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Research Article

Design and Simulation of a Cooling System for FTO/I-SnO_2/CdS/CdTe/Cu_2O Solar Cells

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The temperature in solar cells is one of the main factors affecting their efficiency. Increasing the temperature in solar cells reduces efficiency. According to previously published and recently published studies by our team, with increasing temperature in 5-layer FTO/i-SnO2/CdS/CdTe/Cu2O solar cells, the efficiency has decreased by 8.86% per 100 K. In this research, phase change materials have been used to control the temperature in 5-layer solar cells. Our overall goal in this study is to control the temperature in FTO/i-SnO2/CdS/CdTe/Cu2O solar cells to increase their efficiency. The results obtained using simulations and numerical analysis and comparative analysis show that if one layer is used as a cooling arrangement in 5-layer FTO/i-SnO2/CdS/CdTe/Cu2O solar cells, it reduces the surface temperature of solar cells and increases efficiency.

1. Introduction

One of the weaknesses of photovoltaic systems, especially solar cells, which was also mentioned in previous studies [1] is that with increasing the temperature of solar panels, the maximum output power decreases linearly [1–3]. Due to the increase in temperature, not all of the solar energy absorbed by the photovoltaic cells is converted into electrical energy. To satisfy the law of conservation or survival of energy, the remaining solar energy is converted to heat. Finally, the heat generated on the surface of the panel or module reduces the overall conversion efficiency. Solar cells, depending on their type, convert 4 to 17% of common solar energy into electrical energy. In other words, more than 50% of solar energy is converted to heat instead of electricity [4]. The operating temperature of solar cells in hot seasons reaches more than 338.15 K, so a reduction of 14-22% efficiency will be obvious. Increasing the temperature by more than 298.15 K reduces the efficiency by 0.3 to 0.5% per Kelvin [5–8]. To improve the use of these modules, it is necessary to increase efficiency and reduce costs. Both performance improvements and longevity improvements are important issues for further cost reductions. For this purpose, it is necessary to provide different solutions to solve the temperature problem in solar cells. The study of solar cell simulations is very useful for predicting the output performance of solar cells before the actual construction of the cell and will significantly reduce production costs and avoid excessive costs. Various tools for simulating solar cells are available, including wxAMPS, a 1D solar cell simulation program, Silvaco ATLAS software, SCAPS-1D software [1], GPVDM software, and more. So far, a lot of research has been done and published by these simulation tools [1]. We first did the programming in Maple software, then we did the same again in MATLAB due to the high speed of MATLAB, and checking the accuracy of programming as well as comparison of the results. In our previous work [1], we simulated and studied the structure of a 5-layer solar cell consisting of FTO/i-SnO_2/CdS/CdTe/Cu_2O layers and concluded that lowering the temperature could increase the efficiency of this 5-layer structure. But we did not discuss the method of cooling in this structure. So far, various technologies for cooling the operating surface of 5-layer solar panels with FTO/i-SnO_2/CdS/CdTe/Cu_2O structure in order to increase the efficiency of the entire conversion system have not been studied by researchers. Therefore, studying and selecting a suitable cooling method for this 5-layer structure is essential to improve production efficiency and long-term reliability. There are several cooling methods. Choosing the right cooling method can improve electrical efficiency and reduce cell degradation over time, thus maximizing the lifespan of solar cells. The most important cooling methods are active/inactive heat pipe [9–11], natural/forced air flow [12–14], forced water flow [15–18], concentrator photovoltaics-thermal, photovoltaic-thermal [19], phase change material [20–23], immersion in water[24], disable heatsink, microchannel (active heatsink) [25–27], transparent coating (photon crystal cooling) [28], and thermoelectric module [29]. Our aim in this article is to investigate two of the most important factors affecting the efficiency of cadmium telluride solar cells, which have not been studied in previous works and have not been mentioned in most studies. Important parameters that we will examine in this study are the study of the effect of cooling and the change of radiation angle in 5-layer cadmium telluride solar cells with FTO/i-SnO_2/CdS/CdTe/Cu_2O structure. In the present study, the cooling of cadmium telluride solar cells with 5-layer structure FTO/i-SnO_2/CdS/CdTe/Cu_2O was simulated by phase change materials.

