VARIATION OF ELECTROLUMINISCENT EMISSION OF SOLAR CELLS IN A WIDE TEMPERATURE RANGE

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Summary: In this article the alternations in the intensity of electroluminescent emission of monocrystalline silicon solar cells in a wide temperature range is studied. The article describes temperature influence on solar cells defect detection, measured by the electroluminescent diagnostic method. This study makes it easier to identify accommodating temperature to detect defects in solar cells by the electroluminescent measurement method.

Keywords: Emission, electroluminescence, solar cells, temperature dependence, processing defects, temperature control

1. INTRODUCTION

Due to the increasing demand of photovoltaic modules in the last 10 years, the photovoltaic industry had a major growth, including permanent development and optimization of photovoltaic technologies. During the operation of PV power stations, it is important that the parameters of PV panels have changed the least. This applies primarily to the efficiency of solar cells, what is the most affecting part of photovoltaic systems payback. Solar cells efficiency is influenced by their ability to absorb the energy of the incident light rays and further use of this energy to perform electrical work. Different types of material and manufacturing defects can affect the ability to use sunlight energy for electrical work. Therefore it is important to have some good diagnostic tools, which would be able to detect various types of defects, analyze it and minimize their impact.

Electroluminescence imaging is developing to an established tool for quality assurance in solar cell characterization. In this study, we classify the crystal defects by investigating the temperature dependence under forward-bias electroluminescent emission. As a result, electroluminescent intensity under forward-bias increased. We report that the classification of the defects is possible by analyzing temperature dependence of electroluminescence under forward-bias.

2. THEORY

The Electroluminescence (EL) imaging has been introduced a powerful and fast characterization tool providing spatially resolved information about the electronic properties in solar cells. EL images through different filters use effects of photon reabsorption to determine carrier profile. The EL intensity under forward-bias is proportional to the total number of minority carriers into Si substrates. The number of minority carriers decreases in the crystalline defect part, and EL emission decrease. The relation between the EL intensity under forward-bias and temperature dependence has been reported. Temperature significantly affects intrinsic deficiencies (e.g., crystallographic defects) than extrinsic deficiency (e.g., wafer breakage) since minority carrier diffusion length and lifetime depends on the electronic levels of traps. Therefore, when temperature rises, the EL intensity increase in the intrinsic deficiencies.

The electroluminescence emission due to irradiative band-to-band recombination at adjusted temperature of forward-biased monocrystalline silicon solar cells is surveyed with a CCD grayscale camera. Neglecting photon recycling, the measured photon current is directly related to the local quasi Fermi-level splitting $E_{Fn} – E_{Fp}$ according to:

$$\Phi_{EL} \propto \int_0^w U_{rad} dz = \int_0^w Bpn\, dz = n_i^2 \int_0^w B \exp\left(\frac{E_{Fn} - E_{Fp}}{k_B T}\right) \quad (1)$$

Where:

Φ_{EL} – is the photon flowing
U_{rad} – is the recombination rate [$m^{-}3\times s^{-1}$]
p – is the total number of holes [m^{-3}]
n – is the total number of electrones [m^{-3}]
n_i – is the intrinsic carrier concentration [m^{-3}]
$E_{Fn} - E_{Fp}$ – Fermi-level splitting [eV]
B – is the coefficient of radial recombination [-]
w – is the material thickness [m]
k_B – Boltzmann constant = 1.38×10^{-23}
T – temperature [K]

