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Microscale comparison of solar cell recombination centers

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Abstract:
The aim of this work is an experimental microscale comparison of several imperfection types of silicon solar cells which emit visible light under reverse bias condition. The setup with scanning probe microscope (SPM) and sensitive detector is used for the measurement of light emission in microscale. Used SPM allows a measurement of Light Beam Induced Current (LBIC) with high spatial resolution together with sample topography. Due to a number of observed defects that have no correlation with surface topography, we have found out that there are also defects having strong correlation with surface topography. In the most cases, investigated inhomogeneites could not be localized via light induced beam technique.

INTRODUCTION

Single-junction monocrystalline solar cells are characterized by a large pn junction containing various types of defects and imperfections. Generally, light emission inspection technique is used for the localization of these irregularities. When the pn junction is reversed-biased enough, localized light emission in the visible range is observable, although inspected solar cell is made of indirect band semiconductor. First apparition of the light emission from silicon was observed by Newman in 1955 [1]. He has biased silicon pn junction in the reverse direction to breakdown, and suggested that the light results from radiative relaxation mechanism in the avalanche breakdown process. Since, it was reported that, in diffused silicon pn junctions, the light emitting spots appeared together with microplasma current pulses. The correlation of light emission with electrical noise measurement is frequently applied method for imperfection localization [2, 3].

Another testing technique uses a focused laser beam to locally induced current (LBIC). Consequently, an inhomogeneity in pn junction structure and microcracks can be discovered by measurement of locally induced photocurrent.

MICROSCALE LIGHT EMISSION USING SCANNING NEAR-FIELD OPTICAL MICROSCOPE

For the collection of light emission from biased sample, a scanning near-field optical microscope in collection regime can be used. Unfortunately, the sensitivity is affected by transmission coefficient of the probe and spectrally limited by an optical fiber wavelength range. These factors lower sensitivity of the system. For the cases, when the sensitivity is more important than resolution, a setup with any scanning probe microscopy technique (SPM) with sensitive detector can also be used.

In our case, a photomultiplier tube PMT is used as a sensitive light detector. Because light emission from localized imperfections is almost omnidirectional, the part of emitted light is also emitted towards the PMT photocathode. If a probe tip is situated between an emitting spot and the PMT, the probe will affects a light intensity detected by the PMT. In the SPM, the image is created by scanning the probe over the sample. If the light intensity is measured at each step of the probe trajectory, the resultant image of the probe shadow can be plotted to form an image (see Fig. 1).

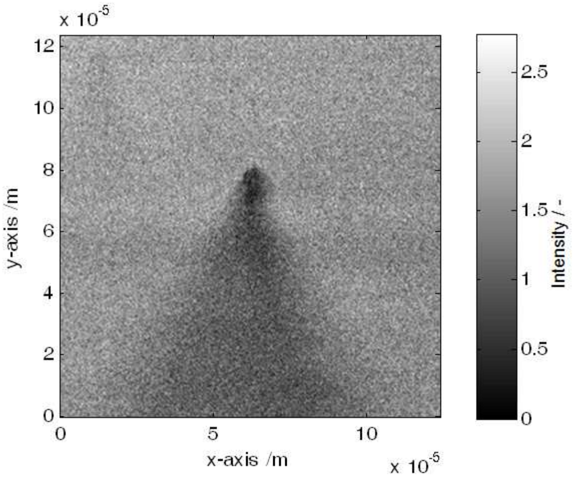

Fig. 1: Shadow image of one light emission spot located near the center of the image.

Compared to optical setup measurement, a described setup also provides sample surface topography data. This probe shadow data can be processed to create a map of local light emission, if the tip shape is known. Method is described in detail in [4]. We present unprocessed light emission data, because we can only estimate the tip shape for measurement that has been done. In general, tip can be modeled as blunted cone with several hundred nanometer large aperture.

NEAR-FIELD LASER BEAM INDUCED CURRENT

The resolution of LBIC technique is limited in the same way as the ordinary optical microscope resolution due to the diffraction of light. One of the high spatial resolution techniques allowing overcome this limitation is near-field optical beam-induced current (NOBIC) [5]. Using this method it is possible to study photoelectric properties of devices with sub-wavelength resolution. This method is based on a joint action of the scanning near-field optical microscope (SNOM), and optical (or laser) beam induced current (OBIC) methods.

The laser beam is scanning over the sample surface and the current generated in a small area is measured in the solar cell shortended contacts. LBIC/NOBIC allows evaluate spatial conversion efficiency and detect possible irregularities due to the presence of defects or imperfections.

EXPERIMENTAL

There were several monocrystalline silicon solar cells with diffusion based pn junction. Each cell was cut into a number of small samples. These samples were measured separately to allow comparison of current voltage plots presented in [6].

