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Experimental Study of the Characteristics of Solar Cells Affected by the Angle of Incidence of Illumination

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Abstract

As the global energy crisis continues to intensify, the search for alternative energy sources has become increasingly urgent. As an emerging clean energy source, photovoltaic power generation not only effectively reduces carbon dioxide emissions, but also has many advantages such as renewability and distribution. Therefore, photovoltaic solar energy has attracted great attention. This article mainly studies the influence of different incident angles of light on the characteristic parameters of solar panels made of different materials under certain light intensity. Using the control variable method, under a fixed incident angle of light, the intensity of the light source irradiance is adjusted by changing the magnitude of the light source current to obtain the open circuit voltage, short-circuit current, maximum output power, and fill factor under different conditions. Use Origin software to draw characteristic curves and fit the variation pattern of photovoltaic characteristic curves. The basic characteristics of solar photovoltaic cells can be characterized by the relationship curve between their current and voltage. Finally, it is concluded that the basic characteristic parameters of solar cells increase with the increase of light intensity; When the incident angle of light is 75°, the conversion efficiency reaches its maximum.

Keywords: *solar cell; incident angle; conversion efficiency*

1 Introduction

By using the photovoltaic effect, solar cells, sometimes referred to as photovoltaic cells, transform light energy into electric energy[1]. Based on the photovoltaic effect, solar cells are conversion devices that directly transform radiant energy into electric energy[2]. The P-N junction depletion zone has a strong built-in electric field, which causes electrons and holes produced there to flow in opposite directions and exit the region due to the force of the electric field. As a result, the photo voltaic effect of the P-N junction is formed at both ends, the potential in the P region grows, and the potential in the N region falls[3].

The most commonly used solar cell today is the silicon solar cell. Silicon solar cells are large-area P-N junctions made of silicon semiconductor materials connected in series and parallel[4]. Metal grid lines are formed on the n-type material layer as contact electrodes, and metal films are also formed on the back side as contact electrodes to form a solar panel. Generally speaking, there are three types of common solar cells, the main difference is that the materials used are different, namely: monocrystalline silicon, polycrystalline silicon and amorphous silicon. Among them, the conversion efficiency of monocrystalline silicon solar cell is the highest, its actual conversion rate is about 18%, and its service life is about 20 years. It is the main component of industrial production and various large-scale production applications. Although the conversion efficiency of polysilicon solar cells is still lower than that of monocrystalline silicon solar cells in application, its conversion efficiency can also reach about 15%. In addition, compared with amorphous silicon solar cells, polycrystalline silicon solar cells are not the best choice due to their lower price, lower efficiency and short lifetime

With the rapid development of China's photovoltaic industry and the increasing penetration rate, the stability and security of the electricity market have become increasingly important. The construction of the power grid is lagging behind the construction of the power supply. However, due to the intermittency, randomness and variability of solar generation, a large amount of solar PV will be connected to the grid, bringing new demands on grid stability and energy security[5].

It is therefore necessary to find ways of improving the performance and stability of solar cells. There are many influencing factors, but the most obvious are the angle of incidence of sunlight, ambient temperature, shading, dust accumulation and so on. In this experiment, the output characteristics of solar cells are studied by selecting different angles of incidence, and at the same time, the influence of different angles of incidence on the performance of solar cells is understood, and the curves of current and voltage are constructed. In addition, it is

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necessary to understand the changing laws of current and voltage emitted by solar cells at different angles of incidence. Through the relevant knowledge in the design process and the practical process of the experiment, the optimal angle of incidence of illumination is determined so that the output efficiency of the solar cell can reach the highest.

2 The Basic Principle of the Experiment

2.1 Photovoltaic effect of P-N junction

Photovoltaic power generation is based on the principle of the photovoltaic effect of the semiconductor P-N junction, which uses solar cells to convert solar energy directly into electrical energy. "Photovoltaic" refers to the phenomenon that when the target is irradiated, the distribution of charges in the target is changed, which causes electromotive force and current in the target. Photoelectric effect is a process of converting photons or light waves into electrons, and then converting light energy into electrical energy, and then voltage will be generated. Under the irradiation of light, the uneven semiconductor and the position where it is connected with the metal appear potential difference.

