iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 Issue: VI Month of publication: June 2018

DOI: http://doi.org/10.22214/ijraset.2018.6108

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue VI, June 2018- Available at www.ijraset.com

Luminescence Diagnostics of Photovoltaic Cells

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***Abstract*: This work deals about diagnosis of photovoltaic cells by radiative recombination of electron-hole pairs. This radiative recombination is known as luminescence. Diagnostic methods using this local light emission in infrared region have innovative potential. The main area of this project research is focused on non-destructive analysis of radiated infrared radiation of monocrystalline and polycrystalline solar cells in modification of standard electroluminescence method.**

In this research the defects were detected at the bandgap luminescence level using a CCD camera. The spectral response of the CCD detector ranged from about 300 to 1100 nm. Method of photon emission microscopy (PEM) is used for magnification element. It is one of the modification of standard electroluminescence method. Local light emission inspection by microscopy should have benefit to qualitative evaluation of solar cells defects.

***Keywords*: Solar cell, silicon, luminescence, microscopy, defect.**

I. INTRODUCTION

The solar cell absorbs the radiation in both visible and near-infrared (energy above 1,125 eV) spectra. The silicon cell itself, however, exhibits only weak luminescence with a maximum in the infrared range. Emission intensity of photons depends on the number of defects in the solar cell, with higher number decreases. It is known that for non-destructive luminescence characterization of silicon solar cells is frequently used electroluminescence diagnostic method. It is a fast characterization method providing spatially resolved information about electrical, optical and material properties of solar cells. This basic diagnostic method can be used for example during the entire solar module production process, but it is also final inspection step to document the quality of the produced solar module [1].

The electroluminescence method (EL) is one of the most widely used luminescence methods for detecting defects. Its modifications are used across the semiconductor industry. In our research we will talk about PEM (Photon emission microscopy) method using.

II. PROJECT APPROACH

The main part of this work focuses on non-destructive analysis of radiated infrared radiation of solar cells in laboratory conditions. In the first part, selected samples were analysed by microscopic method of electroluminescence (see Figure 1.). This method is used to diagnose integrated circuits [2]. It is not used as standard in the diagnostics of solar cells. It was opportunity to new observations.

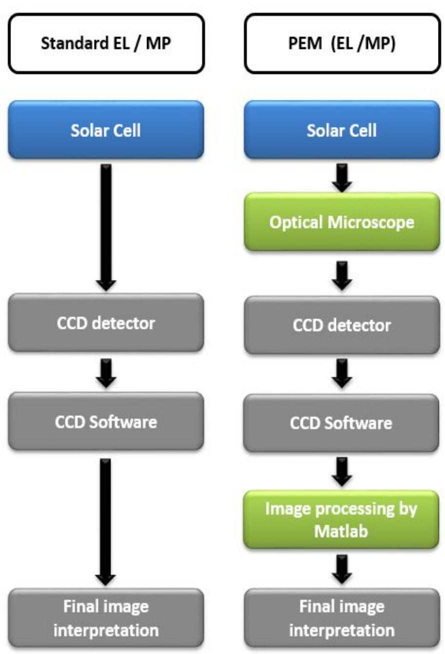

Fig. 1: Standard electroluminescence methods & PEM

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The goal of this method was to prove the magnification factor (microscopy) when displaying the local emission in the micro-area of the solar cell and its contribution to the qualitative evaluation of the defects. Standard electroluminescence method and PEM method are displayed in figure 1. Electroluminescence is called as EL and reverse-bias electroluminescence called as MP in Figure 1. An extended method of electroluminescence in the form of microscopic luminescence methodology for characterization of defects was measured in the practical part by monocrystalline and polycrystalline solar cells.

III. DESCRIPTION OF THE METHODS

As was mentioned before luminescence microscopy is used in the semiconductor industry to diagnose integrated circuits within a so-called FA (Failure analysis) analysis. This method belongs to non-destructive testing (NDT). Figure 2 shows a diagram of the workplace of luminescence microscopy. The physical principle is still the same as for standard electroluminescence. It is a physical action that is based on the principle of exciting luminescence radiation in a solar cell (surface P-N junction) with an enclosed electric field [3].

