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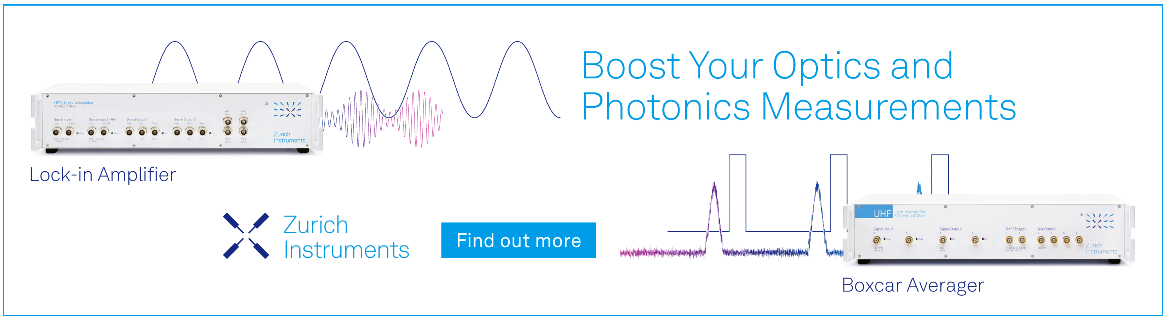

Output Parameters of Photovoltaic Cells at Ultrahigh Radiant Fluxes

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Abstract. Structure defects in PV cells can be identified through I-V curve parameters: short circuit current, open circuit voltage, fill factor and efficiency. In converting high density radiant fluxes, structure heating affects significantly these parameters. For this reason constant temperature (25°C) is a necessary condition for correct characterization. In this paper, a method for recording optical and electronic parameters of PV cells in regimes of converting high density radiant fluxes, which excludes the effect of radiative heating of a device, is presented.

INTRODUCTION

Study of PV converter parameters are usually carried out outdoor under the sunlight or indoor at natural illumination by continuous irradiation [1]. For concentrator PV converters, pulsed light of up to 10ms duration [2, 3] is usually used, what, in most practical cases, allows excluding from consideration tested device heating. Nevertheless, it has been shown that, during about 1ms, radiative heating is possible, which affects PV cell photoelectric parameters recorded at high illumination [4,5]. Therefore, the problem of determination of the normalized characteristics of PV converters operating at ultra-high illumination (more than 1kW/cm^2) or at laser irradiation and of the potential of heterostructures in isothermal conditions remains to be actual.

OVERHEATING OF PV CONVERTERS

Today, semiconductor PV converters show an efficiency of less than 100%. The maximum conversion efficiency is achieved in the optimum load point. In this case, the main amount of radiant energy is converted into electricity and diverted to an external circuit. The rest of the optical power is partially converted into heat (thermalization of charge carriers, nonradiative recombination), partially re-emitted (radiative recombination). Thus, heating of operating PV converters occurs always. Variation of the temperature regime affects the parameters of a tested device and, consequently, the efficiency. At low irradiation, heating is insignificant, and it rises with irradiation. Thus, in outdoor conditions (irradiation of 0.1W/cm^2), overheating of the PV panels is 5-35^{o}C [6]. The sunlight conversion in concentrator solar modules, for example, leads to extreme overheating of a PV converter. Therefore, the use of heat sinks is required [7]. However, even this design solution does not completely eliminate overheating.

A possible way to reduce heat is elimination of losses due to thermalization of charge carriers. Principle of maximum possible correspondence of the forbidden gap and the irradiation wavelength is realized in multi-junction solar cells and in "Power-by-Light" systems.

The main indicator of heating absence is the logarithmic dependence of the open circuit voltage on radiation. At the same time, as the temperature increases, the open circuit voltage drops, what leads to a “kink” on that dependence. It was shown that the “kink” appears for GaAs cells under 810nm laser irradiation and a power density of about 100W/cm^2 [8].