2. General Steps of Conducting Research

Figure 1 summarizes the work done in this study in 5 steps.

In this research, to prevent duplication, the first and second steps of the work, i.e., a numerical study using discretization of mathematical equations and simulation of a 5-layer cadmium telluride solar cell, were cited in reference [1]. Figure 2 shows the structure of a 5-layer cadmium telluride solar cell. We considered this structure as a reference in our work.

3. Different Methods of Cooling Solar Cells

In order to increase the efficiency of cadmium telluride solar cells, we have carefully tested various technologies in the field of their cooling. The active/passive heat pipe method is very suitable due to the high initial cost and more complex construction than other models in cases where there is a need to respond to both electrical and thermal demand and the initial cost is not considered. The natural/forced air flow method is also effective only in cold weather conditions. In forced water flow and microchannel methods, the desired efficiency is not achieved due to the constant water flow, and in order to achieve the desired efficiency, the water flow must be controlled and adjusted. In the water immersion method, efficiency is greatly reduced on cloudy days. In the passive heatsink method, the efficiency decreases in hot areas and the cooling does not work well. Also, no repelled heat is used. In the transparent coating method (photon crystal cooling), heat that can be used for indoor applications is wasted. Another technique that can be used to reduce the operating temperature of the surface of cadmium telluride solar cells to achieve higher electrical efficiency is the use of phase change materials. These are concealed heat storage materials used on the back of the PV panel (Figure 3). As the panel temperature rises, the chemical bonds separate from the solid to the liquid to change phase. When the temperature of the material reaches the phase change limit with heat storage, the material begins to melt, then its temperature remains constant until the melting process is complete. This material is called latent heat storage because heat is stored during the melting process (phase change process). The cooling effect of the phase change material is acceptable and the overall efficiency increases. It is able to store large amounts of heat with low-temperature changes. Phase change occurs at a constant temperature, and the stored heat can be used to heat buildings. Therefore, phase change materials can be a good solution for cooling cadmium telluride solar panels. These substances are divided into three categories: organic (paraffin and fatty acids), inorganic (hydrated salts), and molten (organic and inorganic). Due to the high ability of phase change materials to absorb heat, these materials have quickly been proposed as a factor for the free cooling of various devices. In recent years, many studies have been conducted on the application of phase change materials in controlling the temperature of solar cells. By comparing the performance of a simple solar cell with a solar cell equipped with phase change materials in a laboratory, a group of researchers showed that adding phase change materials to solar cells reduced the panel temperature by 278.15 K and increased the panel efficiency by as much until it becomes 3.1% [30]. Another group examined the effect of phase change materials on concentrating and decentralized solar cells in 2015. They found that adding phase change materials to concentrating solar cells could reduce panel temperatures by 278,349 K. They also reported that phase change materials increase the efficiency of concentrating solar cells by 15.9% and decentralized (normal) solar cells by 10% [31]. In the references [32, 33], the researchers compared a thermal solar cell with a solar thermal cell with water pipes behind which passed through the phase change material. They showed that when the phase change material backed the solar panel added, the water passing through the phase change material is approximately 279.15 K higher than when there is no phase change material. They report that the addition of phase change material in the photovoltaic panels creates this potential in solar cells to make hot water available over a longer period of time. In the reference [16], simple thermal cells used on the roof of the building are modeled and the effect of phase change materials on the efficiency of solar panels is investigated. They reported that the addition of phase change materials on the efficiency of thermal solar cells increases by 8.1% and simple solar cells by 4.2%. In the reference [34], by simulating in Transis software, they compared the performance of conventional photovoltaic panels and photovoltaic panels equipped with phase change materials. They reported that the temperature of solar cells equipped with phase change materials was 308.15 K lower than that of solar cells without phase change materials. In the reference [35], phase change materials were used in a multipurpose hybrid system in the building. The researchers reported in references [36, 37] that the use of phase change materials for underfloor heating could reduce costs by up to 20%.