In Figure 2 can be shown that the Mitutoyo Optical Microscope is equipped with a CCD detector and NIR lenses [4]. Measurement takes place at room temperature (at dark box) and light emission is sensed by a CCD camera with a Hamamatsu S7170 detector.

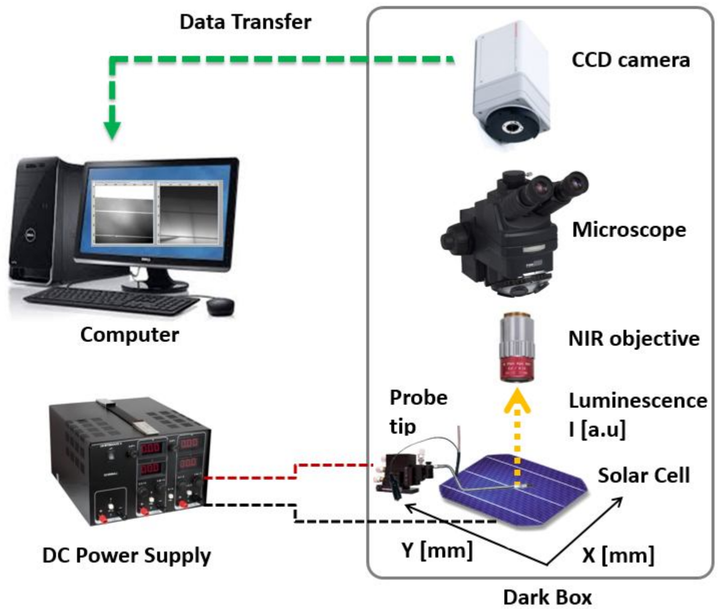

Fig. 1 Workplace of luminescence microscopy (PEM)

As the first innovator of standard electroluminescence method for solar cells, we can consider Takashi Fuyuki, who published a breakthrough article in the 2005: Photographic survey of the diffusion length of the minority carrier in polycrystalline silicon solar cells by electroluminescence [5].

IV. MEASUREMENT DATA

During the measurement of individual samples, EL and MP methods were differently adjusted for current and voltage values. For the measurement of samples by the method of luminescence microscopy the optimal setting in forward-bias (EL) and the reverse-bias (MP) according to Table 1.

TABLE I:
FORWARD-BIAS (EL) AND REVERSE-BIAS (MP) SETTING FOR PEM MEASUREMENT

Methods	Current and Voltage setting	
	Current [A]	Voltage [V]
Forward-bias electroluminescence (EL)	2	1.3
Reverse-bias electroluminescence (MP)	0.37	13

A. PEM analysis of Monocrystalline Solar Cells

A detailed examination of the mono silicon cells by PEM micro-scratches been observed, i.e. areas with damaged PN junction in the approximate length of about 100 microns (see in Figure 3.). This microdefects localized by microscopic electroluminescence method (see in Figure 3. – B and C), not by standard method electroluminescence. The zoom factor display local emissions at micro-area of solar cell thus brings qualitative benefit but at the laboratory level at the expense of time-consuming.

