Express – analysis of Local Current Density Distribution Over the Area of PV Cells Using Thermovision Systems

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Abstract

The current density distribution over the area of photovoltaic cell is an important characteristic for at least two reasons. The first one - the homogeneity of the current density distribution characterizes the quality of solar cell production and second - the heterogeneity of the photocurrent distribution leads to local overheating of the solar cell and consequently decrease in its lifespan. The paper describes the methodology and experimental results of current density distribution research over the area of PV cell by thermovision-thermographic method. Silicon solar cells of different design where researched. Over the area of investigated samples, the spots of local Joule overheating are observed due to higher current density in these localities. The study of these spots by Laser Beam Induced Current (LBIC) method showed the presence of leakage current through p-n junction.

Keywords: *photovoltaic cell, thermal imaging system, infrared (IR) region of spectrum, forward- and back-biased diode, local leakage current, vertical multijunction solar cells, IR thermovision picture*

1. Introduction

The total peak power of photovoltaic (PV) stations is increasing annually by more than 20%. However, this power station lifespan remains twice less than those of atomic or thermal power station. The efficiency degradation of cells (and modules) is one of the main reasons of this. It is evident, that heterogeneity of the photocurrent distribution over the area of PV cell accelerates this degradation because of additional local overheating in spots with high current density.

Production of solar cells requires rapid and effective technology and function control of PV cells. Measurement of photovoltaic characteristics at the output of the production line is an integral feature of the functioning and technology. This measurement does not reflect the details of technology and in particular the important characteristics of the process uniformity for the plate area, which is important when increasing the area of the plates. The purpose of this paper is to identify the heterogeneity parameters of photoelectric conversion on the solar cell area by thermovision - thermographic method.

The method is based on the fact that any body with the temperature above absolute zero, in accordance with Planck's law, emits a continuous spectrum of electromagnetic waves. Infrared imager, sensing infrared region of the spectrum, forms the image. As the average temperature resolution of thermal imaging currently reaches 0.1 K (Weinreich, 2009), the presence of even small overheating will be shown in the infrared image.

2. Methodology of measurements

Si-monocrystal PV cell structure (and, accordingly, the built-in potential) was usual: on one side of p-type plate a diffused p-n junction was formed, on the other - a layer of p^+ for contacts. Photoelectric effect in PV cell is characterized by the current flow, arising from the absorption of solar radiation, through the PV cell built-in potential (if the load is connected to it). It is evident from PV cell equivalent model (Fig.1), PV cell heating is determined by R_{sh} ,R_{ser} resistances distribution over the area of the cell. Shunt resistance R_{sh} is connected in parallel with diode and characterizes the leakage currents of p-n junction, which should be minimal for high efficiency PV cell, i.e. resistance R_{sh} should be maximum. Series resistance R_{ser} is determined by metal - semiconductor contact resistance, n-layer distributed resistance and metallization routings resistance. It is important that all these parameters are distributed through plate area and completely depend

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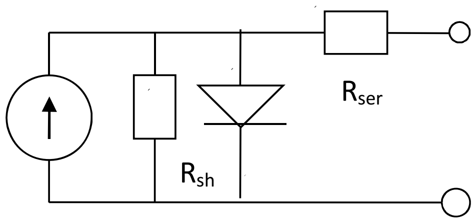

Fig.1: PV cell equivalent model

on the level and quality of photovoltaic production technology. Direct study of PV cell by thermovision system when illuminated by solar radiation or simulator is a complex task. The reason for this is the need to get rid of distracting reflections in infrared (IR) region of the spectrum that distort the IR image of the cell. In addition, silicon has high reflectance in IR region and hence low emissivity. Thus, it is necessary to ensure the flow of current through the PV cell in the absence of light illumination. This is achieved by applying voltage to the PV cell, provided that the contacts are ohmic. However, special measures should be taken to maximize the thermal contrast (Sviridov, 2002), including reflectionless arrangement. When the ratio R_{sh} / R_{ser} of order $10^2 – 10^3$ for usual PV cell and infinite generator resistance, the forward – biased (with respect to p-n junction) current will heat series resistance but reverse – biased will heat shunt resistance.

3. Research of ordinary PV cells

Si-monocrystal bifacial PV cell size (125x125) mm was selected for research. We used infrared NEC thermovision instrument TN5100 (HgCdTe time delay and integration detector, spectral range 8-12 mkm, minimum temperature sensitivity 0,05 K, field of view 20x30 °, working distance approximately 0,5 m).