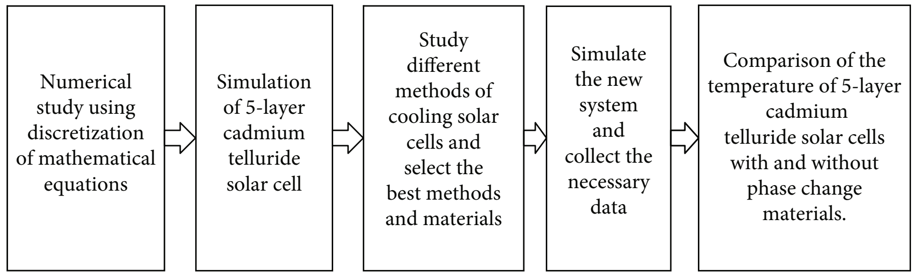

Figure 1: Complete work diagram.

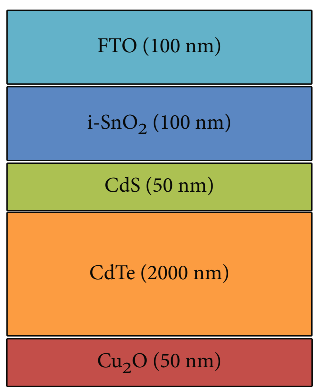

Figure 2: Structure of a 5-layer cadmium telluride solar cell.

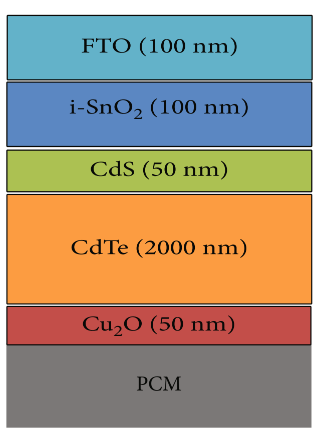

Figure 3: Structure of 5-layer cadmium telluride solar cell with phase change material.

4. Simulate the New System

Our new system consists of a 5-layer cadmium telluride solar cell in which a layer of calcium hexahydrate is simulated as a phase change material to improve the performance of solar cells at its dorsal junction. The structure of this system is shown in Figure 3.

5. Properties of PCM Layer

In this study, calcium hexahydrate was used as the primary PCM. Calcium chloride hexahydrate PCM is far cheaper than other kinds of phase change material, have high latent heat, and have suitable properties. Calcium chloride hexahydrate, as Table 1 presents, melts at 29.6∘C which can assure the melting of the material when absorbing the excess heat from solar radiation and it freezes at 20°C. Furthermore, compared to paraffinic PCMs, calcium hexahydrate has higher thermal conductivity (at least four times) which is a very crucial parameter for the heat transfer process. Table 1 lists the thermophysical properties of calcium chloride hexahydrate.

Table 1: Thermophysical properties of calcium chloride hexahydrate [38].

Property	Calcium chloride hexahydrate
Melting point	26.6°C
Fusion heat	$212\,Jg^{-1}$
Thermal conductivity solid	$1.08\,Wm^{-1}\circ C^{-1}$
Thermal conductivity liquid	$0.56\,Wm^{-1}\circ C^{-1}$
Density solid	$1.71\,Kgm^{-3}$
Density liquid	$1.56\,Kgm^{-3}$
Specific heat capacity solid	$1.6\,Jg^{-1}K^{-1}$
Specific heat capacity liquid	$1.9\,Jg^{-1}K^{-1}$

6. Comparison of CdTe Solar Cells with and without Phase Change Material (PCM)

Figure 4 shows the graph of open circuit voltage in terms of time for 5-layer cadmium telluride solar cells with FTO/i-SnO2/CdS/CdTe/Cu2O structure, assuming a radiation intensity of $1000\,W/m^2$ in the case with red phase change material. And it is shown in blue color without phase change material. According to Figure 4, by adding a layer as a phase change material to the back junction of the solar panel, the voltage increases compared to solar cells without phase change material, which exactly matches the results of the previous work [38, 39] and proves the correctness of our work.

