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CONCENTRATOR PV MODULES WITH MULTI-JUNCTION CELLS AND PRIMARY/SECONDARY REFRACTIVE OPTICAL ELEMENTS

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ABSTRACT:. The following concepts connected with concentrator approach are under development in the PV Lab of the Ioffe Institute: small-aperture area and short focal length primary Fresnel lens concentrators; smooth-surface secondary mini-lenses; “all-glass” design for the modules; close-loop sun-tracking strategy for solar installations. Thermal properties of the sub-modules of different modifications have been experimentally examined; lens-cell alignment procedure including lens panel formation and cell mounting processes has been developed; specialized sun tracker for 1 kWp of installed capacity for the modules under development has been designed and built.
Keywords: Concentrators; Module Manufacturing; Tracking.

1 INTRODUCTION

PV systems with concentrators may provide economical advantages, if high-efficiency multi-junction III-V cells are combined with cheap optical concentrators providing high concentration ratio (500-1000x and above). A promising way for concentrator system development is a concept of small-aperture area sub-modules in PV module design. In this case the advantages of a concentrator system (rise in efficiency, saving the semiconductor and structural materials) may be realized at retention (in the whole) of a distributed character of sunlight conversion and heat dissipation– similar to the case of systems without concentration [1]. In the last few years this approach was under development at the Ioffe Institute in co-operation with the Fraunhofer ISE, Freiburg, Germany [2-4]. At the same time, the special tracking systems for practical operation of the high-concentration modules had been built [4]. As a result of co-operation, the FLATCON ™ concentrator modules have been created [3]. Optical layout of a sub-module in such PV system is shown in Figure 1,a. The module housing is made of glass, including rear side and the sidewalls. Refractive-type concentrators (Fresnel lenses) have a composite structure: microprisms are formed from transparent silicone rubber contacting with front glass sheet as a protective superstrate. A quantity of the lenses are arranged on a common superstrate in a view of lens panel. Outdoor conversion efficiencies as high as 22.7-24.9% have been measured in the FLATCON modules equipped with $Ga_{0.65}In_{0..35}P/Ga_{0.83}In_{0.17}As$ cells fabricated in the Fraunhofer ISE (cells of 2 mm in photoactive area diameter; geometrical concentration ratio of about 500x).

In our previous publications a modified structure of the high concentration “all-glass” PV modules with III-V solar cells had been presented [5-6] (see, also, Figure 1,b). The small aperture smooth surface secondary lenses arranged as an intermediate composite (glass-silicone) panel be inserted between a panel of the primary Fresnel lenses (each of 40 x 40 mm^2) and a panel of the solar cells. The cells as small as 1.2 mm in designated area diameter operating at very high concentration ratio (more than 1000x) can be used in the developed PV modules with secondary lenses. Such a design allows fabricating the modules of large total area (up to 0,5 x 1 m^2) due to the fact, that internal air interspace between front and rear glass plates may have no hermetical sealing with respect to atmosphere, whereas environmental protection of the cells is carried out due to hermetical sealing a thin air gap between rear glass plate and trough-like shaped metallic heat sinks. Additional advantage is that heat dissipation takes place immediately to the surroundings, by-passing the rear glass plate. Taking into account mentioned above, arrangement of the cells behind the rear glass plate of the module has the advantages even in module design without secondary lenses (see Figure 1,c).

Practical realization of such type modules is directly connected with necessity to solve the problems of heat sinking, precision positioning the cells with respect to the corresponding lenses in a module, and positioning the modules with respect to the sun. The present paper describes activity of the PV Lab of the Ioffe Institute in solving all these problems. In particular, a difference in thermal behavior of the sub-modules of Figure 1, a-c has been experimentally established; lens-cell alignment procedure including lens panel formation and cell mounting processes has been developed; a specialized sun tracker for 1 kWp of installed capacity has been designed and built.

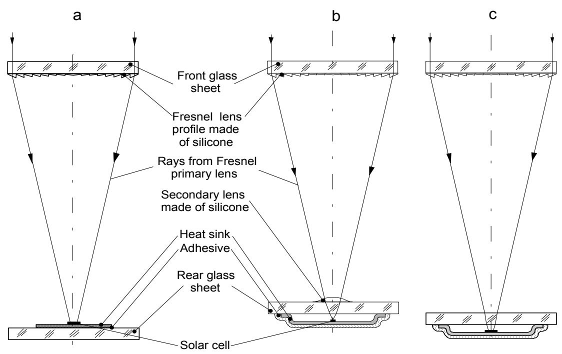

Figure 1: Optical schemes of the sub-modules in the PV modules with primary/secondary refractive concentrators: a- FLATCON ™ without secondaries; b- with secondary lenses; c-without secondaries, but with reduced air interspace, which has to be sealed hermetically.

