Non-Destructive Displaying Defects for Luminescence Image of Photovoltaic Panel Arrays

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***Abstract*— The non-destructive displaying defects of luminescence imaging is presented for inspecting silicon solar cell characterization of photovoltaic panel. The displaying system with photoluminescence can be applied to cleaning robotic device for tracing panel defects after cleaning photovoltaic panel arrays. A comparison method of the photoluminescence images with various illuminations has high sensitivity to reveal micro crack defect by image filter and threshold processes. It is simple to display the micro crack of commercial photovoltaic panel by non-contact inspection of photoluminescence.**

I. INTRODUCTION

The photovoltaic system requires high performance electricity depending on operation and maintenance technology for more 20 years of long-term lifetime. The photovoltaic panel of system works as non-idea silicon semiconductor junction and degrades with defects related to physical properties, diffusion lengths, minority carrier densities and lifetimes [1-5]. The current-voltage curve of photovoltaic panel can be simulated by equivalent circuit model within photo-generated current, ideal recombination dark current of p/n junction, series resistance, shunt resistance and non-ideal recombination current of depletion region [6]. A non-destructive method of defect inspection is applied to specific spatial distribution and to equivalent circuit model by illumination intensity of photoluminescence [7-8]. Therefore, the system owner periodically cleans photovoltaic panels and checks the system component by visual or thermal inspections. Anderson et. al. presented the robotized system with two motorized trolleys and a cleaning head driven by a belt for cleaning photovoltaic panel arrays at large scale solar parks [9]. In the field the operation and maintenance need both cleaning and inspection by the automatic robotic device.

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This paper proposes non-destructive displaying defects within cleaning robotic device for inspecting silicon solar cell characterization of photovoltaic panel by the comparison method of the photoluminescence images with various illuminations. After cleaning and inspecting the micro crack of photovoltaic panel can be easily obtained to observe its long-term reliability.

II. SPATIALLY RESOLVED DEVELOPMENT

A. Non- Destructive Displaying Defects

For photovoltaic panel testing TamizhMani rates the failure analysis of the qualification test results of ASU-PTL as compared to the 1997-2005 period according to IEC 61215(edition 1-1993)與 IEC 61215 (edition 2-2005) [10]. In both crystalline silicon and thin-film modules, the results shows higher percentage of failure in the 1997-2005 and 2005-2007 periods are attributed to the market entry including failure rates of the wet resistance test (5% vs 2%), damp heat test (29% vs 8%), bypass diodes test (31% vs 4%) and humidity freeze tests (12% vs 0%), and thermal cycling test (11% vs 6%). Base on failure analysis of testing results, the photovoltaic panel condition is important to operation and maintenance in real field. The non-destructive inspection method needs sensitively to display defects [11].

B. Defect and Inspection Signals of Silicon Solar Cell

The homogeneous irradiation of the entire silicon solar cell is presented in the wavelength range from 300 nm to 1100 nm. Different cameras can be used to detect radiation in different wavelength ranges as band-to-band (B2B) luminescence located around 1.1μm, dislocation luminescence from approximately 1.2μm to 1.6μm and thermal radiation of >3μm [12-13]. The B2B luminescence can be detected with silicon sensors and with InGaAs sensors. The detectors for dislocation luminescence and thermal radiation are InGaAs and InSb/HgCdTe, respectively.

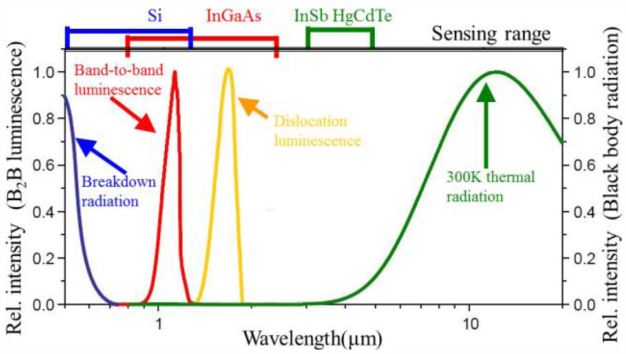

Figure 1. Spectral range and mechanisms of photon emission from silicon solar cell and the detectors used in its contribution

C. *Method Overview for Displaying Defects*

There are many imaging methods of displaying defects for fast and spatially resolved silicon solar cell characterization as shown in Figure 1.

