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Research Article

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Relationship between electroluminescence images and power type parameters of defective silicon solar cells

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ABSTRACT

Based on Electroluminescence (EL) theory, the solar cell detection system were built by the particular wavelength near-infrared CCD imaging device, which mainly included the camera obscura, computer imaging analysis software and constant current source, finally completed the near-infrared image detection of solar cells in a dark room. A number of the same batch of solar cells were divided into normal or recessive defective cells through EL detection, then we could get the appropriate cells of the open circuit voltage, short-circuit current, power and other parameters by standard solar power tester for power test. Finally we could get that the defects would affect the power type parameters of the solar cell, meanwhile EL technology is proved to be an accurate measurement to detect solar cells. It could provide a broad idea for further design of the power test equipment.

Keywords: Solar cells, electroluminescence, hidden defects, Power type Parameters, relationship.

INTRODUCTION

With the rapid development of technology and economy, solar energy has been gradually got the attention of many countries, and also got a better development and utilization. Global photovoltaic industry was developing very rapidly; meanwhile the domestic solar cell industry scale has been expanded. But a defect in a solar cell has a great influence on the battery photoelectric conversion efficiency, external defects was easy to detect, but micro-cracks of internal was difficult to identify only by the human eye. How to effectively detect the crack of the silicon solar cells in the process of industrial production, and find out the cause of the defect of technology as soon as possible , which was a key problem for the development of solar cell industry.

Now, there are three methods for solar cells defect detection in industrial productions, which include artificial visual detection [1], the infrared detection [2] and CCD detection [3]. Infrared image technology was used to the battery components for defect detection, which could achieve four kind of defect detection, such as fragments, virtual welding, broken gate and cracked through the analysis and processing components of electroluminescent image [4]. A detection method was proposed based on cell physical defects, and applied for a patent on crack detection equipment [5]. This equipment was mainly composed of laser source and the laser controller, rotating mirror and controller, reflector, a CCD camera, scanner, cargo and computer composition, it could detect the defect of battery components through the analysis of the infrared image of processing scanning for. But most of the testing equipment only measured single index, and need many even repeat test equipment, it is not conducive to the rapid detection of solar cells defects. As the image of defect detection and power parameters detection equipment integration, the efficiency of cell production testing would improve greatly.

Based on the electroluminescent detection principle, the Solar Panels on-line detection system was designed and assembled, first used the CCD camera to capture the EL image, the micro-cracks of crystalline silicon solar cells were detected by the near-infrared CCD camera, such as the cracks, off-grid, non-uniform resistance, flower slice. Then we compared the EL images with the images under visible light. Power parameters of the defective solar cells was tested, and we got that the parameters such as open-circuit voltage, short-circuit current, voltage of maximum power point V_m , current of maximum power point I_m , efficiency , so as to get the relationship between all kinds of defects in solar cells EL images and power parameters. So if we could use the corresponding relationship for production monitoring and of solar cells defect detection in the industrial production, It could not only reduce the damage rate, improve the product grade effectively, but also could reduce the cost of silicon material and the production cost at the same time, so as to improve the market competitiveness of the component.

EXPERIMENTAL SECTION

1 Experiment principle

1.1 Solar cells electroluminescent principle

If we put the positive electricity to PN junction of solar panels, energy will be released in the form of photons because of the recombination of electron and hole. Electroluminescent spectra has a certain light intensity at 700 nm to 1200 nm range, the image could be captured by CCD imaging device. But for the broken part, the captured image present a clear spots in defect part because of non-recombination phenomenon of electrons and holes For silicon solar cells sending out the near infrared wavelength of 1150 nm when energized, so we can get crystalline silicon solar cells of electroluminescent image by using the near infrared camera [6]. From the infrared image the battery slice of hidden defects can be intuitive analysis, and the hidden defects are unable to distinguish in visible light workers.

