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# Domed Fresnel Lens Concentrator Technology for Space Application

Michael F. Piszczor, Jr.
*NASA Lewis Research Center*
*Cleveland, Ohio 44135*

Mark J. O'Neill
*Entech, Inc.*
*Dallas, Texas 75261*

Over the past three years, NASA Lewis and Entech, Inc. have been investigating the use of high efficiency refractive photovoltaic concentrators for use in space. The design currently under investigation uses a square domed Fresnel lens to focus light on a GaAs concentrator cell. A prismatic cell cover, which directs light away from the front contacts and thus eliminates metalization losses, is applied to the top of the GaAs cell to further enhance array efficiency. This paper will present the latest experimental results based on testing the GaAs cell/prism cover assembly at standard and operating conditions.

## Introduction

Under a Small Business Innovative Research (SBIR) contract, NASA Lewis has been working with Entech, Inc. to develop a highly efficient, relatively lightweight refractive concentrator array which would be applicable to a wide variety of missions. The selection of the domed Fresnel lens design is based on the results of studies conducted during the Phase I SBIR contract [refs. 1,2]. The design uses a gallium arsenide cell with a 4 millimeter diameter active area, which is designed to operate at conditions of 100 suns, 100 C. Based on the preliminary studies, an array performance of 240 watts per square meter and 80 watts per kilogram is possible in the near term. Improvements in lens and cell efficiency as well as weight optimization could further improve future system performance. A Phase II contract, currently under way, will develop hardware and enable further testing of the concept.

Figure 1 shows a conceptual design of the the domed Fresnel lens concentrator module. The domed Fresnel lens uses a curved shape as well as individually designed Fresnel facets along the inner surface. The design maximizes the lens optical efficiency by minimizing reflection losses within the lens by providing equal angles of incidence and emergence from the lens [ref. 3]. Initial optical analysis studies indicate that a net lens optical efficiency of 91.5% is reasonable without an antireflection coating. Use of a good antireflection coating could further improve the lens efficiency to 96%. The domed Fresnel lens can be cut into a square to increase the packing factor of the individual modules and further decrease losses. In Figure 2, the individual lens and cells are incorporated into a panel and illustrate this point.

## GaAs Cell/Prism Cover Measurements

The domed Fresnel lens concentrator concept uses a prismatic cell cover to minimize losses due to metalization. The prism cover directs incoming light away from the metalized surface of the the cell. An optimized prism cover design is shown in Figure 3. The design can accommodate light coming within the 30 degree rim angle of the domed Fresnel lens and can essentially eliminate losses due to gridline obscuration up to a metalization coverage of 21%. This not only increases the system efficiency by eliminating metalization losses, but also improves the operating cell efficiency by reducing series resistance, which becomes important under higher concentration ratios.

The visual effects of the prism cover can be seen in Figure 4. This figure shows two gallium arsenide concentrator solar cells side-by-side on a dime. Each cell has a circular active area with a 4 mm. diameter surrounded by gold metalization. The cells are identical, with the exception that a prismatic cell cover has been attached to the cell on the right. The prismatic cell cover directs incoming light away from the front grid fingers toward the open active areas of the cell. Note that since light is not reflected from the gridlines of the cell with the prism cover, the top grid lines essentially disappear on the cell on the right.

A number of GaAs concentrator cells with the proper front metalization configuration were provided by Varian. Four of the cells were covered with a prismatic cell cover. The cells were measured under AM0 conditions at a concentration of 100×, 25 C both before and after prism cover application. Three of the cells were also measured at 100×, 100 C, which is the expected operating condition of the cell in the domed Fresnel lens concentrator array. The results of the tests are shown in Table I.

After prism cover application, each cell measured over 23% at 100×, 25 C, with the highest efficiency being 24.3%. At an operating temperature of 100 C, the best cell achieved an efficiency over 22%. These results represent the highest efficiencies ever measured under space conditions at NASA Lewis.

The increase in short circuit current, after application of the prism cover, is a direct measure of the effectiveness of the prism cover in eliminating reflection losses from the front surface. Increase in current for the four cells ranged from 9% to 12%. Given the amount of front metalization, a maximum current increase of 13% would be expected. Since the method of applying the prism cover to individual cells is still being perfected, the results of these tests are encouraging.

