ANALYSIS OF PHOTON EMISION FROM SILICON SOLAR CELLS AND CORRELATION WITH MICROPLASMA NOISE

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Abstract: Camera has been used for mapping of surface photon emission in this study CCD. The operation point of the samples has been set to reverse bias mode and the different electric field intensity was applied. It turns out, that some solar cells exhibit an imperfection in the bulk and close to the edges. Defects are often problem because of the increasing current density and the local temperature. In addition, degradation and/or irreversible destruction go hand in hand with this phenomenon. We managed to get information about localized bulk spots using combination of optical investigations and electrical noise measurement in the time and spectral domain. It will be revealed that a direct correlation between noise and photon emission exists in this paper. The results related to several defect spots are presented in detail in this paper.

Keywords: Solar cell, local defect, noise, photon emission

1. INTRODUCTION

The silicon solar cells are currently most widespread sources of "green" energy. Although present-day technology is at the good level failures in c-Si solar cell still occurs. The physical nature of many of them is still in question. In general, these defects arise from technological imperfections during fabrication process and/or in consequence of admixtures, dislocations a particle aggregation. Further defect explanation is quite complex problem because of large surface to volume ratio. Thereupon many defects are present and active in the same time, [1]. It intuitively comes to mint to study small area samples. It should be noted here that the best edge isolation (the minimum leakage current) has been achieved using by simple sample breaking. On this account, samples presented here is only a fragment with the total surface area of about 3 cm^2 and edge radiation is suppressed.

Although reverse bias operation seems to be non-standard for solar cells, let's keep in the mind two situations. Solar cells are in series connection in the solar module. If the operating current (the current through a load) of the module exceeds the short circuit current of a weakest solar cell its operation point shifts to reverse direction. By the same taken similar situation occurs when a part or a whole module is shaded. Electrical stress subsequently leads to the leakage current increasing (*pn* junction are shunted) and/or solar cell total destruction. So, the final goal of our investigation is improving efficiency and reliability of the solar cells.

2. SOLAR CELLS UNDER INVESTIGATION IN DETAIL

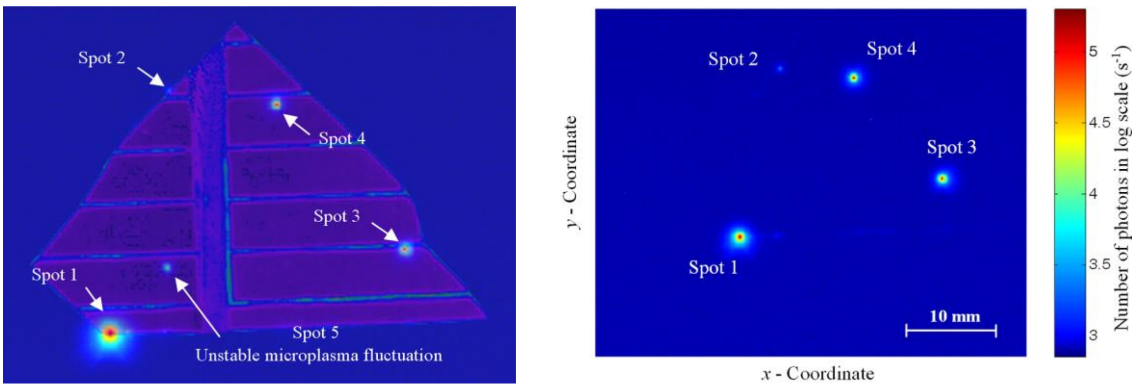
Primary solar cells what we use are made from single-crystal silicon, of dimensions 10 × 10 cm and a thickness of 230 μm. The *p* and *n* (bottom and top-side, respectively) layers are formed by diffusion. The *p* type substrate is made by the Czochralsky process with the resistivity of about 1.2 Ωcm. 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).

