Progress Report on the Integration of the Emcore Triple-Junction Solar Cell into a High Concentration Ratio Fresnel Lens-Based Receiver

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ABSTRACT

The objective of our development work is the integration of a high-efficiency triple-junction (3J) solar cell into a Fresnel lens-based concentrating array operating at average concentration ratios on the order of 400X. Furthermore we intend to determine the fundamental limitations of the conversion efficiency in this configuration. The conversion efficiency of a practical high concentration receiver depends on many parameters inside and outside of the solar cell. Factors such as the uniformity of the illumination, chromatic aberrations from the Fresnel lens, focussing accuracy, the current carrying capacity of the tunnel diode interconnects, and operating temperature all affect the optical receiver efficiency. In this paper we discuss our progress towards understanding and controlling this myriad of factors.

1. Solar Cell Grid Modeling

The design of the collection grid is intimately connected with the intensity and wavelength distribution of the incident light. We have performed one-dimensional grid modeling optimization assuming a uniform illumination source for the purposes of designing a cell to be measured in a high intensity pulsed solar simulator (HIPSS). In this way we will be able to determine the maximum conversion efficiency without the effects of chromatic aberrations and localized heating. In addition, it will allow a measure of the peak tunneling current density in the subcell interconnects. The grid design to be used on-sun in the Fresnel lens receiver was developed using a proprietary two-dimensional finite element analysis code. This Soloptics™ program has been previously described in some detail [1]. The program is used to perform optical ray tracing with the properties of a proprietary Fresnel lens as an input to determine the intensity distribution of the light falling upon the top, middle, and bottom cells of the 3J cell. The results of this modeling are displayed in Fig.1 as relative intensity distributions for each of the three subcells. As a consequence of the illumination profiles shown in Fig. 1, the collection grid has been designed to have circular symmetry and to have a grid spacing that varies a function of distance from the center of intensity.

The intensity distributions shown in Fig. 1 are different as a result of dispersion of the light passing through the Fresnel lens. The dispersion of light by the lens is referred to as a chromatic aberration (CA). A consequence of CA's in multi-junction monolithic solar cells is the generation of lateral currents flowing parallel to the tunnel diode interconnects. The lateral current flow results in losses referred to as chromatic aberration (CA) losses [2,3]. In the next phase of this development program modeling of the CA losses will be performed using the Emcore 3J material parameters and the Amonix Fresnel lens.

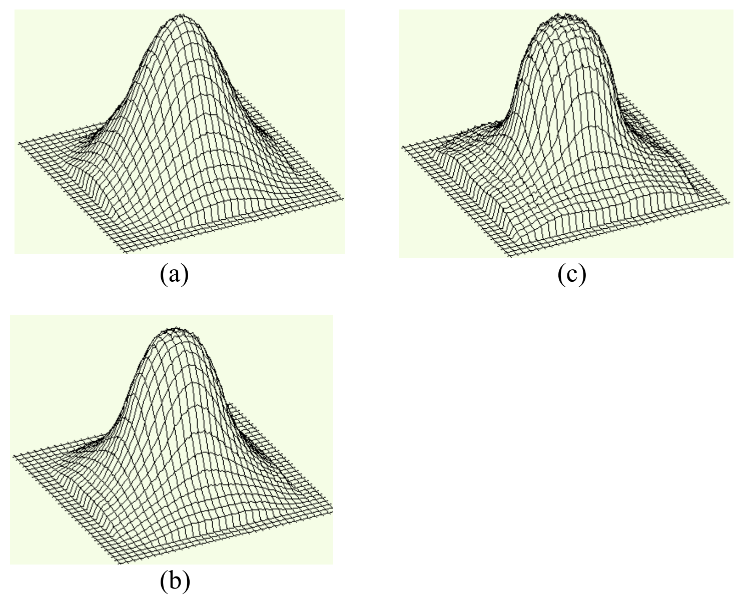

Figure 1. The relative intensity profiles for the top, middle, and bottom cells expected from the 400X Fresnel lens are shown in a, b, and c respectively.

