A New Approach For A Low Cost CPV Module Design Utilizing Micro-Transfer Printing Technology

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Abstract: Semprius is applying a novel massively parallel, automated production process to address CPV's reliability, performance, cost, and scalability requirements. The new design approach utilizing patented micro-transfer printing technology enables the use of many very small cells (0.36 mm^2) with benefits including high efficiency, simple distributed heat transfer, high concentration ratio, and small thin concentrating optical elements. We briefly describe the design approach and provide detailed supporting on-sun measurements.

Keywords: photovoltaic, CPV, concentration, solar module.
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INTRODUCTION

High Concentration Photovoltaic (HCPV) systems enable significant reductions in installed cost/kWh relative to any other photovoltaic (PV) approach currently being deployed. The primary factors that lead to a lower cost/kWh include high geometric concentration ratio to significantly reduce the amount of semiconductor material and to boost the cell efficiency, high optical efficiency associated with the concentration optics, low cost III-V semiconductor materials, highly automated assembly processes, passive heat dissipation without the use of expensive heat sinks or heat spreaders, high efficiency due to the use of multi-junction III-V compound cells, and low cost high accuracy 2-axis trackers that maximize the energy harvested through the day. The unique design approach described below exploits each one of these factors resulting in a very low cost, high performance, light weight and reliable module with a very thin profile.

DESIGN APPROACH

Micro-transfer printing[1] technology was originally developed in John Rogers' group at the University of Illinois and has been applied to many different semiconductor applications including crystalline silicon ICs for OLED displays[2], inorganic LEDs[3], and now multi-junction III-V solar cells. The micro-transfer printing process is shown in Figures 1-3.

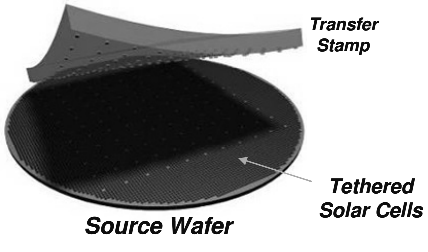

FIGURE 1. The stamp is first aligned to the solar cells on the source wafer, lowered to laminate the stamp to the cells, then raised to release the cells from the source wafer (van der Waals force attracts the cell to the stamp). After all of the cells are printed, the GaAs substrate is re-used in the next epitaxial growth run.

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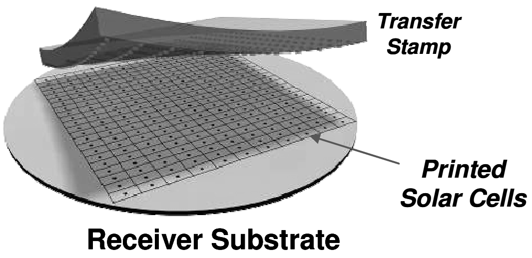

FIGURE 2. The stamp is then brought into alignment with the receiver substrate, lowered to print the cells to the receiver substrate, then raised leaving the cells bonded to the receiver substrate. All of the cells are printed in one operation.

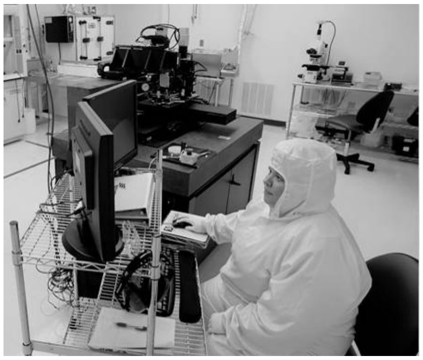

FIGURE 3. Micro-transfer print tool developed at Semprius.

In order to minimize the use of compound semiconductor material, we chose a geometric concentration ratio of 1,000 suns and then designed wide angle of acceptance (±0.85°) 2-stage refractive optics to focus the solar spectrum onto very small (600 μm) dual-junction[4] GaInP/GaAs cells which are micro-transfer printed in a massively parallel fashion. The small cells enable efficient distributed heat dissipation without the use of expensive heat sinks or heat spreaders, low series resistance, and small low cost short focal length optical elements. As a result, an efficient plano-convex silicone-on-glass (SOG) primary lens array can be designed in. Figure 4 shows a picture of the cell.

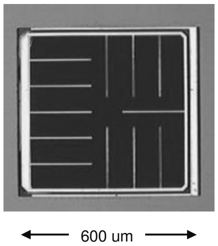

FIGURE 4. Dual-junction CPV cell designed for 1,000x concentration.

The backplane is fabricated using mature Surface Mount Technology (SMT). Because of the highly effective distributed heat transfer, no specialized heat sinks are required. Figure 5 shows a photograph of the SMT backplane after being populated with receivers. The fully assembled engineering prototype CPV module with the attached backplane and SOG lens array is shown in Figure 6.

