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Progress In Developing HCPV Modules Of SMALFOC-Design

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Abstract: This work presents a module generation which has been named as "SMALFOC module design". The abbreviation reflects the main features of the modules: Small-size concentrators; Multi-junction cells; "All-glass" structure; Lamination technology; Fresnel Optics for Concentration. Investigated modules have revealed a quite low over-heating temperature of cells in the MPP regime of operation and a real way for increasing the PV efficiency, if the rear glass base is supplied with an antireflection coating. Outdoor and high/low temperature tests have shown a good potential for long-term operation of such a type of modules.

Keywords: Solar cell; Fresnel lens; Heat sink; Lamination; Concentrator module.
PACS: 88.40.jp; 42.79.Ag; 84.60.Jt; 42.79.Bh.

INTRODUCTION

High Concentration Photovoltaic (HCPV) systems have a potential for significant reductions in installed cost/kWh due to numerous factors. One of them is that the solar cells based on III-V materials have become increasingly popular in solar concentrator systems attaining efficiencies as high as 40%. Another factor is a possibility to use the passive heat dissipation strategy without involving expensive heat sinks or heat spreaders. This approach is just applicable in the case of the relatively small-in-size concentrators and cells operating at high sunlight concentration ratios in integrated modules of the "all-glass" design [1, 2]. In such modules, the front glass sheet plays a role of a base element for silicone-on-glass (SoG) Fresnel lenses concentrating sunlight, and rear glass sheet is a base element for arrangement of cells with their heat spreaders. It has been shown in [3, 4] that the rear glass may play a role of an integrated cover glass for all solar cells, if the cells are placed on the outer side of the rear glass sheet and the lamination technology is applied for their hermetical sealing.

The module design combining the structural features mentioned above has been named by us as "SMALFOC module design". The abbreviation reflects the following: Small-size concentrators; Multi-junction cells; "All-glass" structure; Lamination technology; Fresnel Optics for Concentration. Such HCPV modules are rather similar to the regular flat-plate modules relating to both main structural materials and fabrication technology.

In the present work, the different versions of the SMALFOC modules have been fabricated and investigated. The varied construction features were lens and module sizes, heat spreader material, and transmissivity of the rear glass base. The aim of the investigations consisted in evaluation of operation temperature of cells and determination of the PV conversion efficiency and potential for its further increase.

SMALFOC MODULE STRUCTURE

Optical scheme of a SMALFOC module fragment is shown in Fig.1. There are two module versions relating to lens sizes in the SoG parquet– 40x40 and 60x60 mm² with corresponding difference in focal distances– 70 and 110 mm.

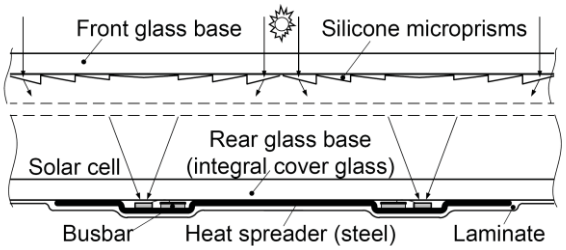

FIGURE 1. Optical scheme of a SMALFOC module fragment.

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In the PV receiver, consisting of the elements on the rear glass base, a distinctive feature was introduction of the heat spreaders common for certain quantity of SCs. To improve transmissivity of the rear glass, in some module versions a two-side antireflection coating (ARC) was applied. Introduction of the integrated heat spreaders was dictated by a tendency to make simpler the module structure and, at the same time, to make easier precise cell positioning on the receiver panel. A problem associated with this step consisted in a possible increase of the mechanical stress arising in the contact between the glass base and the metallic spreader due to the difference in their thermal expansion coefficients. Our experience had shown that thin copper, which is commonly used as a carrier for single small-size cells, is not suitable in attempts to integrate these carriers in a larger-in-size element. The reason is glass bursting after temperature cycling. Indeed, as it is seen from Table 1, the thermal expansion coefficients (TEC) for copper and glass differ significantly. In this regard soft steel seems to be a very attractive material, both from lower TEC and lower cost point of view. Steel is also a more suitable material for the direct mechanical contact with the cell substrate (it is germanium). Unfortunately, steel is characterized by about four times lower thermal conductivity. However, this negative characteristic can be partially compensated by increase in heat spreader thickness. A thicker spreader characterized by a higher heat capacity should arrange better thermal conditions for the cells in the temperature cycling regime. In Table 1, special consideration must be given to the fact that the glass thermal conductivity is very low. It is an important advantage of the current module design that glass is excluded from the process of direct cell-to-ambient heat dissipation (see Fig.1).

