MULTIFUNCTIONAL FLASH SOLAR SIMULATOR: 3 IN 1

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ABSTRACT: At the PV Lab of the Ioffe Institute, a multifunctional flash solar simulator/tester has been developed. It may be used as the cost-effective means applied at characterization of the 1-sun and concentrator cells, as well as large area flat and concentrator modules. At the 1 sun irradiation level and light divergence corresponding to that from the Sun disc, light from Xenon lamps passes through an aperture hole 20 mm in diameter and a large-area Fresnel lens with 2000 mm focal distance to form a collimated flux the 0.5x 0.5 m^2 aperture area. Easy re-configuration of the simulator structure allows characterizing individual cells, or large-area flat modules, under non-collimated light flux. In this case, light flux is much more extended in area, so that a flat solar array may be placed far enough for realization of the 1-sun illumination conditions. In turn, the concentrator solar cells may be characterized at their placing much closer to flash lamps. At a Π-like light pulse shape, it is possible to record an I-V curve in three quadrants during 1 millisecond. The technical parameters and results on the I-V measurements by means of the developed multifunctional solar simulator/tester are presented.
Keywords: Solar simulation; Flash lamp; I-V measurement.

1 INTRODUCTION

Generation of electricity by solar PV systems becomes a real branch of the global energy production facilities. There is a steep rise in the number of the enterprises and institutions for development, production and education connected with solar PV, where solar simulators are widely used for indoor characterization of the solar cells and modules of different design [1-3]. However, structural features of the simulators are as a rule aimed at a certain type of measurements. For instance, different instruments should be used for characterizing PV devices subjected only to one sun illumination, or to concentrated one. The same is related to the instruments for characterizing flat solar modules, or modules with concentrators. In the latter case a strongly collimated beaming is necessary. At the PV Lab of the Ioffe Institute, a multifunctional flash solar simulator/tester has been elaborated capable to fill several requirements at the PV measurements of cells and modules. It may be used as the cost-effective means applied at the I-V measurements of the 1-sun and concentrator cells, as well as the large area flat and concentrator modules. The only limitation is associated with life time of the photogenerated charge carriers in the PV devices under test: they should be based on materials with a short enough life time, since the I-V measurements are carried out in a pulse regime at light pulse duration of about 1 millisecond.

The most serious requirements to the simulator optical design must be satisfied at characterizing large-area concentrator modules: 1 sun irradiation level with good spatial uniformity; proper spectral distribution; light beam divergence similar to that from the Sun disc. Our approach to the simulator design for this application has been described in a previous work [4], where light from Xenon lamps passed through an aperture hole 20 mm in diameter and a large-area Fresnel lens with 2000 mm focal distance to form a collimated 0.5x0.5 m^2 in area flux. Two such units incorporated in one instrument produced collimated light flux sufficient for PV characterization of the 0.5x1 m^2 concentrator modules. In the present work, we have modified a one-lens unit in the simulator structure in such a way that it is easy to change its configuration for characterizing individual cells, as well as large-area (1x2 m^2) flat modules, under non-collimated light flux. A flat solar array may be placed far enough from the lamps for realization of the 1-sun illumination conditions without a collimating lens. In turn, in this simulator configuration, the concentrator solar cells may be characterized as well at their placing much closer to the flash lamps. Certain improvements in light pulse formation have been introduced by us, so that pulse shape is almost Π-like with the flat part of 1 millisecond in duration. Tester function of the instrument is ensured by a measurement unit including an active load. The elaborated simulator may be regarded as a modular unit for arrangement of instruments with a sufficiently increased "collimated" illumination area: 0.5x1 m^2, or 1x1 m^2 (two, or four modular units would be mounted together). Of course, in the instrument versions with "non-collimated" light flux, the illumination areas would be also proportionally larger.

In the present paper, the technical parameters and results on the I-V measurements by means of the developed multifunctional solar simulator/tester are described.

2 DESIGN OF THE MULTIFUNCTIONAL SOLAR SIMULATOR/TESTER

Optical design of the light source is based on two flash Xe-lamps. The lamp tubes are placed at a minimal distance in parallel one to another [4]. In a mode of operation with the collimated light flux, the lamps are screened by a mask with a hole 20 mm in diameter (see picture in Figure 1).