2 THERMAL PROPERTIES OF THE SMALL-APERTURE AREA SUB-MODULES

Sub-module aperture area is 40x40 mm^2 taking into account spreading and dissipation of heat from a cell by means of copper heat sink 0.5 mm thick [2-3]. Expected level of heat, which has to be dissipated, is about 1 W, corresponding to direct solar irradiation of 100 mW/cm^2, concentrator system optical efficiency of 85% and cell conversion efficiency of 25%. Low absolute values of heat, as well as photocurrent, and small dimensions of the cells, comparable with cell thickness, give the possibility to equip the modules even with mechanically stacked multijunction cells. Thermal models of the sub-modules had been made simulating its temperature behavior at indoor measurements. The AlGaAs/GaAs cells 2 mm in diameter were soldered on the heat sink plates with configurations corresponding to certain fragments of heat sinks in sub-modules Figure 1, versions "a-c" (see photograph in Figure 2). Heating under concentrated sunlight illumination was simulated by passing the forward current through the cells from a power supply. Heat sink fragments were glued on the upper (for the sub-module version "a") or lower (for the sub-module versions "b-c") side of glass plates of size 40x40 mm^2. Appropriate conditions for heat dissipation were arranged by thermal isolation of the upper sides of plates and necessary positioning of them.

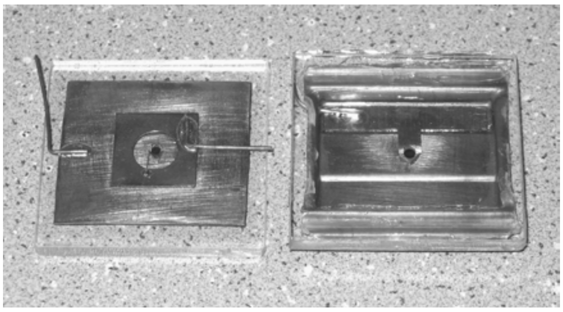

Figure 2: Thermal models of the sub-modules: at the left- for the sub-module version "a"; at the right- for the sub-module versions "b-c".

Overheating temperature of the cells and glass plates (on the outer sides) was measured with respect to ambient temperature. Measurement results are shown in Figure 3. It is seen from Figure 3, that expected overheating the cells and glass base plates is significantly lower in the case of trough-like heat sinks placed on the outer side of a module.

Certainly, reduced temperature of not only cells, but glass base plate too, should be regarded as a positive fact, if modules of larger sizes are planned for fabrication. Indeed, any temperature difference between front and rear (base) glass plates leads to certain misalignments of individual lenses and corresponding cells in the panels, bearing in mind small dimensions of the cells. Fortunately, relatively low value of thermal expansion coefficient for glass additionally mitigates this circumstance.

Mentioned above indoor experiment can not regard also heating the front glass plate with panel of primary Fresnel lenses. It is evident that such heating should take place due to absorption of the longer wavelength part of solar spectrum. Therefore, temperature difference between front and rear glass plates is expected to be lower, than overheating temperature in Figure 3.

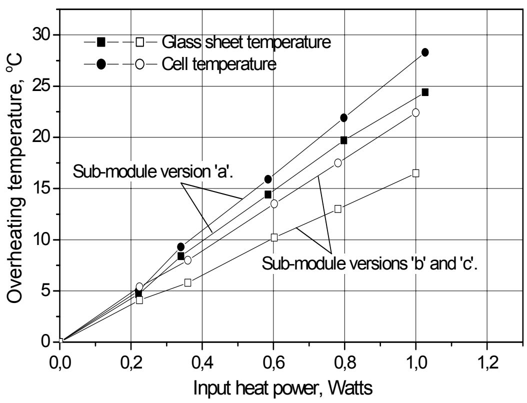

Figure 3: Overheating temperature of the cells and glass plates (see photograph in Figure 2) with respect to ambient temperature depending on input heat power.

It should be pointed out at the end of this paragraph, that there is an additional way for heat dissipation in the modules with optical schemes "b-c" of Figure 1. This way is a natural ventilation of the interspace between front and rear glass plates. Silicone rubber that forms refractive optical elements is inert to water. It means that special channels for convecting air could be arranged, but such channels should exclude penetration of dust into a module. One of the experimental modules with primary and secondary lenses equipped with two ventilation tubes in Figure 4 is shown. The tubes are situated at the diametrically opposite corners of the module housing and prevent direct penetration of both dust and water. Prolonged outdoor testing during 2003-4 has shown that there is no collection of dust in the modules of similar design.

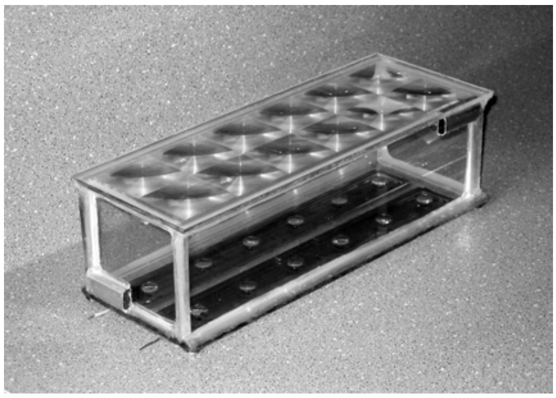

Figure 4: Experimental module with primary and secondary lenses equipped with two ventilation tubes.

