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HIGH EFFICIENCY, BACK-CONTACT BIFACIAL SOLAR CELLS AND APPLICATION

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ABSTRACT: SunPower's corporate mission is to reduce the installed cost of solar electricity 50% by 2012. As part of that mission, the company is continually exploring novel technologies that might enable progress towards the goal. This paper describes SunPower's efforts to decrease the levelized cost of electricity for solar power plants through the use of bifacial cell and system technology. The results of the first production run of SunPower bifacial cells and modules are presented. Future bifacial system development plans are reviewed. Keywords: Bifacial, High Efficiency, Power Plants, Trackers.

1 BACKGROUND

SunPower's corporate mission is to reduce the installed cost of solar electricity 50% by 2012. As part of that mission, the company is continually exploring novel technologies that might enable progress towards this goal.

In recent years, SunPower has successfully commercialized the high-efficiency (20%+) back-contact solar cell, the A300. The basic architecture and performance of this cell have been described elsewhere [1]. It was realized that the A300 back-contact solar cell was adaptable to a bifacial design so it was desirable to explore the feasibility of producing bifacial back contact cells on the standard A300 production line. Bifacial solar cells have the potential to reduce the delivered electricity cost of grid-tied systems through improved kWh/kWp performance from albedo collection on the back of the module.

2 SUNPOWER BIFACIAL CELL DEVELOPMENT HISTORY

SunPower has previously developed bifacial interdigitated back contact solar cells in support of NASA's Helios solar airplane program in the 1990's [2]. These cells were used in conjunction with transparent wings to generate additional energy for the airplane while in flight. Helios set a world altitude record for an airplane of 96,500 feet using the SunPower bifacial cells.

The bifacial cells used for Helios achieved 21.9% front and 13.9% rear efficiency. The cells were manufactured with semiconductor production techniques such as photolithography and as a consequence had a production cost of \$200/Wp, a level prohibitive for terrestrial grid-tied applications. It was desirable to determine if there was a lower cost approach to the mass production of a bifacial back-contact solar cell.

3 BIFACIAL A300 REDESIGN

The approach to produce a mass production bifacial solar cell was to create a new cell design on the standard A300 production process. For the bifacial cell, the A300 was redesigned such that the metal coverage ratio on the back of the cell was reduced from approximately 75% to 25% allowing sunlight to reach the back of the cell. This reduction in the metal coverage ratio was primarily achieved by reducing the width of the P+ metal finger. This exposure of silicon can be seen in Figure 1.

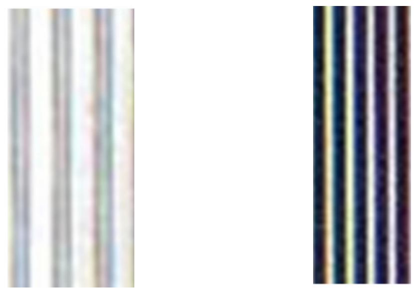
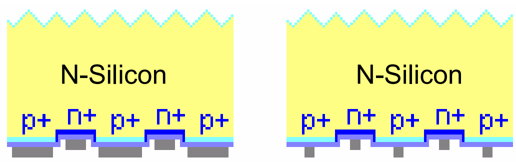


Photo of Rear Monofacial Cell Metalization | **Photo of Rear Bifacial Cell Metalization**

Figure 1: Photographs of the Rear Metallization for Standard and Bifacial A300 Solar Cells



Standard | **Bifacial A300**

Figure 2: Device Cross-section for Standard and Bifacial A300

Figure 2 shows a cross section of the standard SunPower A300 and bifacial design. The reduction in P+ metal coverage to enable backside light capture can be seen.

4 BIFACIAL A300 PRODUCTION RESULTS

To test the bifacial design 1,000 bifacial cells were manufactured on the standard A300 production line in Manila, Philippines. A control lot of 1,000 standard A300 cells was used as baseline.

Figure 3 illustrates the results of the bifacial cell production lot. The average front efficiency of the bifacial cells was 21.0% slightly lower than the 21.2% of the control lot. Figure 4 illustrates the fill factor in the control and bifacial lots, the fill factor was similar between the two lots.