In view of the common silicon solar battery, the relationship between the number of the carrier and the corresponding diffusion length are as the formula [7]:

$$N = \int_0^{\infty} n_p(0)\exp(-x/L_e)dx = n_p(0)L_e \tag{1}$$

Among of the formula, $n_p(0)$ is the number of excess carriers in silicon material, L_e is the effective diffusion length. Under the condition of fixed number of minority carrier, electroluminescence intensity is proportional to the effective diffusion length of minority carrier.

The relationship between minority carrier diffusion length effectively and its longevity is as follows:

$$L_e = \sqrt{D_e \tau_e} \tag{2}$$

So when the silicon cell is switched to forward biased of the power, the electroluminescent intensity depends on the silicone material internal minority carrier lifetime, the CCD camera is the integration of exposure for electroluminescent intensity within the exposure time, the expression is:

$$N_v = \int_0^t E_v dx \tag{3}$$

When the power is connected to offset, silicon cells will radiate about 1150 nm wavelength of invisible light, so we can use near-infrared camera photographs to get the electroluminescent image, this system adopts the high resolution of refrigeration CCD industrial camera.

1.2 The solar cell power parameters

The basic parameters of Solar cells include short-circuit current and open-circuit voltage, maximum power and fill factor and photoelectric conversion efficiency. Features good solar cell which has obtain higher power output of solar cells, and the short circuit current and open circuit voltage and fill factor are also bigger. Conversion efficiency is used to indicate the degree of light energy convert into electrical energy. It is another important measure index of the solar cell performance, which is proportional to the maximum power. For crystalline silicon, upper limit of conversion efficiency in theory is 27%, research and development phase is 24.2%, but in the production scale is only 18%. For the low cost of amorphous silicon solar cells, upper limit conversion efficiency in theory is 25.5%, but solar cell conversion efficiency is only 12% when the type is 10 cm * 10 cm. According to statistics, the actual conversion efficiency is 50% ~ 70% of its theoretical efficiency for the actual production of solar cells. The conversion efficiency in common silicon solar cell is only about 18% [8]. The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph). All manuscripts must be in English, also the table and figure texts; otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use.

2 the solar cells defect detecting system

2.1 The design of EL detecting system

This system mainly consists of three parts: solar panels Camera obscura, computer, and constant-current source. The measured solar panels were placed in an opaque test case, switched on constant direct current that carries on adjustment size according to the size of the panels. And the solar panels can emit infrared light, using the principle of photoelectric conversion. Place an infrared industrial camera in the black case and the panels can be used for real-time monitoring and single frame collection. Industrial camera connects with computer by USB. The stand or fall of panels can be directly observed from the screen and it`s convenient for users to operate [9]. The framework of the EL detecting system is shown in Figure 1.

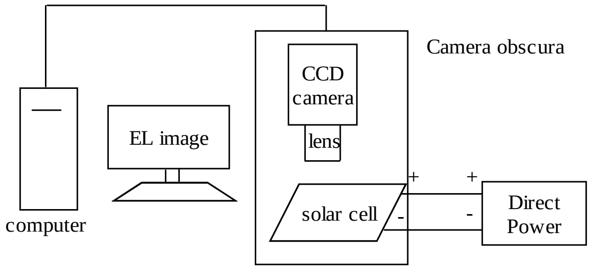


Fig.1 The EL detecting system

The CCD image sensor is made of silicon materials, being high sensitive to the near infrared. Spectral response can be extended to about 1.0 um. When you observed in a closed darkroom, you cannot see the infrared wavelengths but the image can be present in the monitor clearly. So using near infrared imaging method by CCD sensor and the surface of the CCD imaging chip, you can make with electroluminescent image of crystalline silicon solar cells. There are many indicators to test quality of CCD, such as the effective number of pixels, the size, sensitivity, and signal-to-noise ratio, etc. The two important indicators are effective number of pixels and the CCD size .The camera is designed with SONY413 chip with the function of refrigeration and pixels of 6.1 million. And the size of pixels is 7.8 um * 7.8 um, which is twice as large as ordinary common 1.44 million pixels. In order to make the choice of corresponding lens, the size of the testing equipment should be count out by calculating the distance of the light path in the black box, and the size of detecting cells. Besides, a filter is installed at the lens which can filter out the visible light to prevent interference.