When the P-N junction of a semiconductor is exposed to sunlight or other radiation, a voltage is generated on both sides, known as the photovoltaic voltage. On the same silicon wafer, two types of wafers, N and P, namely P-N junctions, have been prepared on two types of semiconductors by different doping processes. Due to the existence of an electric field in the P-N junction, electrons move to the N region and holes move to the P region, so that electrons accumulate in the N region and holes accumulate in the P region, resulting in a potential difference between the two sides of the P-N junction and a photogenerated electromotive force on both sides of the P-N junction.

2.2 Main performance parameters of solar cells

(1) Short-circuit current (I_{sc}): Under the illumination condition, the output current of the solar cell is called short-circuit current if the output voltage is 0 when the two sides of the cell are short-circuited;

(2) Open-circuit voltage (U_{oc}): Under the illumination condition, the output voltage of the solar cell, if the cell is not connected to the load, its output current is 0, and the voltage at this time is called open-circuit voltage;

(3) Maximum output power (P_m): The maximum power that the panel can achieve under normal working conditions, which can be obtained by multiplying the peak current and the peak voltage. Namely: $P_m = I_m \times U_m$;

(4) Fill factor (FF): The fill factor of solar cells refers to the ratio of output voltage to output current at the maximum power point. The higher the filling factor, the better the performance of the battery, that is:

$$FF = \frac{P_m}{I_{SC} \times U_{OC}} \tag{1}$$

(5) Conversion efficiency (η): the light energy irradiated on the battery surface is converted into electric energy:

$$\eta = \frac{P_m}{A \times P_{im}} \tag{2}$$

Where A is the area of the battery panel, $P_{im} = 1000 W/m^2 = 100 mW/cm^2$.

3 Experimental Process

In this experiment, the solar panel used is made of two different materials, one is made of monocrystalline silicon, and the other is made of polycrystalline silicon. The light-receiving area of the solar panel in the experiment is 30.25 cm^2 (55 × 55mm), and the experiment is divided into two parts:

(1) Under different incidence angles, the monocrystalline silicon solar panel with a side length of 55×55mm and an area of 30.25cm2 is exposed to the sun with an incidence Angle of 90°, 75°, 60°, 45° and 30°, the experimental data are shown in Table 1, Table 2, Table 3, Table 4 and Table 5, and the changes of the test results are shown in Figure 1.

Table 1 Experimental data of monocrystalline silicon solar panel at 90° light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	2.10	20.7	31.8	0.731
220	2.12	25.8	40.9	0.748
275	2.15	31.5	51.4	0.759
350	2.17	39.7	66.1	0.767
425	2.18	49.6	83.4	0.771
510	2.18	60.3	102.0	0.776

Table 2 Experimental data of monocrystalline silicon solar panel at 75° light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	2.08	22.6	34.1	0.726
220	2.11	28.6	44.1	0.731
275	2.14	35.3	55.8	0.738
350	2.16	45.2	72.1	0.739
425	2.17	56.2	91.1	0.747
510	2.17	68.2	111.5	0.754

Table 3 Experimental data of monocrystalline silicon solar panel at 60° light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	2.07	17.9	28.4	0.766
220	2.06	24.2	38.0	0.763
275	2.09	31.2	50.2	0.770
350	2.11	39.8	65.3	0.778
425	2.14	49.6	83.2	0.784
510	2.20	59.8	103.9	0.790

Table 4 Experimental data of monocrystalline silicon solar panel at 45 °light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	2.06	15.2	22.0	0.702
220	2.07	18.1	27.4	0.731
275	2.10	22.0	34.1	0.742
350	2.12	28.0	44.6	0.752
425	2.13	34.8	56.2	0.758
510	2.14	42.2	69.1	0.765

Table 5 Experimental data of monocrystalline silicon solar panel at 30 °light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	1.94	11.4	15.6	0.705
220	1.99	14.4	20.9	0.727
275	2.00	16.4	24.0	0.732
350	2.03	20.9	31.4	0.741
425	2.06	24.8	38.5	0.754
510	2.09	28.5	45.6	0.766

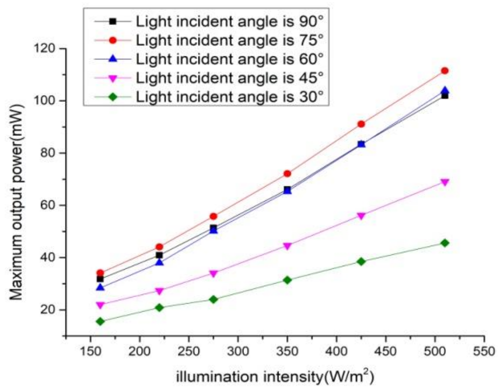

Figure 1 Illuminance of monocrystal silicon solar panels at different angles of incidence