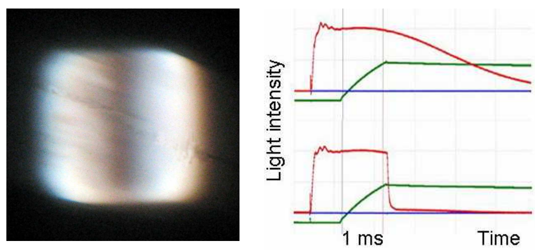

Figure 1. Two screened lamp segments forming "Sun disc" image in the elaborated solar simulator (on the left); light pulse profiles (on the right): a pulse with a "tail" and a Π-like one.

Collimation of light is carried out by a 500x500 mm^2 Fresnel lens with 2000 mm focal distance (see Figures 2 and 3). The dimensions of the optical elements were chosen to arrange a correct angular divergence of ±27 angular minutes for light beams and to eliminate the effect of the chromatic aberrations and non-uniform illumination in the peripheral zones of the measurement plane. Reduced absorption in the lens material in the near infra-red light spectrum was ensured owing to lens fabrication by the silicone-on-glass technology [5]. In this case, the lens body consists mainly of highly transparent silicate glass, so that the polymer material (silicone), being characterized by certain absorption, is only microprisms in the Fresnel profile.

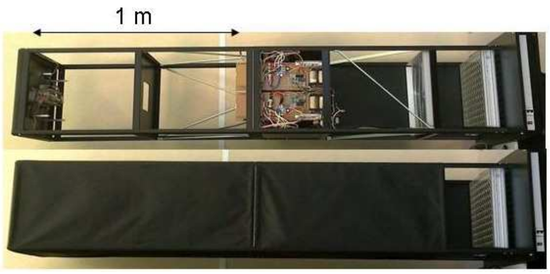

Figure 2: Picture of the elaborated multifunctional solar simulator/tester in configuration for characterizing concentrator PV modules (on the top: light protective cover is removed).

The light spectrum is corrected by special interference filters up to conditions of AM 1.5, or AM 0, with an accuracy corresponding to Class A. A continuously operating tungsten lamp is located behind the opened flash lamp segments for optical alignment of a tested concentrator system before flash illumination.

An advantage of the developed flash lamp power supply is a possibility to form a Π-like light pulse (see the light pulse profiles in Figure 1, on the right) in a special mode of operation. The cell I-V measurement is carried out during the flat part of the pulse, where light intensity is kept with 2% accuracy. After this, a high-current switching circuit re-directs current from the flash lamps to a special resistive load to reduce overheating of the lamps. However, in the mode of operation with light "tail", it is possible to use such an option, as evaluation of the solar cell internal resistance in I-V measurements under flash illumination [6].

The I-V curves of the cells are recorded in three quadrants during 1 millisecond. The corresponding measurement unit (active electronic load) ensures voltage measurements from -3/+10V up to -20/+200V and current range up to 0÷20A. The measurement time for one pair of the "current-voltage" magnitudes is about 10 microseconds. A cell under test is connected with a voltage sweep circuit and with a measurement circuit by terminal blocks +/-I and +/-V. The voltage sweep circuit produces a bipolar pulsed voltage applied to a solar cell, or module. Reverse and forward voltage values are set from a PC keyboard. The measurements are carried out with 16 bit resolution.

3 CHARACTERIZATION OF THE CONCENTRATOR MODULES

The lay-out of the solar simulator parts in the case of the concentrator modules characterization is shown in Figure 3 (on the top). As was described above, light from the Xe-lamps passes through a hole, an interference filter and a collimating lens. To evaluate the illumination uniformity in the measurement plane of the instrument, a lens-cell concentrator unit was used similar to the individual sub-modules in a full-scale module. It consisted of a 40x40 mm² Fresnel lens and a triple-junction InGaP/GaAs/Ge solar cell placed in the lens focal plane. Such a sensor was being moved along the simulator measurement plane and aligned normally to the incident light. The relative difference in the short circuit current was used as a measure deviation. Spatial uniformity across the simulator illumination area of 0.5x0.5 m^2 was measured to be within +/– 3%. An example of the recorded I-V curve for one of the 0.5x0.5 m^2 concentrator modules is also shown in Figure 3 (in the bottom).