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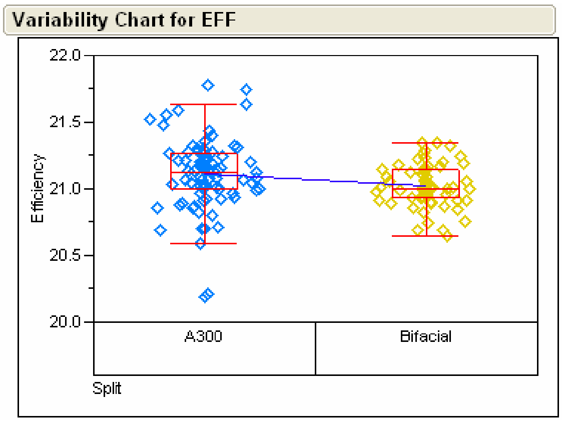

Figure 3: A300 vs. Bifacial Front Efficiency Results

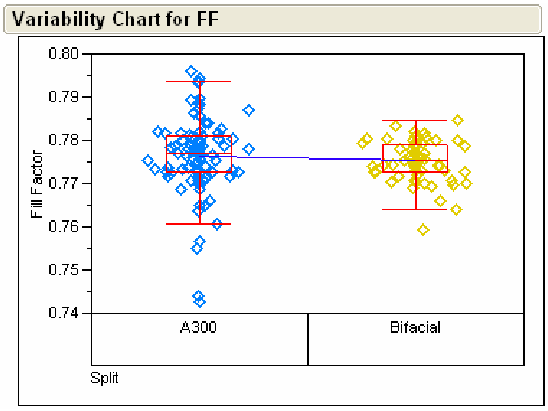

Figure 4: A300 vs. Bifacial Fill Factor Results

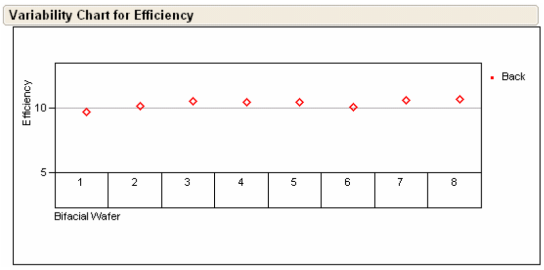

Figure 5: Backside Efficiency for the Bifacial Lot

Rear efficiency results of eight sample bifacial cells are presented in Figure 5. Backside efficiency ranged from 10.0-10.5% in the sample cells. Figure 6 compares this result with the original SunPower bifacial cells manufactured for Helios. The Helios bifacial cells were similar to the A300 bifacial cells in that the back surface was untexturized. The primary difference with both designs was the metal coverage ratio on the back of the cells.

	FF	Front Eff	Rear Eff
"Helios" SunPower Bifacial - 20% metal coverage ratio	81.5	21.9	13.9
"Helios" SunPower Bifacial - 10% metal coverage ratio	79.3	20.6	15.2
A300 SunPower Bifacial - 25% metal coverage ratio	77.5	21.1	10.5

Figure 6: Comparison of Bifacial A300 with Helios Bifacial Cells

Figure 7 plots the metal coverage ratio vs. rear efficiency for the A300 and Helios bifacial lots. As can be seen the higher rear efficiencies in the Helios cells were largely a function of a lower metal coverage ratio. Higher rear efficiencies in the bifacial A300 may be achievable through further reducing the metal coverage ratio provided front efficiency is not negatively impacted. For the Helios a compromise between front and rear efficiency was used where the 0.20 coverage ratio was selected which yielded a 21.9% front and 13.9% rear efficiency. It was found that further increasing rear efficiency had a negative impact on the front efficiency due to increased series resistance in the cell.

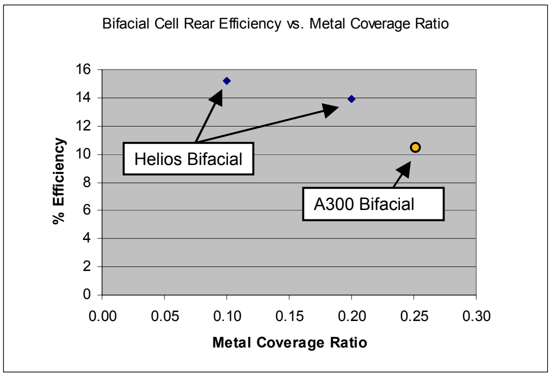

Figure 7: Comparison of Bifacial A300 with Helios Bifacial Cells

5 BIFACIAL MODULE PRODUCTION

To test the performance of the bifacial cells in a real-world application ten standard 72-cell bifacial modules were produced. These modules utilized a clear backsheet as well as a thin junction box to prevent backside shading of the module. Figure 8 shows the frontside IV curve for a bifacial module from the lot. The power output was 207.2 Watts which compares with 210 Watts for a standard A300-based 72-cell module. The difference may be explained by the loss of the internal reflection generated by a white backsheet and from slightly lower frontside cell efficiency. The 207.2 Watts represents a module efficiency of 17.15%. Figure 9 shows the backside IV curve of the bifacial module. The back of the module produced 121.3 Watts for a rear efficiency of 10%. The efficiency of the bifacial cells improve to approximately 13% with encapsulation enabling the 10% module efficiency.