## Program Status and Further Development

The goal of the SBIR Phase II program is to produce two prototype panels and a number of individual lens/cell modules for continued testing. To date, only the gallium arsenide cell/prism cover component of the domed Fresnel lens concentrator array has been tested. Efforts are currently under way to manufacture the domed Fresnel lens. Figure 5 shows the lens design being used for this Phase II contract. The domed shape of the lens is supplied by a microglass superstrate. The Fresnel facets are made from a silicone RTV and then bonded to the inside of the glass dome. Should another lens material prove more appropriate for the space environment, the array design is flexible enough to accomodate such changes. Efforts are also under way on developing a lightweight version of the domed Fresnel lens concentrator array.

## Summary

The domed Fresnel lens concentrator array is currently being investigated at NASA Lewis as an approach to get high efficiency, relatively light weight concentrator arrays. This concept uses a prismatic cell cover to reduce reflection losses from the top gridlines. A GaAs cell/prism cover assembly was recently measured at 24.3% and 22.1% under conditions of 100x AM0, 25 C and 100 C respectively. Future work will concentrate on development of the domed Fresnel lens itself.

## References

[ 1] M.F. Piszczor and M.J. O'Neill, "Development of an Advanced Photovoltaic Concentrator System for Space Applications," *Proceedings of the 22nd IECEC*, August 10-14, 1987.

[ 2] M.J. O'Neill and M.F. Piszczor, "Development of a Dome Fresnel Lens/Gallium Arsenide Photovoltaic Concentrator for Space Applications," *Proceedings of the 19th Photovoltaic Specialists Conference*, May 4-8, 1987.

[ 3] M.J. O'Neill, "Solar Concentrator and Energy Collection System," U.S. Patent No. 4,069,812, January 24, 1978.

**Table 1 GaAs/Prism Cover Cell Performance**

| Cell # | Before Prism Cover 100x, 25°C | With Prism Cover 100x, 25°C | With Prism Cover 100x, 100°C* |
|---|---|---|---|
| 3 | 21.4% | 23.1% | — |
| 18 | 21.7% | 24.0% | 21.9% |
| 25 | 21.8% | 24.3% | 22.1% |
| 26 | 21.7% | 23.8% | 21.8% |