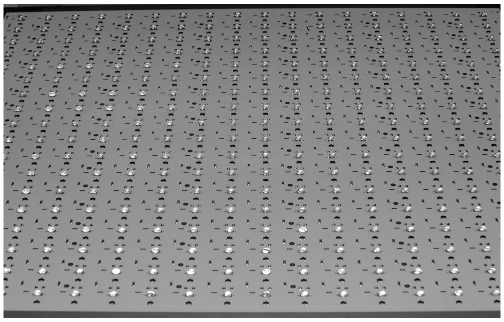

FIGURE 5. SMT backplane populated with receivers.

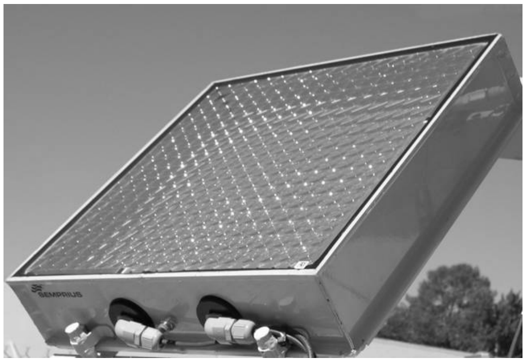

FIGURE 6. Engineering prototype CPV module.

RESULTS

The cell is a conventional lattice matched GaInAs/GaAs dual-junction design, but the structure is grown on top of an epitaxial release layer so that the cells can be epitaxially lifted-off (ELO) as part of the micro-transfer printing process. Table 1 and Figures 7-9 show the performance of these cells under concentration as well as the external quantum efficiency of the material.

Table 1. Performance of dual-junction cell.		
V_{OC}	2.769	Volts
I_{SC}	0.052	Amps
V_{MP}	2.376	Volts
I_{MP}	0.051	Amps
P_{MAX}	0.122	Watts
FF	85	%
Concentration	1,094	Suns

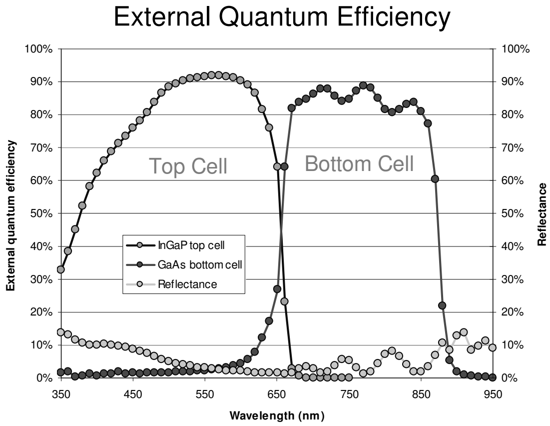

FIGURE 7. External quantum efficiency of the dual-junction structure grown on top of an epitaxial release layer with well current matched top and bottom junctions

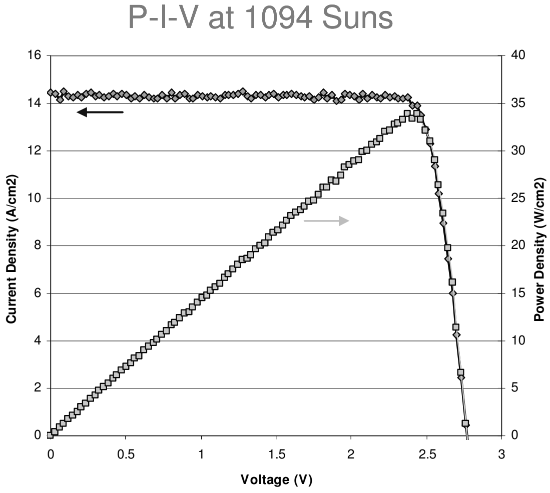

Figure 8. P-I-V curve of cell showing high 85% fill factor.

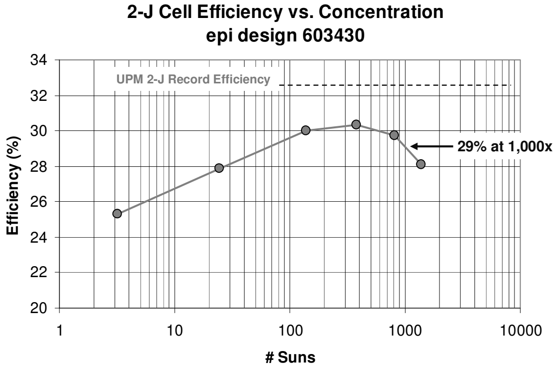

Figure 9. Cell efficiency as a function of concentration ratio showing an efficiency of 29% at 1,000 Suns.

As previously mentioned the small cells enable distributed heat dissipation resulting in excellent thermal performance. The cell temperature is measured using an IR camera while the cell is biased at a condition which matches that of a 1,000x concentration ratio. Figure 10 shows that the cell temperature operates in the range of 76ºC to 83ºC when the backplane temperature is held at 60ºC equivalent to an ambient temperature of 40ºC. Because the cells are maintained at a relatively low temperature, a cell lifetime well in excess of 25-30 years is expected.