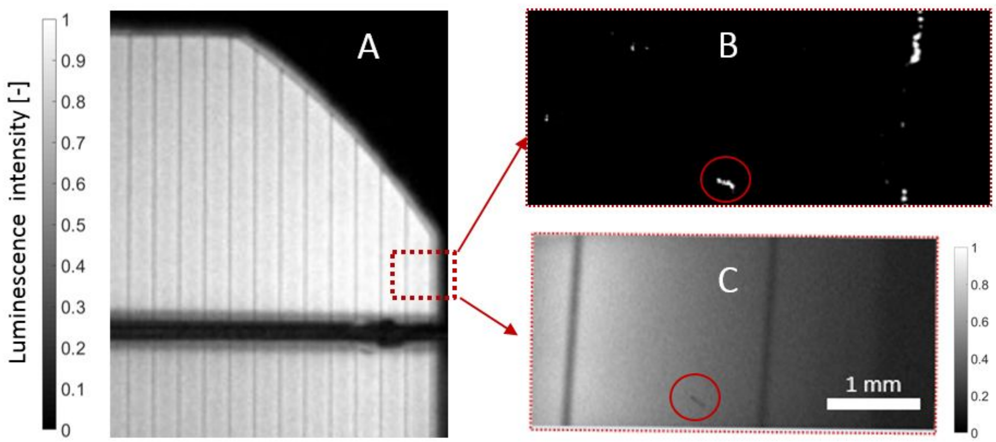

Fig. 3 Micro-scratches measured by standard electroluminescence (A), PEM in reverse-bias electroluminescence mode (B), PEM in forward-bias electroluminescence mode.

B. PEM analysis of Polycrystalline Solar Cells

Grain boundary topography, visualized by optical microscopy within the PEM apparatus, correlates precisely with the result of electroluminescence in the microarray. Figure 4 is divided to three parts. Part A is optic grain microscopy (within the PEM apparatus). Part B is PEM in reverse-bias electroluminescence mode and part C refer with PEM in forward-bias electroluminescence mode.

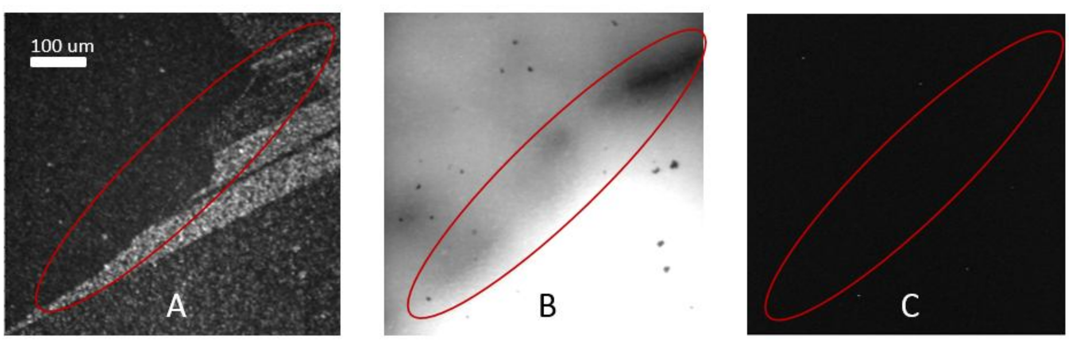

Fig. 4 Grain boundaries of polycrystalline solar cell by PEM

The PEM method in reverse-bias electroluminescence mode (see Figure 4 – C) complements and confirms the theory that micro-plasma occurs in places with mechanically disturbed PN junction, especially in areas of damaged surface, but also in some micro-cracks and damaged edges of solar cells. The resulting images of the surface topography of the solar cell and correlation with the PEM method in EL and MP mode lead to clear information about the origin of the defect. The defect in Figure 4 may be mistakenly referred to as micro-crack when using a standard electroluminescence method.

V. CONCLUSIONS

In the practical part of our research, selected samples were analyzed by standard (macro view) and by microscopic method of electroluminescence. This method is usually used to diagnose faults of integrated circuits and is known as PEM (Photon Emission Microscopy). It is not used as standard in the diagnostics of solar cells, as evidenced by the minimal publications in this area. During this project, the contribution of the magnification effect was evaluated and qualitatively evaluated when displaying the local emission in the micro-area of the solar cell.

The analysis by the microscopic method of electroluminescence has shown that it provides improved information in qualitative assessment of solar cells defectivity. Microdefects localized by microscopic electroluminescence method (PEM), not localized by standard methods of electroluminescence. The zoom factor display local emissions at micro-area of solar cell brings qualitative benefit in evaluation of solar cell but at the laboratory level at the expense of time-consuming.

VI. ACKNOWLEDGMENT

This research was supported by R&D project FEKT-S-17-4595 (Materials and technologies for electrotechnics III) at Brno University of Technology.

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