A Solar Cell Characteristic Measurement Device Based on STM32

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Abstract. With the increasing development of the new energy photovoltaic (PV) industry and in-depth research of PV materials, it has become crucial to measure the characteristics of such materials. This enables R&D personnel to quickly iterate PV materials for further advancements. In the traditional R&D of photovoltaic materials, researchers often need to continuously iterate the materials, repeatedly measure the experimental materials, and ultimately get the best material ratio structure. Therefore, this paper designed an experimental device based on the STM32 chip for measuring solar cell characteristics. It can accurately and quickly measure the characteristics of a certain solar cell. CIGS thin-film solar cells were used as the experimental materials, and the light-dark voltammetry and temperature resistance experiments were done in turn. Therefore, it proved that the device has great commercial prospects.

Keywords: Photovoltaic Material; STM32; CIGS Solar Cell; Precision.

1. Introduction

Energy is the driving force and source of the development of human society, and traditional fossil energy is facing problems such as resource depletion and environmental pollution. Therefore, the development of new energy is getting increasing attention. The upstream part of the new energy industry chain comprises various industries that produce light energy, wind energy, hydroelectric power, biomass energy, and other forms of power. This part includes photovoltaic power generation and wind power generation, which are expected to witness a new installed capacity of over 100 million kilowatt-hours in the first half of 2023. The cumulative installed capacity is projected to reach approximately 860 million kilowatts. To put this into perspective, the total capacity is equivalent to 38 Three Gorges Dams, underscoring the utmost significance of photovoltaic power generation. PV materials are located upstream of the PV industry chain, which is the foundation of PV power generation. So, the research and development of photovoltaic materials has always been the hotspot of the PV industry, and researchers judge the excellence of a photovoltaic material through the testing of photovoltaic materials. For a long time, researchers need to manually build experimental environments, test the voltametric properties of PV materials and ultimately derive relevant evaluation data. However, this traditional measurement method has shortcomings such as long testing times, high human resource consumption, inaccurate test results, and low efficiency[1-4], which need to be solved urgently.

Nowadays, the evaluation tests of PV materials can be mainly categorized into traditional evaluation tests and innovative evaluation tests. Most of the traditional assessment tests use the method of manually building the test environment and then directly measuring[5-7], and some of the current innovative assessment test methods include indirect estimation of the overall battery pack[8], modeling simulation[9-14], battery capacitance simulator[15], particle swarm, deep learning and other new algorithms of computation[16-18], and so on. This paper presents a comprehensive innovation that combines traditional evaluation test methods with innovative ones to design a measurement device using an STM32 chip. The experimental photovoltaic material used is CIGS thin-film solar cells, which led to ideal results.

The measurement device has three functions. Firstly, it measures the photovoltaic material's photovoltaic characteristics. Secondly, to measure the dark voltametric characteristics of the PV

material. Thirdly, measuring the temperature resistance of PV materials. For the traditional measurement method of human resources and time cost consumption, the device adopts electrical automation control technology, which can save a lot of time and labor costs. For the new measurement method of calculation is redundant, modeling difficulties, this device adopts the PID algorithm and through the STM32F103ZET6 chip to calculate the data and ultimately intuitive presentation of the results. For the problem of low accuracy of traditional measurement methods, this device is installed with multiple sensors and adopts the method of averaging multiple measurements in a short period to improve the measurement accuracy. In summary, the device designed in this paper is a high-precision multi-application range device based on an STM32 chip. It can effectively solve the current difficult problems of photovoltaic material evaluation and has high application value.

2. Device design

2.1. 3D model

The measurement part of the device is shown in Figure 1. The device consists of four parts, which are a light voltametric characteristic measurement device, a dark voltametric characteristic measurement device, a display part, and an integrated circuit board. The display part consists of a 7-inch TFT LCD capacitive touch screen, which can realize human-computer interaction. The integrated circuit board adopts PCB technology to integrate the peripheral circuits and STM32 chip into one board. It makes the whole device simple and easy to maintain.

