OPTICAL AND THERMAL ACTIVITIES OF MICRO-SIZED LOCAL DEFECTS ON THE EDGES OF SILICON SOLAR CELLS

Jiří Šicner

Doctoral Degree Programme (1), FEEC BUT

E-mail: xsicne02@stud.feec.vutbr.cz

Supervised by: Pavel Koktavý

E-mail: koktavy@feec.vutbr.cz

Abstract: The article deals with the diagnostics application to local defects on the edge in silicon solar cells by monitoring their optical and thermal activities during electrical excitation. During the measurement is solar cell connected to a voltage source in the reverse direction. Radiation generated from reverse-biased *pn* junction defects is used to study local properties. It proves to be useful to measure surface radiation and to make light spots (defects) localization. By the same way is possible to measure the radiation intensity and optical spectrum.

Keywords: Solar cell, local defect, nondestructive testing

1. INTRODUCTION

Photovoltaic, i.e. the direct conversion of solar energy into electrical energy, has an irreplaceable position in world of power engineering. Although the technological process of manufacturing solar cells is still intensively developed, produced cells have still many imperfections. In general, these defects arise from technological imperfections during fabrication process and/or in consequence of admixtures, dislocations a particle aggregation. These defects are needed to localize and to prevent their origin in the process because these defects subsequently significantly reduce the efficiency and reliability of the solar cells.

All measurements in this text are carried out on solar cells connected in reverse direction. Reverse bias operation seems to be non-standard for solar cells but if a certain part of the cell operating in a solar panel happens to be in a local shade, this particular cell will get into reverse-bias condition. Due to the existence of reduced breakdown voltage local defects, local breakdowns may occur in the neighborhood of the defects, which in turn may lead to heavy current densities in the low-cross-section regions. This phenomenon can give rise to a heavy local temperature increase and, consequently, local diffusion or thermal breakdown, which may result in the cell destruction. So, the final goal of our investigation is improving efficiency and reliability of the solar cells.

2. SOLAR CELLS UNDER INVESTIGATION IN DETAIL

Primary solar cells that we use are made from single-crystal silicon, of dimensions 10 × 10 cm and a thickness of 230 μm. The *p* and *n* (bottom and top-side, respectively) layers are formed by diffusion. The *p* type substrate is made by the Czochralsky process with the resistivity of about 1.2 Ωcm. The upper face of the cell is geometrically textured by pyramids to reduce the light reflection. A silicon nitride layer, which is laid on the cell surface, is intended to passivate the silicon surface and again reduces the reflection losses. The cells are designed for the solar panel fabrication. Both complete cells and their broken fragments have been studied but only selected results are presented here. The screen-printed silver paste metallization was used for contacts on the front side. The back side of solar cells has a structure of Al BSF with Ag/Al busbars. The *pn* junction is localized close to the surface and traces pyramidal texturization. The depletion layer width is about of 0.6 μm (without the applied bias voltage) [1].

