Lens-Based Concentrator Modules: Exploring Critical Optical and System Integration Issues

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N. Kaminar, S. Daroczi, L. Pavani, P. Verlinden
SunPower Corporation
430 Indio Way
Sunnyvale, California 94085
(408) 991-0900

ABSTRACT

This paper describes the research done to identify the critical optical issues, critical system integration issues, and to assess the likely ultimate potential of lens-based concentrator module technology. Of the concentrator configurations studied, the SunPower micro concentrator was identified as having the greatest probability of success.

1. Introduction

Studies have shown that the concentrator could be the ultimate low-cost photovoltaic (PV) device.[1]. This work was done under the High Performance Photovoltaics (HiPer PV) Initiative, an expected 10-year program to approximately double the sunlight-to-electricity conversion efficiencies of thin film and concentrator PV technologies. The HiPer PV Initiative includes the goal of bringing multijunction concentrators to more than 33% efficiency.

In order to accomplish this goal, the potential optical systems must be fully researched and those with greatest probability of success identified. The effect of the balance of the module system, such as optical alignment and tolerancing, must also be identified.

2. Work Performed

During this subcontract SunPower performed fundamental research on Fresnel lenses, secondary optical elements, and module system integration. Various optical elements were designed using SunPower software and tested on a commercial ray tracing program. SunPower designed and fabricated an outdoor test facility to test optical systems. A detailed cost analysis was done on a variety of lens-based concentrator modules using commercial SunPower cells. Two different secondary optical elements (SOEs) were fabricated using an experimental low-cost material.

3. Results

Preliminary outdoor lens studies show that the optimum operation focal length for a Fresnel lens may not be at the maximum optical transmission point due to mal distribution of light at that length, see Figure 1. However, ray trace studies show that it is possible to design an SOE with both good transmission and flux distribution, see Figure 2. There appears to be a tradeoff between uniform flux distribution and acceptance angle. Further work is needed in this area.

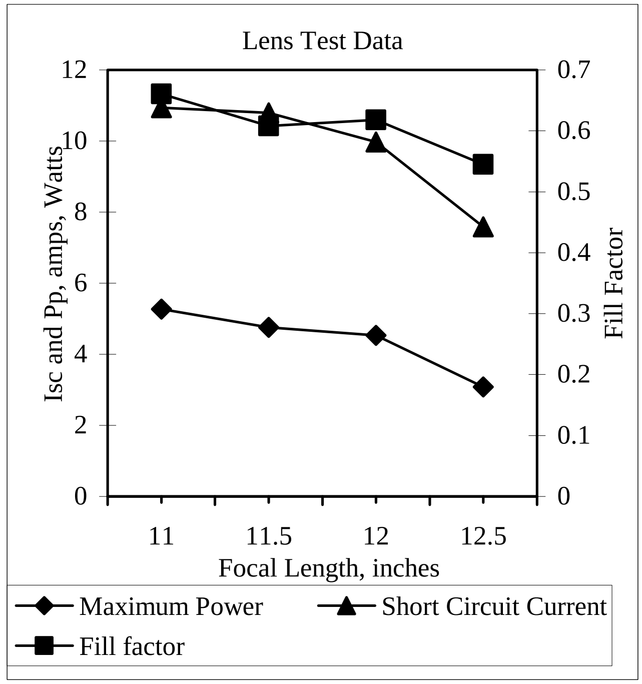

Figure 1, Lens Test Example

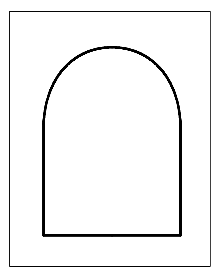

Figure 2, SunPower Pseudo Imaging SOE Design

The costing study was done in two phases. The first phase looked at the general effect of aperture size, concentration ratio, and similar factors. Figure 3 shows a sample of the results where relative cost is plotted as a function of lens size and heat dissipator size. The result indicates that the most cost-effective lens size would be about 11 inches square and the heat dissipator size should also be about 11 inches square. This design point used a SunPower cell with an active area of 1.21 square centimeters.

