

Relationship Between Energy Efficiency Conversion Efficiency and Dynamic Performance of Solar Cells

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Abstract: First, this paper discusses the two most important modes of solar energy utilization - photoelectric and photothermal. Then, the main types, research status and future development of solar cells are described in this paper. A mathematical model is established to describe the performance of photovoltaic devices. The model is simulated and analyzed by MATLAB, PSIM and other software. Various flexible "photovoltaic +" solar energy application technologies are briefly described. The results show that the model is established by the characteristic parameters. If two different solar cells are combined together, their electrical performance can be reflected by appropriate adjustment of some parameters in the system.

Keywords: Solar Cell; Photovoltaic Array; Electrical Characteristics; Solar Power; Light and Heat; Energy Efficiency Conversion Efficiency; Dynamic Performance; Battery.

1. Introduction

The amount of sunlight absorbed by the Earth's surface is about 8.5×10^{16} W, compared to the world's energy consumption of about 1.5×10^{13} W. People use less than one fifth of the sun's energy on the entire planet. Compared with conventional mineral resources, solar energy is also a clean and uniform advantage in the environment. Therefore, making full use of solar energy resources and solving the problem of unbalanced regional development are of great practical significance for promoting the technology. The application of solar energy is divided into two kinds, one is to convert sunlight into electricity, one is to convert sunlight into heat, electricity, and the other is to convert light heat into heat. Photovoltaic power generation has become one of the most important solar power generation methods for its noiseless, easy to install, long service life, less maintenance, light weight and low cost [1]. After more than a decade of development, the world's photovoltaic power generation system has grown to 760 GW. Some research groups predict that by 2050, solar power will account for 40% of electricity supply. The solar cells will be the mainstream power supply in the future. In the photovoltaic conversion system, solar cells play a crucial role. The current modeling of solar cells is closely related to their inherent complexity, some parameters can be checked in the manual, but others are difficult to obtain [2]. After solar cells are connected in series to form an array, a single mathematical model is often not suitable for numerical simulation and calculation of power systems. This paper analyzes and summarizes the development status, advantages and disadvantages of solar photovoltaic, photothermal and photovoltaic integrated application in detail. A calculation model for the electrical performance of solar cells is established.

2. Photoelectric Conversion Technology

Photoelectric conversion is the conversion of sunlight by solar cells. As one of the main photoelectric conversion materials, solar cells have a wide range of application prospects in the field of photoelectric conversion [3]. Now,

the global market share of the first is crystalline silicon solar cells, accounting for more than 90% of the market share; The world's first perovskite solar cell has been put into production in Quzhou City, Zhejiang Province, and the most dynamic of them is the perovskite solar cell. At the same time, because of their excellent performance and flexible Si based solar cells, in recent years have been widely studied.

2.1. Crystalline silicon solar cell technology

Among them, The cells are the fastest growing and most perfect solar cells in the world. Since 2017, with the continuous reduction of crystalline silicon production costs and the continuous improvement of high-efficiency crystalline silicon component technology, the market share of photovoltaic products has exceeded polysilicon and reached 49%; Globally, crystalline silicon solar cells account for more than 70% of the market share [4]. In order to promote the practical application of perovskite solar cells, people are constantly committed to improving their photoelectric conversion efficiency and working stability. At present, two-dimensional seed crystal technology has been used to guide three-dimensional perovskite single crystal orientation growth, which effectively improves the crystal quality of perovskite film and improves the efficiency of battery. Li Meicheng's research group from North China Institute of Energy Resources took the lead in proposing and constructing p-n heterostructures based on perovskite (Figure 1 is quoted in Unveiling the operation mechanism of layered perovskite solar cells). The charge density and space distribution of the device are controlled precisely, and the photoelectric conversion efficiency of the device is improved.

The important factor restricting their industrialization is sensitivity to water, oxygen, heat and ultraviolet light is strong, which leads to ion migration, phase transformation and material degradation during charge and discharge. Additives, interface modification, insertion layer and coating are all effective means to improve its stability [5]. It has been shown that red fluorophores are introduced into perovskite groups. Its supramolecular interaction with inorganic metals can effectively prevent its transmission in perovskite solar cells and improve its stability. The UV resistance of the battery was improved by surface modification of the polymer. Large area

preparation, green preparation and prevention of lead leakage are the keys to achieve large-scale application of high-performance photovoltaic devices.