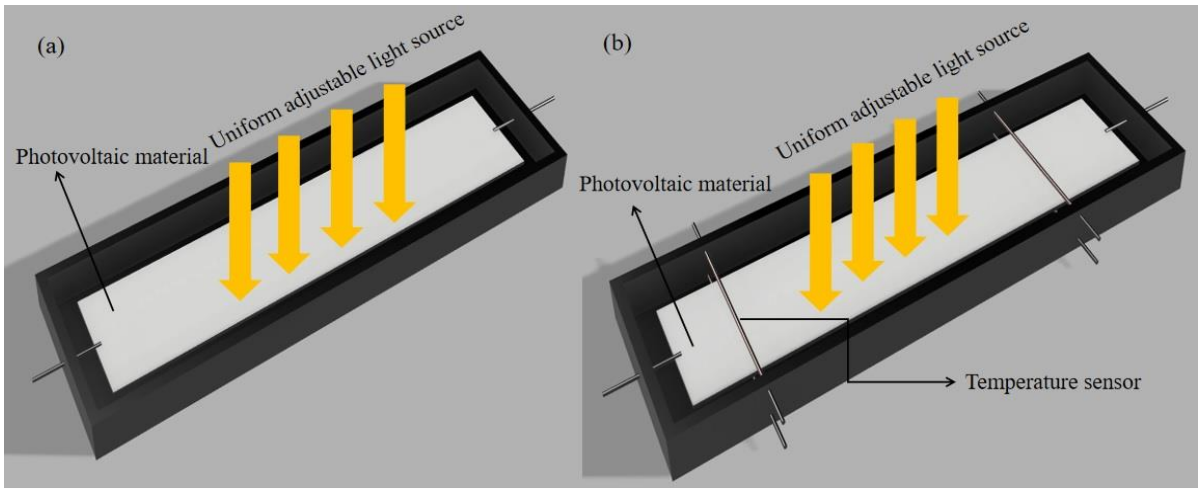


Figure 1. Volt-ampere characterization measuring device.
(a) Light; (b) Dark.

As shown in Figure 1(a), the photovoltaic material is placed in a black light-insulating acrylic box with light sensors on both sides of the photovoltaic material, a uniformly adjustable light source on the top, and a measurement circuit on the outside. The device shell is about 175 mm long, 50 mm wide, and 10 mm high.

Above the device is a rectangular black acrylic plate. It can fit closely with the acrylic box below so that the light received by the photovoltaic material is only provided by the built-in uniform adjustable light source. A rectangular uniform adjustable light source is fixed under the acrylic plate through a screw, which can continuously provide stable and uniform light for the photovoltaic material.

As shown in Figure 1(b), unlike the light volt-ampere characterization measuring device, the photovoltaic material is equipped with eight temperature sensors at the top, bottom, left, and right sides of the photovoltaic material. The photovoltaic material is placed in pure water, and a heating resistor wire is placed underneath to heat the pure water, thus changing the ambient temperature. The temperature sensors, heating resistor wire through the external circuit, and chip control form a closed loop, to ensure the accuracy of the experimental environment temperature.

2.2. Circuit schematic

2.2.1 Light volt-ampere characterization

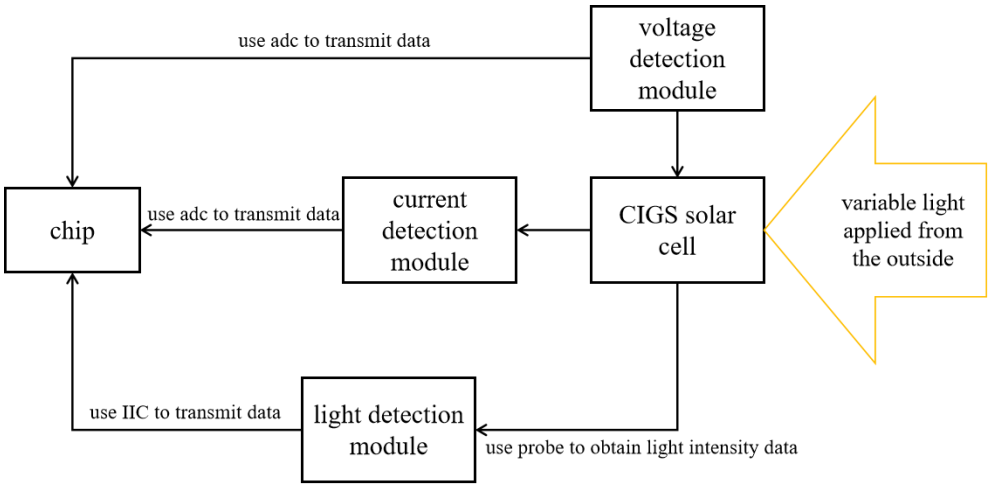


Figure 2. Photovoltaic ampere characterization circuit schematic.