3. PHOTON GENERATING MECHANIZMS AND OPTICAL CHARACTERIZATION

Radiation generated from reverse-biased *pn* junction defects is used to study local properties (far field detection). 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. It uses a silicon chip cooled by dual system of Peltier's modules with the operation temperature down to -50 °C. The 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 (it holds for $T = 0$ °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 focal ratio 1.2 and working aperture 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 300 - 1100 nm. The peak value of the quantum efficiency is of 0.82 at a wavelength of 647 nm. Optical filters are included to an optical path to obtain the spectral characteristics. FWHM (Full Width at Half Maximum) of the regular 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.

Figure 1a depicts fragment of the solar cell K20 with five spots emitting light. It should be emphasized here that the photon emission intensity of the light spots depends on the applied voltage and some of them are suddenly activated with the increasing DC electric field. Figure 1a represents result of dual exposition in the dark and with bias light.



a) b)

Figure 1: a) Photography of measured solar cell with light spots, sample K20, reverse voltage 10 V, b) Light spots and their intensity before avalanche breakdown in spot 5, sample K20, reverse voltage 9 V

Light spots represents, in general, local fluctuations of the *pn* junction width and potential barrier width. It leads to decreasing of the breakdown voltage and local breakdown (conductive channels) may be created, [2]. Local conductive channels concentrate curret from neighbourhood and heavy current densities effects on low dimension region. This phenomenon can give rise to a heavy local temperature increase and, consequently, local diffusion or thermal breakdown, which may result in the solar cell destruction.

Three essential types of defect can be observed as a result of potential barrier fluctuation. First of all let's pay attention to local avalanche breakdowns. If electric field intensity is high enough, act of impact ionization followed by avalanche multiplication occurs. It evokes the microplasma noise waveform in a form of random rectangular impulses (see Fig. 5a) in an external circuit with the noise power spectral density of generation-recombination type (see Fig. 5b), [2]. It should be noted here, that avalanche breakdowns may not necessarily generate current fluctuations. The second mechanism is tunneling through a potential barrier. Last but not least the flowing current can give rise to thermal astabilities. Consider localized regions in a semiconductor material where conductivity is higher compare to neighbouhood. Naturally the current will flow above all through these regions. Power dissipation increases along with conductivity. Consequently local lattice heating leads to thermal astabilities and breakdown.

The first light (see spot 1, Fig. 1) was detected at the sample edge for the reverse voltage from about 4 V. We suppose that the light generation for this case do not evoke by avalanche breakdown with respect to low value of the reverse voltage and the detection limit of CCD camera. It is clear from electrical measurements that the last light spot (spot 5) relates with microplasma noise (Fig. 2b) and it is caused by local avalanche breakdown. Light generation from this spot starts from the reverse voltage of 9.7 V. The solar cell with light spots before and after avalanche breakdown in the spot 5 is in Fig. 1b and Fig. 2a.

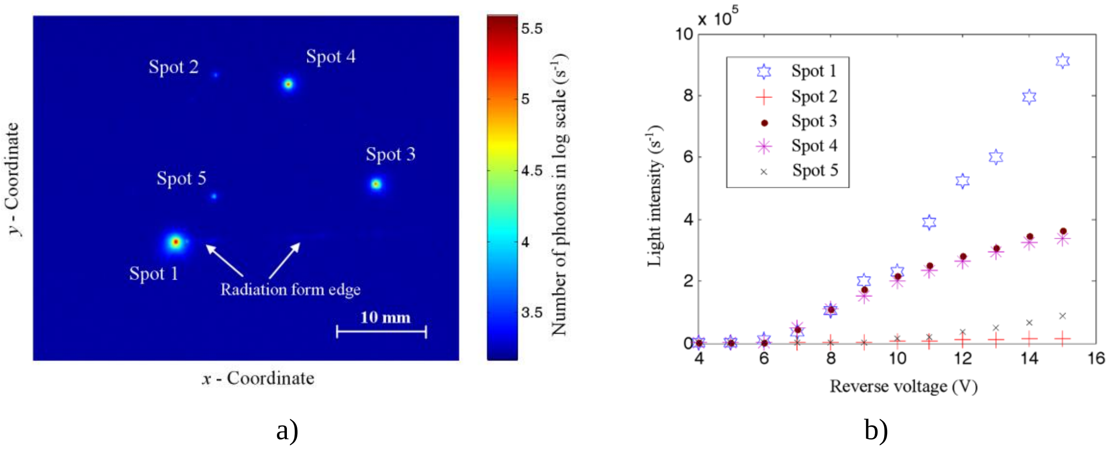
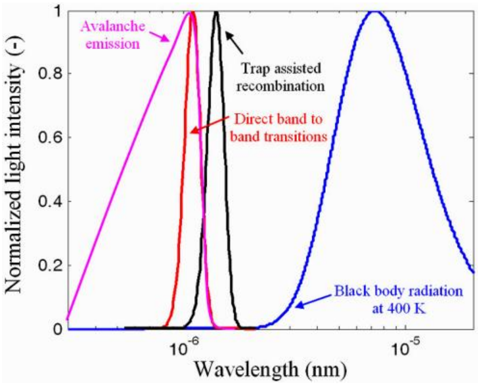


