Phys. Status Solidi C **8**, No. 2, 362–364 (2011) / **DOI** 10.1002/pssc.201000549

physica status solidi c
www.pss-c.com
current topics in solid state physics

Quality diagnosis of silicon solar cell using LED spotlight irradiation method

Kensho Okamoto*, **Nobuhiro Esaki, and Keishiro Goshima**

Department of Information Engineering, Kagawa University, Hayashi-cho, Takamatsu, Kagawa 761-0396, Japan

Received 19 June 2010, revised 24 September 2010, accepted 26 September 2010
Published online 1 December 2010

Keywords LED, solar cell, electroluminescence, quality control

* Corresponding author: e-mail oka@eng.kagawa-u.ac.jp, Phone: +81 87 864 2250, Fax: +81 87 864 2232

Solar cells with some defect should not be flowed into the market. However it seems that there is no method other than infrared light photograpy to inspect the reliability of commercially available solar cells. In this paper, we propose a novel technique, named the LED spotlight scan method, to diagnose whether some electrical defect exists in solar cell module or not.
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1 Introduction

Because of the global heating problem, solar cells are now producing at a tremendous speed in the world. However it is considered that potential risk exists in the mass production of solar cells. That is, it may be irretrievable if solar cells with defect once flow into the market. The recall of solar cells will be very much troublesome and it surely costs a great deal. Therefore, commercial solar cells should be completely free from any defects. However, mere a few methods exist to check the quality of the fabricated solar cell. Typical methods to investigate the uniformity of solar cell are the thermography analysis and the observation of electroluminescence.

In this paper, we propose a novel technique named "LED spotlight scan method" to diagnose the quality of silicon solar cell.

2 Problem of solar cell with defection

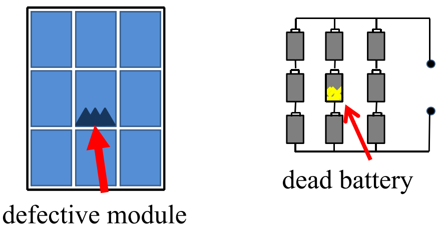


Figure 1 Left: Solar cell with a defective module. Right: Equivalent circuit using 3×3 dry cells matrix.

As shown in Fig. 1(Left), if a solar cell system composed of 3 x 3 module-matrix has a defect in the middle module, then its equivalent circuit may be expressed by the battery connection as illustrated in Fig. 1(Right). Such a defective solar system will occur many problems in the practical use.

3 Method of fault detection in solar cell

There are several methods to inspect whether some electrical anomaly exists in the solar module or not. The typical methods for silicon solar cell are the infrared thermography and the electroluminescence (EL) analysis. In both methods, two-dimensional homogeneity is checked when a direct current is passed through the solar cell module. In the former method, temperature distribution is observed using a thermal imaging camera. We can know some anomalous point from the thermograph. On the other hand in the latter method, electroluminescence image is observed using InGaAs infrared camera with sensitive wavelength region 900-1700 nm. Electrical defect will be found from the EL-image. Silicon cell emits infrared light when a DC current passed through it, although this phenomenon is not so known in general.

4 Our novel method to diagnosis solar cell

We developed a novel method to diagnosis silicon solar cell in this research. The method is illustrated in Fig. 2. We call the method as spotlight scan method. In Fig. 2, LED scan rod is attached to the carriage of an XY-recorder. The output wires of the Si solar cell are connected to the Yinput terminal. The carriage is swept in the X direction by the X-sweep mode (speed=1 cm/sec). In this condition, the recorder pen draws the change of photovoltage on the graph paper corresponding to the position of LED spotlight on the surface of Si solar cell. Thus, we can obtain the photovoltage curve as seen in Fig. 3. The scale of X-axis on the graph paper equals to the actual size of sample cell.

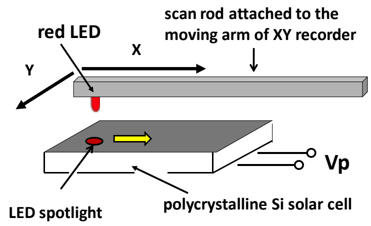


Figure 2 LED spotlight scan method. Change of photovoltage V_p is traced on an XY-recorder when the LED spot light is scanned in the direction of X.

