

## Field Testing and Performance of an Amonix Multijunction Cell Module at the University of Nevada Las Vegas

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### ABSTRACT

This paper discusses the installation, operation, and performance of a high concentration photovoltaic single-plate, multi-junction module developed by Amonix and installed at the Center for Energy Research at the University of Nevada, Las Vegas (UNLV). The paper discusses the objectives and goals of this project and describes the principal of the Fresnel optics, the module, and how it was attached to the Amonix 25-kW unit located at the UNLV Center for Energy Research. How the module is connected to a load and the measurements taken are also described. Data is presented in the paper showing the module has produced power for over 1600 hours at a power efficiency of over 27 % to 28.6 %. Data is also presented

quantify system losses, and to serve as a test bed for testing new advanced technologies.

The U.S. Department of Energy (DOE) in 2003 initiated a multi-year High-Performance Photovoltaic (HiPerf. PV) Project with the goal of providing the required installed cost reduction needed before solar photovoltaics can provide a significant amount of clean renewable energy for the world. Various companies are developing a



Figure 1-1. Amonix 25-kW system at UNLV.

showing the next generation single-plate, multi-junction module achieving an efficiency of nearly 30 %.

### 1.0 INTRODUCTION

Under the direction of the National Renewable Energy Laboratory (NREL) and funded by UNLV, Amonix, and Arizona Public Service installed an Amonix 25-kW High Concentration Photovoltaic (HCPV) System in 2003 in the UNLV Center for Energy Research [1]. The primary objectives of the project were to generate a data base from which both the short-term and long-term power and energy performance can be characterized, identify and

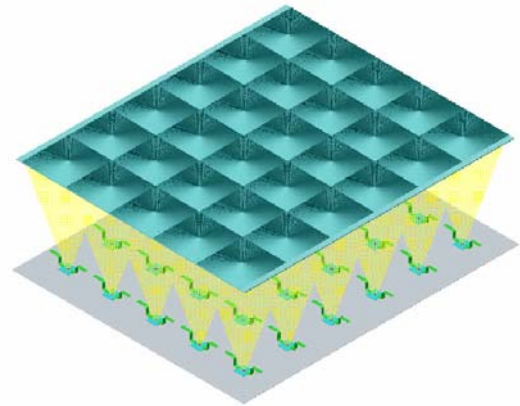


Fig.1-2. Refractive Concentrator Concept.

high-performance, multi-junction solar cell. SpectroLab (Boeing) has developed a multi-junction (III-V) solar cell that has achieved over 39% lab efficiency [2].

The Amonix system shown in Figure 1-1 is based upon refractive optics using a Fresnel lens to concentrate the sun's energy on a solar cell [3]. See Fig. 1.2.

Amonix started the development of this technology in the early 1990s and since then has design, fabricated, installed, and tested over 600 kW of HCPV systems that have generated over 4 GWh of clean electrical power [4]. Under a contract from NREL, Amonix has conducted research and development on integrating the Spectrolab multi-junction cell into the Amonix HCPV system. Amonix is currently field-testing a single-plate, multi-junction module on the Amonix system at UNLV.

The Amonix cells are silicon rear-junction, point-contact solar cells and the multijunction are GaAs. The high efficiency

multijunction cell technology may benefit concentrator systems. Concentrator systems are emerging as a low-cost, high volume option for solar-generated electricity, giving potential lower \$/Watt. The relatively high cost of this cells technology has restricted their use to non-terrestrial applications [5]. However, recent advancements in both multi-junction concentrator cell efficiency and their stability under high flux densities has made their large-scale terrestrial deployment significantly more viable. This paper presents Amonix's experience and testing results of multi-junction solar cells made for concentrated light operation.

## 2.0 Module Development

The following I-V (current-voltage) curve was taken on the single-plate module before deployment in the field. The data represents real world conditions after the module had reached thermal equilibrium.

This module represents a milestone in the development process that began in 2003. Drawing on its experience amassed using silicon cells; Amonix designed all of the module components necessary to integrate the multi-junction cell into a module system. Additionally, a single-cell outdoor tester was developed to track the progress of the module program.