The circuit principle is shown in Figure 2, which utilizes an adjustable brightness lamp panel as a uniform light source to irradiate parallel light on the thin-film solar cell, and the light intensity is measured by the light probe and displayed on the OLED screen for real-time recording and monitoring.

CIGS solar cell ends are connected to the INA226AIDGSR voltage measurement module, which can accurately measure the voltage at both ends of the solar cell. the INA226AIDGSR voltage measurement module transmits the measured voltage data back to the zet6 chip using I2C communication. The ACS712ELCTR-05B-T current measurement module is also connected in series with the measurement circuit, which can accurately measure the current passing through the solar cell and transmit the current data back to the zet6 chip through the ADC analog-to-digital conversion on the zet6 chip. In addition, the zet6 chip is connected to a GY-302 digital light intensity sensor, which is used to measure the light intensity on the CIGS solar cell. This peripheral chip also uses I2C communication to send data back to the zet6 chip. By gradually increasing the light intensity, the volt-ampere characteristic curve of the CIGS solar cell terminals as a function of light intensity can be measured. The open-circuit voltage and short-circuit current of the thin-film solar cell can be measured accurately under a specific light intensity, which is a measurement of the conductive properties of thin-film solar cells under light conditions. Continuously change the light intensity, resulting in different light intensities of the battery open-circuit voltage and short-circuit current data.

2.2.2 Dark volt-ampere characterization

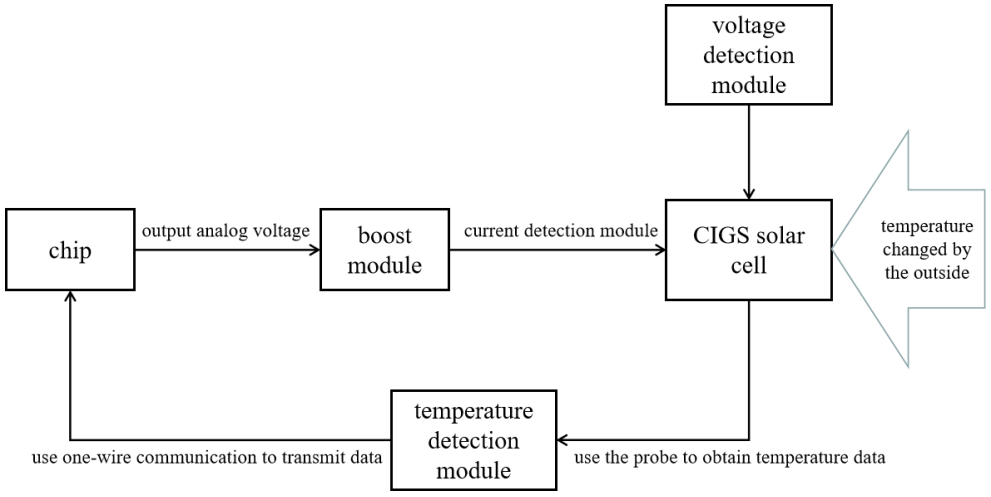


Figure 3. Dark voltametric characterization circuit schematic.

The instrument is modularized using acrylic panels and then shading material is added to its surface to ensure a dark environment. The water bath is used for constant heating to make the thin film solar cell heated uniformly, controlled by a microcontroller to get the desired temperature, and monitored in real-time by an OLED display.

As shown in Figure 3, CIGS solar cell ends are connected to the INA226AIDGSR voltage measurement module, and it can accurately measure the voltage at both ends of the solar cell after the circuit is connected. The INA226AIDGSR voltage measurement module transmits the measured voltage data back to the zet6 chip through the I2C communication. Additionally, the ACS712ELCTR-05B-T current measurement module is connected in series with the measurement circuit. It can accurately measure the current passing through the solar cell and transmit the current data back to the zet6 chip through the analog-to-digital conversion of the ADC on the zet6 chip. Then, the zet6 chip is connected to a DS18B20 temperature sensor, which transmits the measured temperature data back to the zet6 chip through the IO port via a 1-wire single bus protocol. By gradually increasing the temperature, the temperature dependence of the CIGS solar cell ends can be measured to obtain the dark voltametric curve.