Figure 2: a) Edge radiation and light spots with their intensity after avalanche breakdown in spot 5, sample K20, reverse voltage 10 V, b) Intensity of radiation in number of photons per second versus reverse voltage, wavelength interval 300 nm – 1100 nm, sample K20

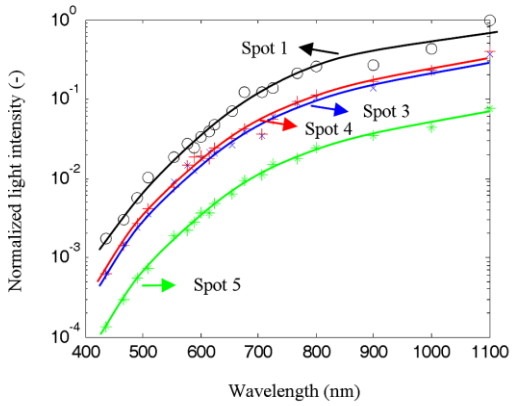
In addition, photon emission, in wavelength range 300 nm - 1100 nm, expressed in number of photons per second versus reverse voltage was measured. Results for individual light spots are depicted in Fig. 2b. Light intensity has been measured in the center of light spots as their maximum. It is clear, that curvature and slope is different and light spots have a different character. Further information is possible to obtain from optical spectrum measurement. Figure 3b depicts optical spectrum again for individual light spots. It should be noted here, that spot 2 was excluded from measurement because of weak radiation intensity.

Measurement has been done using accurate interference filters included into optical path. Optical filters properties (FWHM and insertion loss) weakly fluctuate with the center wavelength. On this account results are presented in relative units and as a reference point was choose the spot 1 at

1100 nm. An interesting fact is that although at least the spots 1 and 5 have probably different nature, optical spectrum of all light spots is very similar. The depth of the *pn* junction centre is about 70 nm for our samples of solar cells. It means that the source of light emission in the *pn* junction must be placed about 70 nm below the cell surface. Absorption of silicon is very small for this thickness. That is why we suppose that we measure an original spectrum of light without distortion by silicon.



a)



b)

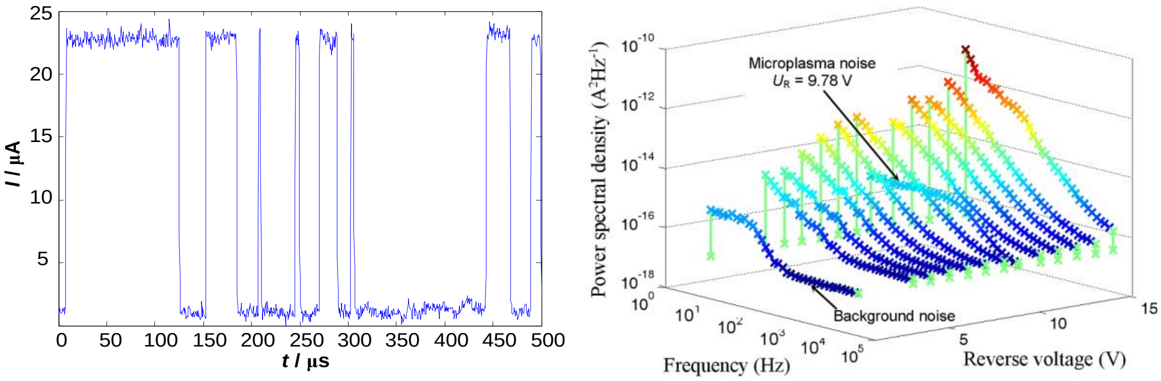
Figure 3: a) Spectral characteristic of different radiative transitions - schematic illustration b) Normalized light intensity versus wavelength, FWHM is about 10 nm, reference value at 1100 nm and spot 1, sample K20, reverse voltage 13.4 V

