# HCPV Modules With Primary And Secondary Minilens Panels

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**Abstract:** We report on research activities at the Ioffe Physical Technical Institute in the field of secondary lenses for HCPV modules based on primary Fresnel lenses and multijunction cells of 12x12 or 8x8 configuration. For this, the smooth-surface secondary lenses, each about 12 mm in diameter, are integrated into a secondary minilens panel placed in front of the solar cells. For both panels the glass sheets 4 mm thick serve as the common base plates. The cells with passive copper heat spreaders are placed on the outer side of the secondary minilens panel, so that this panel is a common protective cover glass for cells integrated in the module. Significant increase in the local sun concentration ratio and in the module acceptance angle have been measured both indoors and outdoors.

**Keywords:** Solar cell; Fresnel lens; secondary lens; concentrator module.
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## INTRODUCTION

The use of the secondary optical elements decreases the accuracy requirements on assembly, alignment, and tracking technology for the high-concentration photovoltaic (HCPV) modules [1-3]. In the case of the secondary lenses, keeping constant the above parameters, it is possible to increase significantly the sun concentration ratio, which leads to the more effective use of the semiconductor materials. Disadvantage of the lens-type secondary elements is the inherent optical losses due to reflection from the air-glass interface. Positive feature of them is possibility to be arranged without a mechanical contact with the cell surface, so that the thermal expansion difference problem, as well as that of the long-term stability of the optical lens-cell contact, is totally eliminated. This work is devoted to usage of secondary lenses in HCPV modules based on small-aperture area primary glass-silicone Fresnel lenses and triple-junction InGaP/GaAs/Ge cells [4-5]. In a module, the Fresnel lenses of 40x40, or 60x60 mm² in aperture area were integrated into a primary lens panel. A panel of secondary minilenses was placed in front of the solar cells. The cells with passive copper heat spreaders are placed on the outer side of the secondary minilens panel, so that this panel is a common protective cover glass for cells. The local sun concentration ratio on cell surface, the acceptance angle and the PV conversion efficiency in test multi-lens modules have been measured both indoors and outdoors.

## SUBMODULES WITH SECONDARY PLANE-CONVEX LENSES

Figure 1 shows the design of a concentrator submodule, in which a secondary element is made in a form of a plane-convex lens.

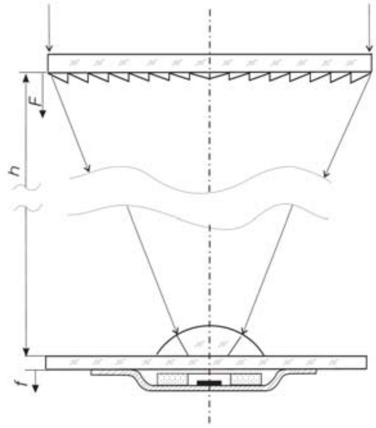


**FIGURE 1.** Optical scheme of an individual solar concentrator submodule. Shown are the planes from which the focal distances F and f are measured.

An ordinary convex lens as a secondary element can distinctly improve the misorientation curve of a module, having such an advantage that it may be placed without a direct contact with the cell surface. Also, the base glass plate for these lenses may serve as a common protective cover for all the cells in a module. The cells under illumination with increased local sun concentration ratio should have certainly improved parameters regarding to the low internal ohmic resistance and the high enough peak current in the built-in tunnel junctions of the cell structure. These problems are illustrated in Figures 2 and 3.

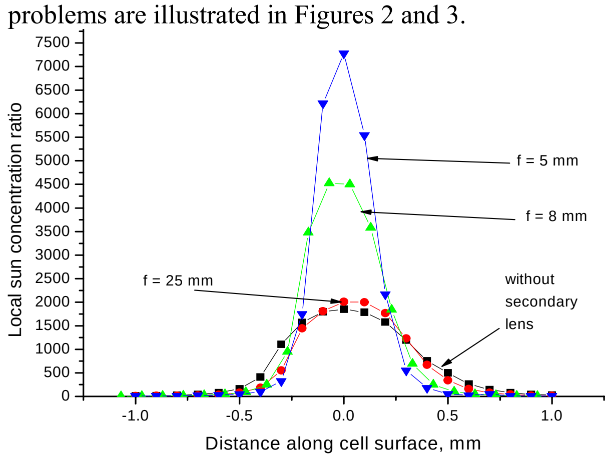


**FIGURE 2.** Local light concentration along the cell surface measured by scanning the focal spot in a PV system with a primary 40x40 $mm^2$ Fresnel lens and a secondary lens of different focal distances *f*.