Fig. 2-4 and Fig. 5-7 show IR thermovision pictures (TVP) of the mentioned above PV cell with current

Fig.2: TVP, *I*=0

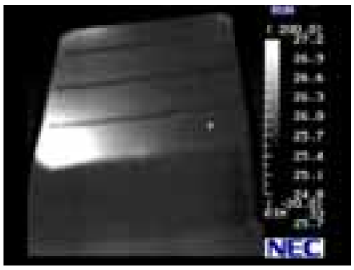

Fig.3: TVP, *I*= - 0,2A

Fig.4: TVP, *I*= +1,4A

I = 0, forward (+) and reverse (-) directions with respect to the p-n junction. Fig. 2-4 show thermovision picture of p-n plate side. Comparison of IR pictures shows that the uniform temperature background when I = 0 (Fig.2) changes significantly at the current I = - 0,2 A (Fig.3). There are three different degrees of heating. The greatest overheating occurs in the left front corner of the plate, weaker heating in the left rear corner and the weakest - in the right rear corner. Local current density in Fig.3 is determined by the differential resistance of back-biased diode in this particular place. Obviously, the overheating of the place is due to the increase in leakage current through the R_{sh} in these areas. In this case, according to the degree of heating, the strongest current flows in the left front corner, smaller current in the left far corner and the weakest in the right rear corner of the cell image. In the case of forward biased photodiode (Fig.4, I = +1,4 A), the heating picture, determined by R_{ser} as mentioned above, is more uniform. Only left front spot picks out. It can be assumed that here the shunt resistance R_{sh} is comparable to series resistance R_{ser} , which is caused by shot on the end face of the p-n junction. In addition, in the Fig.4 three dark metallization routings are clearly visible, the emission of which is due to the metallization significantly lower than that of silicon.

The p^+ side TVP of the same cell (sample inverted to the right) is represented by Fig.5-7. The same three

Fig.5: TVP, *I*=0

Fig.6: TVP, *I*= - 0,4A

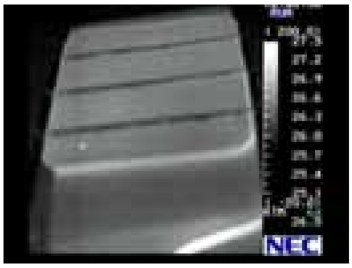

Fig.7: TVP, *I*= +1,8°

leakage areas through shunt resistance are observed with back bias (Fig.6), but to obtain the same temperature contrast picture, as in Figure 2, it is necessary to increase the current by two times (I = - 0,4 A). It confirms the fact that the source of the heating is on the lower (i.e. p-n) side of the cell. p^+ side of the cell, as would be expected, is heated uniformly with direct current (Fig.7), however, to get image contrast as in Fig. 4, the current must be increased (I = +1,8 A). In this case lower (p-n) side of the cell is warmer, as indicated by a significant reflection of the infrared light from the table in Fig.7. Note that the metallization routing on p^+ side is less clear than on p-n side (Fig.4); which may be caused by lower quality of contacts (e.g. non-ohmic) on the p^+ side of the cell.

These results confirm the use of thermovision system for PV cell technology analysis. Indeed, if in the technology process non-uniformity takes place in any area of Si-plate, heterogeneity arises (in p-n junction or tunneling in the metal-semiconductor contact due to, for example, pollution), the local current density at this point will change and it will lead to changes in temperature (Joule heat). Resulting local temperature inhomogeneities are fixed by thermovision system.

4. Comparative study of PV cell by thermovision system and LBIC

IR thermovision and LBIC methods are used for comparative study of 100 mm diameter cell with low efficiency of PV conversion (some less than 12%). Fig.8 shows TVP of this cell. The increase of temperature by 5 degrees corresponds to the transition from blue to raspberry color. The highest temperature is white color.

