MEASUREMENT INDUCED SOLAR CELL DEFECT CHARACTERIZATION

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Abstract: Light emission from reverse biased solar cell can reveal structure inhomogenity. Although there is large variety of defects, this paper shows simple method for their basic classification. The method allows to determine imperfections caused by mechanical damage of sample (microcracks and structure snapping). It is based on the measurement of light emission at fixed reverse voltage while the temperature is changing in the range of 20 K. Experimental light emission results are consequently correlated with light induced beam current map.

Keywords: solar cell, nondestructive testing, imperfections

1. INTRODUCTION

Electrical testing and photoelectrical measurements of solar cells are being widely used for the purposes of quality control and solar cell parameter determination. Although electrical measurements can reveal defects and some of the sample properties, for the defect localization another technique has to been used. Defects or imperfections are substructures in solar cell structure that can leads to destruction of solar cell under certain operation conditions. They can be also responsible for the deterioration of the solar cell parameters. Information about serious defects is important for modification of production procedure to avoid them.

The testing has to be definite, repeatable with well known uncertainty, and should not affect investigated sample parameters. In this case the testing is called nondestructive testing. Of course, from the production point of view, the testing should be also fast enough.

Except optical study, photoluminescence techniques and special electromagnetic testing, the absolute majority of testing methods require samples wired into measurement circuit or excitation circuit. Especially in laboratory conditions the connecting differs with each sample and experiment. Now a thickness of ordinary monocrystalline solar cell is only of several hundreds of micrometers, hence the clutch connecting can generate local cracks. Hence, a special effort is needed for proper and nondestructive electrical connecting of samples.

2. USED TESTING METHODS

2.1. LASER BEAM INDUCED CURRENT

Laser beam induced current (LBIC) is a method used for defect localization in structure of exposed pn junction. The method is based on interaction of laser beam with matter [1]. Focused incident photons generate carriers in optically excited pn junction area. This local current response is then measured. By scanning of laser beam the LBIC image can be acquired.

The current can be measured as a voltage drops at sufficiently low resistance, but preferable is measurement using transimpedance amplifier TIA due to zero input impedance. TIA has a high gain and together with input capacity is decreasing the phase margin. So TIA usually inclines to oscillation. Especially for solar cell, which has relatively high capacity compared to small photodiode, proper feedback capacitor has to been used to restore phase margin [2].

2.2. LIGHT EMISSION FROM BIASED SAMPLE

The light emission can occur in both direct and indirect semiconductors when they are electrically biased. Moreover emission of photons can also occur in imperfection regions while the sample is under reverse biased conditions [3].

For an injection process the sample is biased in forward direction and the emission peak corresponds to junction's energy gap. Although indirect semiconductors are considered as bad electroluminescence sources, electroluminescence can be also measured there. In this case, electroluminescence can be used for detection of cracks, mapping of series resistances or distribution of minority carriers diffusion length.

On the other side, the apparition of light emission from reverse biased solar cell is also very interesting effect. Generally a photon emission can only occur during photon exchange process. Shockley-Read-Hall and Auger recombination are considered as non-radiative processes. In reverse bias condition, the recombination of electron-hole pair can happen via avalanche multiplication, carrier tunneling and incandescence in the case of resistive defects.

Sensitive measurement system with photon counting PC cooled photomultiplier tube (PMT) has been employed for the detection of weak light emission (Fig.1). A sample of solar cell was placed in thermally stabilized electrode system and the bias was controlled by computer. The scanning probe collected light emission over the sample. PMT was used as detector in PC mode [4]. The PMT has been mainly working in visible range where the peak sensitivity was located (wavelength range from 350 to 800 nm).

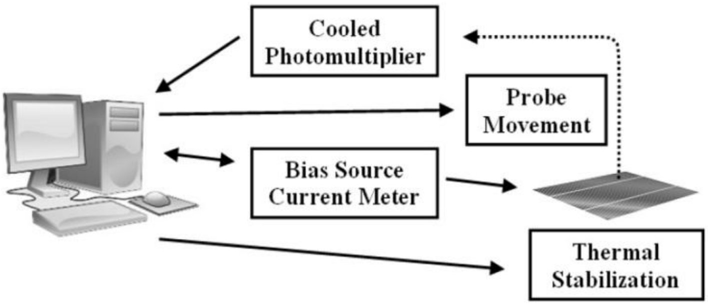

Figure 1. Computer controlled measurement system for low radiant flux detection using photon counting mode.

