LOW RADIANT FLUX DETECTION SYSETM FOR SOLAR CELL ELECTROLUMINESCENCE CHARACTERIZATION

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ABSTRACT

This paper deals with low radiant flux detection system used for solar cell electroluminescence characterization. Two-measurement setups are used for the low light level detection. First, analog measurement mode with visible sensitive photomultiplier is used and than the photon-counting mode with the same photomultiplier is used. The experimental comparison of both modes is presented and as a result, the photon-counting mode is found more sensitive. Possible application of detection system is demonstrated in emission spectra measurement and reverse bias solar cell characterization.

1. INTRODUCTION

Electroluminescence is one of the non-destructive techniques for imperfection localization of exposed *pn* junction. Single junction monocrystalline solar cells have large *pn* junction containing various types of defects and imperfections. The light emission can occur in imperfection regions when the sample is electrically biased [1]. No matter of the junction bias direction the light emission can be still observed. There are three possible processes of electroluminescence participating in the light emission from biased silicon: injection process, avalanche process and tunnel process.

As was published in the first paper reporting the light emission from reverse bias *pn* junction the light emission intensity is dependant on bias [2] and for the low voltage bias the radiation detection is difficult. Unfortunately, there is need for low voltage bias of some samples to avoid sample degradation. Another challenge is measurement of spectral properties of sample radiation.

The power of light is not spread in the spectrum uniformly and the information about spectral properties of emitted light can provide information about local properties of the sample. The easiest way for measurement of spectral properties is using monochromator or band pass filters with well-defined properties. Nevertheless, the optical power in small wavelength range is only part of optical power in the whole range. That means sensitivity of detection system has to been increased for measurement in the small wavelength range.

2. DETECTION AND MEASUREMENT SYSTEM

Measurement system for detection of light emission from silicon solar cells is shown in Fig. 1. Optical scanning probe made from plastic fiber with flat end without any focusing system is fixed at the scroll box of the x-y plotter. Light coupled in to optic fiber is guided to the cooled photomultiplier tube detector PMT working in visible. PMT is cooled to minimize the thermal emission from photocathode and dynodes. The solar cell under examination is placed in the thermally stabilized electrode bias system on the desktop of plotter. For the light spectral properties measurement the monochromator is used.

At the first, the analog mode of PMT output measurement was investigated. In principle, the PMT output signal is composition of discrete pulses. Each pulse is consequence of detected quanta or spurious noise. In analog method, the output impulse signal is considered as analog waveform and so the mean value of PMT output signal is measured. Practically the electronic is consisting of integration logarithmic amplifier. In photon counting PC mode the discrete pulses are counted for a certain period of time. It is obvious that in this mode the amplifier noise is unimportant, the dependence on supply voltage is lower and DC leakage current do not affect the measurement.

PC mode is used for very low light-signal measurements. For the high light-signal is unsuitable due to nonlinearity of counting rate. The linearity of PC mode for low light-signal range is shown in Fig 2. As a comparison between analog mode and PC mode the voltage of measurement electronic U_{AMP} is plotted in the same figure. The voltage is plotted in power form due to logarithmic amplifier and internal gain. The noise level for analog mode and dark count rate is plotted for the mode comparison. As can be seen from graph there is possible detect two order lower radiant flux using PC mode than in analog mode.

Although PC mode allows measurement in low light levels in high-level range, the measurement is affected by time resolution (pulse pair resolution) of counting electronic. Two pulses, which are overlapped, can not be distinguished in PC mode but can be measured using analog mode, hence the analog mode is more suitable for measurement of high light levels. In the PC mode, the dynamic range reaches as high as 10^6 s^{-1} and the minimal detected input light power is 0,5 fW at wavelength 650 nm. Optical probe detection area was 1 mm^2.