TABLE 1. Thermal expansion coefficient (TEC), thermal conductivity (TC), and heat capacitance (HC) for the materials being in the mechanical contact in the modules.

Material	TEC, um/m/K	TC, W/(m·K)	HC, J/(kg·K)
Germanium	5.8	60	320
Copper	16.7	384	385
Glass	9	1	800
Soft steel	12	85	460

In the present work, the heat spreaders were made of soft steel plates 1 mm thick, as well as of 0.5 mm thick copper plates (for comparison), with using a press tool for shallow profiling. The spreaders were electroplated with the Sn:Bi alloy. The cells, by-pass diodes and busbars were soldered in the hollows of the spreaders. Fig.2 depicts two versions of the spreaders with mounted cells – for the parquets of 40 x 40 and 60 x 60 mm² lenses. In the first case 12 cells are mounted in a single structural unit, and in the second case – 8 cells. Being placed on the glass base with necessary accuracy, these units are covered with EVA and Tedlar films, whereupon fixed and hermetically sealed in a routine lamination process. The integrated spreaders are just similar in sizes to the conventional large-area silicon cells in the regular flat-plate modules. In this case, the assembly process for the CPV modules is quite similar to that for flat modules: connection of the units into serial-parallel strings; placing of the strings on a glass holder; lamination process; mounting a standard junction box.

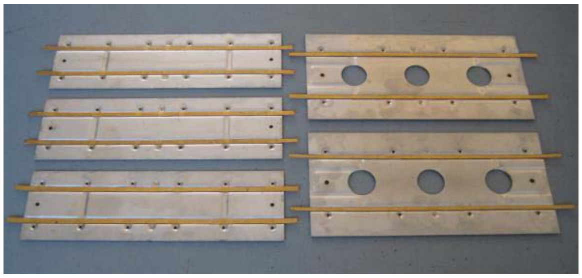

FIGURE 2. Picture of the heat spreaders with triple-junction InGaP/GaAs/Ge solar cells 2.3 mm in diameter and by-pass diodes for the lens parquets of 40x40 (left) and 60x60 mm² (right).

For the experiments, the full-size modules and smaller-in-size ones (for test measurements) have been fabricated. The test modules have been involved in two kinds of experiments: for cell temperature evaluation; for measurements of the PV efficiency in versions with and without rear glass, as well as applying glass with two-side antireflection coating. The modules for temperature test consisted of a panel with eight 60x60 mm² lenses and a rear glass base with one heat spreader similar to that shown in Fig.2 (on the right). The full-size modules had lens parquets of 12x24 or 8x16 (40x40 mm² or 60x60 mm² lenses, respectively).

CELL TEMPERATURE EVALUATION

Two test modules mounted on a sun tracking mechanism for temperature experiments are shown in Fig. 3. The difference between them was in materials for the heat spreaders– copper or steel. The modules were subjected to sun illumination in laboratory conditions through a window to exclude many uncertainties associated with normal outdoor experiments. The measurement procedure for cell temperature evaluation is described in details in [3].

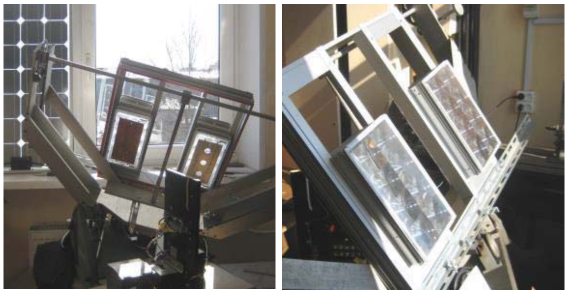

FIGURE 3. Back and front pictures of two test modules (8 lenses of 60x60 mm^2 in size) with parallel-connected triple-junction InGaP/GaAs/Ge solar cells mounted on copper and steel heat spreaders: sunlight illumination intensity of 610 W/m^2; no wind; ambient temperature T_{amb}=23÷24˚C.

