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Identification and Characterization of Solar Cell Defects using Thermal Imaging

Neel Kamal, Vineet Shekher, Surya Deo Choudhary, Vikash Tiwari

Abstract**:** ***Solar energy has been a basic need since aware of the energy crises throughout the world. Now the researchers are turning toward solar photovoltaic (PV) power system for future energy needs. However, some drawbacks of the field testing are existing with photovoltaic modules such as cost and heavy dependence on the weather conditions. The problems associated with photovoltaic system are the non-linear supply of power and it leads to complexity in matching the load. The PV solar module produce the nonlinear that changes with the variation in solar irradiance during entire day. Research work is on improving the performance, quality and reducing its cost. Researchers face the challenges in fabrication and materials used and due to this fact its performance decreases. In this paper, a method has been introduced to locate shunts using thermal images. IR inspection is used to observe the location of such shunts. After the electrical testing and measurements of the characteristics, the effect on degradation on solar cell materials from light IV curves and dark IV curves has been depicted. The shunts are isolated and performance is tested again and compare to observe.***

Keywords: ***Edge etching, IR camera, Hot spot, Thermography in Solar Cell***

Abbreviations: PDMS, Polydimethylsiloxane; IR, Infra-red; ITO, Indium Tin Oxide; PV, Photovoltaic.

I. INTRODUCTION

The photovoltaic effect converts solar photovoltaic energy into electrical energy in semiconductors. It is a clean renewable energy to reduce the energy crisis without any harm. Different fabrication methods of photovoltaic solar cells have been developed and their performances are characterized. Researchers are looking forward to develop materials and structures to obtained higher conversion efficiency. The solar energy conversion is leading fast. Attempts have been made in positive direction to prove the significant role of solar energy in society.

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***** Correspondence Author
Neel Kamal*, Associate Professor, EEE, Noida Institute of Engineering & Technology, Greater Noida, India Email:drsaini25aug@gmail.com
Vineet Shekher, Associate Professor, EEE, Noida Institute of Engineering & Technology, Greater Noida (vshekher2407@gmail.com)
Surya Deo Choudhary, Assistant Professor, ECE, Noida Institute of Engineering & Technology, Greater Noida (suryadeo.bit@gmail.com)
Vikash Tiwari, Assistant Professor, EEE, Noida Institute of Engineering & Technology, Greater Noida (vikashwish@gmail.com)

Figure 1 shown is the equivalent circuit of photovoltaic cell consist of series resistance (RS), shunt resistance (RSh) and the diode and current source.
When the photovoltaic cell is illuminated, it generate electrical current which flow in diode and in shunt.

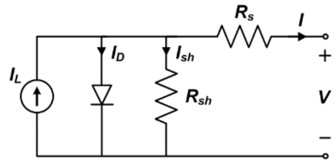


Fig.1 Solar cell Equivalent circuit

Its output current is:

$$I = I_L - I_D - I_{sh} \quad (1)$$

And the output voltage (V) is:

$$V = V_i - I.R_S \quad (2)$$

V_i is diode voltage and shunt resister R_{Sh}
According to Shockley diode equation the current will be:

$$I_D = I_0\left\{\exp\left[\frac{qV_j}{nkT}\right]-1\right\} \quad (3)$$

$$I_{Sh} = \frac{V_j}{R_{Sh}} \quad (4)$$

Where I_0 is the reverse saturation current, n is ideality factor, Q is the charge, k is Boltzmann`s constant and T is absolute temperature. Therefore Equation (1) can be further write as follows:

$$I = I_L - I_0\left\{\exp\left[\frac{q(V+IR_S)}{nkT}\right]-1\right\} - \frac{V+IR_S}{R_{Sh}} \quad (5)$$

Equation (5) is the relation between current (I) and voltage (V).

A. Effects of shunts

According to O. Breitenstein in 2004, [8] there are nine main shunts in silicon based solar cells. Out of which, six are process induced shunts and rest three are materials induced shunts. Low value shunt resistance affect the performance of solar cell. With the variations in shunt resistance, the voltage also varies. Slope of the curve affect significantly by the variation in shunt resistance. Low shunt resistance produces low fill factor. The reduction in shunt resistance leads to the improvement in the efficiency [2]. The presence of shunts in solar cell affect their performance.