An attempt will be made to measure chromatic aberrations in this receiver design. We have designed a photolithography mask with series of grids to allow for the mapping of the current generation in each of the three subcells that comprise the triple-junction. The current generation of each subcell will be mapped with the use of diagnostic die similar to those shown in Fig.2. The region of the die shown in black represents the active region, with the remainder used for electrical contact.

2. Concentrator Cell Build

Modifications to production 3J-space solar cells are necessary for high concentration terrestrial applications [4]. Such modifications include: a reduction in the top cell emitter sheet resistance; top cell base thickness adjustments to allow for current matching in the AM 1.5D spectrum; a reduction of the contact resistivity to the front metal grid;

and possible improvements to the peak tunneling current density of the two tunnel diode interconnects.

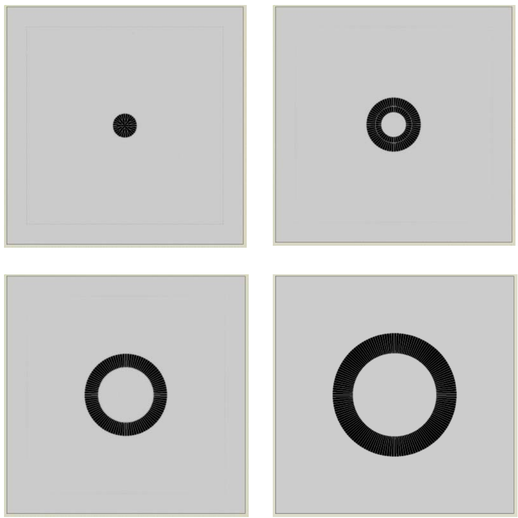

Figure. 2 A set of four diagnostic die that will be used to map the short circuit current generation in each of the three triple-junction subcells.

Grid modeling and quantum efficiency measurements have provided the target values of the emitter sheet resistance and top cell thickness. Transfer length method (TLM) structures have been fabricated on our 3J solar cell epi-layers. Resistivity measurements of the TLM's have enabled us to make the necessary adjustments to the emitter sheet resistance and grid metal contact resistance. We have chosen to use concentrator die with a 1-cm^2 active cell area. This allowed for ease of integration of the cell with the optical design presently used for Si-based concentrator arrays. Measurement of the peak tunneling current density of the tunnel diode interconnects is underway. Diagnostic structures have been fabricated and tested for this purpose. Because the diagnostic structures are not identical to the actual solar cell one can not be sure that the peak tunneling current density determined with these structures is representative of that obtained in the actual 3J solar cell. In addition, we do not have the capability to measure photocurrents as high as those generated by a 1-cm^2 active cell area under 400X AM 1.5D illumination. Consequently we have sent 3J cells to the National Renewable Energy Laboratory NREL) for testing in the high intensity pulsed solar simulator (HIPSS). Those tests have not yet been completed as of this writing.

3. Concentrator Cell Tester Build

Design considerations for this part of the project included the mechanical design of the housing used for mounting the primary Fresnel lens along with a proprietary cell carrier. The components used for housing the primary lens and cell carrier have been acquired and the test receiver build has begun. The concentrator cell carrier consists of a substrate that provides both mechanical rigidity as well as heat extraction from the cell. The cell carrier also has a protective diode to prevent damage from reverse biases that result from shading. Electrical contact to the solar cell grids will be made through weld tabs. Experiments have been conducted to establish easy and reliable bonding techniques of the solar cell to the cell carrier substrate for electrical and thermal contacts. One-sun AM0 illuminated I-V measurements of the cells were made before and after bonding to the cell carrier. This was done to determine what effects if any the cell mounting procedure has upon cell performance. In addition, preliminary on-sun tests have been made to geometrical concentrations as high as 500X. The results of these tests will be presented at the National Center for Photovoltaics Review (NCPV) Review Meeting.