* Expected Array Operating Conditions

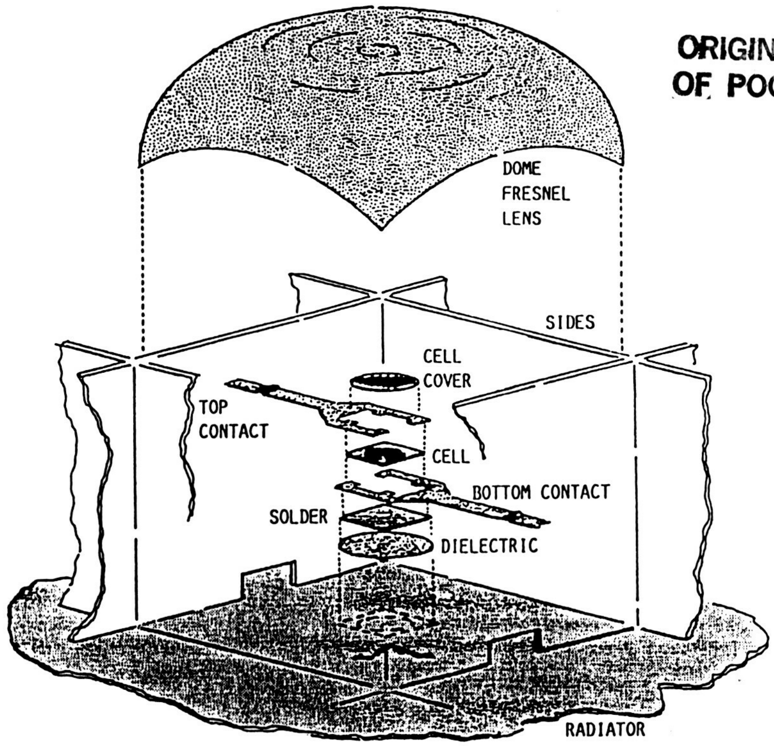


Figure 1  Domed Fresnel Lens Module Conceptual Design

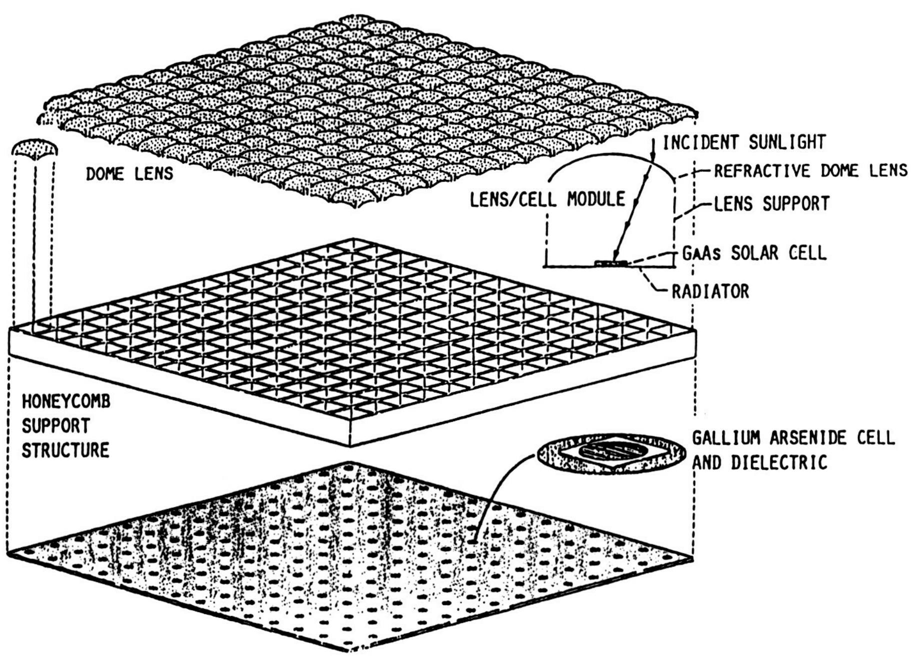


Figure 2  Domed Fresnel Lens PV Concentrator Panel Design

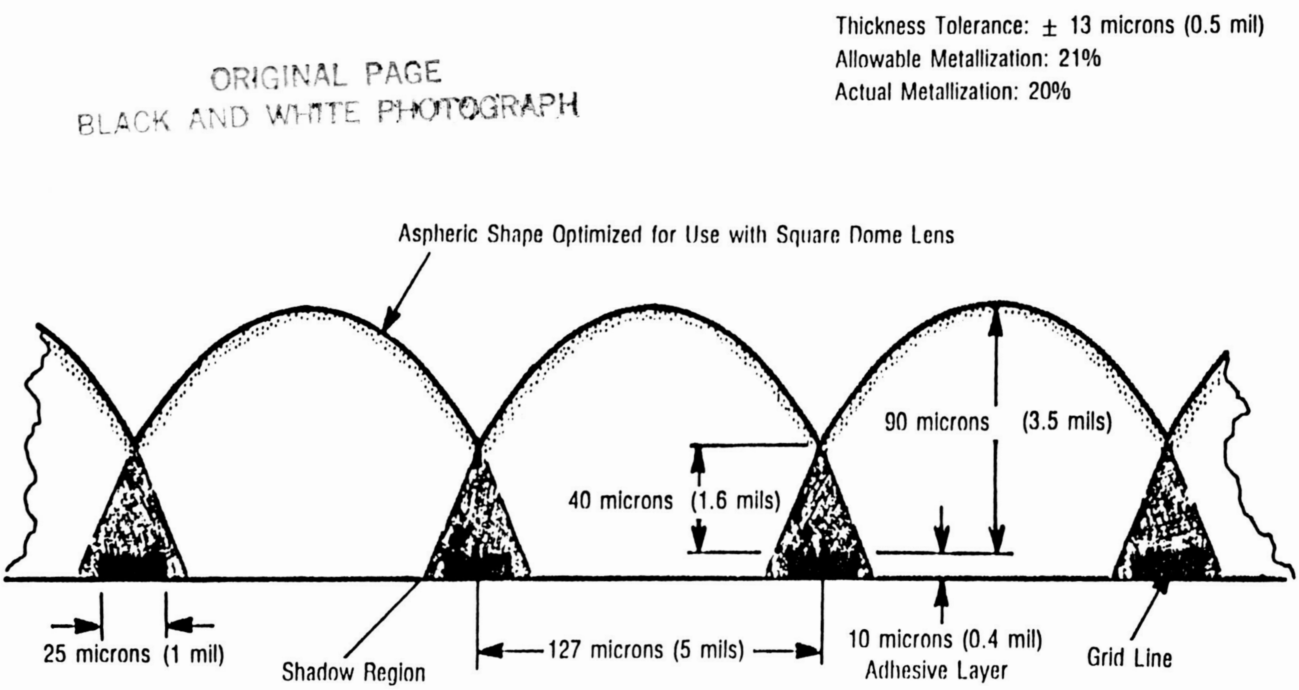


