OPERATING CHARACTERISTICS OF MULTIJUNCTION SOLAR CELLS

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ABSTRACT

The multijunction solar cells produced by Spectrolab are the most efficient solar cells in the world, with a record efficiency of over 40%. Cell designs have been modified for high performance in concentrator photovoltaic systems with the potential for low-cost, high-volume manufacturing. High-performance concentrator photovoltaic (CPV) cells have been designed, tested, and entered into production for field testing in CPV systems. Performance under variable concentrations and temperatures has been characterized and compared to semiconductor theory. The cell response has been applied to a spectral irradiance model to predict field performance at reference locations. Cell qualification has been completed for the current-generation C1MJ design. Development of these high-performance multijunction CPV cells promises to accelerate growth in photovoltaic power generation.

1. INTRODUCTION

Concentrator photovoltaic systems using multijunction solar cells promise to deliver electrical power at a lower cost than is possible with traditional flat-plate systems. The CPV system must be designed to extract maximum performance from the expensive multijunction solar cells while minimizing system costs associated with the concentrating optics, temperature control, and the remaining balance-of-system costs. Cell conversion efficiency will increase with concentration until series resistance limits performance. Multijunction concentrator cells have achieved a record efficiency of 40.7% at 240 suns [1]. Candidate CPV systems typically become economically viable as the concentration design point is increased to 400 suns and above [2]. In order to translate the high multijunction cell performance into low system-level energy costs, the system must therefore be designed with optimum multijunction operating characteristics in mind.

The current generation of CPV cell is the “C1MJ”. (This structure was formerly referred to as “CITJ”.) Performance as a function of temperature and concentration for the C1MJ has been analyzed using indoor flash testing. The spectral response has been integrated with a spectral irradiance model to predict annual energy output at various locations. C1MJ cells have passed a qualification program designed to demonstrate viability for long-term operation in field-deployed CPV systems.

2. RESULTS AND ANALYSIS

2.1 Variable Intensity and Temperature

Indoor testing using calibrated, flash solar simulators has been used to evaluate multijunction solar cell performance over a temperature range of 0° C to 120° C and an illumination intensity range from less than 1x up to 1000x. 1x is defined as 0.09 W/cm^2, ASTM G173-03 standard spectrum. The resulting current-voltage characteristics allowed for the extraction of temperature coefficients (see Fig. 1 and Table I). Using a derivation of the simple diode equation, it is possible to model the expected voltage temperature coefficient [3]:

$$\frac{\partial V_{oc}}{\partial T} = -\frac{1}{T}\left(\frac{E_g}{q} - V_{oc} + \frac{nkT}{q}\cdot\left(3+\frac{\gamma}{2}\right)\right) + \frac{nkT}{q}\cdot\frac{1}{I_{sc}}\cdot\frac{\partial Isc}{\partial T} + \frac{1}{q}\cdot\frac{\partial E_g}{\partial T} \quad (1)$$

Empirical values for each of the expressions in (1) are available except for the γ term. The γ term derives from an expression of the reverse saturation current. Assuming γ=-6 implies a linear component to the reverse saturation current temperate dependence and results in the fit shown in Fig. 1. This fit allows for prediction of cell performance at concentrations beyond 1000x.

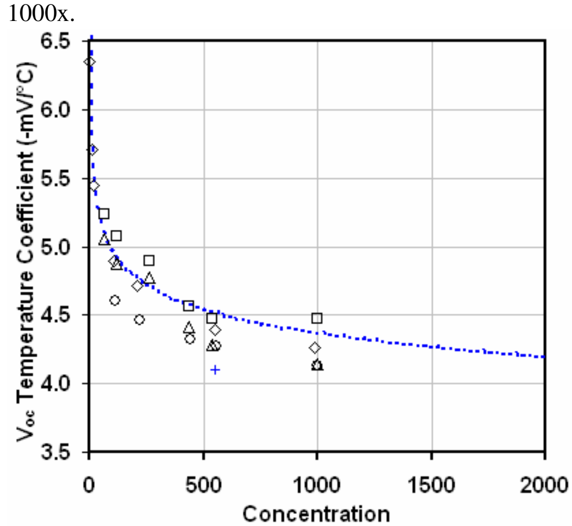

Fig. 1 Open-circuit voltage temperature coefficients.