3 LENS-CELL ALIGNMENT

Development of concept of the small-aperture area PV sub-modules implies necessity to mount a great number of small in size cells in a view of arrays with high spatial accuracy. This task is similar in some features to that concerned with wide use of the high-bright light-emitting diodes for conventional lighting. A real "revolution" in the field of lighting technique lies ahead. It is not improbable that lighting technique is one of two fields where use of semiconductors becomes to be dominant and extremely wide. That is why specialized equipment for mounting the large area diode arrays has to be under development during forthcoming years. In the future, another field could be large-scale generation of electricity by means of solar photovoltaic devices.

Every so often capacity for work of a concept can be examined using equipment in its simplest form. For concentrator PV modules under discussion the mounting procedure should ensure proper positioning the cells with respect to corresponding lenses with accuracy of about 0.1-0.2 mm. At given stage of work the problems of cell mounting and module assembling are solved in the following way. The panel of primary Fresnel lenses is arranged as a number of identical fragments. Each fragment is a string of six lenses. A negatively profiled mould, intended for polymerization of silicone rubber in a view of lens panel, consists of necessary number of identical mould fragments. In regard to the panel of cells, it is arranged as a corresponding number of identical units, where six cells and by-pass diode are mounted in parallel circuit on a common heat sink. A set, including negatively profiled mould for lens string, individual lens string, and cell unit, is shown in photograph Figure 5.

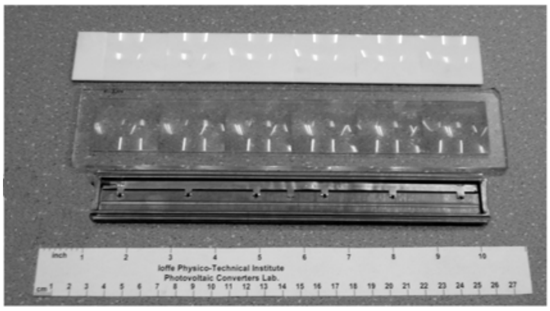

Figure 5: Photograph of the negatively profiled mould for lens string, individual lens string, and cell unit, intended for work with one of the lens strings.

It should be noted that soldering the cells on a trough-like heat sinks is carried out in accordance with real spacing on centers in lens strings. To ensure right position of the cells, identical foil strips of accurate configuration are used for initial cell positioning and upper contacting. In view of the facts, that the copper troughs are shaped by a press tool, and the strips are fixed inside the troughs in a definite position, any cell string can be aligned with respect to corresponding lens string using mechanical template, which fixes both the lens panel and the troughs. In the case of module design with secondary lenses, the panels with secondaries have to be fabricated with spacing on centers corresponding to that in primary lens panel.

Special mechanical and optical equipment have been developed for control of the lens–cell alignment procedure at different stages of module parts fabrication and module assembling. Also, a pulse solar simulator reproducing divergence of the sun rays has been designed and built for indoor characterization of the concentrator modules with reduced sizes.

4 SUN TRACKER FOR 1 KWP OF INSTALLED CAPACITY

High accuracy of tracking to the sun is a specific feature of the high-concentration PV method. Technical and economical aspects, concerned with necessity to ensure alignment in the system “sun–modules”, are among the crucial ones, determining success in this field. That is why PV Lab of the Ioffe Institute is involved in corresponding development.

Last our design of the sun tracker is based on the following approaches. In the construction the cheapest structural materials are used, such as roll-formed perforated channels and angles, made of zinc-protected steel. All members are no longer than 2 meters. Tracker consists of two main moving parts (see photograph in Figure 6): a base platform moving around vertical axis, and a suspended platform with PV modules moving around horizontal axis. The base platform is equipped with three wheels one of which is connected with an azimuth drive. Only a flat territory is necessary for the tracker operation. The suspended platform is a frame where concentrator modules are installed as three steps of a stair. Position of the suspended frame can vary in the range of ±45° symmetrically about a horizontal plane ensuring alignment of the modules in elevation. The base platform is driven by one of the wheels moving along a circle of a large radius. If motors (DC 12 V) are switched in use continuously, rotation velocity of the platforms is near to 1 rotation per hour, i.e. much faster, than it is necessary for a normal tracking. Continuous rotation of the motors is carried out for returning the trackers from “sunset” to “sunrise” position and for fast “searching” the sun after cloudy periods. At normal tracking the motors are switched on periodically, after each 8-10 seconds. Tracking mechanism is fully automatic managed by analog sun sensor similar to that described earlier [4].

Figure 6: Photograph of the developed sun tracker for 1 kWp of installed capacity on the roof of the Ioffe Institute.

The tracker was designed for arrangement of 21 concentrator PV modules 50x50 cm^2 in size. One prototype of such modules has been installed on the tracker. In each of three rows the modules will be installed without gaps.

5 CONCLUSIONS

A difference in thermal behavior of the small-aperture area sub-modules with refractive concentrators has been experimentally established. Expected overheating the cells and glass base plates is significantly lower in the case of trough-like heat sinks placed on the outer side of a module. Lens-cell alignment procedure at the different stages of module fabrication including formation of concentrating optical elements and cell mounting process has been developed. A specialized sun tracker for 1 kWp of installed capacity of the modules under development has been designed and built.

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