Due to the wavelength of visible light range is 380 nm to 645 nm, and silicon solar cell could send out a wavelength of 1150 nm near-infrared at the time of electricity, we designed camera obscura for testing [10, 11]. There are three parts in the camera obscura, CCD camera fixed frame, the mirror support, Adjustable voltage power supply with constant current and solar energy battery components. We could get the near-infrared images by using CCD camera when loading positive bias voltage to battery components through the adjustable voltage constant current source. Test panels are loaded by the opening and closing Windows controlled of the cylinder, at the same time blocking the visible light. The dark room installed in solar cell production process middle pressure of each link, with the needs of the production process for detecting defects and power test. During the test electroluminescent drive mode using Panels connected to the constant dc source， the size of the current can be adjusted according to the measured of the specifications of the panel accordingly. The adjustment range of general voltage was adjusted from 0 to 60 V in the production line, current range from 0 to 10 A. The smaller production site has, the smaller size of the obscura should have. In order to achieve greater size detection, plane optical reflector could be use to achieve infrared way, so as to adapt to different sizes of panels.

2.2 construction of the power testing platform

We choose solar module tester as power test equipment which manufactured by Taiwan instrument electronics co., LTD., the model is PROVA200. It consists of the tester host, computer, display parts. Solar module tester is a kind of solar battery and component test special equipment with high reliability, high precision. Some parameters such as I-V curve, P -V curves, short-circuit current I_{sc} , open-circuit voltage V_{oc} , voltage of maximum power point V_m , current of maximum power point I_m, efficiency .At the same time it can also display the corresponding current, voltage and power parameters of arbitrary point on the curve. Using this instrument, it not only guarantee the accuracy of the measurement results，but also guarantee the measuring range of the linear error within %. The structure of power testing platform are shown in figure 2.

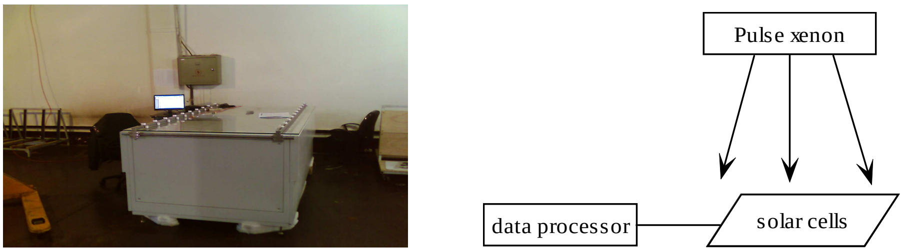
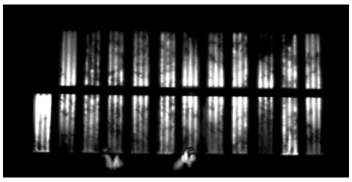


Fig.2 Power testing platform

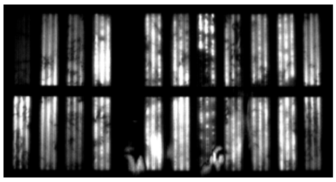
3 Experimental procedures

Some cells were selected as the experimental samples for doing EL defect testing. All of them were come from the same experimental batches of the same production line. We selected seventeen pieces cells with hidden defective from the sample, which have some defects such as the cracks, off-grid, non-uniform resistance, flower slice. And different cells have different effects on power. In order to analyze the influence of these defects, we filter out two solar cells with flower slice as later power test comparison samples from the seventeen defective cells. Then two defective cells and two normal cells randomly are selected to do EL tests respectively.

In order to ensure the consistency of the testing data, firstly we re-weld the same length and cross-sectional area for the testing lines; unify the positive and negative link lines for test sample. This ensures that the test have the same conditions. The test time of EL common line is 8-15 seconds; power-on test cells will bring current fluctuations if the test time is too long, so we adopt a method of relatively large current (3A), and accurate short-time test (3S). In order to reflect the invisible defects affect power of solar cells, a normal cell is selected to do an earthing treatment, simulating the condition of outdoor installation and long running. The experimental results of the EL testing image are shown in Figure 3.