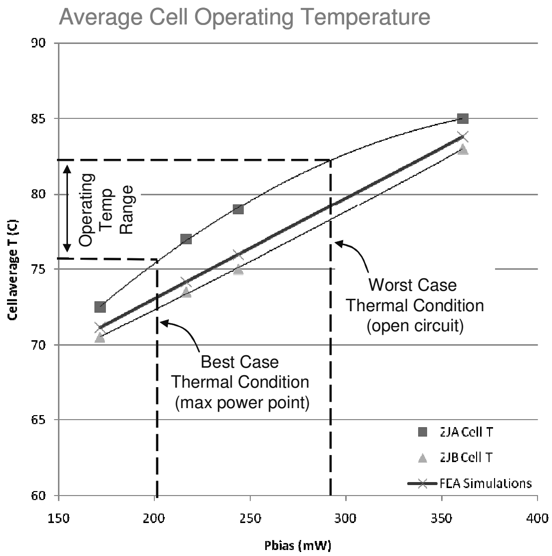

Figure 10. Cell temperature while under forward bias based on IR camera image. Backplane held at 60ºC.

The engineering prototype CPV module is assembled by attaching the SMT backplane and SOG lens array to the frame. The module performance is shown below in Figure 11. The conditions and resultant measurements are listed in Table 2.

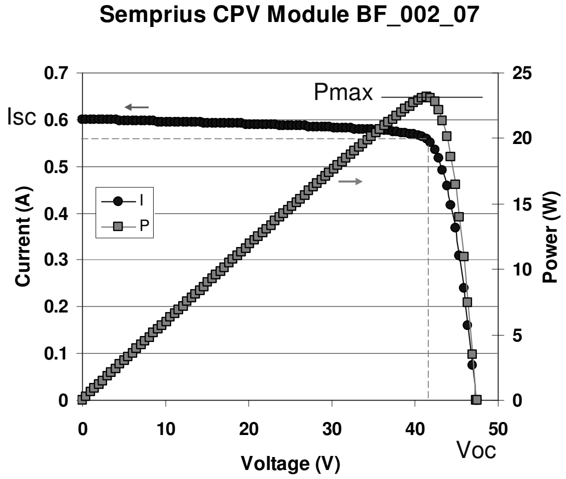

Figure 11. PIV curve for engineering prototype CPV module.

Table 2. Performance of CPV Module		
Conditions		
DNI	915	W/m^2
T$_{AMBIENT}$	22.4	°C
Measurements		
V$_{OC}$	47.6	V
I$_{SC}$	0.601	A
P$_{MAX}$	23.2	W
Fill Factor	81	%
Optical Efficiency	80	%
Module Efficiency	22	%
Optical Aperture	0.117	m^2

Efficient dual-stage optics provides an optical efficiency of 80% and a wide Angle of Acceptance (AOA) of ±0.8° as shown in Figure 12. The wide AOA allows the use of inexpensive lower accuracy 2-axis trackers and maximizes the harvest of energy throughout the day. Figure 13 shows the full day performance of a typical module on a 2-axis tracker.

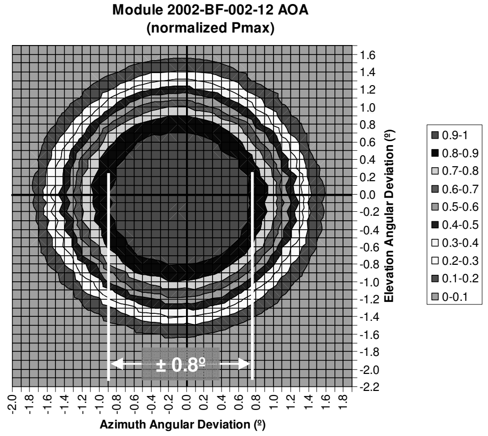

Figure 12. Full module acceptance angle defined at 90% of power at 0º.

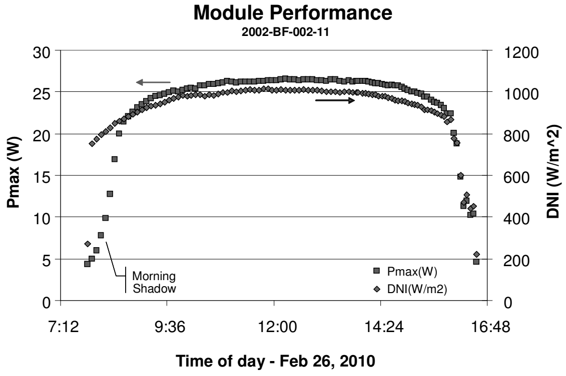

Figure 13. Pmax of one module and Direct Normal Irradiance (DNI) vs. time of day.

CONCLUSIONS

Micro-transfer printing technology enables significant benefits for the design of a low cost CPV module including very small, thin, reliable, high performance cells, GaAs substrate re-use for significantly reduced semiconductor materials cost, small, low cost, high efficiency optics, and scalability to high volume manufacture resulting in a very low installed cost ($/kWh).

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