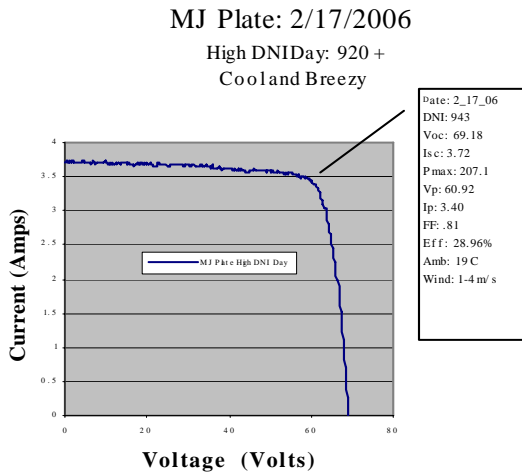


Fig 2-1. Initial on-sun test for MJ module.

The outdoor tester was designed to benefit from testing under real concentrated sunlight, yet with the ability to control and adjust relevant parameters such as temperature, lens aperture, Z-axis height, and off-axis performance. The tester was an invaluable tool in assessing the viability of the individual solar cell packages.

Early attempts with the package emphasized the importance of void free soldering, but improvements in the packaging process culminated in the deployment of the single-plate module in early 2006.

The module development merged nicely with the continued improvements made by Spectrolab with the multi-junction cell. The multi-junction cell efficiencies have improved from a nearly 33% lab cell to now over 40% for a lab cell. The production cells used for the module were estimated to be 36%–37% efficient. With this cell/module ratio, a 40% production cell would quite possibly produce the 33% module efficiency desired.

## 3.0 Single-Plate Multi-junction Module

The next development phase after completion of initial testing on the Amonix testbed tracker was to initiate field testing. Before mass production can begin, extensive field testing would have to be conducted to verify the design. The first step in the development



Figure 3-1. Module sitting on mounting frame.

plan called for a single-plate module to be fabricated and installed on the UNLV system. Because the design had some components that have a long lead-time for fabrication, the decision was made to use a slightly alternate design that used on hand components. Although the performance would be less, the importance of getting a module into field testing was felt to be very important.

The baseline design of the module would use the current 21 inch production Fresnel lens that has 24 lenses in the parquet. It was important to keep the geometric concentration ratio of 450, the same as the current Amonix module design. This assists in performance comparisons between the Amonix and multijunction cells under concentration, and thermal responsiveness. Understanding the cells performance under high concentration and high temperatures is important for long term field operation.

The frame was designed and fabricated so that it would hold the Fresnel lens on the top surface and the receiver plate with 24 multi-junction cells on the bottom. The cells were connected in series and fin heat sinks were attached to the back of the receiver plate for heat dissipation. The module frame was then covered with thin sheet metal. The fabricated module is shown in Figure 3-1. A frame to mount the single plate module on the 25 kW HCPV system at UNLV was designed and fabricated. The module is shown sitting on the mounting frame in Figure 3-1. There is a blue film attached to the Fresnel lens to protect the surface during the installation process.

Because of the difference in electrical performance (voltage and current), the single-plate module could not be connected to the



Figure 4-1. Mount location of single plate module.

inverter. To ensure the multi-junction cells would operate under load conditions, a heat resistor load was designed to make the module operate near its peak power point at 850 W/m<sup>2</sup>. Connectors were used to electrically connect the heat resistor to the module. Tests are done monthly to the module, where the heat resistor is disconnected and an I-V curve tracer is used to measure the performance.

## 4.0 Installation of a Single-Plate Multi-junction Module



**Figure 4-2. Module mounted in the support frame.**

The single-plate module was mounted on the UNLV unit by attaching it to the weldment shown in Figure 4-1. The frame to hold the single-plate module was attached to the top and bottom of the



**Figure 4-3. Mounting frame bolted to weldment.**

weldment and a brace was made to stiffen the frame.