Solar cell temperature in the maximum power point (MPP) operation regime and that in the open circuit (OC) regime (T_{MPP} and T_{OC}) are computed using voltage measurements in varying fast the cell load conditions. The OC voltage values serve as an indicator of T_{MPP} in short multiple periods of the load disconnection. Fast extraction or introduction of a definite portion of power from/into a cell chip by electrical commutation of the external load allows estimating the temperature behavior of the cells mounted on the heat spreaders made of different materials [3]. The results of corresponding voltage measurements for the test modules (Fig.3) are shown in Fig.4.

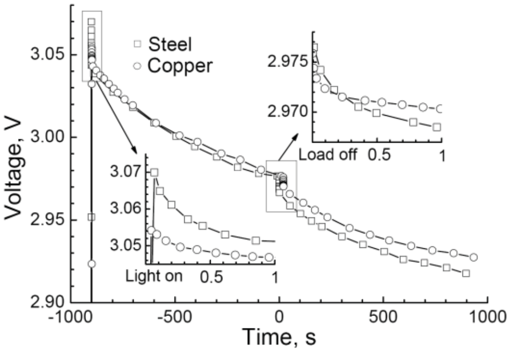

FIGURE 4. Time-dependent V_{OC} measurements of the modules shown in Fig. 3. Time interval on the left of the "0" point (except the first second) corresponds to the MPP regime of the cells, when the electrical load is being disconnected periodically for a short time and V_{OC} is measured at temperature T_{MPP}. Time intervals on the right of "0", as well as the first second after the "light on" moment, correspond to the "normal" OC regime [3].

In Fig.4, a sharp decrease in voltage after a sharp rise of the incident optical power (after "light on" moment) corresponds to the increase in T_{MPP}, because the modules are connected with the external optimum load. A similar decrease after zero time (after "load off" moment) corresponds to the further increase in temperature, because the modules are disconnected from the external load, and now cell temperature corresponds to T_{OC}.

The results of the experiments have been corrected using procedures described in [3], including conversion of the data to incident illumination level of 850 W/m^2. They are as follows:

- cell chips on the 1 mm thick steel spreaders are characterized by over-temperature of around 33÷35˚C in the MPP regime and 50÷52˚C in the OC regime;
- in the case of the 0.5 mm thick copper spreaders, these temperatures are by 3÷4ºC lower.

It should be noted that these over-temperatures are related to cell illumination conditions stronger than that in [3] (lenses are 2.25 times larger in area). Nevertheless, insignificant increase in temperature in substituting copper for steel seems to be quite acceptable.

APPLICATION OF GLASS WITH ARC

The rear glass sheet in the modules under consideration should be highly transparent for sun rays. A solution for this is application of a two-side antireflection coating. A favorable feature of the SMALFOC modules for ARC application is that the rear glass is protected from environment (see Fig. 1). Also, ARC technology becomes to be easily accessible in the market [4, 5].

A "one sun" flash tester with a light collimating system [6] has been applied for conversion efficiency measurements in a module, where rear glass is replaceable. In the test module with 40x40 mm² Fresnel lenses, twelve TJ cells characterized by the initial efficiency of 37% have been connected in parallel. The results of measurements of the PV parameters are presented in Table 2.

TABLE 2. Impact of rear glass on PV module parameters.

PV parameter	No rear glass	Optiwhite glass	Glass with 2-side ARC
I_{SC}, A	1.85	1.64	1.75
V_{OC}, V	3.05	3.06	3.06
FF	83.5	83.7	83.6
Eff., %	30.7	27.3	29.2

It is obvious that application of a rear glass with ARC (in our case it was glass produced by DSM firm [5]) increases the module PV efficiency significantly. We hope that a moderate increase in price for ARC glass will be compensated by a considerable rise of the module lifetime, if the lamination technology for cell protection is used.