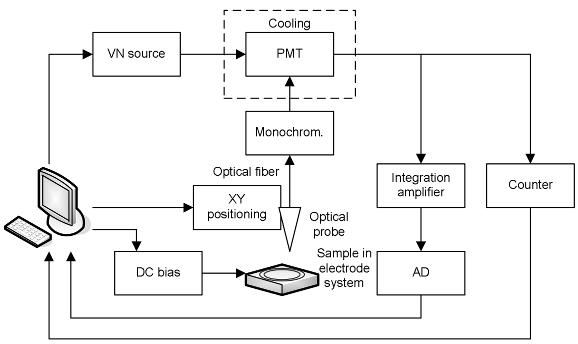

Figure 1 Computer controlled measurement system for low radiant flux detection using PC mode and analog measurement mode

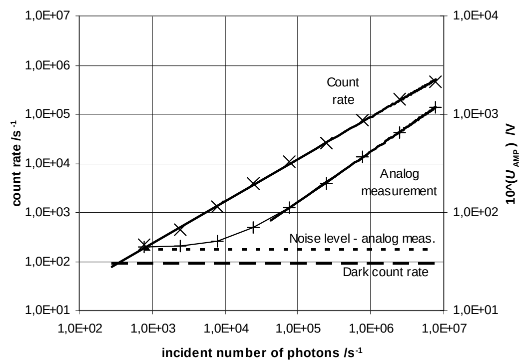

Figure 2 Linearity of count rate in PC mode and measured voltage for analog mode, excitation wavelength $\lambda = 650$ nm; PMT temperature $T = 263$ K

Except amplifier noise, which is in PC mode irrelevant, there are several shot noise sources. First one is shot noise resulting from signal light. Since the secondary emission in a photomultiplier tube occurs with statistical probability, the resulting output also has statistical fluctuations. Second one is the noise resulting from dark current. In this noise there is included thermionic emission from photocathode and dynodes, field emission current and ionization current from residual gases inside the tube. For the shot type noise the Poisson distribution is applicable. The dark current respectively thermal noise can be decreased by cooling.

From results of PMT noise analysis published in [3] for PC mode the PMT detection limit can be approximated with equation (1). In PC mode the amplifier noise is irrelevant and the thermal noise from dynodes can be suppressed by proper setting of counter discrimination level. The detection limit can be defined as light level where the signal to noise ratio equals to 1. Spectral dependence of incident light power threshold $P_i(\lambda)$ is caused by spectral dependence of PMT quantum efficiency $\eta(\lambda)$; N'_d is average number of dark counts per second. For PMT temperature T = 263 K the detection limit is plot in Fig. 3.

$$P_i(\lambda) \approx \frac{2{,}8 \cdot 10^{-25} \cdot \sqrt{N'_d}}{\lambda \cdot \eta(\lambda)} \tag{1}$$

Compared to analog mode in PC mode the signal to noise ratio SNR can be improved by increasing the observing time because an increase of observation time has no effect on power increase of white noise. Nevertheless, the special effort is needed for finding the proper discrimination level of counter. As was published in [4] when the discrimination level is set at (or higher than) the optimal value then (1/f) noise is found to be dominating. Therefore, the SNR increases slowly when there is an existence of (1/f) noise in dark current.

SNR can be defined as the ratio of mean to standard deviation of the signal. Measured time of observation dependency on SNR is shown in Fig. 4. It is clear the SNR can be improved by integration time and it is also dependant on proper setting of counter discrimination.