By the method, photovoltage V_p will be constant with the scanning distance if there is no defect along with X-axis as shown in Fig. 3(Left). But V_p will drop when the LED lightspot comes to the portion where electrical defect exsists as Fig. 3(Right).

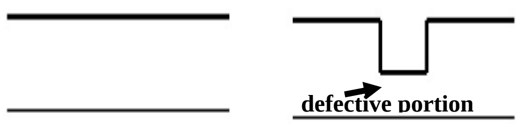


Figure 3 Supposed V_p change with LED spotlight scan. Left: No defect along the scanning direction. Right: In case an electrical defect exists.

5 Experiment

5.1 Solar cell sample

Two polycrystalline silicon solar cells of the same type were used in the experiment. Figure 4 shows one of the two sample cells. The effective area of the cell is 108 cm×165 cm, and it consists of cell rows, *e.g.* A, B, C and D. Further each row is composed of eight silicon plates (each 25 mm×20 mm) electrically-connected in series.

For convenience, we denote the plate address as shown in Fig. 4, *e.g.* A-1, C-5.

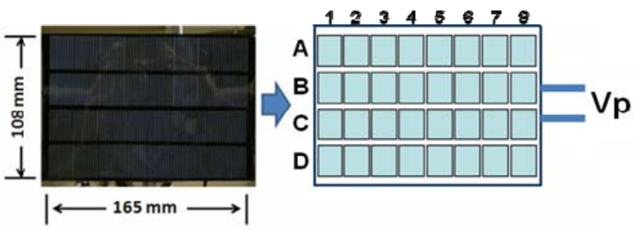


Figure 4 Polycrystalline Si solar cell used in the experiment. Each row is composed of eight silicon plates. Let us denote the site address of each plate such as A-1, B-2.

5.2 Experimental result of cell diagnosis

Two Si solar cell samples; named Sample-1 and Sample-2 were diagnosed by the LED spotlight scan method. The results are shown in Fig. 5. It is seen that there are anomalous points in the rows C and D, i.e. site address C-2 , C-3, D-2 and D-3 in Sample-1. On the other hand, such an anomalous point is not seen in the case of Sample-2. The extraordinary points in Sample-1 are considered to be caused by some internal electrical defects in the Si solar cell. By the way, the small peaks on the V_p curves in Fig. 5 are occurred when the LED spotlight is laid across the two neighbouring silicon plates as shown in Fig. 6. However, the reason for this is not known at present.

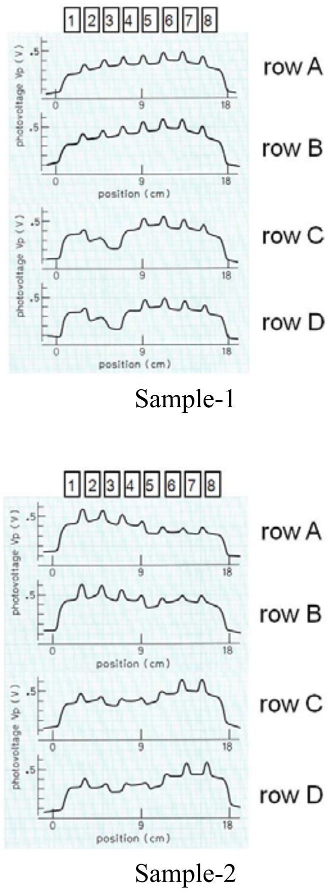


Figure 5 Change of cell photovoltage with the scan of LED spotlight. Upper: Sample-1, Lower: Sample-2. Feature of LED: 5 mm in diameter. Wavelength: 644 nm, light power: 2 mW (input current 30 mA). Diameter of spotlight: 1.5 cm (measured on the surface of Si cell).

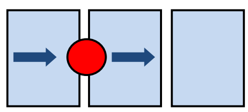
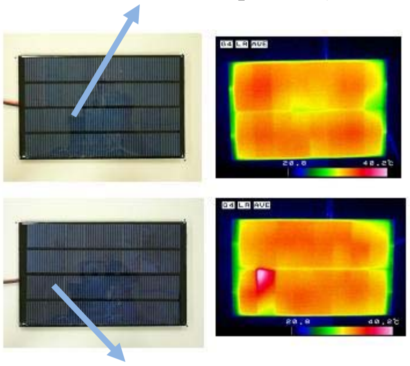


Figure 6 V_p peaking position of LED spotlight.