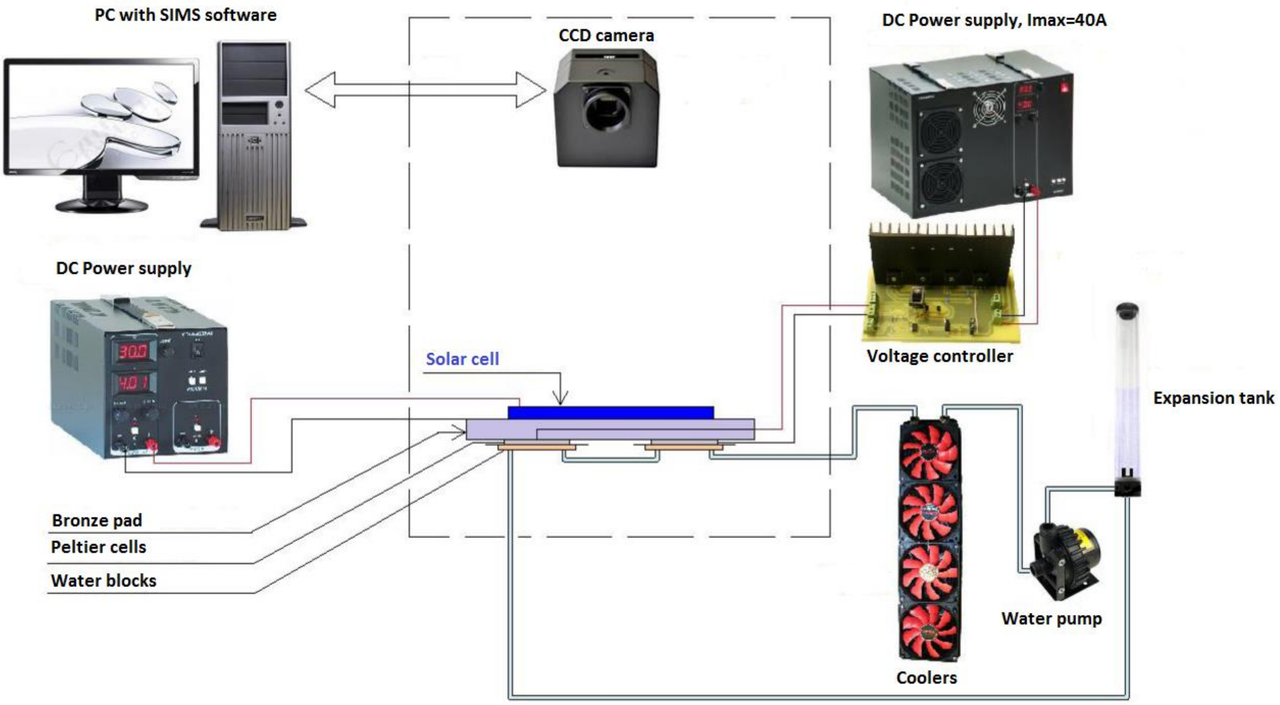

Figure 1: Measurement workplace of solar cells with temperature control

3. EXPERIMENTAL

Figure 1 shows the temperature controlled station for solar cells measurements. This workplace consists of a dark chamber with a bronze pad inside. The bronze pad is used for solar cell's heating and cooling. It is also used as a contact pole for a solar cell's power supply. To establish the desired temperature of the bronze pad are used Peltier cells with the voltage controller. The EL images of solar cells are captured with high-sensitive Si-CCD camera. CCD camera is used with IR filter on it's lens (the wavelength of 850 nm or less is cut), the exposing time is 240 s and applied forward current is 2.5 A. We have measured and analyzed 11 monocrystalline solar cells at temperatures 279 K, 285 K, 300 K, 313 K, 333 K, 343 K. All of the measured solar cells have material and processing defects. Figures 2-7 show EL image of a solar cell sample measured at different temperatures. The darker area in the center of the solar cell indicates the presence of a defect caused by the process of diffusion. Non-uniformity of the diffusion layer is better observed at EL snapshots of solar cell at high temperatures. This solar cell also has faulty contact in the lower right part and a mechanical damage in the upper right corner. After comparing of the EL images of solar cells obtained during the measurement, was found that intensity of EL emission is changing with temperature variation.

This phenomenon corresponds to the mechanism of temperature influence on electroluminescent emission in Si solar cells, which is described in the theoretical part.

4. CONCLUSION

This study shows, that EL imaging allows high-quality measurement of solar cells in the whole investigated temperature range 279-343 K. Further, can be stated the fact, that at temperatures higher then room temperature the total luminescence intensity increases. The experiment proves theoretical basis, corresponded to formula (1). With the temperature rising the photon flowing also rises. Due to that fact we can recognize higher electroluminescent irradiation from the solar cell surface at higher temperatures. At the same time a slight contrast decrease between non-defective and defective areas is observed. It can be positively used in the case of less sensitive detection equipment. However, care must be taken at high temperatures to avoid thermal damage or destroying of a solar cell. Unfortunately, our measurement workplace does not allow reaching very low temperatures. Therefore it was impossible to observe, at what temperature EL emission stops working. We can only assume, that at very low temperature EL imaging cannot be used.

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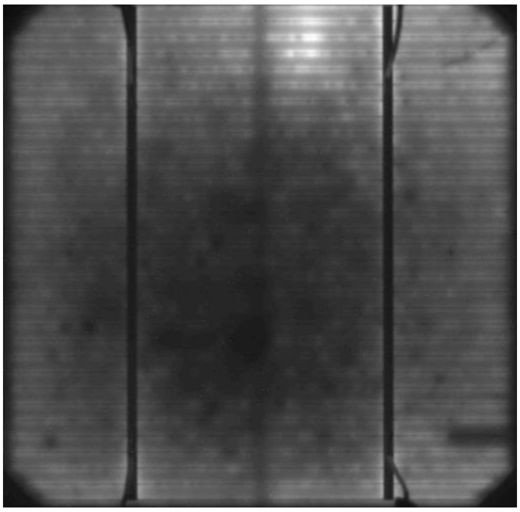