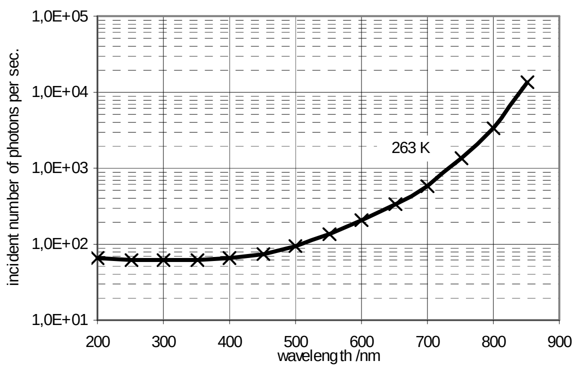

Figure 3 Detection limit as a function of wavelength; PMT temperature T = 263 K

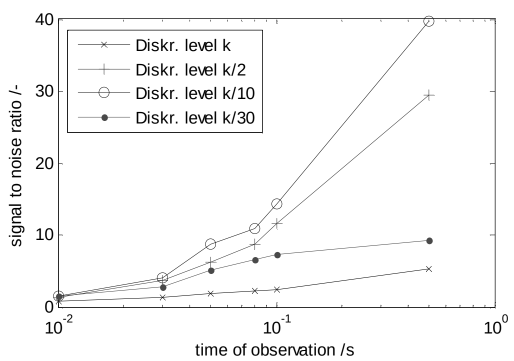

Figure 4 SNR as a function of observation time; PMT temperature T = 263 K

3. APPLICATION OF DETECTION SYSTEM

One of shown application is measurement of spectral properties of emitted light from reverse bias solar cell. The emission spectrum can provide information about local sample properties and its imperfections. Because sensitivity of PMT is not uniform and optical fiber has wavelength dependant transmission for the spectra measurement the correction has to been done. Additional wavelength dependant element is monochromator. The reference measurement of attenuated light from the red light emission diode is shown in Fig. 5. The emission spectrum from solar cell imperfection spot is shown in the same figure. The intensity of light is increasing with wavelength and the spectrum is wide and continuous. Maximum intensity wavelength has to be in infrared region. In the literature, the emission spots are referred to as microplasma noise that can be observed by electric measurement [5] but not all of light emission spot are particularly caused by impact ionization respectively local avalanche breakdown due to light emission in the low voltage bias range [6]. Nevertheless, the light emission mechanism is still under debate [7].

Another application is just *pn* junction imperfection localization. Using this nondestructive technique it is possible to detect the badly processed edges of solar cell, some defect in contact region and imperfection of structure, where the possible destruction of cell can start at higher bias voltage range. The light emission of whole solar cell sample is shown in Fig. 6. In this case the edges of solar cell are badly processed. The light emission can occur in cracks caused by cutting process. There are also some localized imperfections in bulk region.

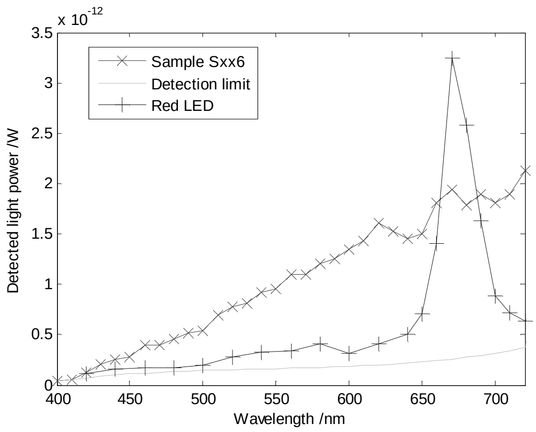

Figure 5 Measurement of light emission spectra of sample Sxx6 and red LED radiation spectrum using analog measurement mode; PMT temperature T = 263 K

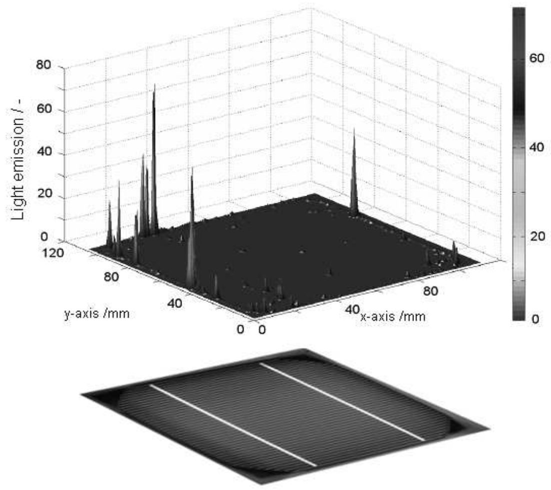

Figure 6 Localization of imperfection areas of solar cell sample using reverse bias light emission.

4. CONCLUSION

Low radiant flux detection system was described and two measurement techniques was compared. The PC mode is more sensitive in low light range while analog measurement is suitable for high light range. The detection limit of system was measured and its spectral behavior was calculated. Using photon-counting mode the SNR can be improved in the case of the white noise. The dependence of integration time and proper discriminator setting on signal to noise ratio was shown on experimentally measured data.

Possible application of low radiant flux detection system was presented. In the first case the system was used for measurement of spectral properties of light emitted from reverse bias solar cell. In the second case the detection system was used for localization of low light level emission from reverse biased solar cell.

ACKNOWLEDGEMENTS

This research has been supported by the Grant Agency of the Czech Republic within the framework of the project GAČR 102/09/H074 "Diagnostics of material defects using the latest defectoscopic methods" and by the Czech Ministry of Education in the frame of MSM 0021630503 Research Intention MIKROSYN New Trends in Microelectronic System and Nanotechnologies. These supports were gratefully acknowledged.

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