OUTDOOR INVESTIGATIONS OF THE FULL-SIZE MODULES

A full-size HCPV module with 8x16 lens parquet (128 lenses of 60x60 mm²) and triple-junction InGaP/GaAs/Ge solar cell is shown in Fig. 5. The cells were mounted on 16 integrated heat spreaders. After serial connection of the PV units and their lamination on the glass base, a standard junction box was mounted on the rear side of the receiver. Also, the modules with 288 40x40 mm^2 lenses and cells were fabricated in the same way.

FIGURE 5. Pictures of the front and rear sides of a SMALFOC module with 128 lenses of 60x60 mm² and 16 integrated PV units.

Figure 6 shows one of the full-size modules (with 40x40 mm^2 lenses) at outdoor I-V measurements. Illuminated I-V curve is presented in Fig. 7, where conditions of the measurements and PV parameters are indicated as well. It should be noted that the rear glass in the investigated module had no ARC. The laminated modules have been subjected to the thermocycling tests (500 cycles of –10/+100˚C and about 1000 cycles of 0/+100˚C), as well as to a long-term high-temperature exposure (6 months at T= +100˚C) without loss in working capabilities.

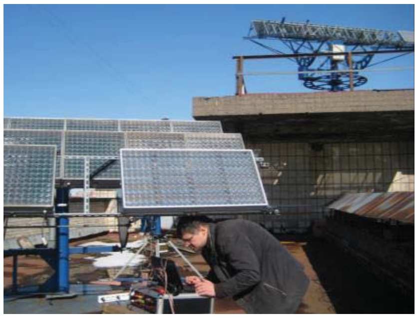

FIGURE 6. One of the full-size modules (288 pcs of 40x40 mm² lenses and cells) at outdoor I-V measurements.

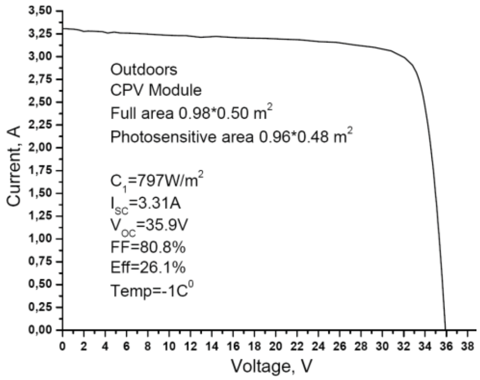

FIGURE 7. Illuminated I-V curve for the 288-lens module with triple-junction InGaP/GaAs/Ge solar cells.

CONCLUSION

Investigated modules of SMALFOC design have revealed a quite low over-temperature of the cells in the MPP regime of operation and demonstrated a real way for increasing the PV efficiency, if rear glass base is with ARC. Outdoor and high/low temperature tests have shown a good potential for long-term operation of modules of such a type.

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REFERENCES

1. V.D.Rumyantsev "Terrestrial concentrator PV systems" in Concentrator Photovoltaics, edited by A.Luque, V.Andreev, Springer Series in Optical Sciences, vol.130, 2007, pp. 151-174.
2. V.D.Rumyantsev, "Solar concentrator modules with silicone-on-glass Fresnel lens panels and multijunction cells" OPTICS EXPRESS, Vol. 18, No. S1, 2010, pp. A17-A24, eISSN: 1094-4087.
3. V.D.Rumyantsev, A.V.Chekalin, N.Yu.Davidyuk, D.A.Malevskiy, P.V.Pokrovskiy, N.A.Sadchikov, A.N.Pan'chak, "Cell chip temperature measurements in different operation regimes of HCPV modules". This Conference.
4. D.A. van Wezep, M.H.L. van der Velden, D.M. Borsa, R.C.M. Bosch, "Low cost PECVD of anti-reflection coatings on module glass". 27th European Photovoltaic Solar Energy Conference and Exhibition
5. www.dsm.com
6. 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". Proc. of the CPV-7 Conference, Las Vegas, April 2011.