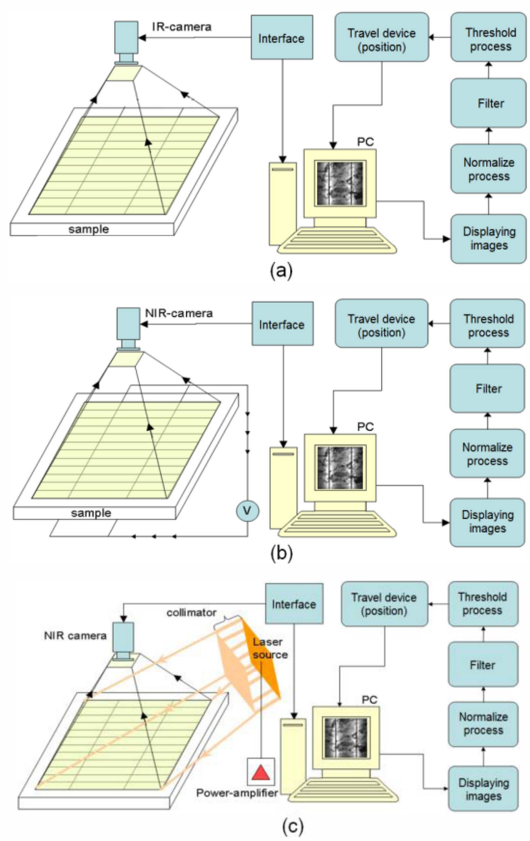

Figure 2. The imaging setups for displaying defect: (a) infrared ray imaging, (b) electroluminescence imaging, (c) photoluminescence imaging

Fig. 2(a) shows that the infrared ray imaging reads the temperature changes in resistance relate to thermal radiation by IR-camera (infrared ray camera). Fig. 2(b) presents solar cell luminescence as light emitting diode under driving voltage by NIR-camera (near infrared ray camera). For Fig. 2(c) the solar cell is illuminated by photoluminescence system with exciting light source and displaying by NIR-camera.

III. Non- Destructive Inspection

A. *Non- Destructive Inspections and Defect Imaging*

For Fig. 3(a) infrared thermography has been widely used in various domains to measure the temperature distributions of photovoltaic panel by IR-camera, but it is not sensitive to micro crack distinction. Solar cell inspection by machine vision with InGaAs NIR-camera reveals high sensitive image in silicon solar cells. Beyond finding physical defects, solar cell inspection of electroluminescence (EL) and/or photoluminescence (PL) permits actively finding micro crack with non- destructive inspection as shown in Fig. 3(b) and 3(c).

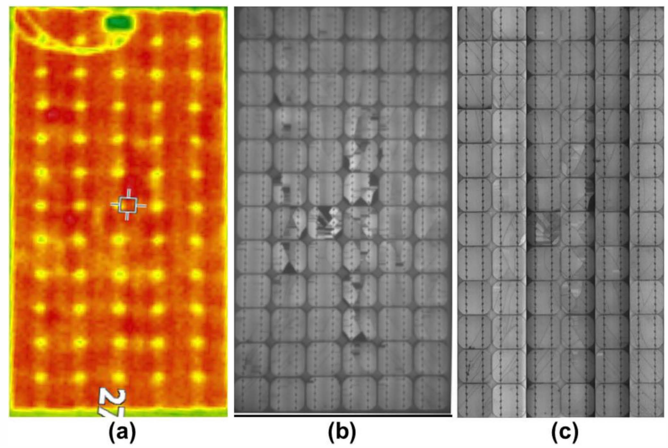

Figure 3. The imags for displaying defects: (a) infrared ray image, (b) electroluminescence image, (c) photoluminescence image