3. USED TESTING METHODS

3.1. OPTICAL CHARACTERISTICS

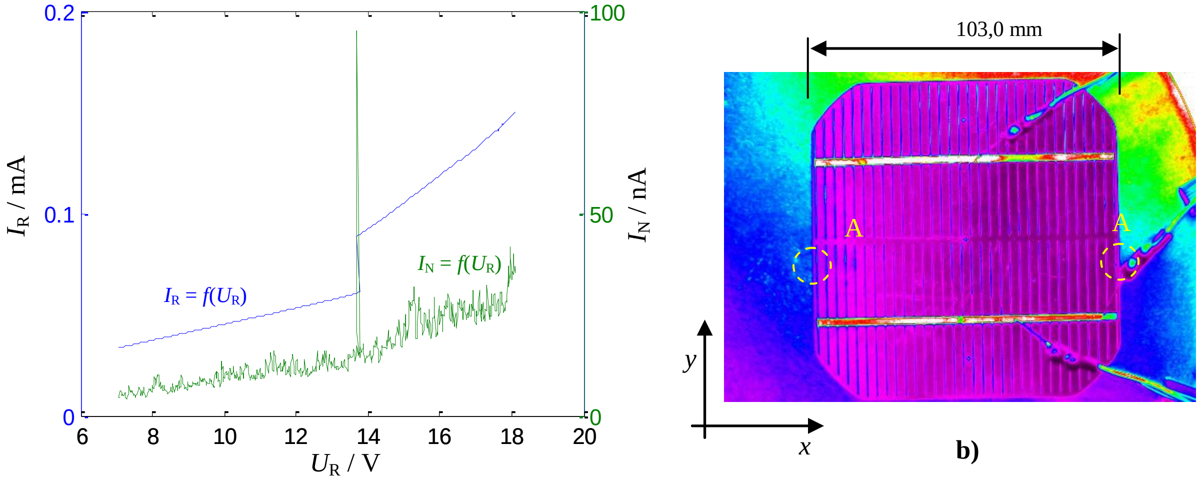
Radiation generated from reverse-biased *pn* junction defects or their neighborhood is used to study the near field or far field local properties. It proves to be useful to measure surface radiation and to make light spots localization, to measure the radiation intensity versus voltage plot, its correlation with other, mainly noise characteristics and radiation spectrum. A scientific CCD camera G2-3200 with a 3.2 MPx resolution was used for measuring of the radiation from a *pn* junction solar cell surface in optical far field. It uses a silicon chip cooled by dual system of Peltier's modules with the temperature down to -50 °C. Sufficient temperature for normal working mode is of -10 °C. The Dark current of an optical sensor and a single pixel is 0.8 e/s ($T = 0$ °C) and the doubling of its value is reached for a temperature rise of 6 °C. The dynamic range of the elementary pixels with a usable range up to 16 bits is very good. A camera lens with the focal ratio of 1.2 and the working aperture of 41.7 mm is used with the camera. It is possible to measure in the useful range of wavelengths of 300 nm – 1100 nm. Since the producer defines the spectral characteristics of the particular CCD chip, photometry measurements can be performed as in our case. The mean quantum efficiency <QE> = 0.51 is reached in the interval from 300 nm to 1100 nm. The peak value of the quantum efficiency is of 0.82 at the wavelength of 647 nm. Optical filters are included to an optical path to obtain the spectral characteristics. Automatic carousel system is equipped with filters to watch for visible and infrared radiation and in addition with interval filters separating the visible part of spectrum into red, green and blue parts. FWHM (Full Width at Half Maximum) of the filters are 150 nm and their optical response is calibrated. It is possible to include interference filters with FWHM of about 10 nm ahead of the lens. Detected radiation is relatively weak due to their high selectivity and this measurement is very technically and time demanding. The calibration is not performed separately for each of these filters, but measurement is carried out with the average spectral transmission function. The results are therefore correct in principle but we work with them in relative terms [1].

3.2. THERMAL CHARACTERISTICS

For measurement of thermal characteristics there was used infrared camera Micro-Epsilon TIM160 Infrared Process Imager. The 160x120-pixel detector and high-performance optics guarantee precise temperature measurements of target objects as small as 1.5 mm (3 pixels) at a measuring rate of 120 Hz. The IR camera has wide temperature range from -20°C to 900°C and spectral range from 7.5 to 13 μm. Thermal sensitivity is very good and starting from 80 mK.

