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# An On-Sun Comparison of GaInP2/GaAs Tandem Cells with Top-Cell Thickness Varied

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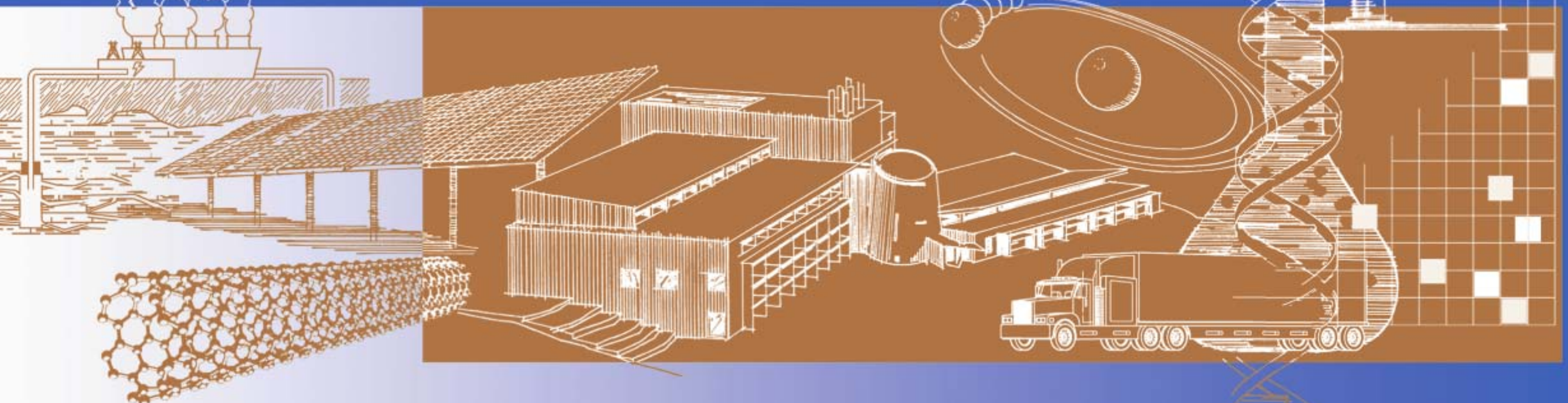

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# An On-Sun Comparison of $GaInP_2$/GaAs Tandem Cells with Top-Cell Thickness Varied

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## ABSTRACT

This study compares the on-sun performance of a set of $GaInP_2$/GaAs tandem cells with different $GaInP_2$ top-cell thicknesses. Because high-efficiency III-V cells are best suited to concentrating photovoltaic (CPV) applications, the cells were mounted on a two-axis tracker with the incident sunlight collimated to exclude all except the direct beam. Current-voltage (I-V) curves were taken throughout the course of several days, along with the direct solar spectrum. Our two major conclusions are: (1) $GaInP_2$/GaAs tandem cells designed for an "air mass 1.5 global" (AM 1.5G) or a "low aerosol optical depth" (Low AOD) spectrum perform the best, and (2) a simple device model using the measured direct spectra as an input gives the same result. These results are equally valid for $GaInP_2$/GaAs/Ge triple-junction cells.

## 1. Objectives

To maximize the performance of $GaInP_2$/GaAs tandem cells and $GaInP_2$/GaAs/Ge triple-junction cells, the top $GaInP_2$ cell must be "thinned" slightly to allow some above-band-gap photons to pass through to the GaAs bottom cell. Because the solar spectrum changes throughout each day, the optimal top-cell thickness ($t_{top}$) constantly changes. Nonetheless, when tandem cells are manufactured for use in a concentrator system, a single $t_{top}$ must be specified. This study is intended to aid in $t_{top}$ selection for CPV applications.

This study is an extension of a previous theoretical study [1], in which we simulated the performance of $GaInP_2$/GaAs tandem cells under "standard day conditions" as a function of $t_{top}$. Here, we will examine all of the same issues, but by actually monitoring the performance of real cells over a period of several days, outdoors under direct sunlight. We find good agreement between our theoretical and experimental results, validating the methods used in our theoretical model.

Measurements were made over the course of several days in Golden, Colorado. To a first approximation this represents the spectral variation of sunlight at a typical concentrator site in the southwestern United States.

## 2. Technical Approach

To give some background, the model results in Fig. 1 show how performance should vary with $t_{top}$ under four standard reference spectra [2]. For each spectrum, there is an optimal $t_{top}$.

For this study, we grew a set of tandem cells (named 'A' - 'E') with five different top-cell thicknesses, with a $t_{top}$ range spanning all foreseeable applications. Approximate $t_{top}$ values for these cells are shown along the bottom axis. Cell A has the thinnest $t_{top}$ and is well suited to "blue-rich" space applications. Cell E has the thickest $t_{top}$ and is better for "red-rich" morning and evening light. The other three cells have intermediate $t_{top}$ values which are compromises between midday power production and overall daily energy production. As a gauge of experimental error, two cells were grown with the median $t_{top}$ (C1 and C2). Cell C should perform best under a Low-AOD spectrum [3] proposed for concentrator applications. A "clear sky" direct spectrum which is similar to the Low-AOD spectrum has also been proposed [4].