The single-plate, multi-junction module without the multi-



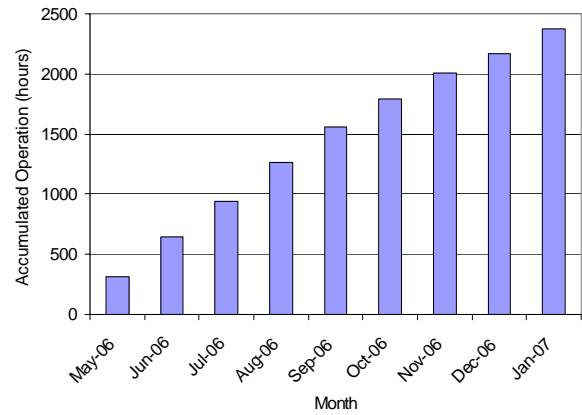
**Figure 4-4. Multi-junction module on the UNLV HCPV system.**

junction plate was set on the frame and bolted to it as shown in Figure 4-2. In order to have the capability to align the module, a three-bolt mounting system was used with long bolts and nuts on each side of the module mount brackets. These nuts could then be adjusted up or down to change the angle of the module. The Fresnel lens protective film was removed from the lens and the unit was commanded to sun track as shown in Figure 4-4. Once the UNLV

unit was tracking the sun, the single plate multi-junction module position was adjusted until the sun beam was in the middle of the cell.

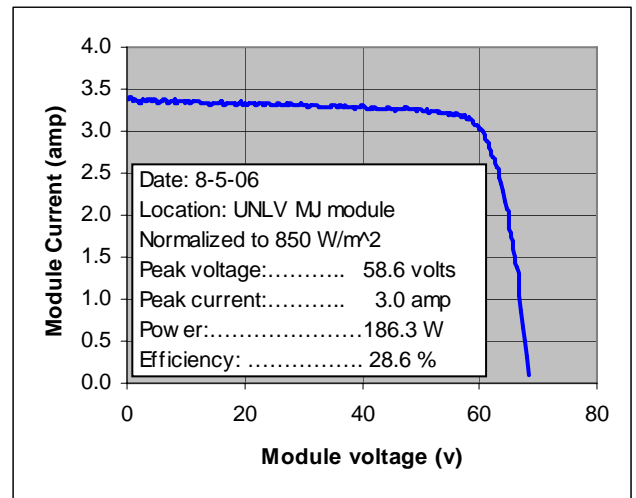
## 5.0 Performance of the Multi-junction Cell Single-Plate Module

The installation was completed and on-sun operation of the module started on May 15, 2006. Since that time, it has operated on-sun over 2200 hours as shown in Figure 5-1, without any failures. The general procedure used is to take three measurements, wash the



**Figure 5-1. On-sun operating time of module.**

lens and allow it to dry, and repeat three more measurements. A summary of the results are shown in Table 5-1. The data has been normalized to a DNI of  $850 \text{ W/m}^2$  and to an ambient temperature of  $20^\circ\text{C}$ . Part of the variation of the efficiency is believed to be the result of a variation in the solar irradiance spectrum. The spectrum



**Figure 5-2. One of I-V measurements taken on 8-5-06.**

will vary over the day, from day-to-day, and time of year. Some of the variation could also be the result of different wind conditions. The wind can cause variation in the performance by changing the plate cooling rate. The change, of course, would result in a different cell temperature even though the ambient temperature might be the same. The wind, if strong enough, can also result in a different tracking position, which would introduce some tracking error. The I-V data from one of the measures is plotted in Figure 5-2 and the I-V power curve is shown in Figure 5-3. The values are very close to the original factory I-V curve after normalizing. The values do not take into account any variation in the spectral content of the light between the factory reading and the field reading. The factory reading was

also performed under a fresh lens that had not seen any potential degradation from minor scratches.

**Table 5-1. Multijunction Module power and efficiency data**

Data adjusted to 850 W/m <sup>2</sup> and 20 deg C		
Date	Average Power	Average Efficiency
6/30/2006	169.2	26.1%
8/5/2006	183.8	28.4%
10/11/2006	177.0	27.4%
10/15/2006	176.9	27.4%

### 7.0 Future Plans

To establish a performance and reliability database, the operation of the single-plate, multi-junction module at UNLV will be continued. Periodically, the performance of the module performance will be measured by UNLV by taking I-V measurements.