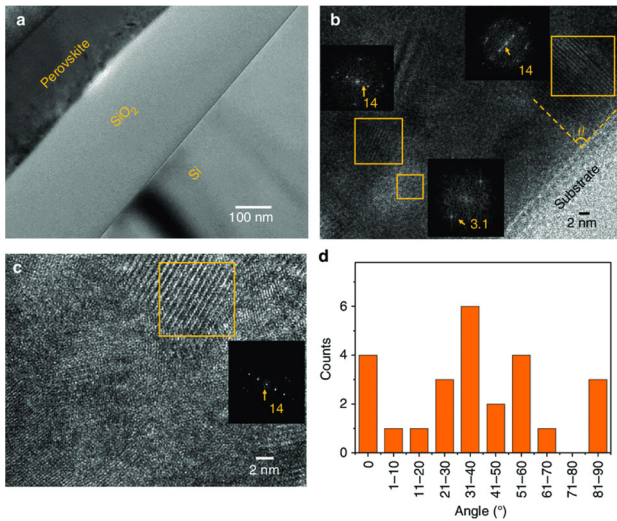


Figure 1. Transmissible electron microscopy characterization of perovskite homojunction structures

2.2. New silicon-based solar cells

Silicon materials exhibit good flexibility below 20 microns. The flexible solar cell based on Si is a hot topic in the world. At present, PEDOT: PSS/Si heterojunction solar cells with PEDOT: PSS as the hole transfer layer have been studied more. However, due to the low utilization rate of silicon-based light, it is difficult to be fully utilized in solar cells. Coupling the relationship between photovoltaic characteristics and thin film thickness to obtain maximum spectral utilization is the key to improve the conversion efficiency of silicon-based heterojunction solar cells [6]. Non-substrate silicon nanowire arrays are expected to become fully transparent solar cells because of their flexibility and transparency. In the preliminary work, the applicant found that a variety of silicon nanowire structures such as cylindrical, trilobate, quadrangular, quadrilateral and spiral showed excellent transparency and light absorption characteristics, especially the scattering spectrum width of spiral silicon nanowire basically covered the bandgap width of the entire crystal [7]. It is found that the short-circuit current and photoelectric conversion efficiency of triangular and spiral silicon nanowire array solar cells are higher, which indicates that light management technology is an important way to improve the photoelectric conversion efficiency. Red fluorescein was used to chemically modify the silicon-based material, and the photoelectric conversion efficiency was 12.59% (Figure 2 cited in RSC Adv., 2022, 12, 27625-27632). The suspended bond at the back of silicon was passivated by tin oxide layer. By using tin oxide layer instead of Schottky barrier, the barrier at the back end is reduced, and the photovoltaic device with photoelectric conversion efficiency of 14.1% is obtained.

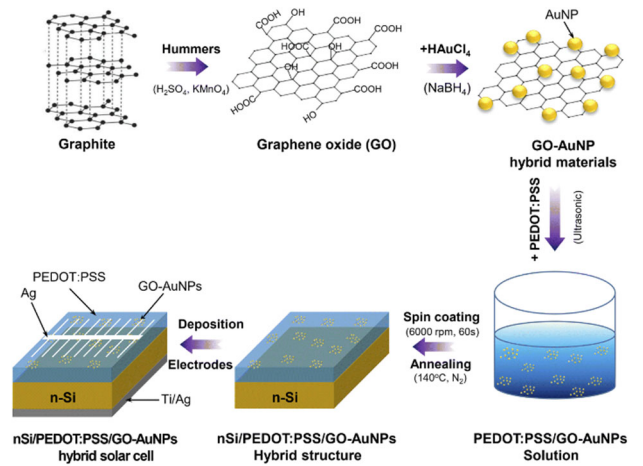


Figure 2. Interaction mechanism between silicon surface and rubrene in PSS/Si hybrid solar cell