B. Origins of shunts

Researchers always focus on the development of solar cells with higher efficiency and lower cost. The shunts present in the solar cell due to the defects decreases the efficiency of solar cells. Due to the material defects like dislocations and impurities or processing induced, several types of shunts are found in solar cells.

II. METHODOLOGY & EXPERIMENTAL SETUP

The solar panels used for experiments were taken from Power Film Company using a-Si thin film solar cells. The methodology used to identify/characterize of shunts is as: 1. Cut samples and etch the edges for testing; 2. Inspect and set IR camera to locate the hot spots, 3. Testing for VI characteristics; 4. Etch selected hot spots and isolating the shunts; 5. Testing with IR camera again; 6. Electrical testing and data acquisition.

A. Camera Calibration

By using a thermal camera the images and measurements can be calibrated from the infrared radiation emitted from the sample. These measurements are considered as a temperature function. The camera receive the radiation from the sample and from the reflection of surroundings, which is affected by atmosphere absorption. Hence, there are some other parameters like emissivity, reflection radiation e, which affects the temperature. The emissivity of the sample is evaluated using electrical tape and a hot plate.

The emissivity of the solar cells measured by his method was consistent with pre-defined values. The distance between sample and camera was 10 cm. The default humidity has been used at room temperature.

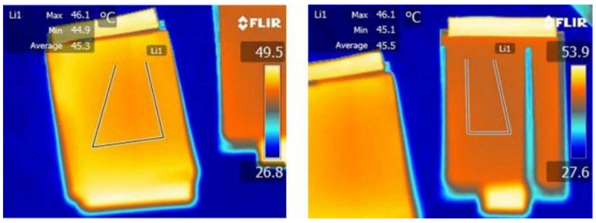


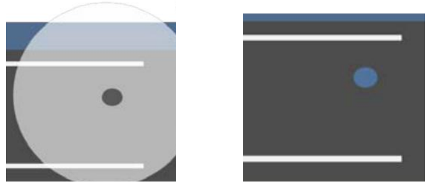
Fig.2 Sample with electrical tape and without electrical tape

B. Sample preparation

Solar cell should cut because it results in shunts at the edges. Hence, etching is required to remove the ITO. This can be achieved with an ITO etchant. Many etchants are being used but hydrochloric acid is the most effective. The acid solution attack the metal layer beneath the silicon layer results cracks around the edges and affect the entire performance of solar cells. Hydrochloric acid in aqueous solution with additional of nitric acid and zinc powder has been used to etch ITO.

C. Etching process and hot spot location

Using the technique optimized, the etching process has been performed. Tape to cover and protect the ITO and middle part was wrapped leaving the edges unwrapped. To identify hot spot, the cells have been connected to the bus bar area with tape. Hot spots has been identified using thermal camera by applying a bias on the cell. Due to big size of hot spots, these can be easily located and masked. A Poly-di-methyl-siloxane film has used as shown in Figure 3 (A).



A B

Fig.3 (A) Inspected sample and masked for hot spot etching and (B) Sample after etching.

After mask placing, an acid droplet fed into the hole in Polydimethylsiloxane (PDMS). After 15-20 seconds etching, the sample then rinsed with water and dried by nitrogen, as shown in the above Figure 3(B).

D. Measurement and characterization

Using the Lab View, amplifier and multimeter the V-I measurement has been conducted. Lab VIEW has been programmed to supply power. Voltage increments was swept in 0.2V. Using multi-meter the amplified current has been measured and then computer recorded. Stable light source is required for a precise measurement of the light V-I.

III. RESULTS AND DISCUSSION

A. Edge Etching

For the V-I measurement sample cutting play a very important role, as the solar cell was cut, all the surfaces deformed. Therefore the etching is required to remove such generated shorts. Before the sample cutting 1.5V forward biased voltage has been applied to the entire series of cells before the sample cutting. The hot spot has been showed the temperature at 28°C (Figure 4A). After cutting the edges (Figure 4B), defects at the edges found as evidence. All the shorts were removed in the thermal images after etching the edges as indicated in Figure 4C. The left edge has a darker color due to the removal of the thin conducting oxide layer.