2.3. Selection of components and important modules

The device utilizes the STM32F103ZET6 control chip along with a peripheral development board. This combination offers low power consumption, abundant peripheral functions, and access to crystal clock resources. It is a mainstream microcontroller chip with low power consumption, rich functions, and crystal clock resources.

Copper indium gallium selenide flexible thin-film solar cells (hereinafter referred to as CIGS thin-film solar cells) were selected for this experiment, which are lightweight and have great application prospects.

Current detection module: ACS712ELCTR-05B-T, which utilizes the Hall effect to detect the current in the circuit and works well in a weak magnetic field environment, with an accuracy of up to 0.01 mA.

Voltage detection module: INA226AIDGSR, accuracy up to 0.001 mV.

Boost module: DC-DC SX1308, DC boost module, boost part of the high-quality boost controller, by using the on-resistance of the power MOSFET and eliminating the current detection resistor, improve the conversion efficiency, conversion efficiency up to 96.4%.

Light intensity detection module: GY-302, adopting ROHM original BH1750FVI chip, can measure light in the range of 0-65535 lux, with a built-in 16-bit AD converter, it can measure the wide range of brightness with a high precision of 1 lux.

Temperature sensor: DS18B20, measuring temperature range from -55 ℃ to 125 ℃.

3. Data processing method

For researchers to better observe the data and evaluate the performance of photovoltaic materials, the device processes the original data through the built-in algorithm and finally presents it to researchers in the form of images. Two methods of cubic spline interpolation and linear interpolation are used to process the data.

To begin with, the linear interpolation method was described. There are three general linear interpolation methods: Newton interpolation method, Lagrange interpolation method, and piecewise linear interpolation method. The use of polynomial interpolation methods such as Newton interpolation and Lagrange interpolation could cause excessive computation and distortion of the results and even the Runge oscillation phenomenon due to the large number of data samples obtained by the device. The piecewise linear interpolation method can solve this problem well.

In short, piecewise linear interpolation is to connect each adjacent node with a straight line, so that each broken line is a piecewise linear interpolation function, denoted as$K_n(x)$. It satisfies $K_n(x_i) = y_i$, and $K_n(x)$ is a linear function in each interval $[x_i, x_{i+1}]$. Using $K_n(x)$ to compute the

interpolation at x, only the two nodes to the left and right of x are used. The amount of computation is independent of the number n of nodes. However, the larger n, the more segments, and the smaller the interpolation error.

Then we discuss the cubic spline interpolation method. Although the interpolation result of the piecewise linear interpolation method is more accurate, the smoothness is not high at the endpoints of adjacent subintervals, for example, the first derivative does not exist at the interpolation node. The spline interpolation method can solve this problem well.

However, different interpolation methods are adopted according to the experimental data in this paper. The cubic spline interpolation method is used since the data of dark voltammetry and temperature resistance experiments are discrete. The piecewise linear interpolation method is used, because the data of the photo voltammetry experiment are linear.

4. Dark voltametric properties experiment

CIGS solar cells as experimental materials, measured at 40, 60, 70, and 80 ℃ under the CIGS solar cell resistance with the voltage changes at both ends of the data. R about U change curve is local oscillation curve. The use of the linear interpolation method can cause local unsmooth for the interpolation of this data using cubic spline interpolation to ensure that the curve of the second is smooth.