As it was shown in [5], there are several types of solar cell defects caused by cracks and holes, inclusions, precipitates, etc. But it is not yet clear if all produced shunts can be observed as light emission under reverse bias conditions. Also the problem of light emission mechanism is still under discussion.

2.3. THERMAL PROPERTIES OF LIGHT EMISSION

Nevertheless, some defects are observed in current voltage characteristics like a partial breakdown. Thermal dependence of this breakdown was correlated with thermal dependence of light emission as was reported in [6]. Moreover thermal dependence of light emission from bulk and edge imperfections shows different characteristics, respectively. Therefore not all of the light emitting spots are the same nature. In some cases, they could be connected with avalanche multiplication or microplasmas, but the further study of this problem is foreseen in our laboratory.

3. RESULTS

3.1. LASER BEAM INDUCED CURRENT

Selected part of solar cell sample was tested with LBIC. In figure 2 the border of solar cell sample can be seen on the top of the image. Black horizontal lines are top contacts of the sample. These parts of solar cell do not contribute to integral solar cell current. Interesting cross can be seen in the right lower part of image. This cross is not visible with ordinary optical microscope. Nevertheless this cross is a microcrack in the crystal turned in crystal lattice directions. This crack was created by connecting the sample for electrical measurement. Too heavy connecting probe force leads to creation of this microcrack.

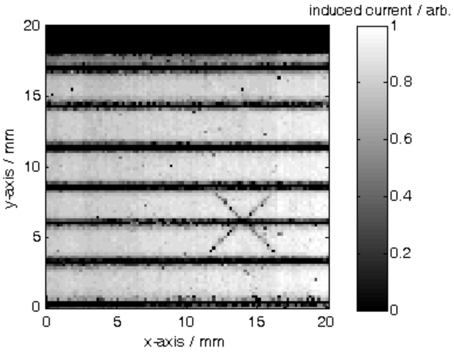

Figure 2. Laser beam induced current map of selected solar cell sample part (T = 298 K).

3.2. LIGHT EMISSION FROM BIASED SAMPLE

The same area of Fig. 1 was tested for light emission. The reverse bias of solar cell was increased while the reverse current has been set bellow 13.0 mA. This is the safe current density value for given sample that does not cause the sample degradation. While using this criterion the reverse voltage of U_R = 24.0 V was reached. After that, the light emission was measured over the sample surface. Light emission map can be seen in Fig. 3. Here, the color map matches the logarithm of detected counts per second.

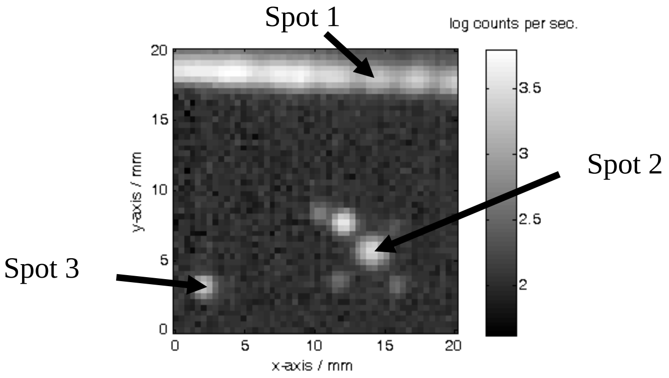

Figure 3. Light emission from reverse biased sample (U_R = 24.0 V, T = 298 K).

The phenomena of light emission from border can be seen. In this lighting border one of the luminous spots “spot 1” has been selected for further testing. In the bulk area, there are several localized light emitting spots. Note, that in area of LBIC cross (Fig.2), the light emission in visible range occurs and has the same shape as in LBIC case. This means that this light emission is a consequence of crystal microcrack made by sample testing. Main spot of this part was then selected for further testing “spot 2”. The last light emitting spot is marked “spot 3”.