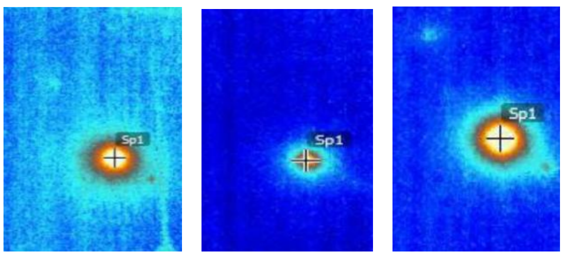


Fig.4. Images of the solar cell in forward bias of 1.5V (A) before cutting, (B) after cutting, (C) after edges etching.

VI characteristics in both cases of etching have been plotted, indicating that shunt resistances removed successfully by etching process. Figure 5 and 6, show the significant difference in dark VI curves before and after acid etching. Nearly linear curve obtained in figure 5 show the presence of severe shorts at the edges. After edges etching, the figure 6 shows the behavior of a diode under reverse bias, the current was not zero. This happen when a reverse-biased solar cell have more hot spots.

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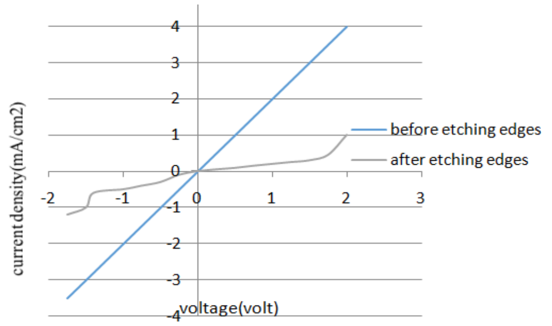


Fig.5. Dark VI curves before and after etching the edges

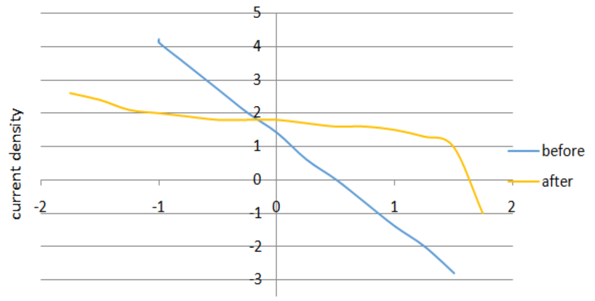
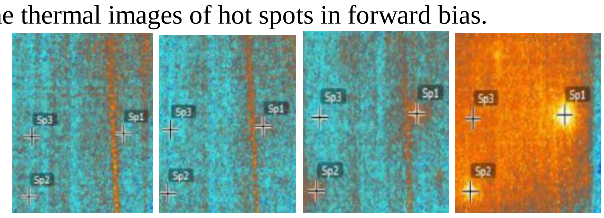


Fig.6. Light VI curves before etching the edges and after etching the edges

Shunt current and open circuit voltage remains due to photovoltaic effect of solar cell hence the fill factor is poor, around 25%. As the shorts are removed at the edges, both ISH and VOC increased results fill factor increased significantly. Series resistance indicate defects occurred in solar cell. By Light and dark VI curves and the thermal images, it can be concluded that shorts can be successfully removed by cutting edge due to the acid etching.

B. Thermal Imaging

The images obtained by thermal camera have been used to detect and locate hot spot. This method show the effect of eliminating the damage through etching. Figure 7 represent the thermal images of hot spots in forward bias.

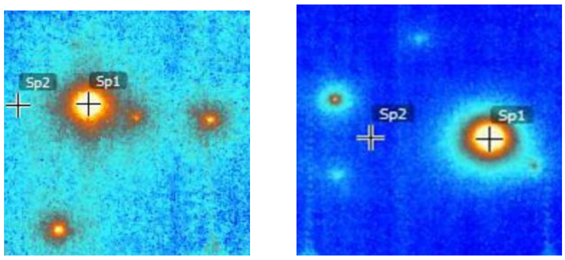


A B C D

Fig.7 Images of solar cell hot spots in forward bias of (A) 0 V; (B) 1.0V; (C) 1.5V; (D) 2.0V

Figure 7 showed thermal images of the same sample at the same position with the different forward bias of 0 V, 1.0V, 1.5V and 2.0V respectively. Figure 7A represent thermal image with 0 volt with forward bias showing no hot spots. As the increase of voltage, temperature of hot spot also increased. Figure 8 shows the different type of defects produce hot spots of different intensity.