4. RESULTS

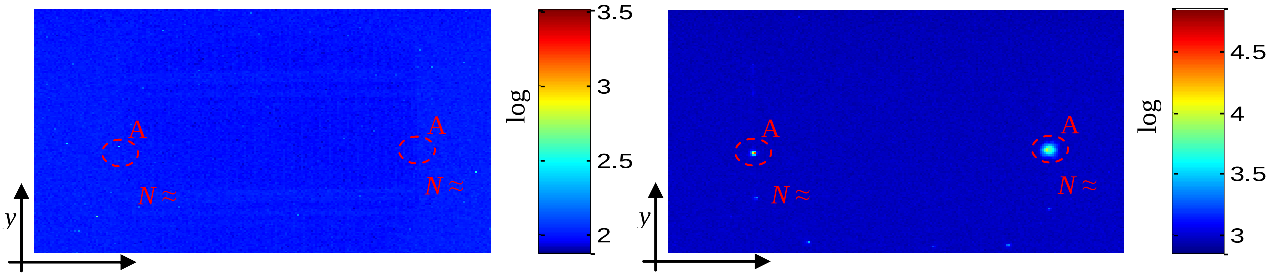
Presented research is focused on the defects localized on the edges of solar cells. Existing knowledge indicates that areas on the edges or near them are responsible for huge breakdowns, [3], [4]. This interpretation is supported by measurement of specimen X2 as presented below (see characteristics on fig. 1a and photography on fig. 1b).



a) b)

Figure 1: a) Narrowband noise signal and the reverse current dependence on applied reverse voltage U_R . Sample X2 at temperature T = 24.3 °C. b) Photo of solar cell X2 taken by a CCD camera with light bias

The measurements clearly show that after reaching a critical voltage there are two points, both on the edges (see fig. 2), and it is not obviously clear which of them dominantly contributes to the shape of characteristic. Nevertheless, important results are related to non-existence of bulk defects creating massive conductive channel [5]. In additional, in course of another measurement has not been found similar defects located close to the break-like edges. It means that the studied edges that were created by breaking solar cell seem to be much better quality than edges which are subjected to passivation process in production. Suggested results indicate that passivated edges by producer are not processed properly.



a) b)

Figure 2: a) State of photon emission before reaching the critical voltage (U_R = 11 V), b) after the breakdown (U_R = 16 V), T = 24.3 °C

This suggestion was supported by measurement of sample K20 (see fig. 3), where was found local defect at the boundary. Next we use again CCD camera with extraordinary lens and electron microscope to study minute details of the defect. As it can be seen from the detail in the figure 3, the defective area is located on the border between surface and edge of solar cell i.e. PN junction region. This fact can be very dangerous for lifetime of a solar cell.

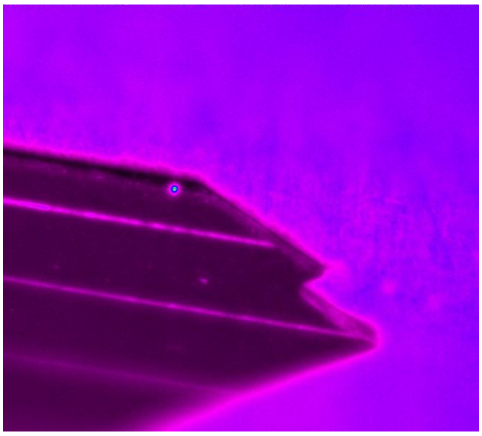


Figure 3: Detail of light emissions from defect on the edge. Sample K20 taken by CCD camera with light bias

As shown in fig. 4, sample K20 contains several significant local defects, but when examining the thermal radiation can be seen that the thermal degradation causes only defect on the edge (see fig. 4). When sample is connected to a reverse voltage 6V, the temperature at the defect on the edge increased by 4 °C and it is clear that at higher voltages may occur complete destruction of the sample. This finding was confirmed by measurements on many samples. We observed this type of structure defects by an electron microscope which could be assume as surface texturization break.