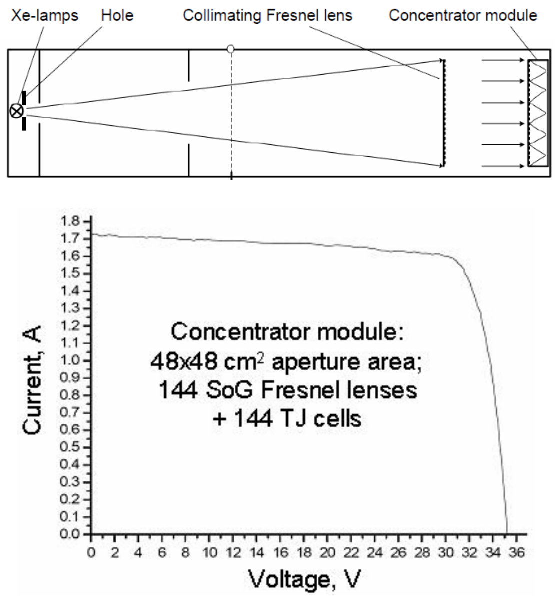

Figure 3: On the top– the lay-out of the solar simulator parts in the case of characterizing concentrator modules; in the bottom– I-V curve for one of the 0.5x0.5 m^2 concentrator modules recorded at 1-sun AM 1.5d illumination conditions with collimation of the light beams.

4 CHARACTERIZATION OF THE CONCENTRATOR SOLAR CELLS

The lay-out of the solar simulator parts in the case of characterizing individual concentrator cells is shown in Figure 4 (on the top). A part of the instrument with a collimating lens is used as a pedestal for the part with Xe-lamps, which, in turn, is vertically positioned by 90˚-bending of the mechanical frame around a special joint. A screening mask with a hole in front of the Xe-lamps is not necessary in this case.

The elaborated illumination system allows recording the I-V curves in two modes of operation. The first one implies the whole I-V curve measurement during one flash (this is about 150 points). This mode is used for characterizing cells with a short life-time of photogenerated charge carriers (for instance, III-V cells). The light intensity level is varied by changing the distance between the flash lamps and the cell. The sun concentration ratios as high as 10000 suns can be achieved at the shortest distance between a tested cell and the lamps. The second mode of the I-V measurement is carried out point by point from flash to flash. Each pair of the I and V magnitudes is measured at the end of the flat part of the each light pulse. This mode may be used for characterization of the solar cells based on materials with larger life-times of the photogenerated carriers. A family of the illuminated I-V curves recorded for one of the small-in-area concentrator InGaP/GaAs/Ge solar cell is shown in a bottom part of the Figure 4. The use of the mesh-type neutral filters allows measuring the cells in near to 1-sun illumination conditions.

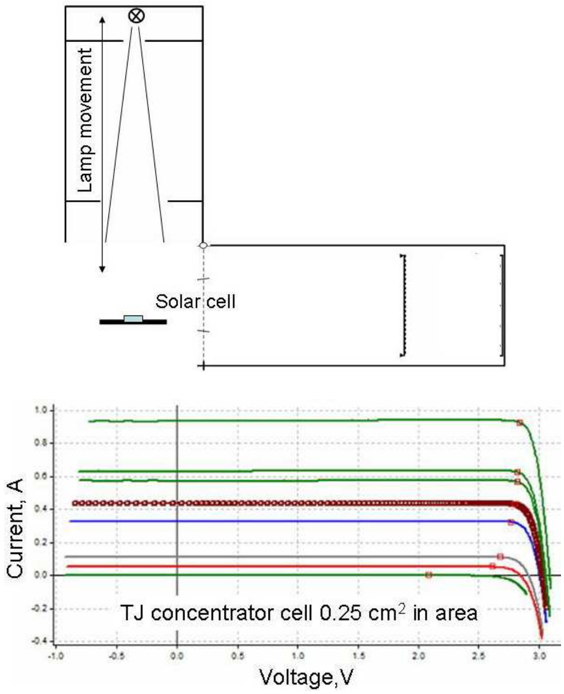

Figure 4: On the top– the lay-out of the solar simulator parts in the case of individual concentrator cells characterizing. A family of the illuminated I-V curves recorded for one of the small-in-area concentrator InGaP/GaAs/Ge solar cell is shown in the bottom part of the Figure.

5 CHARACTERIZATION OF THE FLAT PV ARRAYS

The lay-out of the solar simulator parts in the case of the flat PV arrays characterization is shown in Figure 5 (on the top). The part of the instrument with a collimating lens is used as a pedestal for the part with Xe-lamps, but the latter, in turn, is horizontally positioned by 180˚-bending of the mechanical frame. A screening mask with a hole in front of the Xe-lamps is absent. At the distance of 5.5 m from the lamps to the PV array, the illumination intensity around 1.5 suns was measured with uniformity of about 4% (no special "black room" requirements have been applied in this experiment). The intensity can be varied not only by changing in distance, but, also, by lamp voltage variation (±20%) and mesh filters.