The theoretical photon spectrum emitted by a silicon solar cell is schematically shown in Fig. 3a. The light intensity in relative units for each process enables form comparison. The peak at the wavelength of 1100 nm represents band-to-band luminescence process. It is emitted during a radiative recombination event of an electron and hole. Although silicon has indirect bund structure it is the most probable process. The second peak located at 1400 nm is generated by radiation via traps assisted recombination (impurities and mechanical defects). In the same picture black body radiation according the Planck law is illustrated. All of these mechanisms are out of the CCD chip detection range in the spectral domain. What we measure is breakdown radiation due to impact ionization and avalanche multiplication. In this case, electrons are accelerated by electric field from *p* to *n* type semiconductor. Local regions become conductive in the reverse direction. The electron kinetic energy or the velocity has broad statistic distribution. On this account, inter-band recombination forms broad photon emission. The avalanche current typically decreases with the increasing temperature because of the limiting kinetic energy by collisions with the crystal lattice. Collisions are more likely because of increased thermal movement of the lattice. So, thermal dependence of radiation spectrum can be used for confirming of our assumption.

4. NOISE SOURCES IN SOLAR CELLS

The noise diagnostics is based on the assumption that the device structure defects give rise to excess noise. As mentioned earlier we can observe number of different noise sources and their superposition respectively. In many cases the stationarity is in question and physical nature is not evident. In addition, noise developed its character with applied DC voltage, see [3]. The noise experimental method has been put into connection with optical surface observation and photon emission detection. Thanks to that, we are able to distinguish the defect contributions from each other even in the case the device contains a number of field activated defects [1], [3].

The first noise type, so-called microplasma noise, usually appears at sufficiently high reverse voltages, yet lower than the breakdown voltage of the complete defect-free junction regions. It is caused by avalanche ionization breakdown in astable form, more in [2]. Figure 4a depicts microplasma current noise in the time domain.



a) b)

Figure 4: a) Microplasma noise waveform, sample K20, reverse voltage 9.81 V, b) Current noise power spectral density for various reverse voltages, sample K20

Spectral analyses show that the current noise power spectral density, which depends on the reverse voltage, is in a form of generation-recombination noise for the microplasma noise source, see Fig. 4b. Since other local inhomogeneties in a *pn* junction of the presenting sample do not exhibit strong voltage dependence behaviour, it is not possible to distinguish particular noise sources. The current noise power spectral density is in a form of 1/*f* noise for the reverse voltage out from the microplasma instability region and pointed out rather thermal astable mechanism. It corresponds to non-field activated process (spot 1) as presented before. Then 1/*f* fluctuations may mask another noise sources.

5. CONCLUSIONS

We can conclude that electrical noise measurement, e. g. measurement of the current flowing through solar cells and its spectrum, is very sensitive to detect defects that exhibit unstable local avalanche breakdowns and produce microplasma noise. 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. We can make light spots localization, measure the radiation intensity versus voltage plot, its correlation with other, mainly noise characteristics and measure radiation spectrum. It turns out that the number of light spots on the surface of solar cells is much higher than the number of light spots caused by unstable local avalanche breakdowns. The measured spectrum of emitted light is very similar for more types of light spots. That is why it is often not possible to find the type of defect. It turns out that it will be necessary to study thermal dependence of light emission from a solar cells surface and distinguish stable avalanche breakdowns from different mechanisms.

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