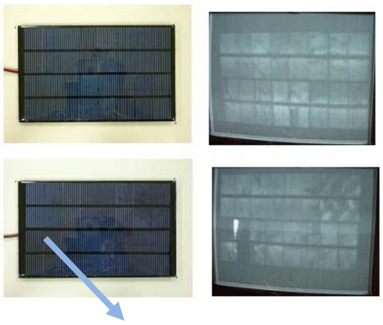
In order to investigate the anomalous points in Sample-1, we observed the infrared images of the two samples usin thermography and electroluminescence method. Figures 7 and 8 are the experimental results. Figure 7 (right) is the temperature distribution observed by a 3-5 μm IR-camera (Nikon LAIRD-S270A and Fig. 8 (right) is the image of electroluminescence by a 0.9-1.7 μm InGaAs IR-camera (Hamamatsu Photonics C10633-13).

Photovoltaic anomalous portion (C-2, C-3)



Thermally anomalous portion (C-2)

Figure 7 Thermal images (thermographs) of the two Si solar cell samples when 2 A current is passed. Wavelength region: 3-5 μm. Upper: Sample-1, lower:Sample-2.



Anomalous portion in EL image (C-2)

Figure 8 Electroluminescence image observed by InGaAs infrared camera. Input current: DC 3A. Wavelength region: 0.9-1.7 μm. Upper: Sample-1, lower: Sample-2.

It is not well known that Si solar cell emits weak infrared light when a direct current is passed in the forward direction as a diode. Such a phenomenon in Si solar cell is generally called as electroluminescence. In order to investigate the origin of the light, we measured the spectrum of the emission light using a high-sensitivity optical spectrum analyzer (Yokogawa Electric Co. AQ 6370B). Figure 9 is the spectrum of light emitted from Si solar cell Sample-2. The wavelength of the peak lies at 1140 nm. This approximately corresponds to the energy band gap of silicon.

It is seen in Fig. 7 that there is a thermal anomaly in the plate C-2 of Sample-2. Such a distinct anomaly is also seen in the electroluminescence image (Fig. 8) at C-2 of Sample-2. Such an anomalous point is considered to be an electrically defective portion. On the contrary, the extraordinary portions of the photo-voltage of sample-1 (see Fig. 5) of photo-voltage seen in the rows C and D of Sample-1 do not agree with the anomalous points which are seen in the infrared pictures Fig. 7 and Fig. 8.

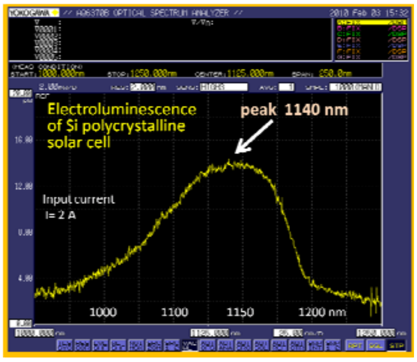


Figure 9 Spectrum of the light emission from silicon polycrystalline solar cell sample used in the experiment.

However, the anomaly at C-2 of Sample-2 observed in Figs. 7 and 8 is not seen on the photovoltage curve in Fig. 5 for Sample-2 (row C). It is not clear at present why there is a discrepancy between the experimental results obtained by our LED spotlight scan method and that obtained by the infrared image methods. It is conceivable that the anomaly in thermograph corresponds to internal short-circuit. On the other hand, the anomalous portions observed by the EL image and the LED spotlight method may relate to internal open-circuit defects in the silicon plates.

6 Conclusion

It is demonstrated in this study that our LED spotlight scan method is a new tool to diagnose the quality of silicon solar cell. Using this method, we can find some electrical defect in the solar cell. However, the defect detected by this method does not necessarily coincide with the defect by conventional infrared image observation method. Therefore, we should evaluate the quality of solar cell using the both methods.

Acknowledgements The authors thank Yokogawa Electric Co. and Hamamatsu Photonics K.K. for their help in the measurement of optical properties of silicon solar cell.

Reference

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