Fig.8: TVP 100mm cell

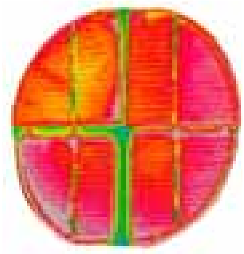

Fig.9: TVP catted cell

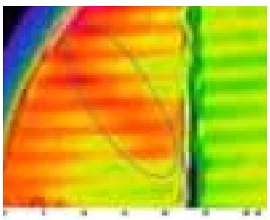

Fig. 10: TVP of upper left quarter

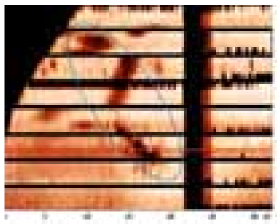

Fig.11: LBIC scan of upper left quarter

The characteristic features of the picture are: temperature increase is observed around the perimeter of the specimen, i.e. junction leakage currents increase from the center to the edges of the plate; there are local areas of high currents, for example, area 1; evident temperature non-uniformity of metallization routings.

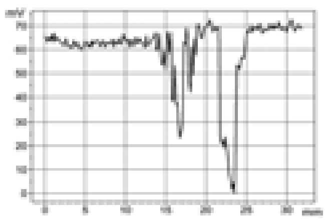

Fig.12: LBIC current along Fig. 9 red line

This PV cell was cut into four pieces for LBIC investigation. The corresponding TVPs are shown in Fig.9. The comparison of images in Fig.8 and Fig.9 shows that all the features of thermovision images remain. Upper left quarter of the cell with local inhomogeneity marked number 1 (Fig.9) was chosen for LBIC investigation using NT-MDT instrument «Spectrum». The field of scanning is ~ 20x35 mm. Fig.10 and Fig.11 show upper left quarter of cell and LBIC scan image of this area. In Fig.11 LBIC current reduction under laser illumination corresponds to the darkening of the picture. It is an evident coincidence of temperature increasing area (Fig.10) and low LBIC current (Fig.11), due to an increase in leakage current in the last case. Fig.12 shows LBIC current along red line on Fig.11. There is correspondence to Fig.11: the right line (21-25mm) is in keeping with highway and left (15-20 mm) conforms to the darkening (leakage current increasing).

5. Thermovision pictures of Vertical Multijunction Solar Cell

TVP of silicon Vertical Multijunction Solar Cells (VMSC) were also researched in IR region 3-5 mkm. VMSC are made by connection (soldering) in series of ordinary PV cells with continuous metallization on p- and n-sides of the Si-plate and consequent cutting of the pile perpendicular to the p-n junction plane (Strebkov, 2010). When illuminated, the light front is perpendicular to the plane of p-n junction but is not parallel as for ordinary planar PV cell. The main advantage of VMSC (production by usual planar Si-processing) is high voltage with density more than 15 V/cm.

In our experiments we research VMSC with 25 microelements in series on facial side of the cell. Methodology of image getting is subtraction of the picture without bias out of the picture with forward or reverse bias. Fig.13 shows TVP of VMSC with reverse bias and Fig.14 - TVP of VMSC with forward bias. Comparison

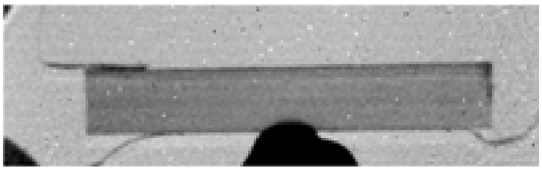

Fig.13: TVP of VMSC with reverse bias, V= - 30V, I= 10mA

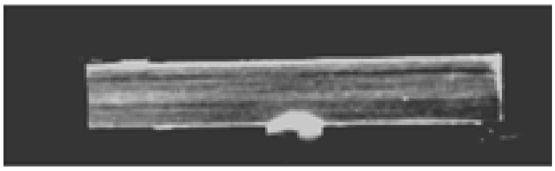

Fig.14: TVP of VMSC with forward bias, V= + 10V, I= 100mA

of these pictures leads to the conclusion about the inversion of temperature pattern. The reasons of this inversion require more detailed research. However, if we assume that the composition of the sample consists of microelements with different indices of ideality in the exponential diode characteristics, the ratio of the differential resistance will be inverted with forward and reverse bias. Accordingly, temperature pattern will also be inverted.

6. Conclusions

1. Thermovision-thermographic method is useful in inspection of PV cells quality and its production technology. Also, the functioning of solar power station in field conditions may be controlled to identify the faulty elements in the modules, substandard wiring and terminal connections, etc.

2. In the above procedure tests a lot of attention should be paid to the exclusion of side illumination, reflections, etc.

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