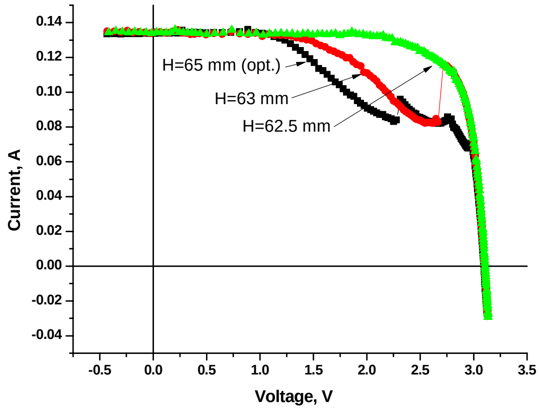


**FIGURE 3.** Illuminated I-V curves of a triple-junction cell with a primary Fresnel lens and a secondary flat-convex lens under illumination from flash solar tester. A distance *H* between primary and secondary lenses was varied. The maximum local sun concentration was at the distance of 65 mm (poor I-V curve due to trace of the tunnel junctions), and shortening the distance resulted in defocusing of light (improvement of the fill factors took place).

To reduce losses due to reflections, an antireflection coatings (ARC) may be applied, so that residual losses for two lens sides could be achieved at a level of 2÷3%. Contribution of this process to the cost of lenses may be of the same "weight" as that of highly reflective coatings in the case of the reflective pyramids. Operation capabilities of cells at a very high local concentration were confirmed for practical structures of the high efficiency triple-junction cells. Indeed, the I-V curve fill factors *FF* were in the range of 85÷86% at local concentration ratios of about 5000x (see below).

As the first step of investigations of the submodules with secondary lenses, the optimum distance *D* was found for each pair of the primary and secondary lenses from the prepared set of convex lenses with different focal distances *f*. The maximum efficiency value of the photovoltaic conversion measured indoors by a solar tester was the optimization criterion. It is known that the cell efficiency may increase due to better light collection at better focusing. Also, it can decrease due to too high local light concentration and, hence, decrease in *FF* of the I-V curve. The fact that local light concentration is actually high is confirmed by the result of scanning the focal spot in a PV system with primary and secondary lenses of different focal distances *f* (see Figure 2). It should be noted that "sharp" focusing was not the criterion of optical adjustment, but that of the highest *FF* of the cell I-V curve.

At misorientating the submodule axis, a light spot of smaller diameter can remain for a longer time on the SC surface. In Figure 4, the results on misorientation angle measurements are presented for a sub-module with a primary Fresnel lens of 40x40 mm, solar cell 1.7 mm in diameter and secondary lenses of different focal distances *f*. The data are in relative units for better comparison of the curves.

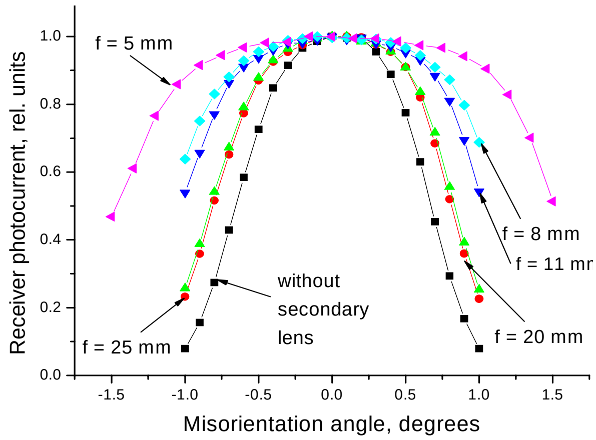


**FIGURE 4.** The results on misorientation angle measurements for a PV sub-module with 40x40 $mm^2$ primary Fresnel lens, a solar cell 1.7 mm in diameter and secondary lenses of different focal distances *f*.

In Figure 5, the similar results are presented for the case of a cell 2.3 mm in diameter. Widening the contours of the module misorientation characteristics almost in three times in the case of the shortest-focus secondary lenses was observed.