Figure 3 Optimized Prism Cover Design

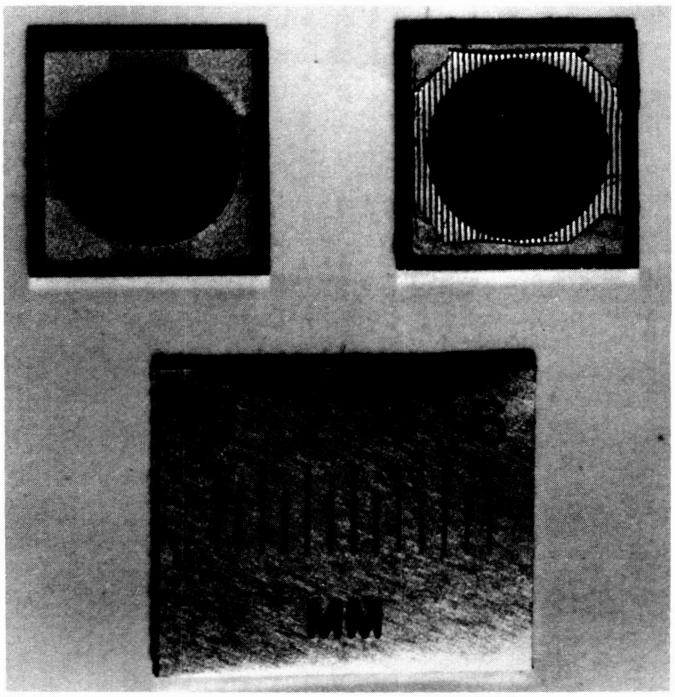

Figure 4 Gallium Arsenide Concentrator Cells With and Without a Prismatic Cell Cover Applied to the Top Contacts

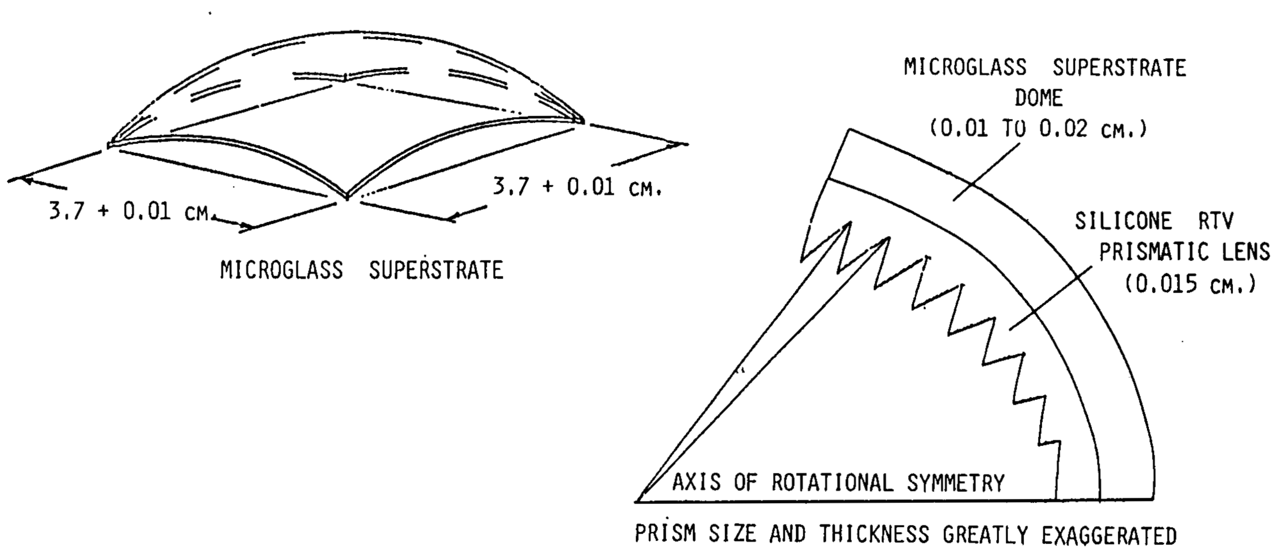


Figure 5 Current Domed Fresnel Lens Development