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Mark J. Keevers, Cho Fai Jonathan Lau, and Martin A. Green
University of New South Wales

Ian Thomas and John B. Lasich
RayGen Resources Pty. Ltd.

Richard R. King
Spectrolab Inc.

Keith A. Emery
National Renewable Energy Laboratory

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HIGH EFFICIENCY SPECTRUM SPLITTING PROTOTYPE SUBMODULE USING COMMERCIAL CPV CELLS

Mark J Keevers [1], Cho Fai Jonathan Lau [1], Martin A Green [1],
Ian Thomas [2], John B Lasich [2], Richard R King [3], Keith A Emery [4]
1. School of Photovoltaic and Renewable Energy Engineering, UNSW, Sydney NSW 2052 AUSTRALIA,
2. RayGen Resources Pty Ltd, 15 King St, Blackburn VIC 3130 AUSTRALIA
3. Spectrolab Inc, 12500 Gladstone Ave, Sylmar, CA 91342 USA
4. NREL, 15013 Denver West Parkway, Golden CO 80401 USA

ABSTRACT

We report on the design, fabrication and testing of a proof-of-concept, prototype spectrum splitting CPV submodule using a custom bandpass filter and commercial triple-junction (TJ) and Si CPV cells. An independently certified 40.4% submodule efficiency is demonstrated in outdoor testing, including losses from the concentrating optics and filter, which is the highest efficiency ever reported for sunlight conversion to electricity. This spectrum splitting approach was motivated by potential practical application to CPV power tower technology.

1. INTRODUCTION

Despite their high efficiency, commercial triple-junction (TJ) CPV cells waste photons in the Ge bottom subcell. This is a result of the compromise required for lattice matching in the cell stack. An example of a state of the art cell of this type is the Spectrolab 'C3MJ+' cells composed of a monolithic stack of GaInP (1.88 eV), GaInAs (1.41 eV) and Ge (0.67eV) [1]. Lateral spectrum splitting with a custom-designed bandpass filter can be used to divert some of the otherwise wasted incident sunlight to a commercial Si CPV cell (1.1 eV), effectively adding a fourth junction to improve electrical output by over 10% as well as reducing heat load.

Perhaps the most practical, cost effective application of this spectrum splitting approach is to the CPV power tower technology currently being commercialized by RayGen [2]. Their single 200-kW planar TJ dense array receiver, illuminated by a field of 64 heliostats, could be replaced by a V-shaped spectrum splitting receiver [3], combining the same TJ array with an additional Si dense array which uses the bandpass filter as cover glass.

2. DESIGN AND FABRICATION

The prototype uses reflective (enhanced silver coated) concentration optics (8-inch parabolic mirror, 287 cm^2 aperture area), a custom bandpass filter (Omega Filters), and two 1-cm^2 high efficiency commercial CPV cells (38.5% Spectrolab III-V TJ cell and 26% SunPower back-contact Si cell), each mounted on a concentrator cell assembly (CCA) and a water-cooled heatsink, with an optional reflective secondary optical element (SOE) to improve flux uniformity. The optical design achieves the required high optical efficiency (up to 96.8%) and the mechanical design, based on optomechanical components, provides a lightweight, robust and fully adjustable structure for on-sun optimisation. One advantage of this lateral spectrum splitting approach is that the TJ and Si cells are connected independently, in a 4-terminal arrangement, which can improve energy yield over a 2-terminal connection.

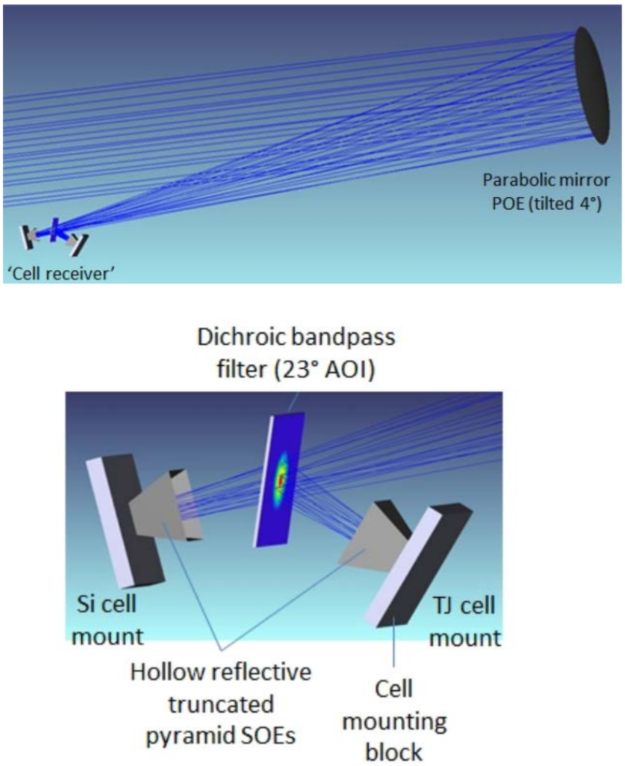

Fig. 1 Optics of the spectrum splitting prototype, modeled in the 3D ray tracing software Zemax.