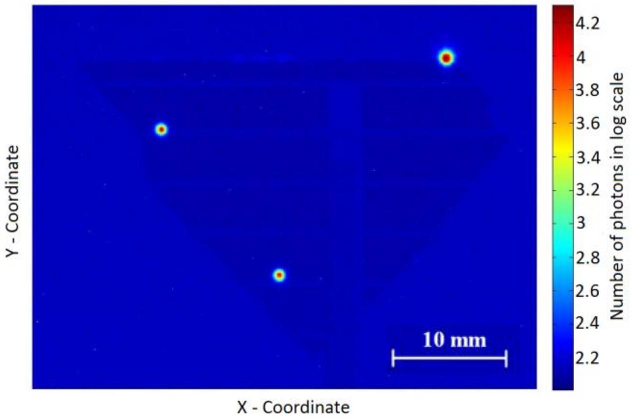


Figure 4: Photography of measured solar cell with light spots and their intensity, sample K20, reverse voltage 6 V

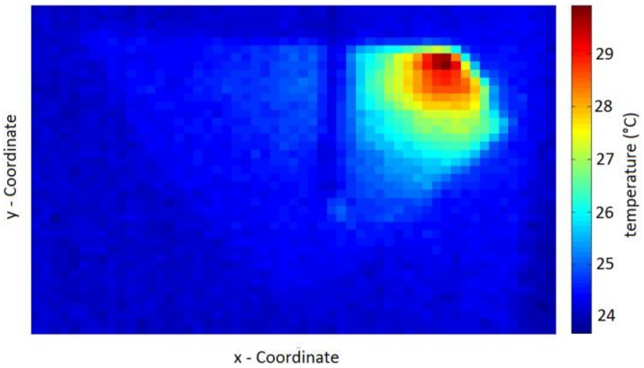


Figure 5: Surface temperature distribution, thermal flux induced by defect on the edge, sample K20, reverse voltage 6 V

5. CONCLUSION

We can conclude that light and thermal emission from reverse biased solar cell can reveal structure inhomogenities. Many defects exhibit radiation from a surface of solar cells. It proves to be useful to measure this radiation by means of the CCD camera. In this paper we focused on defects on the edge of solar cells. As we have shown, this type of defect can be very dangerous for efficiency and service life of solar cell. This approach proves to be useful to measure micro-scale surface imperfections and fractures. Important results are related to non-existence of defects creating massive conductive channel in geometrically similar form located in the bulk. Nevertheless, mass-produced crystalline material exhibits this type of defects very often. This points to the fact that the process of passivate the edges of solar cells is not ideal. An interesting fact is that the edges that are created by breaking solar cell does not contain this type of defect.

ACKNOWLEDGEMENT

This research has been supported by the Brno BUT Specific Research, by the Grant Agency of the Czech Republic within the framework of projects GACR 102/09/H074 "Diagnostics of material defects using the latest defectoscopic methods" and by the grant No. P102/10/2013.

REFERENCES

[1] KOKTAVÝ, P.; MACKŮ, R. Noise and Optical Activities of Local Defects in Solar Cells pn Junctions. In ICNF2011: 2011 21st International Conference on Noise and Fluctuations. 1. Toronto, Kanada: IEEE, 2011. s. 409-412. ISBN: 978-1-4577-0191- 7.

[2] MACKŮ, R. Analysis of photon emision from silicon solar cells and correlation with microplasma noise. In proceedings of the 17th conference student eeict 2011 vol. 3. Brno: Novpress, 2011. s. 417-421. ISBN: 978-80-214-4273- 3.

[3] CHYNOWETH, A. G., McKAY, K.G. Photon Emission from Avalanche Breakdown in Silicon. *Phys. Rev*, 1956, vol. 102, no. 2, p. 369 – 376.

[4] ŠKARVADA, P.; TOMÁNEK, P.; KOKTAVÝ, P.; MACKŮ, R. Light emission from silicon solar cells as characterization technique. In 2010 9th International Conference on Environment and Electrical Engineering. Wroclaw: Reprotechnika Wroclaw, 2010. s. 97-100. ISBN: 978-1-4244-5371- 9.

[5] PARAČKA, P.; KOKTAVÝ, P.; KRČÁL, O. Studium záření vznikajícího při lokálních lavinových průrazech PN přechodu solárních článků. In Non-destructive testing in engineering practice. 1. Brno: VUT v Brně, 2007. s. 97-101. ISBN: 978-80-7204-549- 5.