Figure 2 υ = 279 K I = 2,5 A t = 240 s

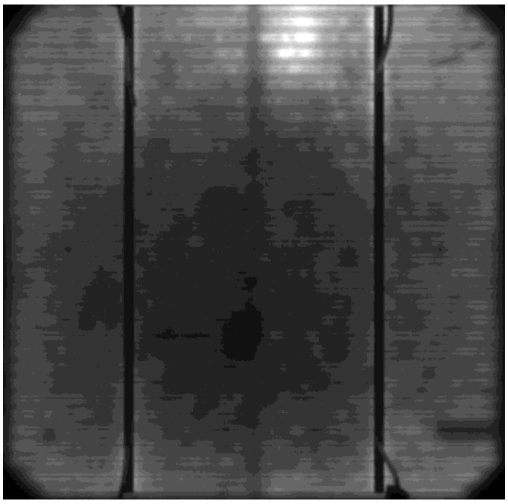

Figure 3 υ = 285 K I = 2,5 A t = 240 s

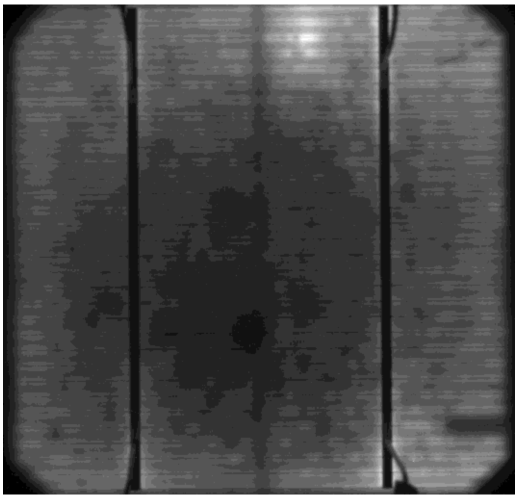

Figure 3 υ = 300 K I = 2,5 A t = 240 s

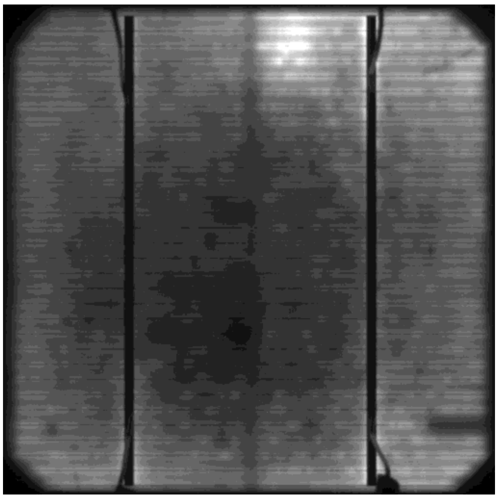

Figure 4 υ = 313 K I = 2,5 A t = 240 s

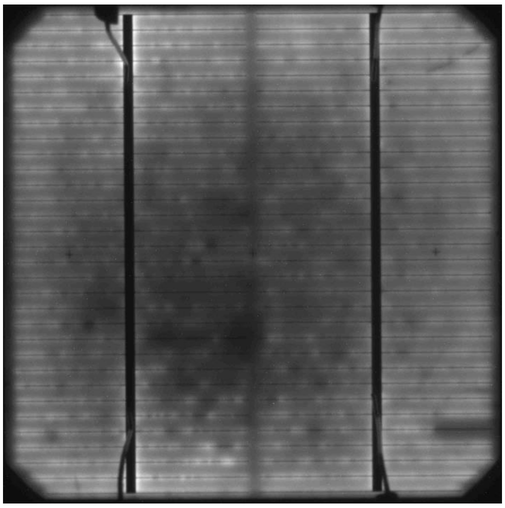

Figure 5 υ = 333 K I = 2,5 A t = 240 s

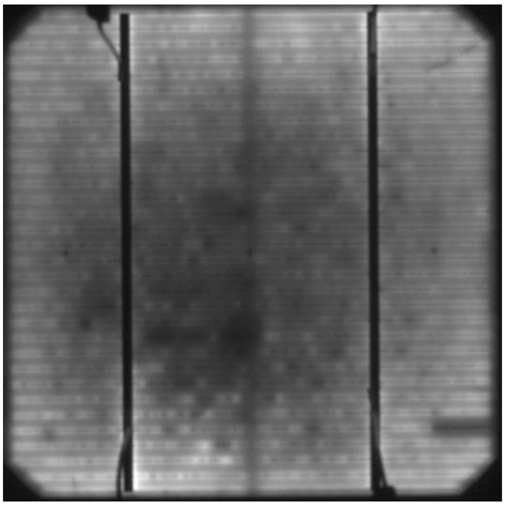

Figure 6 υ = 343 K I = 2,5 A t = 240 s