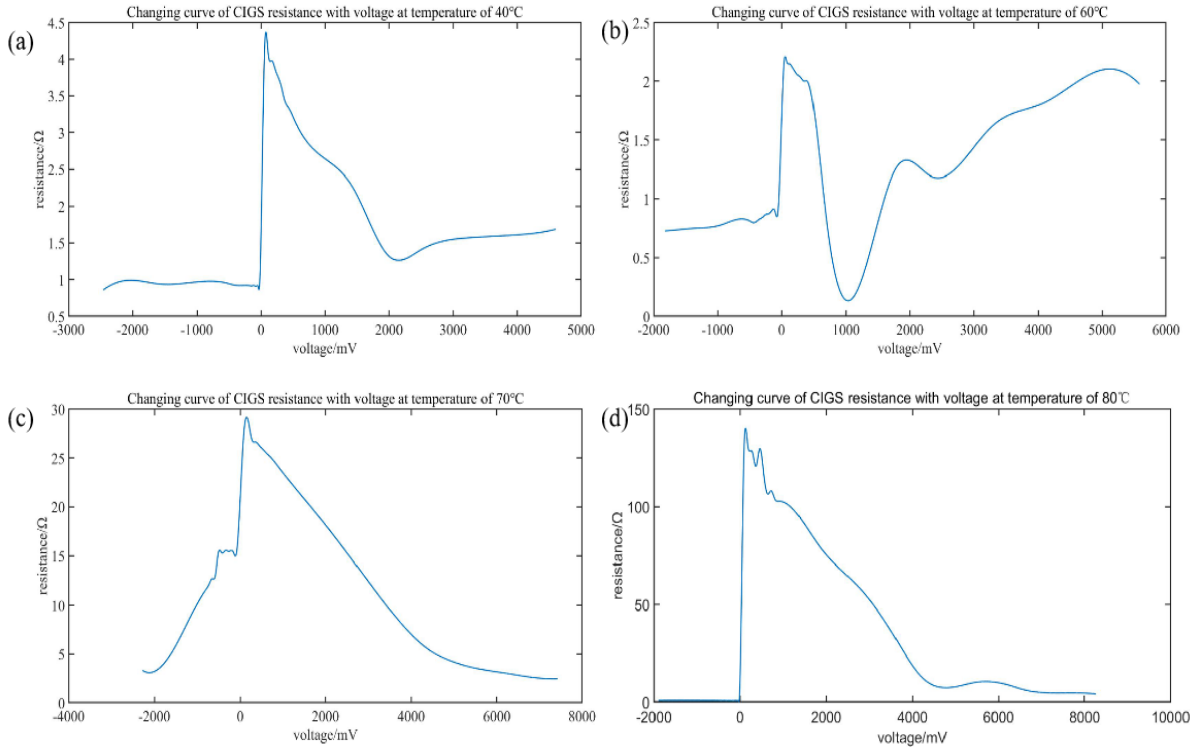


Figure 4. The plot of CIGS solar cell resistance at different temperatures.
(a) 40 ℃; (b) 60 ℃; (c) 70 ℃; (d) 80 ℃.

As shown in Figure 4(a) and Figure 4(d), the dark voltametric characteristics of CIGS solar cells at 40 and 80 ℃ are in accordance with the dark voltametric characteristics of semiconductors. They both are that the resistance changes with the voltage when turned on in the forward direction and the resistance is smaller, the voltage is higher. When turned on in the reverse direction, the resistance is almost constant and does not change with the voltage, and the resistance is smaller than that when turned on in the forward direction. While the ambient temperature is 60, 70 ℃, the CIGS solar cell does not conform to the dark voltammetry characteristics of semiconductors, and the trend of resistance change with voltage is not obvious, which is presumed to be probably related to the internal structure of the CIGS solar cell material changed due to the higher temperature.

In addition, the resistance voltage of CIGS solar cells has a tendency to increase in the range of 0-2 V with the increase of temperature. Especially in the range of 60-80 ℃, this trend is very obvious. Temperature changes and the resistance value of CIGS solar cells have oscillations, but its trend with the voltage at any temperature basically converges to the same. This shows that the dark voltametric characteristics of CIGS solar cells are different at different temperatures. But the overall trend is basically the same, reflecting the better temperature resistance of CIGS solar cells. The specific temperature resistance properties will be discussed below.

5. Light voltametric properties experiment

The raw data are obtained through instrumental measurements, and it can be roughly concluded that the relationship between open-circuit voltage, short-circuit current and light intensity is linear. So, the correlation curve is derived through the method of MATLAB linear interpolation shown in Figure 5.