Figure 8(i) shows the hot spot in forward bias of 1.6V and in Figure 8(ii) the hot spot is also under1.6V forward bias but hotter than the entire cell.

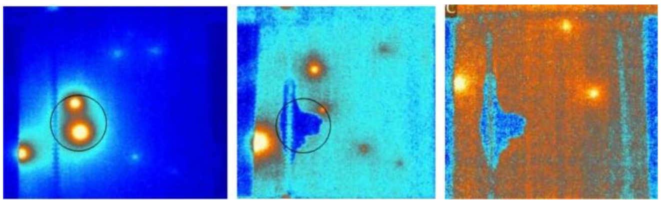


(i) (ii)

Fig.8. Images represent the two samples with primary hot spots in the forward bias of 1.6V. (i) Cell one; (ii) Cell two.

C. Effects of Hot Spot Etching

Etching play an important role in the process of removing the hot spot. After edge etching, the hot spots are also inspected with the thermal camera and selected hot spots can be removed by acid etching. Figure 9 shows thermal images the location and removal of hot spots indicating the effectiveness of etching in removing hot spots.



A B C

Fig. 9.Images (A) before etching hot spots, (B) after etching hot spots, (C) after a set of measurement, with the forward bias of 1.5V

VI curve obtained that the acid etch changed the performance of solar cell. Figure 10 shows dark VI curves measured before and after etching hot spots. The one observed before etching shows behaving somewhat like a natural resistor but after removing the hot spots, curve showed configuration like a diode.

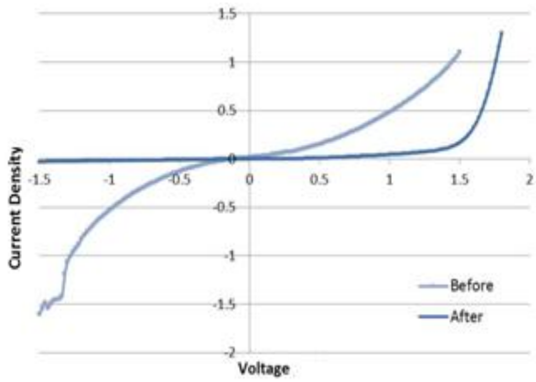


Fig.10. Dark VI curves measured before and after etching hot spots

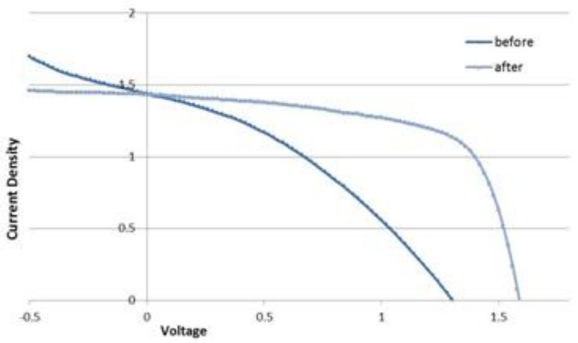


Fig.11. Light VI curves measured before and after etching hot spots.

Conclusion made by the table is that in presence of light source the open circuit voltage has been improved by 20%, the fill factor improved by 68% and maximum power has been improved by 96.8% at a specific light intensity.

Table: Show the improvement in solar cell performance with etching effect

	Before	After	Improvement
Isc	1.40 mA/cm^2	1.41 mA/cm^2	1%
Voc	1.30V	1.56 V	20%
FF	34.83	58.56	68%
Pmax	2.35mW	4.59 mW	96.8%

D. Characterization of Solar Cells

There are so many causes of hot spot formation like isolation of transition metals impurities with the silicon crystal during processing and fabrication. It can cause a diode breakdown if higher current passing through it. Clusters can form without a manufacturer defect. In addition to more manufacturing process causes defects in solar panels include scratches on the frame or glass, excessive or uneven glue marks and gaps. Shunt formation are taken place due to cracks and holes in the silicon layer. If there were holes and cracks before final coating process of TCO, it will lead to severe ohmic shunts. The holes and cracks are the primary cause of hot spots formation.

IV. CONCLUSIONS

Identification and characterization of solar cell shunts are systematically analyzed by using cut samples and etching process. Hot spots are inspected using IR camera and VI properties before and after etching has been examined and compared. Etching has physical significance and required to remove the generated shorts. After the etching process, shorts are found removed in the thermal images.