Since installation of the multi-junction system at UNLV, Amonix has continued component and plate performance characterization testing at Amonix and analytical analysis to improve the performance. A number of design changes have been identified that would result in an increase in the power performance of the single-plate multi-junction module over the module installed at UNLV. Assembly of the multijunction cell is much more time constraining than the Amonix cells. If these cells were to be integrated into the current module design, the package assembly would be changed to increase the production efficiency and try to reduce failures.

As part of the investigation, a new single-plate multi-junction module with several of these design changes has been fabricated. The I-V measurements shown in Figure 6-1 show an improved efficiency of nearly 30 % with the same cell efficiency used in the UNLV module.

cells, receiver plates, and heat sink temperatures would vary more and give more information on cell performance.

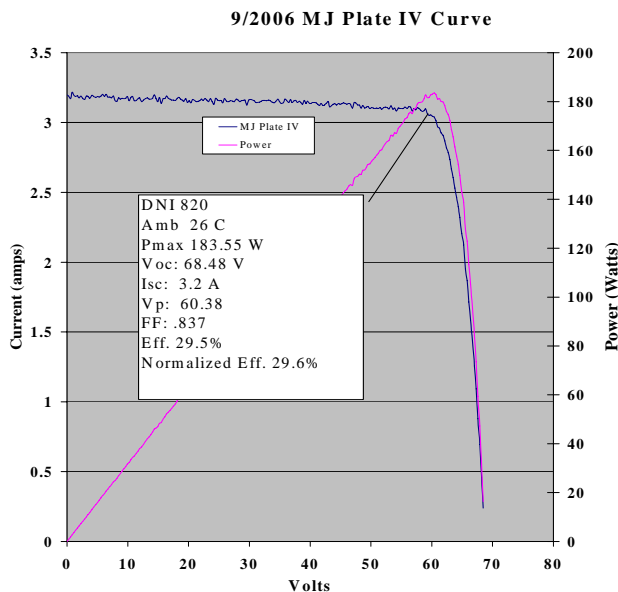
### Summary

A Spectrolab 36% to 37% multi-junction cell has been integrated into the Amonix HCPV system. The first step was to design a cell package for the multi-junction cell that would integrate into the present system. After several design iterations, a package design was developed that achieved 29% efficiency. The next step was to integrate the cell package into a receiver plate. After some design investigations and a thermal analysis the design was fabricated and the plate achieved 29% efficiency. A single receiver plate module was designed, fabricated, and installed on the UNLV HCPV system. This module has been in on-sun operation for over 1600 hours and has achieved a measured efficiency of 26% to 28.6%.

With over 2200 hours of operation on sun and no failures, the multijunction cell may have potential as being a good candidate for concentrator systems in the future. Work still needs to be done with this technology to verify that these cells under concentration are viable but this first step has been a good foundation for future work.

### References

- [1] Stone, K., et. all. "Installation, Operation, and Performance of the Amonix High Concentration Photovoltaic System at the University of Nevada, Las Vegas", ISEC2005-7609, 2005
- [2] Spectrolab. 15 March 2007. <<http://www.spectrolab.com/com/news/news-detail.asp?id=172>>
- [3] Teplyakov, D.I., Tver'yanovich, E.V., "Fresnel Lenses as Part of Solar Power Plant Modules: the concentrating ability in the monochrome Approximation." *Geliotekhnika* n 5 (Sep-Oct, 1992): pg 53-58.
- [4] Stone, K. et all. "Analysis of five years of field performance of the Amonix high concentration PV system." *Powergen* 2006, April, 2006, Las Vegas, NV.
- [5] Slade, A. et. all. "High Efficiency Solar Cells for Concentrator Systems: Silicon or Multijunction?" *SPIE Optics and Photonics*, August, 2005, San Diego, CA



**Figure 7-1. New plate achieves 29.6 % efficiency.**

Amonix is currently doing the detail design of a next generation single-plate module and plans to install it at UNLV for long-term testing. It is estimated that this module should achieve higher than 30% efficiency. In order to insure this technology as a viable option for HCPV, it would need to be integrated into an entire module and studied. The temperature distribution in an entire module would be larger than the current chamber being investigated. The chamber air,