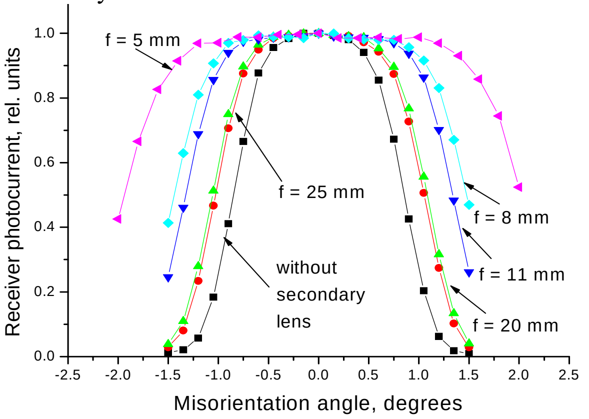


**FIGURE 5.** .The results on misorientation angle measurements for a PV sub-module with a 40x40 $mm^2$ primary Fresnel lens, a solar cell 2.3 mm in diameter and secondary lenses of different focal distances *f*.

Table 1 presents some of the PV parameters (overall conversion efficiency, maximum local sun concentration ratio, and misorientation angle, at which efficiency is on the 0.9 level from the normal position) of test submodules with primary Fresnel lens of 60x60 mm and SC of 2.3 mm in diameter using secondary lenses of different focal distances *f* . Measurements were carried out with the help of a "solar" tester in the laboratory conditions (simulation of sun spectrum. 1 sun intensity and the divergence of the sun rays of 32'). The following may be pointed out for the given dimensions of the modules. As was expected, introduction of the intermediate rear glass for placing the secondary lenses already alone leads to reduction of the current and the efficiency because of light reflection from two additional "glass-air" interfaces. The use of relatively long-focus secondary lenses with one-side antireflection coating increases the current owing to both the partial decrease in reflectivity and the better collection of light on the SC surface by focusing. In the case of the shorter-focus secondary lenses, a significant current improvement takes place even when ARC is absent – only due to additional focusing the radiation. A positive fact was that, in all cases, the *FF* appeared to be greater that 85%, in spite of the significant decrease in the light spot diameter and quite essential increase in the local sun concentration ratio. By the sum total of the parameters in Table 1, the secondary lenses with *f* = 8 mm may be considered as optimum ones for application in practical modules. This focal distance is in a good correlation with results of theoretical consideration, where lens top surface curvature of 7 mm and total lens thickness (together with common flat plate) gave the mentioned above focal distance.

**TABLE 1.** Parameters of a concentrator submodule for a primary Fresnel lens of 60x60 mm with SC of 2.3 mm in diameter using secondary lenses of different focal distances *f* .

| Output submodule parameters and experimental conditions | PV Eff. % | C suns | ±W ang. deg. |
|---|---|---|---|
| Primary Fresnel lens 60x60 $mm^2$ and SC 2.3 mm in diameter, without a rear glass | 24,2 | 1640 | |
| The same, but with a rear glass, without the secondary lenses | 21,7 | | 0,257 |
| Secondary lens with *f* = 25 mm with ARC on the convex side | 23,2 | 2226 | 0,367 |
| The same, *f* = 20 mm | 23,0 | | 0,374 |
| The same, *f* = 8 mm, without ARC | 23,2 | 4320 | 0,587 |
| The same, *f* = 5 mm, without ARC | 22,5 | 6960 | 0,900 |

## DESIGN AND MANUFACTURE OF THE SOLAR CONCENTRATOR MODULES WITH CONVEX SECONDARY LENSES

Figure 6 shows one of the 8-lens test modules (60x60 mm primary Fresnel lenses) with triple-junction InGaP/GaAs/Ge solar cell (2.3 mm in diameter) and secondary lenses, which were intended for indoor and outdoor tests.