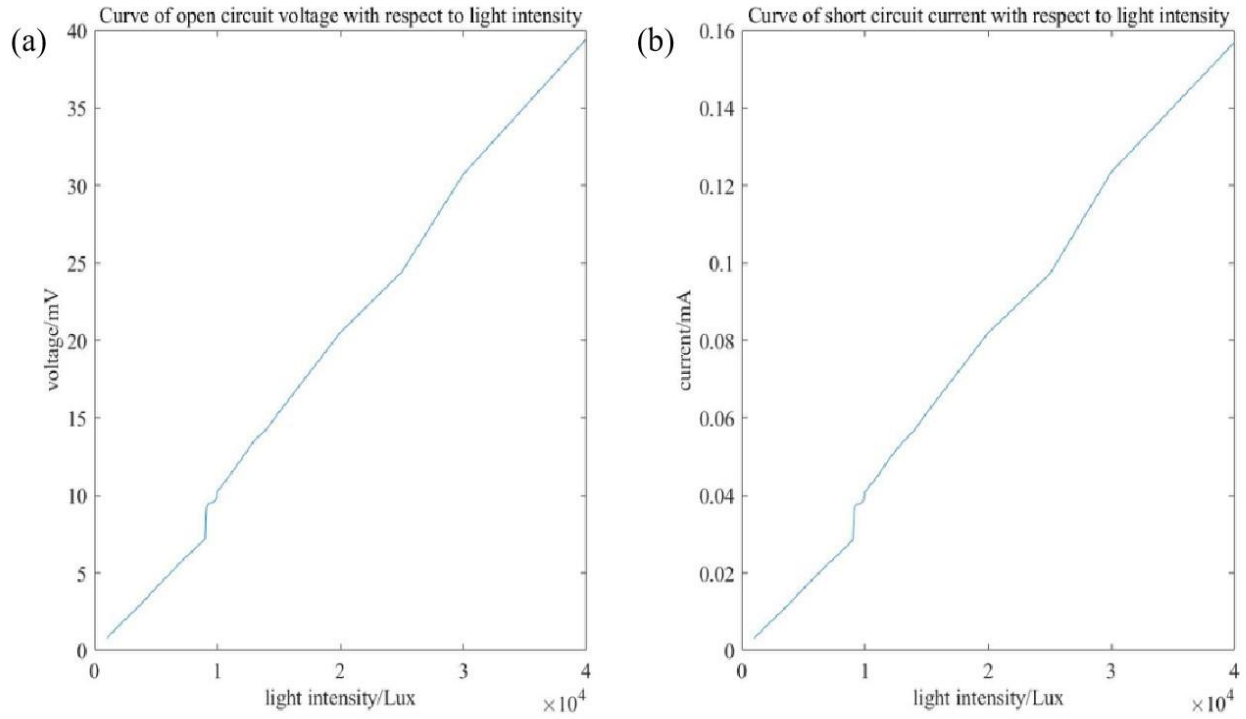


Figure 5. (a) The curve of open circuit voltage; (b) The curve of short circuit current.

Figure 5(a) shows the relationship between the open-circuit voltage of CIGS solar cells and light intensity, and the open-circuit voltage is linearly and positively correlated with light intensity. It should be noted that the open-circuit voltage has a positive mutation at 8000-10000 lux, indicating that the structure of the CIGS solar cell has changed at this time. It has been verified by several experiments that this mutation is reversible. Another point of interest is that at 25000-30000 lux, the open-circuit voltage is less than the previous mutation, but the mutation still occurs. And because of the experimental conditions, device cannot get a larger light intensity under the value of open-circuit voltage. The paper can only speculate that the light intensity is greater than 40,000 lux, the open-circuit voltage still exists mutation, which could prove that the CIGS solar cell can be a very excellent photovoltaic material. Because the greater the light intensity, the more mutations, the greater the degree of mutation, the greater the output power.

Figure 5(b) shows the relationship between the short-circuit current and light intensity of CIGS solar cells, and the trend is basically the same as the open-circuit voltage, which confirms the excellent photovoltaic characteristics of CIGS solar cells.

