar is more refined than the all electrodeposition method done in the lab. Since the prototypes were of smaller solar cells, a linear extrapolation was used to predict the performance of a full panel made by this method. The limitations of linear extrapolation and the lifetime electricity generation extrapolation was described in section 2.2.With further refining in the manufacturing process achieved by an energy audit, the EPBT of all electrodeposited solar cells may rival the time of First Solar.

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Thomas A. Mertens "Comparison of Epbt of Solar Cells Produced By All-Electrode Position Method" Research Inventy: International Journal of Engineering And Science, vol. 08, no. 02, 2018, pp. 01–04.