Samples under investigation were biased in reverse using voltage source. Visible light emission was mapped with scanning multimode optical fiber and cooled PMT in photon counting regime. Used PMT has peak sensitivity at visible range. Thus, only inhomogeneites emitting light in the visible range were localized with millimeter accuracy. After that, the samples were measured by SNOM, and areas of light emission were localized accurately. Topography of the samples was measured together with light emission. Finally, NOBIC measurement was done in the same surface area.

RESULTS

Monocrystalline silicon solar cell sample Szb4 was biased in reverse from stabilized voltage source Ur = 3 V during whole light emission measurement and the signal from photodetector was measured. It seems that there is only one light emission spot in macroscale range. Nevertheless the imperfection consisting of several small light emission spots were also found out in microscale range. The distance between these spots is approximately hundred micrometers. Shadow image of light emission mapped on topography of the dominating spot can be seen in Fig 2.

Because the shadow image of light emission only indicates from where the light is emitted, the size of the emission area can be only estimated. Nevertheless there is evident surface imperfection in the case of Fig. 2. The shape of this imperfection is not in accordance with surface form created by etching.

Relative NOBIC signal mapped on topography is shown in Fig. 3. Uniformity of photocurrent distribution reflects the fact that imperfection does not affect the pn junction or conversion efficiency. Therefore, the imperfection is probably a surface imperfection rather than the inclusion.

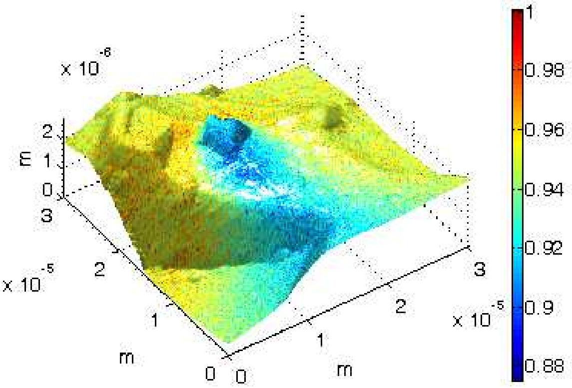

Fig. 2: Shadow image of light emission mapped on topography of sample Szb4. Reverse voltage bias U_r = 3 V.

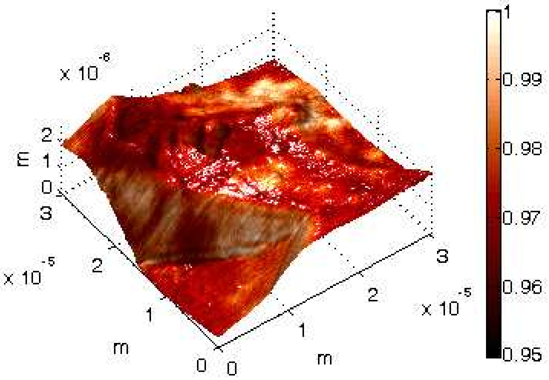

Fig. 3: Relative NOBIC signal mapped on topography image of sample Szb4.

Shadow image of light emission mapped on topography of sample Szb2 is shown in Fig. 4. Sample under investigation was biased in reverse U_r = 21 V (light emission is measurable from U_r = 19.4 V). There is no evident topography imperfection in the region of the light emission. As can be seen in Fig. 5, NOBIC measurement does not reveal any extensive inhomogeneity. There is no correlation between topography, light emission and induced current.

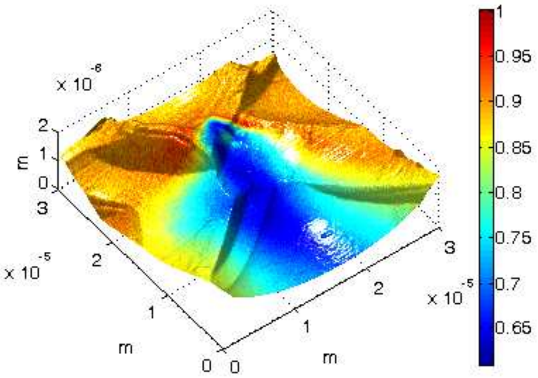

Fig. 4: Shadow image of light emission mapped on topography of sample Szb2. Reverse voltage bias U_r = 21 V.

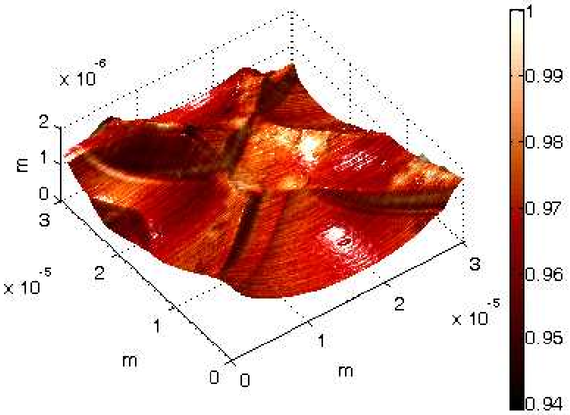

Fig. 5: Relative NOBIC signal mapped on topography image of sample Szb2.