B. *The Signals of Photoluminescence for Silicon Solar Cell*

The photon flux excited by photoluminescence of n-type solar cell

$$\Phi_{PL,n} = A_i \cdot B(T)\left[n \cdot p - n_o \cdot p_o\right]$$

n is electron generated by illumination in the n-type region of solar cell and p is hole generated by illumination in the n-type region of solar cell. n_0 is electron in the n-type region of solar cell and p_0 hole in the n-type region of solar cell.

$$n = n_o + n_a + n_D$$

n_a is electron generated by illumination in the n-type layer of the solar cell and n_D is electron generated by illumination in the depletion region of the solar cell

$$p = p_o + p_a$$

p_a is hole generated by illumination in the n-type layer of the solar cell. The photon flux excited by photoluminescence of p-type solar cell $\Phi_{PL,p}$

$$\Phi_{PL,p} = A_i \cdot B(T)\left[n' \cdot p' - n'_o \cdot p'_o\right]$$

n' is electron generated by illumination in the p-type region of solar cell and p' is hole generated by illumination in the p-type region of solar cell under illuminations by photoluminescence. n_0' is electron in the p-type region of solar cell and p_0' is hole in the p-type region of solar cell.

. C. *Photoluminescence for Silicon Solar Cell*

The setup of photoluminescence used for near infrared imaging is shown in Figure 4. In the measurement where illumination and dark room is required, the excitation irradiated with laser in the wavelength range of 790nm to 920nm. The active area of photo-illumination is 6 squre foot as a solar cell, and detection by NIR-camera (Andor, iKon-M series).

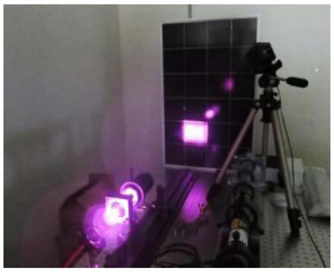

Figure 4. The Photoluminescence system

The displaying system with photoluminescence can be applied to cleaning robotic device for tracing panel defects after cleaning photovoltaic panel arrays. The robotic device includes many units, general of support vehicle, drive of travel, control of operation, maintenance of consumables, cleaning of array capacity and photoluminescence system of displaying defect.

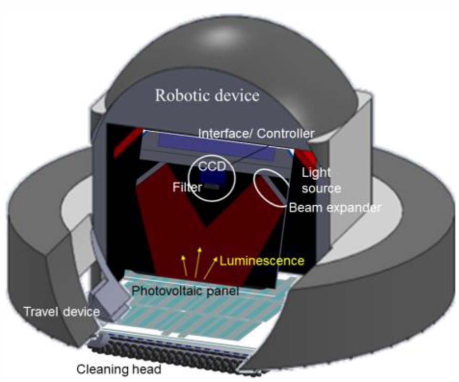

Figure 5. The Photoluminescence system within robotic device

IV. MICRO CRACK INSPECTION AND DISPLAYING SENSITIVITY FOR ROBOTIC CLEANERS

A. *Robotic Cleaners*

Robotic device can make photovoltaic panel clean and defect inspection easier by providing an automated hand with operation and maintenance. The system consists of three main components of travel motions, cleaning units and photoluminescence system. The robotic cleaner can get micro crack displaying images after cleaning photovoltaic panel and reconstruction the image of full panel according to travel positioning system as shown in Fig. 6.