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It is also important to note that the large irradiance value here does not mean great integral illumination and super-high operation currents. For example, in [9], irradiance was 30W/cm^2 and the surface size of tested samples did not exceed 10mm^2, but the integral cell surface illumination was less than 3W. In this paper, ultrahigh irradiations are also achieved by concentrating light fluxes on small PV cell surfaces 0.07-0.2mm^2 in size.

METHODS TO KEEP A CELL AT ROOM TEMPERATURE

The task to study the "cold" parameters of PV cell I-V characteristics at high irradiance (greater than 1kW/cm^2) can be solved by applying active cooling systems. In this case, it is necessary to select the cooling system power with high accuracy to compensate the tested cell radiation heating. The imbalance between heat fluxes and the time lag of active cooling systems can lead to structure overheating or supercooling, what will lead to distortion of the data being obtained. It should be noted that, at this operation mode, there is a temperature gradient in the structure. At the first approximation, the "photoactive region - heat sink" heat flux can be described by the Fourier thermal conductivity equation [10]:

$$grad(T) = -\frac{\vec{q}}{\chi} \tag{1}$$

where ***q*** is the heat flux density vector, χ is the thermal conductivity of the PV structure.

For example, for GaAs PV cells (*) with a photo-receiving surface diameter of 300μm and a thickness of 250μm at 0.1W (150W/cm^2) continuous radiation , the rated temperature difference between the rear contact and the p-n junction is about 7°C in the open circuit mode without accounting for heat dissipation. If the irradiation power density increased to 1W (1.5kW/cm^2), this difference will be 76°C. Therefore, maintaining temperature of the rear contact at the level of room one is not enough. And maintaining the temperature of the p-n junction at 25°C will lead to supercooling the substrate and to changing current flow mechanisms.

Another approach in investigating conversion of high density radiant fluxes is using a pulsed irradiation regime. The input power is reduced according to the duty cycle. However, the photoactive region can be heated at the moment of illumination and cooled in the interval between light pulses. Therefore, it is also necessary to consider not only the thermostatic state of the cell, but also the thermodynamic one.

During a pulse, a PV converter receives power Q = P * D, where P is the pulse power, D is the duty cycle. The change in the temperature of a p-n junction at the end of the pulse will be determined by the expression:

$$\Delta T = \frac{P * D}{c * m} \tag{2}$$

where c is the heat capacity, m is the p-n junction mass. In this case, $m = S * h * \rho$, where S is the area, h is the height, ρ is the density of the material of the photoactive layers (the p-n junction region).

For the PV cells described earlier (*) with a photoconductive layer thickness of 1μm, the temperature variation per pulse of 300ns is about 1°C without taking into account the substrate and the environment heat sinking.

A similar principle of testing laser PV converters was described in [3]. However, the high-irradiance PV conversion regime requires the shortest illumination period to avoid sample heating. On the other hand, it should be noted that it is impossible to decrease the pulse width infinitely to maintain temperature of 25^{o}C at ultra-high illumination. The minimum pulse duration depends not only on the sampling rate of the measuring circuit and the illumination pulse generator. For a semiconductor PV cell, the important parameter is the charge carrier lifetime in a tested cell. Since illumination starts, the generation and recombination fluxes of the nonequilibrium charge carriers change. Their stabilization is only possible, if the illumination period exceed the charge carrier lifetime. The stationary mode of the PV conversion could be characterized only in this case. Therefore, in order to study parameters in the quasi-stationary mode, the irradiation pulse time should greatly exceed the lifetime of nonequilibrium charge carriers in the tested sample.

PROCEDURE FOR STUDYING PV CELLS IN ULTRAHIGH IRRADIATION CONDITIONS

The presented procedure was realized in measuring parameters of GaAs PV cells irradiated by a laser with wavelength of 840 nm, frequency of 1kHz, and the pulse duration of 300ns. Such a configuration of laser pulses is suitable for measuring PV cells with charge carrier lifetime less than 150ns. The GaAs PV cells have the lifetime of minority charge carriers of about 10ns [11].