3.3. THERMAL PROPERTIES OF LIGHT EMISSION

Light emission versus sample temperature has been measured for three selected spots. Solar cell sample was biased from voltage source $U_R = 24$ V during the measurement. Light emission from spots 1 and 2 reflects a positive thermal dependence,, and concurrently a negative thermal dependence from bulk spot 3 has been observed (Fig. 4).

For avalanche type breakdown, the negative light emission temperature dependence is expected. With growing temperature the crystal lattice vibration increases and hence the carrier movement is inhibited. Consequent on breakdown voltage increase with temperature, the light emission is decreasing. This result means, that only a spot 3 is due to the avalanche multiplication.

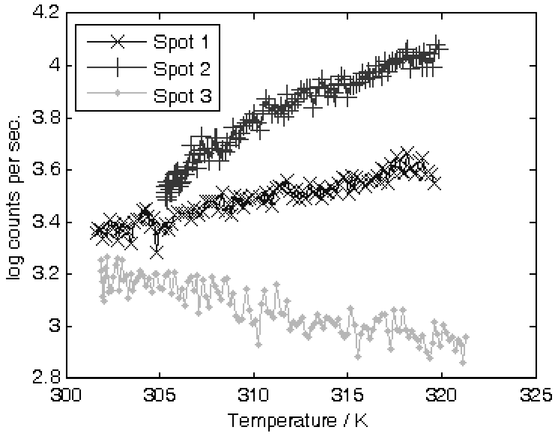

Figure 4. Thermal properties of light emission of selected spots ($U_R = 24$ V).

For the positive light emission temperature dependence, Zener and thermal breakdowns come in to question. Other defects caused by microstructure snapping have the same thermal dependence. This defect can be created by scratching by sharp probe over the fragile sample surface. All other tested bulk defects have negative light emission thermal dependence.

3.4. MICROSCOPIC STUDY OF BULK DEFECT

The area of the spot 3 was measured in scanning probe microscope to visualize the imperfection surface in microscale (Fig.5). Here unique structures that are probably inclusions causing local change of electric field distribution are resolved in this figure. Hence the breakdown will occur in this sample area when the sample is enough biased.

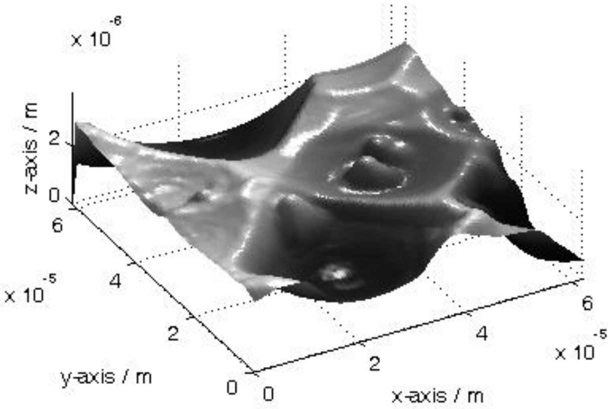

Figure 5. Microscopic image of the sample surface (spot 3).

4. CONCLUSIONS

Light emission from reverse biased solar cell can reveal structure inhomogenities, and together with control of sample temperature can provide the basic defect classification. For this classification only 20 K temperature change is enough.

During connecting of sample, two types of defect can arise. The first is crystal crack caused by too heavy force of connecting probe. The second is snapping of microstructure caused by scratch of sharp probe over the sample surface.

Bulk structure defects show negative light emission temperature dependence while the border emission, microstructure cracks and snapping defects show positive light emission temperature dependence.

Crack defects were revealed using LBIC measurement. There is evident correlation between LBIC image and light emission image taken in the same sample area at $U_R = 24$ V. The bulk spot 3 which has different thermal dependence than other two investigated spots, was measured by scanning probe microscopy. Unique structures in the surface were observed, that are probably the inclusions. They cause local changes of electric field distribution and can lead, under some bias conditions, to the local breakdown.

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