Figure 5 shows the short-circuit current density graph in terms of time for 5-layer cadmium telluride solar cells with FTO/i-SnO2/CdS/CdTe/Cu2O structure, assuming a radiation intensity of $1000\,W/m^2$ in the case of color phase change material. It shows red and no phase change material in blue color. By adding a phase change material layer to the back junction of the solar panel, the short-circuit

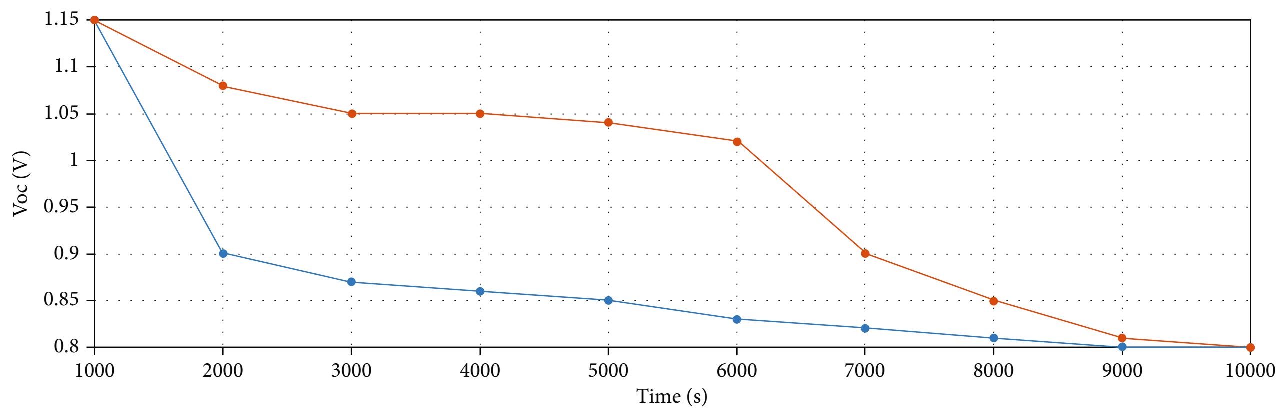

Figure 4: Open circuit voltage in terms of time, assuming a radiation intensity of 1000 watts per square meter in the state with and without the phase change material.

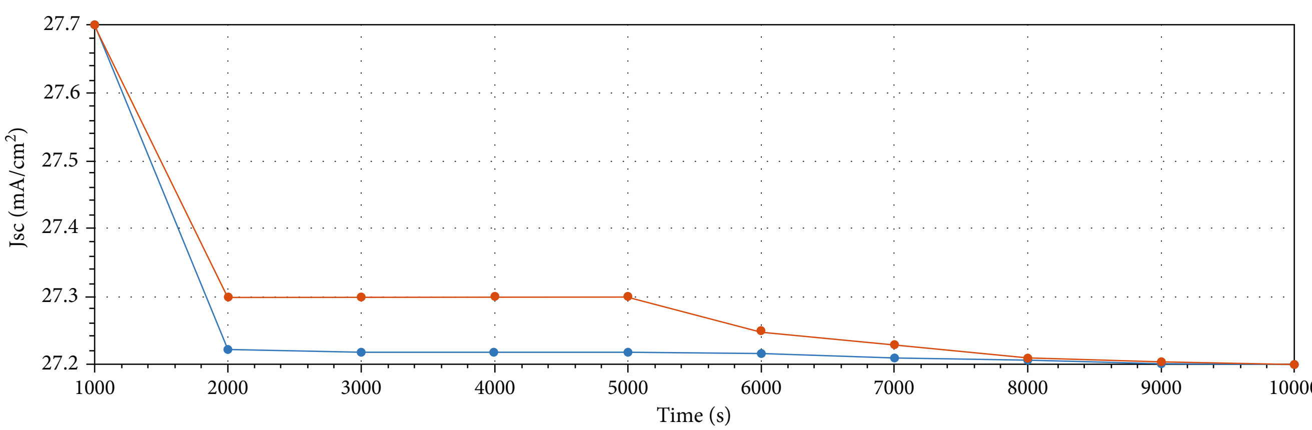

Figure 5: Short-circuit current density in terms of time, assuming a radiation intensity of 1000 watts per square meter in the state with and without the phase change material.

current density is increased compared to solar cells without phase change material, which is in close agreement with the results of previous work [38, 39] and proves the correctness of our work.