6. Temperature resistance experiment

In the temperature resistance experiment, the light intensity of the fixed light source remains unchanged and is measured to be about 45000 lux. Changing the circuit, the external 1Ω resistor is used as the analog power generation load. Then the voltage data and current data are still transmitted to the chip through the current detection module and voltage detection module, and the chip is displayed through the OLED screen. Gradually increase the temperature, the device measured the load resistor voltage and current values under 55 ℃, 60 ℃, 65 ℃, 70 ℃, 75 ℃, and 80 ℃.

To ensure the overall smoothness of the curve, the cubic spline interpolation method is used to obtain the temperature-output power curve as shown in Figure 6.

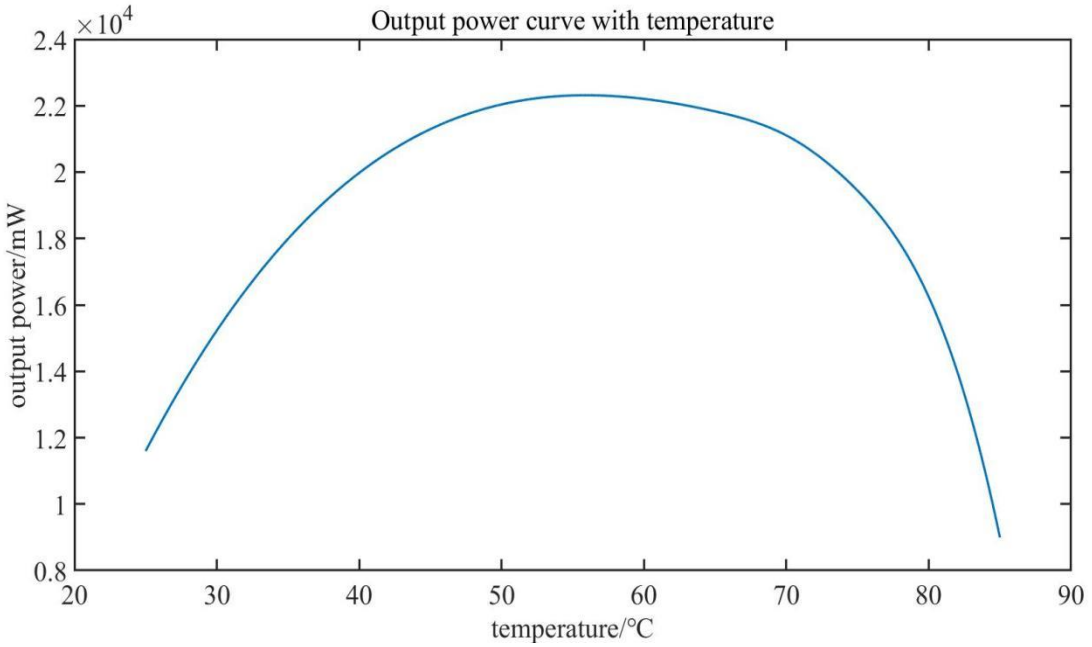


Figure 6. Output power curve with temperature.

In Figure 6, with the increase of temperature, the output power of the CIGS solar cell increases slowly from 12000 mW at 25 ℃ to 22000 mW at 50-60 ℃ and then decreases to 10000 mW at 85 ℃. The output power of the CIGS solar cell shows a trend of first increasing, then stabilizing, and finally decreasing. The output power of CIGS solar cells tends to reach the maximum value of 22000 mW at 50 ℃-60 ℃, which indicates that CIGS solar cells have excellent temperature resistance in this temperature range. The temperature of 50-60 ℃ is also basically equal to the surface temperature of PV panels in practical production applications, reflecting the excellent photovoltaic characteristics of CIGS flexible thin film solar cells.

7. Conclusions

Herein, solar energy could become the main source of energy for human beings, and photovoltaic materials could convert light energy into much-needed electricity by virtue of the photoelectric effect, and the study of photovoltaic materials is crucial. Therefore, this paper designed a convenient and accurate measurement device for solar cell properties. This device adopts automation control, which realizes the easy operation of the experiment and makes the experimental results more accurate. This device can measure the conductive properties of the object to be measured in a more extreme environment, and the measurement function is powerful and abundant. This device can be applied to a variety of thin-film material measurements and has very excellent general applicability. In the future, the device will empower the photovoltaic materials research and development industry, and make excellent contributions to the application of solar energy.

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