V. FUTURE SCOPE

Many etchants are available but presently, most effective ITO etchants is hydrochloric acid. The acid solution can also attack the metal layer beneath the silicon layer, which can made hydrogen and lift off the silicon. This results cracks on the edges and it shows the diverse effect on the solar cell performance. More etchants will be developed to use in sampling process of the solar cell etching to find out the shorts.

REFERENCES

1. Brian O'Regan, Michael Grätzel, "A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO2 films". Nature 353 (6346): 737–740
2. Dhass. A.D., Natarajan E., Lakshmi Ponnusamy, Influence of Shunt Resistance on the performance of solar photovoltaic cell, International Conference on Emerging Trends in Electrical Engineering and Energy Management, IEEE Conf, 2012, pp: 382-386.
3. A. Simo, S. Martinuzzi, Proc. 21st IEEE PVSC (Kissimee 1990)
4. G. Acciani, O. Falcone and S. Vergura, Analysis of the thermal heating of poly-Si and a-Si photovoltaic cell by means of Fem, International Conference on Renewable Energies and Power Quality, Granada (Spain), March, 2010
5. Keogh W, Blakers AW. Natural Sunlight Calibration of Silicon Solar Cells. 17th European Photovoltaic Solar Energy Conference. 2001
6. B. Sopori, Impurities and Defects in Photovoltaic Si Devices: A Review, 10th International Workshop on the Physics of Semiconductor Devices, Delhi, India, December 13, 1999
7. Isolde E. Reis, Stephan Riepe, Wolfgang Koch, et al., Effect of impurities on solar cell parameters in intentionally contaminated multicrystalline silicon, 24th European Photovoltaic Solar Energy Conference, 21-25 September 2009, Hamburg, Germany
8. O. Breitenstein et al, Shunt Types in Crystalline Silicon Solar Cells, Prog. Photovolt: Res. Appl. 2004; 12:529–538
9. Y. Chibal, A. Islam, Y. Watanabe, R. Komiya, N. Koide and L. Han, Dye-sensitized solar cells with conversion efficiency of 11.1%, Jpn. J. Appl. Phys. Vol. 45, 638-640 (2006)
10. I. Chung, B. Lee, J. He, R. P. H. Chang, M. G. Kanatzidis, All-solid-state dye-sensitized solar cells with high efficiency, Nature, 2012, 485, 486

AUTHORS PROFILE

Neel Kamal received his Ph.D. degree in Electrical Engineering from Mewar University, his Master of Technology from M. D. University, Rohtak, Haryana and his Bachelor of Technology from G. B. Pant University of agriculture and technology, Uttrakhand. Presently he is working as an Associate Professor in Electrical & Electronics Engineering department of Noida Institute of Engineering & Technology, Greater Noida, India. His research interest includes Renewable Energy, Power Electronics. He has published many National & International Journals in repute journals. He has attended various training programmes in the area of interest

Vineet Shekher received his Ph.D. degree in Electrical Engineering from BIT Sindri, Dhanbad under Vinoba Bhave University, his Master of Technology from Delhi College of Engineering under Delhi University. Presently he is working as an Associate Professor in Electrical & Electronics Engineering department of Noida Institute of Engineering & Technology, Greater Noida, India. His research interest includes Fractional Order Control System, Robust Control and Artificial Intelligence.

Surya Deo Choudhary received his Ph.D. degree in Electronics & Communication Engineering from B.R. Ambedkar Bihar University in 2014, his Master of Technology Degree from BIT Sindri, Dhanbad under Vinoba Bhave University in 2011 and his B. Tech. in 2008 from same University. Presently he is working as an Assistant Professor and Deputy Head of Electronics & Communication Engineering department of Noida Institute of Engineering & Technology, Greater Noida, India. His research Interests include Antenna and Microwave Engineering.

Vikash Tiwari received his M.Tech. Degree in Power Electronics, Electrical Machines & Drives from Lingayas University, Faridabad, Haryana, his B.Tech. in Electrical & Electronics Engineering from V.I.E.T., G. B. Nagar under Uttar Pradesh Technical University. Presently he is working as an Assistant Professor in Electrical and Electronics Engineering department of Noida Institute of Engineering and Technology, Greater Noida, India. His area of interest includes Electrical machines and drives control, nonlinear control system.