In contrast to previously shown defects, the last imperfection has a strong correlation between NOBIC, light emission and topography. Shadow image of light emission mapped on topography of sample Sxx5 is shown in Fig. 6.

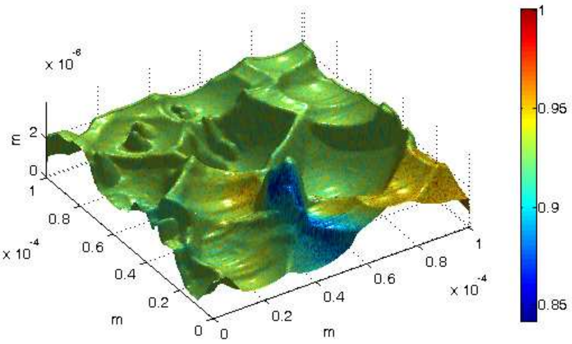

Fig. 6: Shadow image of light emission mapped on topography of sample Szb2. Reverse voltage bias $U_r = 21$ V.

Sample under investigation was biased in reverse $U_r = 12$ V (light emission measurable from $U_r = 5$ V). Except main surface topography imperfection, there are also small structures in the left of the image. In areas of these structures, the decrease of induced current is indispensable (Fig. 7). Thus, we consider few formations on the surface, which lower the absorption of light, or more probably, these formations are metallic inclusions making a tunnel contact to the emitter [7]. For these metallic inclusions, the visible luminescence in reverse bias region was also observed.

Light emission and current-voltage plots of measured samples are in Fig. 8 and Fig. 9. From Fig. 8 light emission threshold of imperfections can be determined. The light emission values near 50 counts per second are caused by dark counts of PMT detector. Sample Szb2 has one local breakdown visible in reversed current voltage plot. This breakdown appears at $U_r = 5.6$ V. One local breakdown can be clearly seen from current-voltage plot of sample Szb2. Otherwise, there is no noticeable correlation between light emission and current-voltage plots.

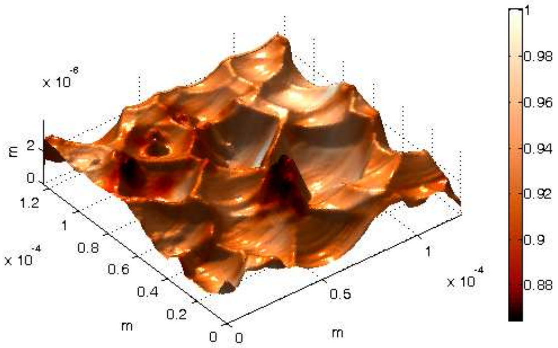

Fig. 7: Shadow image of light emission mapped on topography of sample Szb2. Reverse voltage bias $U_r = 21$ V.

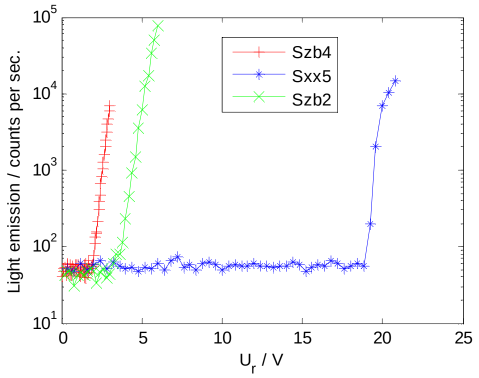

Fig. 8: Light emission of measured imperfections, temperature T = 298 K.

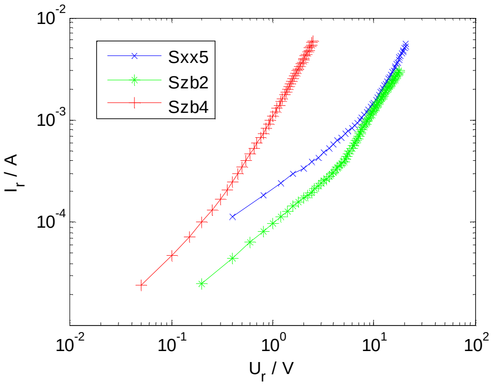

Fig. 9: Current-voltage plots (reversed) of measured imperfections, temperature T = 298 K.

CONCLUSIONS

There are three types of imperfections shown in this paper. All imperfections emit light in reversed bias conditions. First imperfection has been observed in a topography image, but has no correlation to NOBIC. Second imperfection is neither observable via topography nor NOBIC. The last imperfection is probably an inclusion observed in topography, as well as in NOBIC image.

Although the fundamental of imperfections differ, the light emission area is almost the same size. The diameter of emission area is in order of several micrometers to a couple of tens of micrometers. For the particular imperfections, the reverse bias thresholds for light emission differ in range 2 V to 20 V.

ACKNOWLEDGMENTS

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