In world practice, a great amount of the flat PV arrays is fabricated on the basis of the silicon cells. The most efficient cells may be characterized by sufficiently long life time of the photogenerated charge carriers. To identify probable problems with I-V measurements in such a case, two regimes of the curve records are provided in the instrument – from short circuit to open circuit conditions and vice versa. This two-flash procedure reveals probable hysteresis in I-V tracing. If this takes place, the I-V measurement should be carried out in point by point mode from flash to flash. The number of points in the curve is set by the operator. An example of the illuminated I-V curve recorded in 1-sun conditions during one flash for one of the Si-based solar arrays is shown in the bottom part of the Figure 5.

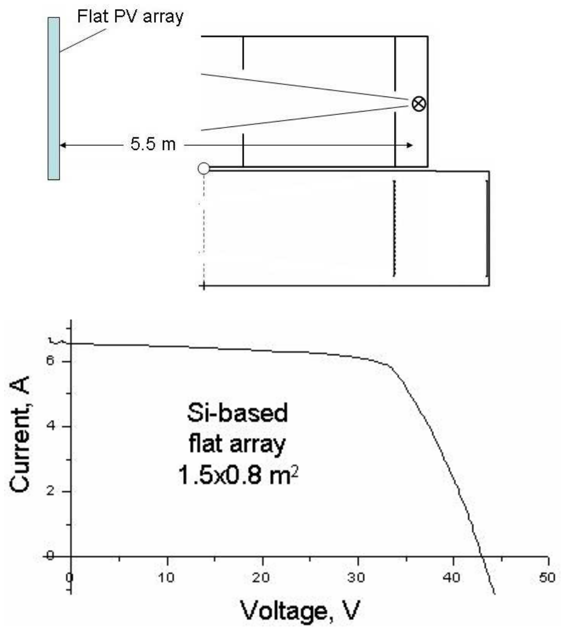

Figure 5: On the top– the lay-out of the solar simulator parts for the case of the flat PV arrays characterization. An illuminated I-V curve recorded in 1-sun conditions for one of the Si-based solar arrays is shown in the bottom part of the Figure.

6 CONCLUSION

The multifunctional flash solar simulator/tester described in this paper may be used as the cost-effective means applied at characterization of a variety of solar PV devices – 1-sun and concentrator cells, large area flat and concentrator modules. The simulator currently developed for the "collimated" illumination area of 0.5x0.5 m^2, may be regarded as a modular unit for arrangement of the instruments with sufficiently increased illumination areas, for instance, 0.5x1 m^2, or 1x1 m^2 in configuration with collimated light, or even greater. In the instrument versions with "non-collimated" light flux, the illumination areas will be much bigger. Tester function of the developed instrument is ensured by the versatile measurement unit and corresponding software.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

[1] V.D.Rumyantsev, V.R.Larionov, D.A. Malevskiy, M.Z.Shvarts, V.M.Andreev "Indoor characterization of multijunction concentrator cells under flash illumination with variable spectrum", Proc. of the Fourth Int. Conf. on Solar Concentrators for the Generation of Electricity or Hydrogen, El Escorial, Spain, 2007, pp. 277-280.

[2] César Domínguez, Ignacio Antón, and Gabriel Sala "Solar simulator for concentrator photovoltaic systems" Optics Express, Vol. 16, N 19, 2008, pp. 14894-14901.

[3] A.Virtuani, D.Chianese, G.Friesen, G.Rigamonti, M.Peguiron, P.R.Beljean "Results of the MPVT (Multi-Purpose PV Module Tester) project- a highly innovative and versatile solar simulator". Proceedings of the 26th Eur. PV Solar Energy Conf., Hamburg, September 2011.

[4] V.D.Rumyantsev, V.R.Larionov, D.A.Malevskiy, P.V.Pokrovskiy, N.A.Sadchikov "Solar Simulator for Characterization of the Large-Area HCPV Modules". Proceedings of the CPV-7 Conference, Las Vegas, April 2011.

[5] V.D.Rumyantsev "Terrestrial concentrator PV systems" in: "Concentrator Photovoltaics", Eds.: A.Luque, V.Andreev, Springer Series in Optical Sciences, vol.130, 2007, pp. 151-174.

[6] V.D.Rumyantsev, V.R.Larionov, D.A.Malevskiy, P.V.Pokrovskiy, A.V.Chekalin, M.Z.Shvarts "Evaluation of the Solar Cell Internal Resistance in I-V Measurements under Flash Illumination". Proceedings of the CPV-8 Conference, Toledo, April 2012.