(2) Under different incidence angles, the polysilicon solar panel with a side length of 55×55mm and an area of 30.25cm2 is exposed to the sun with an incidence Angle of 90°, 75°, 60°, 45° and 30°, the experimental data are shown in Table 6, Table 7, Table 8, Table 9 and Table 10, and the changes of the test results are shown in Figure 2.

Table 6 Experimental data of polycrystalline silicon solar panels at 90 °light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	3.07	10.4	21.4	0.671
220	3.10	12.7	27.1	0.689
275	3.13	15.1	32.9	0.696
350	3.17	19.2	43.3	0.712
425	3.20	23.8	55.2	0.724
510	3.26	28.6	68.6	0.736

Table 7 Experimental data of polycrystalline silicon solar panels at 75 °light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	3.07	11.9	25.6	0.702
220	3.12	14.5	33.2	0.733
275	3.14	15.8	36.8	0.743
350	3.15	20.1	47.7	0.753
425	3.18	25.1	60.1	0.753
510	3.19	30.4	73.3	0.756

Table 8 Experimental data of polycrystalline silicon solar panels at 60 °light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	2.99	10.9	22.9	0.704
220	3.02	13.2	27.9	0.670
275	3.05	15.3	33.5	0.717
350	3.09	19.7	44.3	0.728
425	3.14	24.5	56.5	0.735
510	3.26	29.5	71.7	0.746

Table 9 Experimental data of polycrystalline silicon solar panels at 45 °light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	2.99	8.9	18.9	0.710
220	3.04	10.5	23.2	0.725
275	3.06	10.9	24.2	0.724
350	3.10	14.0	31.9	0.734
425	3.13	17.7	40.8	0.737
510	3.14	21.5	50.0	0.741

Table 10 Experimental data of polycrystalline silicon solar panels at 30 °light incidence angle

Lux(W/m^2)	U_{oc}(V)	I_{sc}(mA)	P_{max}(mW)	FF
160	2.76	6.1	10.9	0.650
220	2.83	6.7	12.6	0.664
275	2.87	6.3	11.8	0.654
350	2.93	8.2	16.2	0.675
425	3.00	10.5	21.5	0.683
510	3.10	12.7	27.7	0.704

According to the above conversion efficiency, we can see that the conversion efficiency of monocrystalline silicon solar panels is better than that of polycrystalline silicon solar panels. The reason why monocrystalline silicon solar cells have high conversion efficiency is that their silicon material crystallizes as a single crystal, with a complete crystal structure and fewer impurities, which can more effectively convert light energy into electrical energy. In contrast, polycrystalline silicon solar cells are made by mixing multiple silicon sources, and their crystal structure is not as complete as monocrystalline silicon, resulting in lower conversion efficiency.

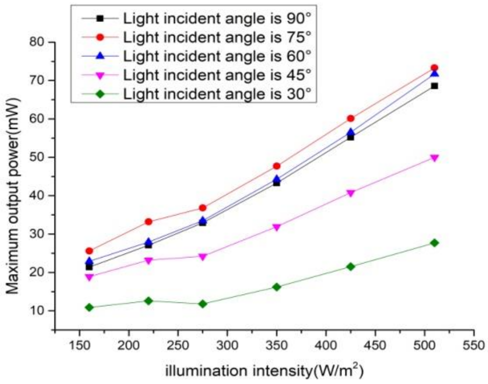

Figure 2 Illuminance of polycrystalline silicon solar panels at different angles of incidence

4 Conclusion

From the data, it can be concluded that the characteristic parameters of solar panels made of the two materials are basically the same. Under the same temperature and light intensity, the same solar panel has the maximum power output when the angle of incidence is 75, and the conversion efficiency of solar panels is the highest. Under the same temperature, light intensity and angle of incidence, the power generation efficiency of monocrystalline silicon solar panels is higher than that of polycrystalline silicon. Therefore, in order to obtain higher power generation efficiency, we should choose a monocrystalline silicon solar cell where the incident angle of light is about 75 and the illumination intensity is high.

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