The tested cell temperature regime can be described by the “Voc vs. Light irradiance” dependence, shown on Fig.1

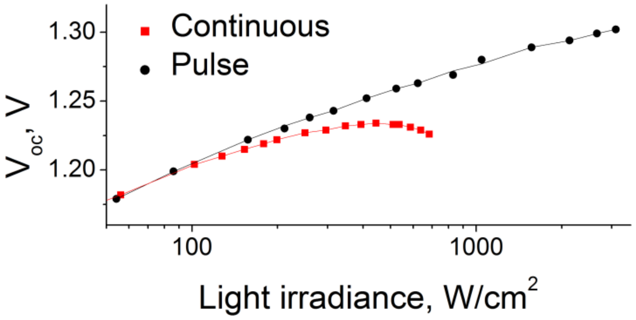

FIGURE 1. Logarithmic dependence of the open circuit voltage on irradiance for continuous and pulsed regimes.

Deviation from the logarithmic dependence can serve as an indicator of the structure heating. For the tested sample (*), the maximum irradiance of the “cold” regime is at about 100W/cm^2. At greater irradiance, the open circuit voltage rises slowly and then drops. In the pulsed regime, the open circuit voltage always rises in the range of 0.01-9kW/cm^2.

Recording of the I-V characteristic was carried out in using an external voltage bias source. The external source was connected in synchronism with the irradiation pulses. It was done to avoid the forward current flow between pulses at the forward bias.

The schematic of the experiment is shown in Fig.2

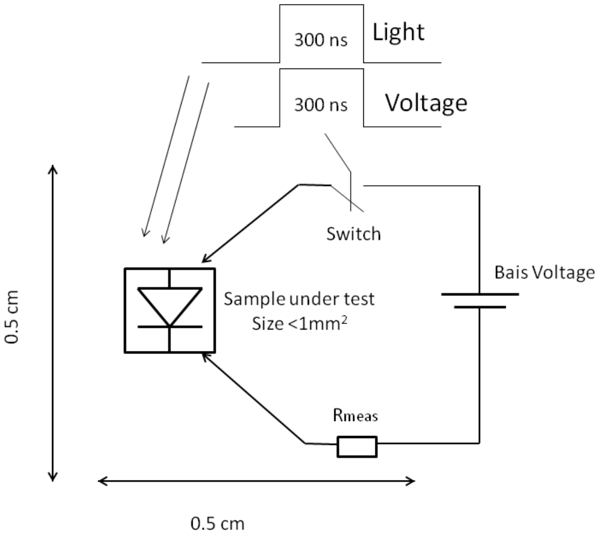

FIGURE 2. Schematic of the pulsed current-voltage measurement technique.

One “I-V” pair values is recorded during one pulse duration unlike in the method described in [3]. A short period of illumination does not allow obtaining full I-V curve during a single pulse. However, during a short pulse, the sample under test is not heated which was confirmed by constant values of current and voltage. The short circuit current value was determined by linear approximation, since it was not possible to eliminate the external circuit resistance (including the resistance for measuring the circuit current).

In using the described scheme of the experiment, PV cells with a photo-receiving surface diameters of 300 and 500μm were investigated. The maximum peak power of laser pulses reached 6W. In terms of the irradiation density for the 300μm cells it was ~ 9kW/cm^2. The results of the measurements are shown in Fig. 3