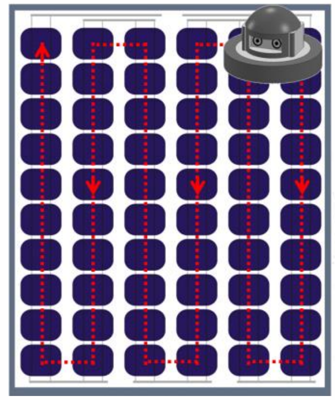

Figure 6. The travel and inspection by robotic device

B. *Displaying Sensitivity with Photoluminescence Images with Various Illuminations*

The image frames per output transfer to threshold via image process of normalize, pixelize, extension, filter and thresholding. A comparison method of the photoluminescence images with various illuminations has high sensitivity to reveal micro crack defect by photon counting images. The photoluminescence intensity is expressed in the gray scale and the signal is obvious to bus bar, grain boundary, finger and crack by two illuminations comparison. Compared with the various illumination cracks, the crack has a profound effect on intensity.

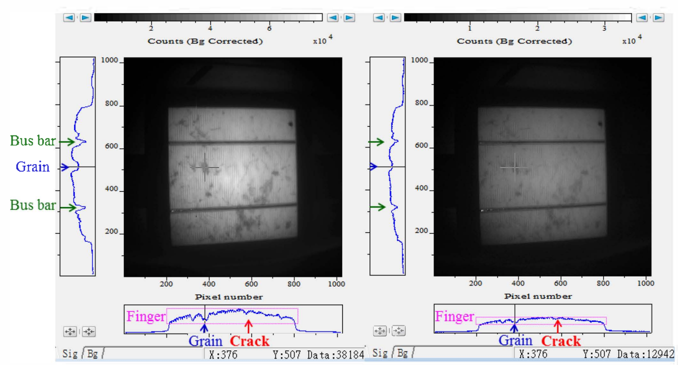

Figure 7. The Photoluminescence system within robotic device

The photoluminescence image with various illuminations is demonstrated in which the deficiencies in one frame of direct measurement can be clearly detected by thresholding displaying with non-contact tools. It could be shown that cracks or defects in photovoltaic panel were detected within very short time less than 1s at room temperature as shown in Fig. 8. After the field such as heat cycle or wind warping and micro crack were detected clearly and the result demonstrated that photoluminescence have the potential of field inspection within robotic cleaners.

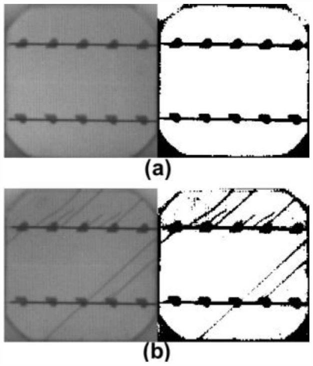

Figure 8. The sensitive threshold displaying after image process: solar cell (a) without micro crack, (b) with micro crack

C. Displaying Micro Crack Defect of Photovoltaic Panel

The full-size photovoltaic panel can be easily obtained by rearranging photoluminescence images as travelling 6*10 cell positions. The photoluminescence images with various illuminations and are presented by threshold image process for the detection of micro crack defects in the photovoltaic panel.