3. The Mode of Photovoltaic Modules

The data manual parameters required by the model in this paper are tested under standard test conditions and common test strips respectively [8]. The standard test conditions refer to the rated cell junction temperature of 25°C, rated light intensity of 1000W/m², and solar spectral content of 1.5. General test conditions refer to the battery junction temperature of 20°C, light intensity of 800W/m², wind speed of 1m/s. The electrical performance of the solar cell is expressed by I-V curve. The effects of battery temperature, percentage of effective light intensity, characteristic constant of I-V curve, shadow linear coefficient, the performance of the battery were studied. The relationship between solar panel IV and PV in this mode is as follows (1)

$$I(V) = \alpha \times I_{\max} \times \tau_i \times \left(1 - \exp \left(\frac{V}{b \times (\gamma \times \alpha + 1 - \gamma) \times (V_{\max} + \tau_v) b} \right) \right) \quad (1)$$

$$\left(1 - \exp \left(\frac{P(V) = V \times \alpha \times \ln x_{n_x} \times \tau_i}{b \times (\gamma \times \alpha + 1 - \gamma) \times (V_{\max} + \tau_v)} - \frac{1}{b} \right) \right)$$

α is the percentage of the effective light intensity of the solar cell.

$$\alpha = \frac{E_i}{E_N} \quad (2)$$

γ is the shadow linear factor, defined as the percentage of open circuit voltage loss of a solar cell when the light intensity decreases from 1000W/m² to 200W/m²

$$\gamma = 1 - \frac{V_{\min}}{V_{\max} + \tau_v} \quad (3)$$

Ideal maximum current

$$I_{\max} = \frac{E_C}{1 - \exp \left(\frac{-1}{b} \right)} \quad (4)$$

Rate of current change

$$\tau_i = 1 + \frac{TC_i}{100} \times (T - T_N) \quad (5)$$

Voltage variation rate

$$\tau_v = \text{TCV} \times (T - T_N) \quad (6)$$

4. Model Verification

This article follows the parameters in the data sheet for various types of solar cells. PSIM and Matlab programs are used to build a real photovoltaic system, and the performance of the designed photovoltaic cells is verified by experiments. Figures 3 to 4 show the simulation of the SX-10 solar cell. Figure 5 shows a photoarray and a combination of them used to simulate a HIP200BA19 solar cell. The parameters of the SX-5 and SX-10 are listed in Table 1. The parameters of HIP200BA19 are listed in Table 2.

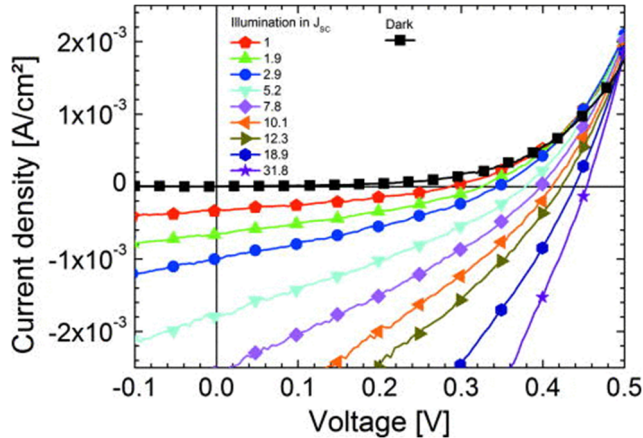


Figure 3. IV curves of SX-10 and SX-5 at different temperatures with light intensity of 1000W/m²

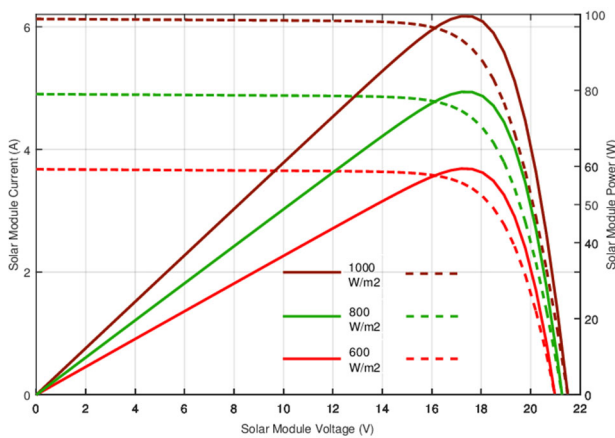


Figure 4. PV curve of SX-10 at different temperatures with light intensity of 1000W/m²

Table 1. SX-5 and SX-10 solar cell parameters

SOLA	SX-10	SX-5
I _{SC}	0.65A	0.3A
V _{OC}	21.0V	20.5V
TCi	(0.065±0.015)%°C	(0.065±0.015)%°C
TCV	-(80±10)mV°C	-(80±10)mV°C

A real simulation system is established by using Matlab program and PSIM technology based on the relevant parameters of HIP200BA19 given by SOLAREX Company.