A Defect solar cell1 1



B Defect solar cell1 2

C Normal solar cell

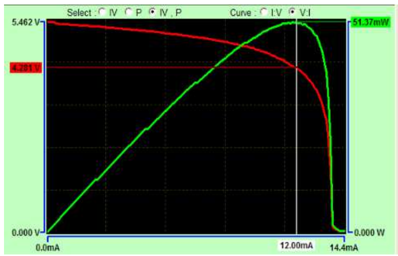
D Earthing solar cell

Fig.3 EL test image

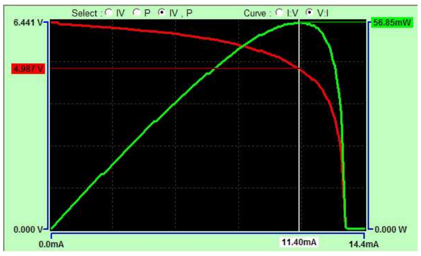
RESULTS AND DISCUSSION

Power test are carried on the solar cell with defects respectively, In order to ensure data consistency, we chose the test with the same time, the same place, the same location for the cells, as well as the installation angle of the sun. We also chose the cloudy weather so as to reflect the greater degree of influence on power. The Power test curve the cells as shown in Figure 4.

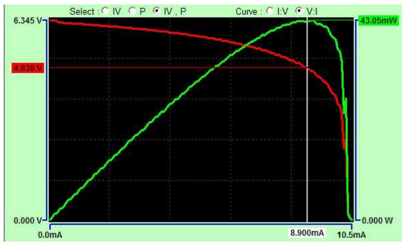
A Defect solar cell 1



B Defect solar cell 2



C Normal solar cell



D Earthing solar cell

Fig.4 Power test curve

The results of test performance are shown in Table 1.

Table 1 the test performance of solar cell

	type	Defect area	Test temperature(℃)	open-circuit voltage （V）	short-circuit current (mA)	max power (mW)
A	Defect1	12.5%	11	6.359	14.0	55.86
B	Defect2	18.7%	11	5.462	13.3	46.35
C	Normal	0%	11	6.441	14.4	56.85
D	Earthing	Simulation the outdoor	11	6.345	10.5	43.05

The correspondence between the EL image and the power can be obtained from these test results. The following conclusions can be obtained from the table 1:

①The defects such as the cracks, off-grid, and non-uniform resistance, flower slice have different degrees of impact on the solar cell when compared the defect cells to the common cells. The short-circuit current, efficiency are both decreased, and it has less impact on the open circuit voltage.
② In order to eliminate the outdoor environmental impacts for the cells (such as overburden), we could adopt erase, automatic cleaning and other methods. Before leaving factory the hidden defects must be detected, otherwise the impact will be long.
③ Because of the correspondence between the power and the EL image, possible defects can be analyzed by the photoluminescence experiments of the cells. This method is faster than conventional direct measurement, and it has broad prospect.

CONCLUSION

Near-infrared imaging experiments are carried out in polycrystalline silicon solar cell using the electroluminescent principle, and compared the visible light image with EL images of the polycrystalline silicon solar cell in the same position, EL images accurately detect the defects of the solar cell, such as the cracks, off-grid, non-uniform resistance, flower slice. and these defects are the micro-cracks and could not observed in visible light, then using standard solar battery tester, measured some parameters such as I-V curve of the cells, short-circuit current and open-circuit voltage, maximum power, and got the preliminary corresponding relationship between cell EL image and power parameters. Test results confirm the existence of defects make polycrystalline silicon solar cell efficiency decreased significantly. Because of the corresponding relationship, we would analysis the battery slice of possible defects through the electroluminescent experiment. If gray level analysis, statistical analysis of infrared photosensitive points on image processing could be used in later experiment, make it to integrate the EL tester and power tester and other production equipment. We can judge the types of defect through the power characteristic curve, finally to reduce the silicon material consuming, cost savings, and improve the market competitiveness.

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