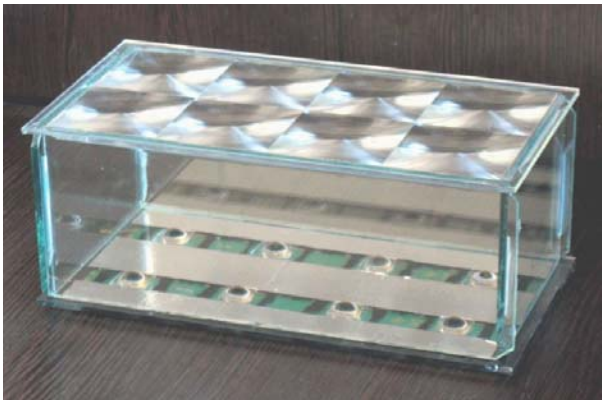

**FIGURE 6.** Picture of one of the 8-lens (60x60 $mm^2$ lenses) test modules with triple-junction InGaP/GaAs/Ge solar cell (2.3 mm in diameter) and secondary lenses intended for indoor and outdoor tests.

The SCs were mounted on a copper heat sinks glued to the lower side of the rear glass base of the module. Protection from the environment was ensured by hermetical sealing the narrow air gaps between the profiled thermoconductive plates and the common glass base. Plane-convex glass lenses were placed in front of the SCs by gluing on the internal side of the module rear base. the optimum distance between a primary lens panel and a panel of receivers had been found. Side walls of the modules were made of glass plates and fixed by silicone-based adhesive.

Figure 7 presents the I-V curve for the 8-lens module with 60x60 mm$^2$ Fresnel lenses, cells 2.3 mm in diameter and secondary lenses with $f = 8$ mm, in illuminating by solar rays incident normal to the module frontal surface. The measured efficiency was 23.4% (no temperature correction).

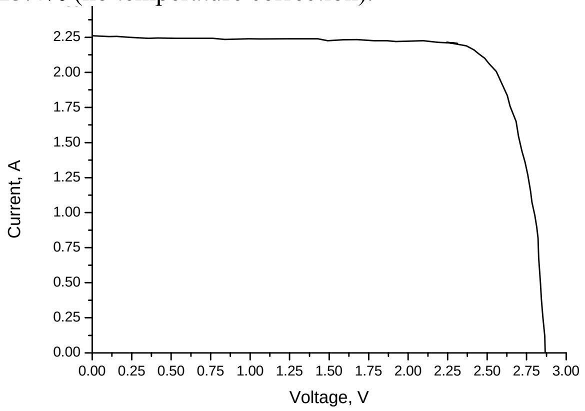


**FIGURE 7.** I-V curve for a 8-lens module with 60x60 mm$^2$ Fresnel lenses, cells 2.3 mm in diameter and secondary lenses with $f = 8$ mm, in illuminating by solar rays incident normal to the module frontal surface. The measured efficiency was 23.4% (no temperature correction).

Figure 8 shows widening of the misorientation curve in this module due to introducing the secondary lenses (outdoor measurements). To reveal the influence of the secondary lenses, the modules with and without secondary lenses were fabricated and initially tested indoors. More than two times widening was achieved in the modules with secondary lenses.

Therefore, the advantage of application of the secondary lenses in the HCPV modules was demonstrated in several aspects. First, owing to the decrease in the focal spot diameter, the misorientation curve of the module is wider (at the same cell size), or cell size may be reduced significantly. Second, the common glass holder of secondary lenses may serve as a cover for total hermetical sealing of the cells. Third, there is no mechanical contact of secondaries with the cell surface, which ensures easier mounting and long-term stability of the modules under environmental conditions.

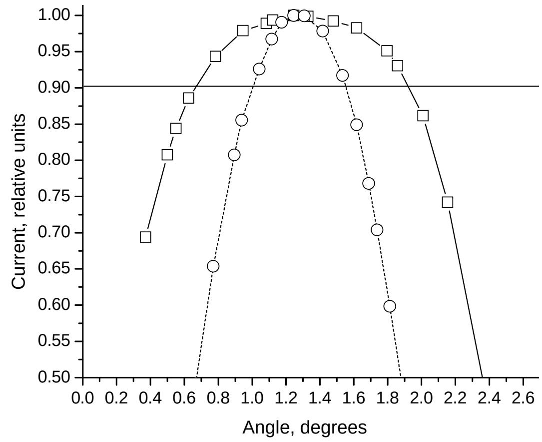


**FIGURE 8.** Widening of the module misorientation curve from ±0,27 to ±0,64 degree due to introducing the secondary lenses. In both cases, 8-lens concentrator modules with and without secondary lenses were measured (outdoor measurements).

## ACKNOWLEDGMENTS

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