A photograph of the prototype is shown in Fig. 2.

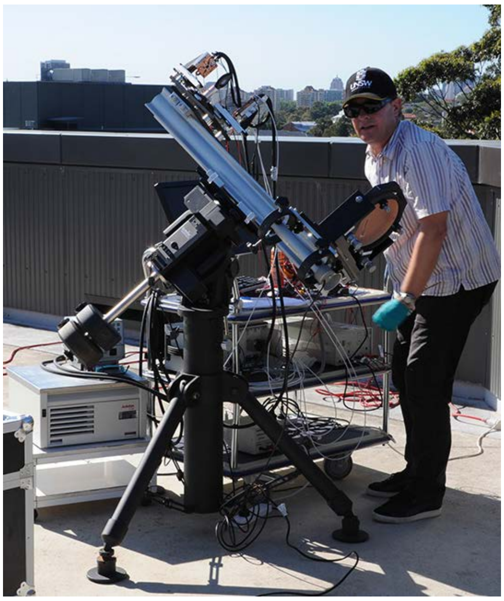

Fig. 2 Spectrum splitting prototype.

3. OUTDOOR TESTING

3.1 Testing at UNSW

An outdoor test capability was established at UNSW consisting of a solar tracker, normal incidence pyrheliometer (NIP), resistance temperature detectors (RTDs), and a computerized light current-voltage (LIV) curve tracer which can rapidly alternate between measurements of the TJ and Si cells. On-sun tests demonstrated proof-of-concept that our simple spectrum splitting approach using commercial cells gives a net performance benefit. Optimization during the on-sun tests resulted in a measured efficiency of 40.1% (Fig. 3 and Table I).

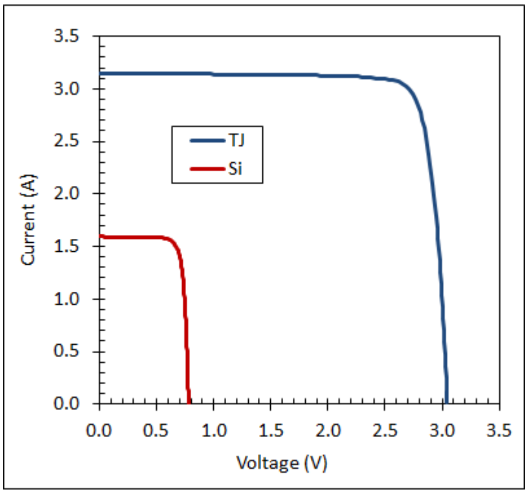

Fig. 3 UNSW measurements demonstrating proof-of-concept of the benefit of spectrum splitting on the electrical output of the prototype submodule.

Table I. Spectrum splitting result measured at UNSW.

Cell	Split: TJ	Split: Si	Split: Total
DNI (W/m^2)	795	798	
T_{CCA} (°C)	23.5	21.7	
V_{oc} (V)	3.04	0.78	
I_{sc} (A)	3.14	1.59	
FF (%)	85.0	81.1	
Efficiency (%)	35.7	4.4	40.1

TJ cell W1-7, Si cell 333, filter AOI 21°, air mass 2.3

3.2 Independent testing at NREL

The prototype was transported from Sydney to the NREL outdoor test facility in Golden, Colorado and reassembled there. NREL confirmed an efficiency of 40.4% ± 2.8% for measurements made on 6 November 2014 under a pressure-corrected air mass of 2.5, direct normal irradiance of 883.7 W/m^2, with cell temperature referenced to 25°C. This is the first demonstration of the conversion of sunlight to electricity with efficiency above 40%.

4. CONCLUSION

A spectrum splitting prototype submodule using a custom bandpass filter and commercial CPV cells has achieved an independently confirmed efficiency of 40.4%. This is proof-of-concept that this spectrum splitting approach improves efficiency, with possible application to CPV power towers.

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REFERENCES

[1] Richard R King et al, "Band-Gap-Engineered Architectures for High Efficiency Multijunction Concentrator Solar Cells", *24th European Photovoltaic Solar Energy Conference* (2009).

[2] RayGen website: www.raygen.com (last accessed 17 Nov 2014).

[3] Hui Lv et al, "High Efficiency V-shaped Spectrum Splitting Power Tower Receiver", to be presented at the *Asia-Pacific Solar Research Conference*, UNSW (8-10 Dec 2014).