Figure 6 shows the graph of the filling factor in terms of time for 5-layer cadmium telluride solar cells with the structure of FTO/i-SnO2/CdS/CdTe/Cu2O, assuming a radiation intensity of 1000 W/m^2 in the case with red phase change material. And it shows blue color without phase change material. By adding a layer as a phase change material to the back junction of the solar panel, the fill factor increases compared to solar cells without phase change material, which exactly matches the results of previous work [38, 39] and proves the correctness of our work.

Figure 7 shows the graph of efficiency in terms of time for 5-layer cadmium telluride solar cells with FTO/i-SnO2/CdS/CdTe/Cu2O structure, assuming the radiation intensity of 1000 W/m^2 in the state with red phase change material and without the phase change material shown in blue color. By adding a layer as a phase change material to the back junction of the solar panel, the efficiency is increased compared to solar cells without phase change material, which exactly matches the results of previous work [38, 39] and proves the correctness of our work. As can be seen from Figure 7, the addition of the PCM layer prevents the reduction of 4.48 percent efficiency due to the heating of the cell surface.

The efficiency of this cell under constant radiation for 6000 seconds without phase change material reaches 20.35%, which by adding the PCM layer in this period of time, the efficiency becomes almost 24%.

We define relative efficiency as formula (1), in which the efficiency of two solar cells with the structures FTO/i-SnO_2/CdS/CdTe/Cu_2O and FTO/i-SnO_2/CdS/CdTe/Cu_2O/PCM is measured relative to each other under the same conditions.

$$\eta = \frac{P_{\max}\text{withPCM} - P_{\max}\text{withoutPCM}}{P_{\max}\text{withoutPCM}}. \quad (1)$$

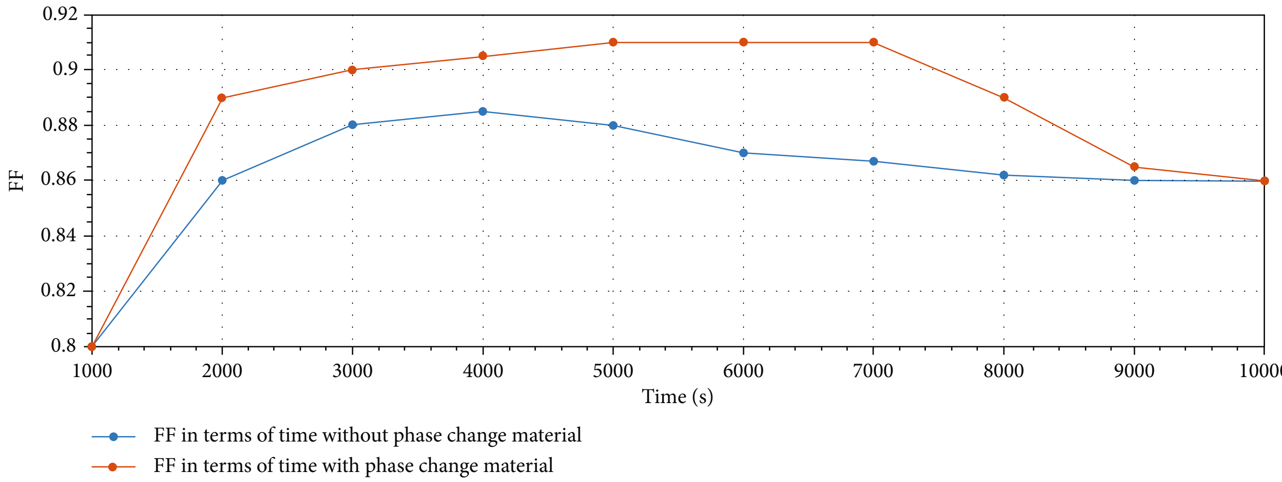

Figure 6: Filling factor in terms of time, assuming a radiation intensity of 1000 watts per square meter in the state with and without the phase change material.