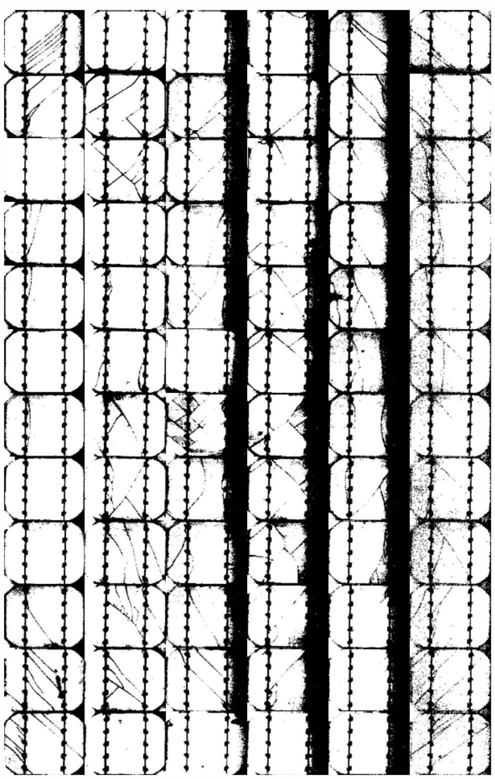

Figure 9. Displaying micro crack defect of photovoltaic panel

V. Conclusion

The photoluminescence images with various illuminations are presented by threshold image process for the detection of micro crack defects in the photovoltaic panel. The displaying system with photoluminescence can be applied to cleaning robotic device for tracing panel micro crack after cleaning photovoltaic panel arrays. The full-size photovoltaic panel can be easily obtained by rearranging photoluminescence images as travelling 6*10 cell positions. It is simple to display the micro crack of commercial photovoltaic panel by non-contact inspection of photoluminescence.

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References

[1] Isenberg J., S. Riepe, S.W. Glunz, and W. Warta, Imaging method for laterally resolved measurement of minority carrier densities and lifetimes: Measurement principle and first applications, Journal of Applied Physics, Vol. 93, no. 7, pp. 4268-4275, 2003.

[2] Bail, M., J. Kentsch, R. Brendel, and M.A. Schulz, Lifetime mapping of Si wafers by an infrared camera [for solar cell production], in Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth IEEE., pp. 99-103, 2000.

[3] Würfel, P., T. Trupke, T. Puzzer, E. Schaffer, W. Warta, and S.W. Glunz, Diffusion lengths of silicon solar cells from luminescence images, Journal of Applied Physics, Vol. 101, no. 12, pp. 123110, 2007.

[4] Giesecke, J., M. Kasemann, M.C. Schubert, B. Michl, M. The, W. Warta, and P. Würfel, Determination of Minority Carrier Diffusion Lengths in Silicon Solar Cells from Photoluminescence Images, in Proceedings of the 23rd European Photovoltaic Solar Energy Conference., Valencia, Spain, 2008.

[5] Sze, S. M., Ng, Kwok K., Physics of Semiconductor Devices, John Wiley & Sons Inc, ISBN：0471143235, 2006.

[6] E.E. van Dyk, , E.L. Meyer, Analysis of the effect of parasitic resistances on the performance of photovoltaic modules, Renewable Energy, Vol. 29, pp. 333–344, 2004.

[7] Chung T. Y., Chung Y. C. and Chen S. H., Specific series resistance evaluation using photoluminescence signal of Si solar cells, Optics Express, Vol. 20, No. S6, pp. A822-A827, 2012.

[8] Trupke, T., Influence of photon reabsorption on quasi-steady-state photoluminescence measurements on crystalline silicon, Journal of Applied Physics, Vol. 100, no. 6, pp. 063531, 2006.

[9] Anderson M., Grandy A., Hastie J., Sweezey A., Ranky R., Mavroidis C., Robotic device for cleaning photovoltaic panel arrays, Department of Mechanical and Industrial Engineering, Northeastern University, (http://www.coe.neu.edu/Research/robots/papers/CLAWAR09.pdf)

[10] G. TamizhMani, B. Li, T. Arends, J. Kuitche, B. Raghuraman, W. Shisler, K. Farnsworth, J. Gonzales, A. Voropayev and P. Symanski, Fauilure analysis of design qualification testing: 2007 VS. 2005, in IEEE Photovoltaic specialists conference, San Diego, CA, USA, 2008.

[11] Shravan Kumar Chunduri, Displaying defects, Photo International, January, p. 150-160, 2009.

[12] Kasemann, M., W. Kwapi et. al, Spatially resolved silicon solar cell characterization using infrared imaging methods, in IEEE Photovoltaic specialists conference, San Diego, CA, USA, 2008.

[13] Kasemann, M., W. Kwapil et. al, 2008 Progress in silicon solar cell characterization with infrared imaging methods, in IEEE Photovoltaic specialists conference, San Diego, CA, USA, 2008.