Thermal modeling has been performed with the properties of the materials used in the cell carrier along with a solar insolation of 1000 W/cm^2 as inputs. In addition the cell was assumed to be under a no-load condition. The results of the modeling for the proprietary cell carrier are shown in Fig. 3. These data indicate an expected cell temperature rise of 31^{o}C. Monitoring of the cell temperature during on-sun testing is difficult because the expected temperature is too low to allow for conventional optical techniques such as optical pyrometry. Instead we will use the known temperature coefficient of the 3J open circuit voltage to monitor the cell temperature during on-sun testing. The on-sun testing will be performed with the cell carrier temperature controlled to 20^{o}C by a thermo-electric cooler.

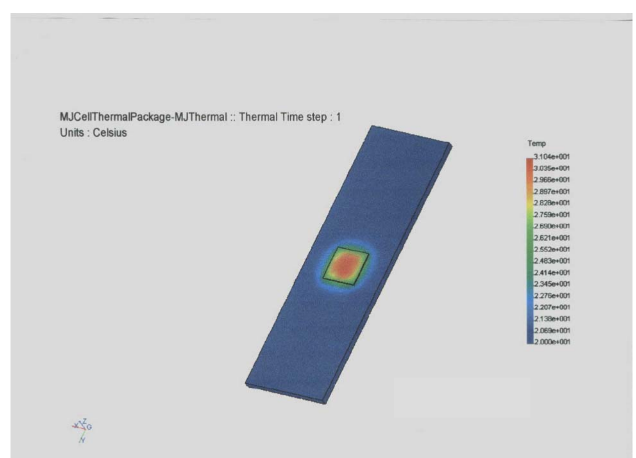

Figure 3. Modeled temperature distribution with a 3J cell at no-load conditions with the 1000 W/cm^2 incident upon the primary Fresnel lens.

4. Future Work

Most future development work planned under the present contract is contingent upon funding approval for FY '03. Provided that the planned funding becomes available the following items will be addressed in the next phase of development. Once the peak tunneling current data is available from the HIPSS measurements at NREL the tunnel diode development project will continue, if the present diode design proves to be inadequate. The peak tunneling requirement is rather stringent for operation at 400X suns with point focussed optics due to the peak intensity at the cell's center.

Future modeling work will be undertaken to determine the magnitude of losses attributable to chromatic aberrations and tunnel diode breakdown. Inputs to the model will include Emcore 3J solar cell design parameters, sheet resistance between the subcells, and the incident fluence.

We estimate that six weeks will be required to achieve full functionality of the single cell tester at the 400X concentration level.

Development of the metamorphic 3J solar cell will continue. To that end, we have investigated a number of III-V structures/materials as candidates for lattice parameter grading and have eliminated all but two possibilities to date. Additional development work is required for final selection of the best buffer structure/material system as judged by photoluminescence intensity and minority carrier lifetimes of double heterostructures.

4. Summary

We have presented progress towards the integration of the Emcore 3J solar cell into a single cell tester that is compatible with Amonix concentrator technology. We have chosen a concentrator cell with an active area of 1-cm^2 for this demonstration. Grid modeling and optical ray tracing have been performed and concentrator cells have been fabricated. In addition to the concentrator cell, diagnostic die have been designed that will enable the measurement of the spatial dependence of the photocurrent generation in each subcell. This data will be used in conjunction with modeling to estimate the chromatic aberration loss from the Fresnel receiver. Presently the cells are in the process of being integrated into the Amonix cell carrier for subsequent on-sun tests. In addition, cells have been sent to NREL for peak tunneling current measurements in the HIPSS system. Construction of the Amonix single cell tester is well underway and we expect that a fully functional tester capable of I-V measurements at an average concentration of 400X is possible with an additional six weeks of development work.

ACKNOWLEDGEMENTS

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