Table 2. Parameters of HP200BA19

HIP200BA19SOLAREX	HP ²⁰⁰ BA ¹⁹
I _{SC}	3.83A
V _{OC}	68.7V
TCi	0.88Ma°C
TCV	-0.172°C

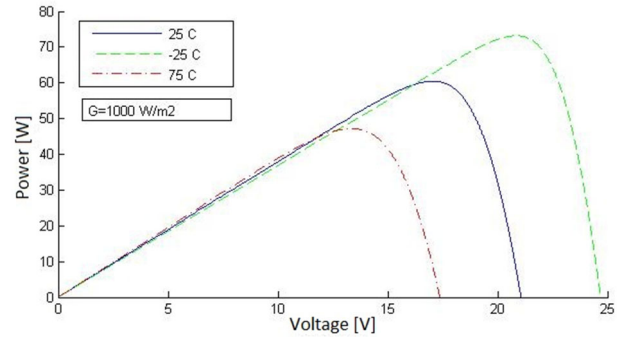


Figure 5. PV curve of HIP200BA19 PV array at 25°C and 1000W/m²

The effect of light intensity on its electrical properties is much greater than that of temperature, and the maximum output energy increases with the decrease of light intensity and temperature. At an impedance of 3.4 ohms, the current of the solar array is about 30 amps, while its voltage is about 103 V, which is consistent with the observed situation at about 3100 amps.

5. Discussion

When conventional water-cooled PV/T systems operate at high altitudes or in cold areas, the water inside the copper pipe is prone to icing, resulting in internal structure distortion and battery failure. In addition, in water-cooled PV/T systems, direct contact between cold water and the pipe will lead to corrosion of the pipe, thereby shortening its service life. The use of gravity or annular heat pipe combined with heat pump technology and phase change heat storage technology. Researchers have studied the effect of covering layer on the efficiency of solar photovoltaic/T-type solar cells through experiments, and found that although the efficiency of solar cells with non-film covering has improved, its photovoltaic characteristics have decreased; And in the absence of coverings, the system is more sensitive to external changes. By reducing the inner distance of the heat pipe, the overall performance of the heat pipe is improved to some extent [9]. With the increase of mass flow rate of heat pipe, the photothermal and photovoltaic conversion efficiency of heat pipe also increases, but decreases with the increase of pipe diameter. As the coverage area of photovoltaic modules increases, the photoelectric gain and photoelectric conversion efficiency of the system also increase, further improving the utilization rate of solar energy, and thus improving the quality of power generation. From the perspective of thermal performance, tap water is recommended for warm areas, and R134a is recommended for low temperature areas. Heat pipe PV/T with thermal diode structure has the advantages of low night loss, long heating time and good photothermal performance, but the photovoltaic performance has little

change; For the final temperature and solar coverage, the volume of the water storage tank has a more significant effect on the overall benefit. In most cases, the thickness of liquid film is basically unchanged under the condition of inclined plane [10]. With the increase of the inclination Angle, the relative liquid film resistance at the condensation end decreased and increased, while the liquid film resistance at the evaporation end and the condensation end showed a reverse trend. The total thermal resistance of the heat pipe depends on the vaporization end, and the thermal resistance of the steam end depends on the effective liquid tank height. The test and simulation show that the tilt Angle of 40 degrees is the best. Annular heat pipe PV /T has high photothermal conversion efficiency, but there are secondary heat transfer problems. The above theory is further verified by the fitting curves of two typical integrated efficiency of photothermal and photovoltaic by simulating it for a long time.

In this project, the direct expansion solar heat pump is taken as the research object, and a photovoltaic/T-type evaporation device is constructed on the top of the evaporator by layering. It is found that the evaporator can effectively cool down and improve its photoelectric conversion efficiency. In addition, sunlight can increase the vaporization temperature of water vapor, thus increasing energy efficiency. Practice has proved that PV/T direct drive refrigeration/heating system can achieve high solar cooling efficiency.

6. Conclusion

The problem of future energy demand on crystalline silicon solar cells have been transitioned from P-shaped electrodes to high-efficiency N-shaped crystalline silicon cells, and HIT cells are the most promising new solar cells. At present, the research of perovskite solar cells is still in its infancy. In addition, the development of large-scale perovskite device manufacturing technology is also an urgent problem to be solved. How to improve the photoelectric conversion efficiency is the focus of current research on silicon-based solar cells. Further research on mechanical properties, stability and preparation technology is expected to be a hot topic in the future.

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