Table I. Efficiency temperature coefficients. (absolute %/°C)

X	Test A	Test B	Test C
10	-0.08		
20-70	-0.08		-0.083
110-120	-0.07	-0.07	-0.062
210-270	-0.07	-0.04	-0.069
440		-0.04	-0.051
540-560	-0.06	-0.04	-0.046
990-1000	-0.06	-0.05	-0.035

2.2 Integrated Energy Output

To date, multijunction CPV cells have been optimized for performance under various AM 1.5D spectra. In the future, it will be important to go beyond this single-point approach & design the multijunction structure to deliver maximum energy output over the course of a year at a given location. As a step in this direction, the response of the C1MJ cell has been convolved with daily and annual spectral irradiance data in atmospheric conditions generated with the NREL SMARTS model [4]. Analysis of several locations attractive for CPV systems, such as Alice Springs, Australia, has been obtained (see Fig. 2). By integrating the volume under the contours, the annual energy output can be estimated. This approach can be used to optimize future multijunction designs (C2MJ, C3MJ) for specific locations and/or systems.

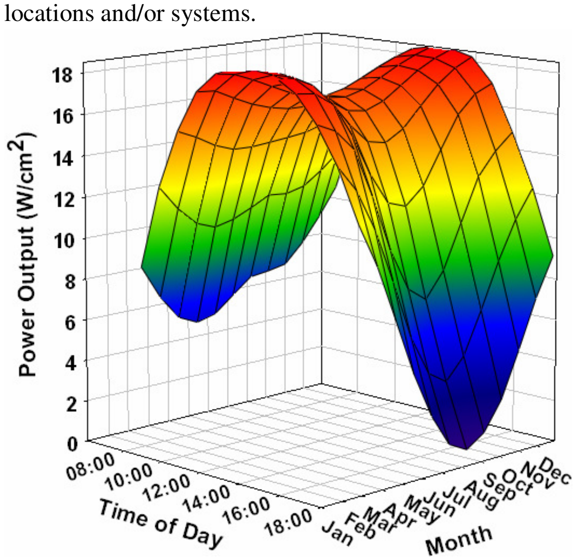

Fig. 2 Integrated energy output of the C1MJ at the latitude of Alice Springs, Australia is 64 kW-hr/cm^2-yr.

2.3 Reliability

A principal focus of effort in CPV development must be to demonstrate long-term device-level and system-level reliability in the field. To this end, Spectrolab is working to distribute C1MJ cells to a host of CPV systems that are either in the prototype stage or already being deployed in the field. In parallel, both test-to-failure experiments and rigorous qualification will be required in order to identify and eliminate any reliability issues.

The C1MJ has passed the first dedicated CPV cell qualification. The qualification schedule was derived from both the IEEE 1513 and IEC 62108 standards (for highlights, see Table II). Future generations of multijunction CPV cells will be qualified according to the finalized IEC 62108 standard.

Table II. Highlights of the C1MJ qualification schedule.

Test	Conditions	Result
Temperature and Intensity	20°, 25°, 45°, 65°, 90° and 110° C under 36, 50, and 59 W/cm^2	$\frac{\partial V_{oc}}{\partial T} = -4.3 \frac{mV}{°C}$
Damp Heat	85% relative humidity at 85° C for 1000 hours	NP_{mp}=0.97
Temperature Cycle	500 cycles in air from -40° to 110° C, 10-18 cycles/day	NP_{mp}=0.98
Humidity Freeze	Following temperature cycling exposure, 20 cycles of -40° C to 85° C with 85% RH	NP_{mp}=0.98

3. CONCLUSION

Multijunction solar cells have been characterized across a range of temperatures and illumination intensities. Models have been developed to predict cell energy output over the course of a year at target system locations. The first multijunction CPV cell, the CIMJ, has been qualified. These results are encouraging for near-term operation of multijunctions in high-concentration CPV field systems.

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