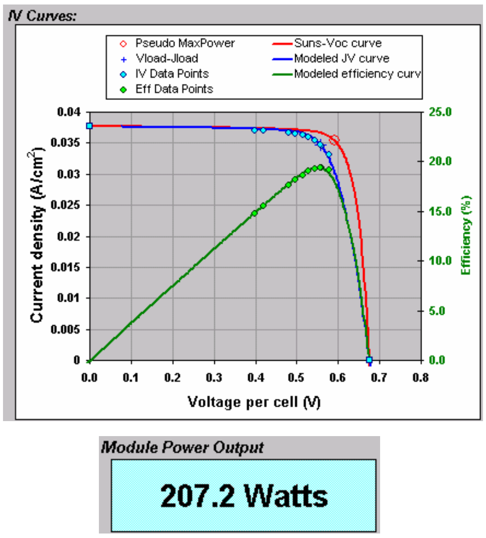

Figure 8: Front Bifacial Module Efficiency

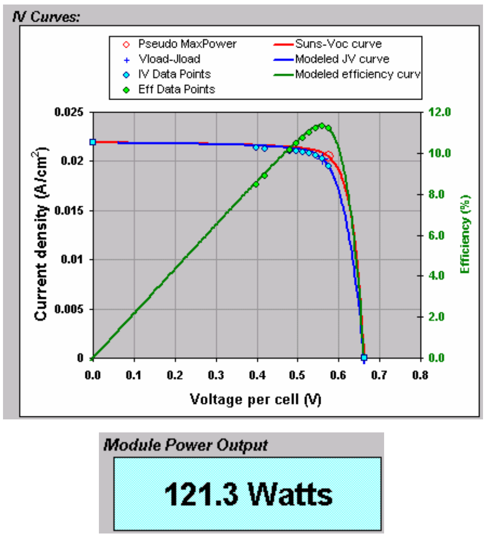

Figure 9: Backside Bifacial Module Efficiency

6 BIFACIAL MODULE SYSTEM TESTING

The ability to manufacture bifacial cells and modules has been demonstrated but the critical question is whether the bifacial modules will produce enough additional energy to justify the added cost and complexity of a bifacial module and system. SunPower is developing a number of bifacial systems to test the long-term performance of the technology to answer this question. Figure 10 shows the test platform for SunPower bifacial modules mounted on a single axis tracker tilted at 20 degrees. Testing will begin in October 2007 to compare the performance of the bifacial modules with standard SunPower 210 watt panels.

Figure 10: Bifacial T20 Tracker

In addition to developing SunPower bifacial A300 cells and modules, SunPower has begun investigating the performance of commercially available bifacial modules in large system projects. SunPower Systems has recently completed the 600kWp Springs Preserve project in Las Vegas Nevada using bifacial modules. Springs Preserve consists of elevated fixed and tracking structures that have been optimized to enable the collection of Albedo on the rear of the panel.

Figure 11: Springs Preserve Bifacial Fixed Installation

Figure 12: Nellis AFB 2.5MW Bifacial Tracker Installation

SunPower is also building 2.5MW of bifacial trackers as part of the 15MW Nellis AFB project in Las Vegas, Nevada. This project is set for December 2007 completion. The bifacial modules at Nellis are mounted on the SunPower T20 Tracker, a single-axis North/South tracker with a 20 degree tilt. The goal for the system is to take advantage of the desert albedo to improve kWh/kWp performance. Measurements indicate 200W/m2 on the back of the trackers in one-sun conditions. This level of back irradiance could provide a significant energy gain.

7 CONCLUSION

The manufacture of bifacial, back-contact solar cells on the standard A300 production line has been demonstrated. These cells achieved a front efficiency of 21% and a rear efficiency of 10.5%. The bifacial cells had similar frontside efficiency to standard A300 cells. Bifacial modules with 17.15% front and 10% rear efficiency were built. The important next step will be to test bifacial modules in real world applications to determine if the increased energy yield warrants the added cost and complexity of a bifacial approach to system design. If successful, bifacial-based systems offer an interesting approach to system cost reduction.

8 REFERENCES

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