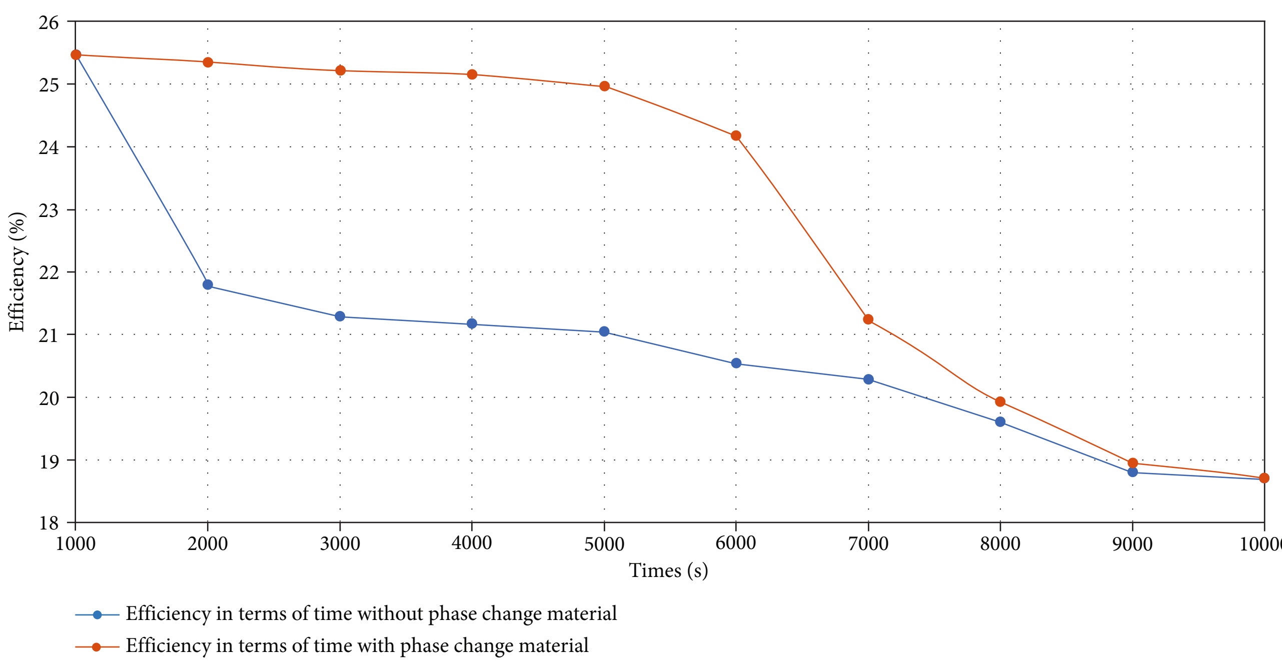

Figure 7: Efficiency in terms of time, assuming a radiation intensity of 1000 watts per square meter in the state with and without the phase change material.

In Equation (1), η is the efficiency and P_{max} is the maximum power and PCM represents the phase change material.

7. Conclusion

One of the chief aims of this investigation was to enhance the efficiency of the electrical performance of the PV panel. To that end, CaCl2$6H2O was applied to regulate the PV surface temperature and increased power output. To clarify how and why this happens, based on the physics of photovoltaics, reverse saturation current rises up if surface temperature increases. Thus, Voc (open circuit) falls down in value which decreases the fill factor leading to a lower efficiency of the solar cells. Also, a temperature increase results in a decrease of bandgap energy that causes an increase in Jsc (short circuit) which enhances the overall efficiency. Considering the reduction of Voc and Jsc raising up, it can be concluded that the overall efficiency will decrease if surface temperature increases and vice versa. In this research, we designed and simulated a cooling system for 5-layer cadmium telluride solar cells with FTO/i-SnO2/CdS/CdTe/Cu2O structure using phase change materials. The results showed that the cooling of cadmium telluride solar cells using phase change materials has a significant effect on voltage and current and finally the power of these panels.

Data Availability

Data are available at the Department of Physics, Urmia University of Technology.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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