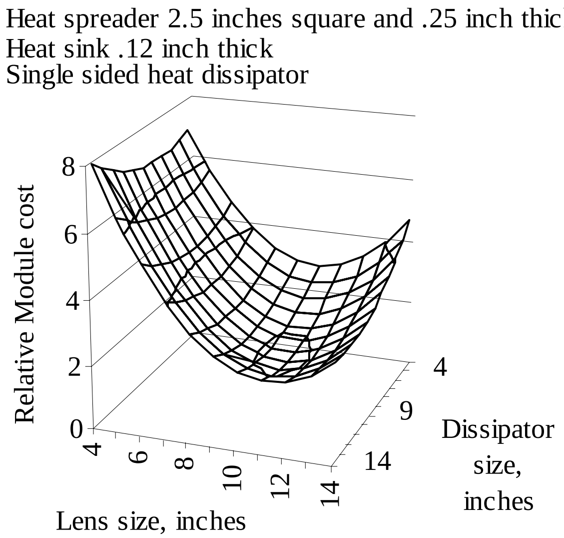

Figure 3, Effect of Relative Cost on Lens Size and Heat Dissipator Size

The second phase of the costing study compared specific designs. We found that the SunPower micro concentrator was lower relative cost than the competitive designs studied due to various factors, see Table 1.

Name	PL 2	PL 4	CP	MC	LI	PL 5
Type description	Plastic housing, Fresnel lens, sheet metal heat dissipator	Plastic housing, Fresnel lens, cast heat dissipator	Cold plate housing, Fresnel lens, no heat spreaders	Micro concentrator	Large Integrated System	Plastic housing, Fresnel lens, roll bonded dissipator
Production rate (MW/yr)	DC relative costs					
3	3.44	4.03	3.81	3.48	3.67	3.51
30	2.36	2.92	2.7	2.28	2.63	2.43
100	1.82	2.37	2.09	1.68	2.07	1.88
300	1.47	1.98	1.72	1.33	1.63	1.49
Assumptions: Total DC cost including tracker and module installation						
Production rate (MW/yr)	Module relative costs					
3	2.52	3.13	2.9	2.45	2.7	2.61
30	1.54	2.05	1.85	1.39	1.76	1.62
100	1.1	1.57	1.33	0.92	1.29	1.16
300	0.84	1.27	1	0.7	1	0.88
Assumptions: Module direct costs, no tracker or installation						

Table 1, Summary of Module Cost Study

The types of designs studied were:

1. A large integrated type design where the modules are self supporting structures and also part of a tracker structure (LI)
2. Modules with sheet metal housing where the housing is the heat dissipator (not shown, more expensive)
3. Modules with sheet metal housing and separate heat dissipators (not shown, more expensive)
4. Modules with plastic housing and separate heat dissipators (PL2, PL4, PL5)
5. The SunPower micro concentrator (MC)

Note: Not all designs are shown in Table 1.

A variety of heat dissipators were evaluated, including extruded aluminum, sheet aluminum, and nucleate boiling (roll-bonded cold plate) (CP). Different manufacturing rates were studied: 3, 30, 100, and 300 megawatts per year. Costs were based on quotes and internal estimates.

The SunPower micro concentrator would make an ideal candidate for a module using III-V concentrator cells [2]. A very high concentration ratio is possible. The cells are tiny, providing high wafer yield. The III-V cells would not suffer from edge degradation effects like silicon cells do. The shipping costs are low compared with bulky traditional Fresnel modules. The primary lens uses a combination of a solid aspheric center and a Fresnel reflective/refractive outer portion. An SOE is used on top of the cell to improve acceptance angle. The total height of the micro concentrator is less than one inch. The module has wide customer acceptance because it looks somewhat like existing flat-plate product.

We tested several candidate materials for low-cost SOEs. These included acrylic, polycarbonate, and exotic high temperature plastics. We discovered one candidate material that has the potential for molding low-cost SOEs. Additional testing is necessary, but the preliminary results are encouraging. The cost of these SOEs could be on the order of 10 cents, whereas the molded glass SOEs are close to 6 dollars. The material can be easily molded to any shape and also used to encapsulate the receiver in the same molding.

4. Conclusions

The SunPower micro concentrator design appears to have the lowest cost per Watt. It also has the highest customer acceptance because it looks like existing flat-plate product. This design is recommended for further study as a high-concentration III-V module.

SunPower has identified an SOE material that has the potential to dramatically lower the cost of this component. Additional testing is necessary on this material.

REFERENCES

[1] R. M. Swanson, "The Promise of Concentrators," Progress in Photovoltaics Research and Applications 8, 93-111 (2000)

[2] W.P. Mulligan, "A Flat-Plate Concentrator - Micro-Concentrator Design Overview," Proceedings 28th IEEE PVSC, (2000)