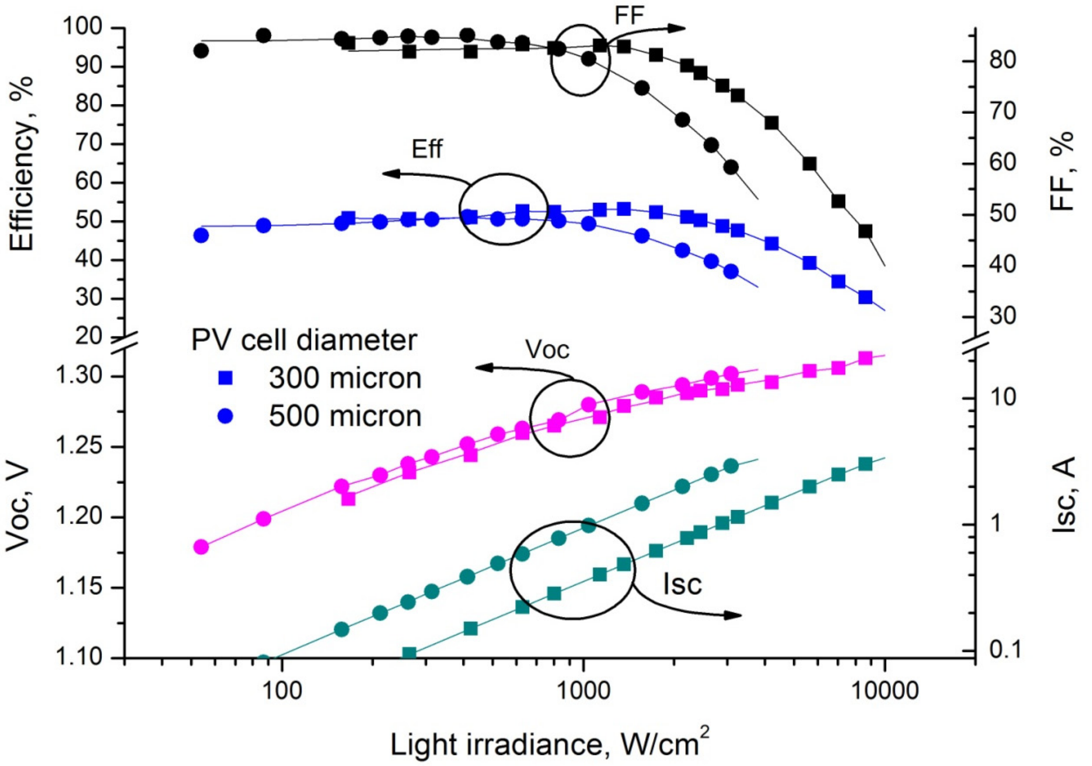

FIGURE 3. Efficiency, open circuit voltage, fill factor, short circuit current for GaAs PV cells with a photo-receiving surface diameter of 300 and 500μm irradiated by laser radiation pulses with a wavelength of 840nm.

The studies have demonstrated a possibility of PV conversion with the efficiency of greater than 50% at irradiations of 2.4kW/cm^2 for GaAs cells. The isothermal state of the tested PV converters was confirmed by the close to logarithmic dependence of the open circuit voltage on irradiance in the whole range of recorded powers being supplied and currents being registered. The registration of the "cold" parameters has demonstrated a direct measurement of the open circuit voltage of more than 1.3V at irradiations of about 9kW/cm^2.

It should be noted that attempts to reduce losses for thermalization of charge carriers and for thermal "pressure" due to the laser wavelength shift towards the edge of the PV cell spectral sensitivity did not completely eliminate the effect of heating on PV parameters being registered at densities of laser pulses of greater than 9 kW/cm^2.

CONCLUSIONS

Investigation of the GaAs PV converter parameters with using the proposed procedure at ultrahigh pulsed irradiation have been carried out. It was possible to keep an isothermal state of tested cells by using pulsed laser illumination of 0.1-9kW/cm^2 in peak. Constant temperature was confirmed by the “Voc vs. Light irradiance” dependence. The irradiation parameters were adjusted in such a way that, on the one hand, the duty cycle is small, but, on the other hand, the pulse duration exceeded the lifetime of charge carriers in the tested sample. So the quasi-stationary parameters at a direct measurement were obtained. The voltage source was connected in synchronism with the irradiation pulses. So there was no cell heating due to the forward current flow between pulses at the forward bias. Therefore it was possible to reach the open circuit voltage of greater than 1.3V at irradiation of 9W/cm^2. Also the efficiency of the GaAs cell exceeding 50% at irradiation of 2.4kW/cm^2 has been shown.

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