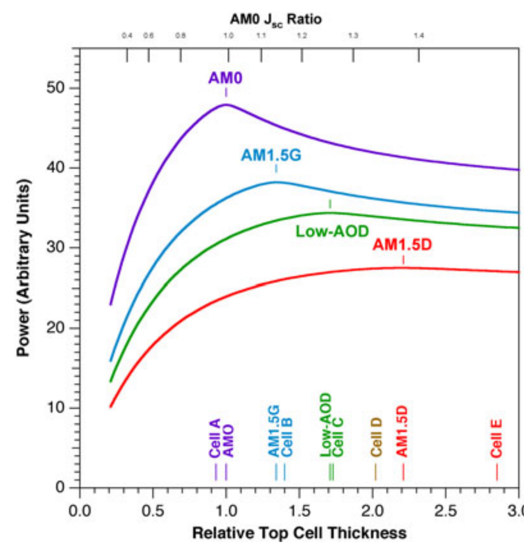


Fig. 1. Calculated power produced by a GaInP/GaAs/Ge triple-junction cell as a function of $t_{top}$ for Air Mass 0, 1.5 Global, 1.5 Direct, and Low Aerosol Optical Depth standard reference spectra. Relative $t_{top}$ values are shown, normalized to the optimal AM0 $t_{top}$. Although the power produced by a GaInP/GaAs tandem cell will be less, the optimal $t_{top}$ for any given spectrum will not change. Approximate $t_{top}$ values for cells A - E are indicated.

The cells were then mounted on a two-axis tracker, with the incident sunlight collimated to exclude all except the direct beam. The collimators followed the design shown in the annex of Ref. [5], with a 5° field of view. To most accurately study $t_{top}$ effects, no protective glass, antireflection coatings, or bypass diodes were used.

The cells were actively cooled to a nominal temperature of 25° to 30° C, and current-voltage (I-V) measurements were made for each cell throughout the day. To relate cell performance to the incident spectrum, the direct solar spectrum was measured concurrently.

## 3. Results and Accomplishments

Figure 2 shows the power produced by each cell on a particularly clear (blue-rich) day. Cell B (designed for ~AM1.5G) was best for midday power production, whereas cell E performed best during the morning and evening. Cell A (designed for ~AM0) is out-performed by other cells throughout the day. Although not shown here, the measured midday power for cells B and C during slightly hazy, partly cloudy days was approximately the same.

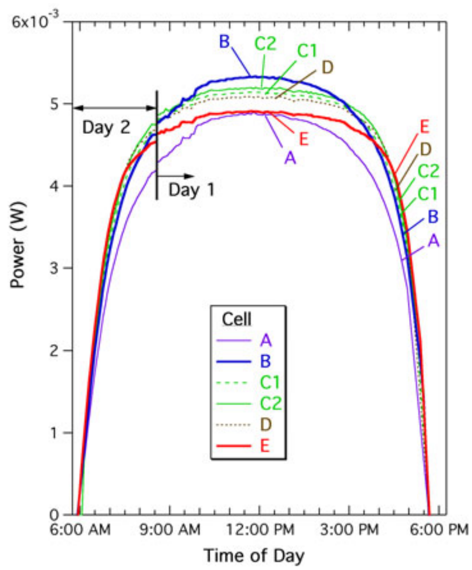


Fig. 2. Measured powers for cells A - E on Sept. 23-24, 2004, at NREL, in Golden, Colorado. Because no morning data were taken the first day, data from the morning of the second day are substituted. Cells are labeled in the order of performance midday and during the evening.

Table 1. Daily energy calculated by integrating the measured power for each 0.2533-$cm^2$ cell over the test day shown in Fig. 1.

| Cell | Energy (Wh) | Relative Energy (%) |
|---|---|---|
| **A** | .4626 | 89.51 |
| **B** | .5140 | 99.46 |
| **C1** | .5082 | 98.34 |
| **C2** | .5168 | 100.00 |
| **D** | .5092 | 98.53 |
| **E** | .4988 | 96.52 |

The power produced by each cell over the course of the day shown in Fig. 2 was integrated to determine its daily energy (Table 1). If cells C1 and C2 are averaged, the daily energies for cells B and C are about the same. On a slightly hazy, less blue-rich day, cell C is favored.

The performance of each cell was also modeled using the measured direct spectrum as an input, with similar results. A thorough comparison between measured and modeled results will be presented at the 31st IEEE PV Specialists Conference.

## 4. Conclusions

We have satisfied a FY2004 milestone by measuring and modeling the on-sun performance of GaInP/GaAs tandem cells under direct illumination for concentrator applications. This study gives direct support for the use of the Low AOD spectrum to design cells for maximum daily energy and midday power. A similar "Clear Sky" standard spectrum, and even the AM 1.5G spectrum will also work quite well. The AM 1.5D spectrum is a poor choice, unless maximizing morning and/or evening power production is a priority.

## ACKNOWLEDGEMENTS


The authors would like to thank Bill Marion for providing the "standard day" spectra used in this study. This work was performed at the National Renewable Energy Laboratory under DOE contract DE-AC36-99GO10337.


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[3] K. Emery, D. Myers and S. Kurtz, "What is the Appropriate Spectrum for Characterizing Concentrator Cells?," *Proc. of the 29th IEEE PV Specialists Conference, 2002, New Orleans, LA,* pp. 840-843.

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## MAJOR FY 2004 PUBLICATIONS


W.E. McMahon, K.E. Emery, D.J. Friedman, L. Ottoson, M.S. Young, J.S. Ward, C.M. Kramer, A. Duda, and Sarah Kurtz, "An on-sun comparison of $GaInP_2$/GaAs tandem cells with top cell thickness varied," *31st IEEE PV Specialists Conference, 2005, Orlando, FL*; accepted for presentation.

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