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Abstract. A 1-axis carousel tracker equipped with four 3-sun low-concentration mirror modules has now been under test outdoors at the University of Nevada in Las Vegas (UNLV) for three years. There are three unique features associated with this unit. First, simple linear mirrors are used to reduce the amount of expensive single crystal silicon in order to potentially lower the module cost while potentially maintaining cell efficiencies over 20% and high module efficiency. Simple linear mirrors also allow the use of a single axis tracker. Second, the azimuth carousel tracker is also unique allowing trackers to be used on commercial building rooftops. Third, an experiment is underway comparing aluminum based mirrors with novel 3M Company multilayer polymeric mirrors which are potentially very low cost. Comparing the data from March of 2008 through March of 2011 shows that the aluminum mirror degradation to date is negligible and that the carousel tracker has been operating continuously and reliable. Also, no degradation has been observed for the 3M brand cool mirrors after one year in use.

Keywords: CPV, LCPV, solar trackers, Si cells.
PACS: 88.40.hj; 88.40.fr

INTRODUCTION

The goal at JX Crystals Inc is to develop solar cell technology that can produce retail electricity at 10 cents per kWh for commercial customers without subsidies. Starting from today's baseline Silicon cell technology, this can be done by implementing three improvements. First adding rooftop solar trackers will produce more kWh per kW of solar module. Second, substituting low cost mirrors for expensive single crystal cell material will reduce module cost, and third, using less cell area will make higher efficiency cells affordable leading to higher efficiency modules. JX Crystals Inc has a patented [1] technology that implements these three improvements as shown in figure 1.

FIGURE 1. Photograph shows JXC carrousel tracker with four 3-sun mirror modules in operation and under test at UNLV since 2008.

LOW CONCENTRATION MODULE

The JX Crystals Inc 3-sun mirror module shown in figure 2 has been described previously [2, 3]. The carousel tracker shown in figure 1 has also been described previously [3, 4].

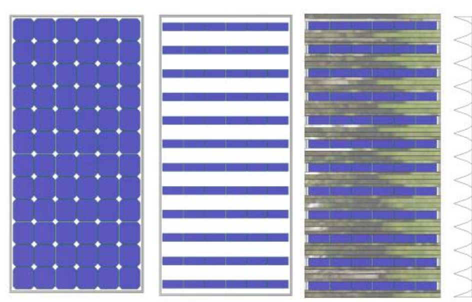

FIGURE 2. The drawing on the left shows the standard c-Si planar module. The drawings in the center and right show a planar concentrator module with 1/3 as much expensive crystalline silicon. Since mirrors are 10 times cheaper than single crystal cells, the module cost can be reduced dramatically while maintaining the high module efficiency.

There are two key questions addressed here:
Do the mirrors last?
Is the tracker reliable?

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To answer these questions, the carousel with four 3-sun mirror modules shown in figure 1 has been in operation and under test at the University of Nevada in Las Vegas for the last 3 years.

OUTDOOR TESTING

The JXC carousel equipped with four 3-sun mirror modules was installed at UNLV in March of 2008. Figure 3 shows typical test results recorded during a day in June of 2008.

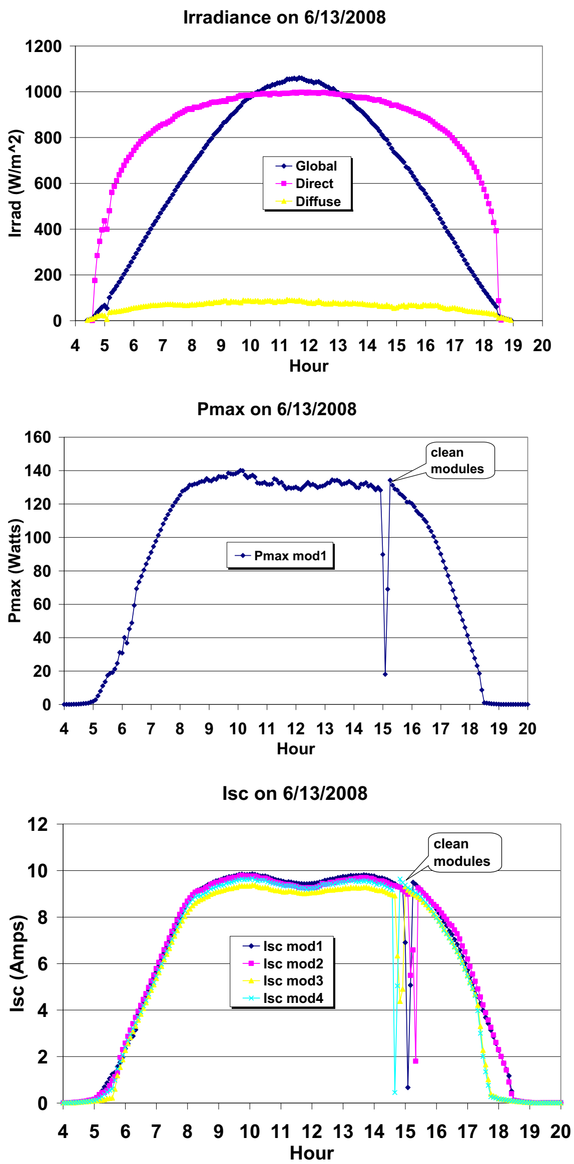

FIGURE 3: On a hot day in June of 2008 for a direct solar flux near 1 kW/m2, the module maximum power output peaks at 140 W with a module peak current near 10 A.

Measurements at the UNLV MDIC site recorded the direct, diffuse, and global solar radiatio. Illuminated current vs voltage curves were recorded every 5 minutes for each of the four modules. As is shown in figure 3, module power and current peaked at near 140 W and 10 A when the DNI was near 1 kW/m^2.

Figure 3 also shows that when the mirrors were cleaned after 3 months in the field, the current improved by 5.6%.

The performance data in figure 3 can be compared with the data for February 17 of 2011shown in figure 4 for a most recent sunny day (as of this writing).

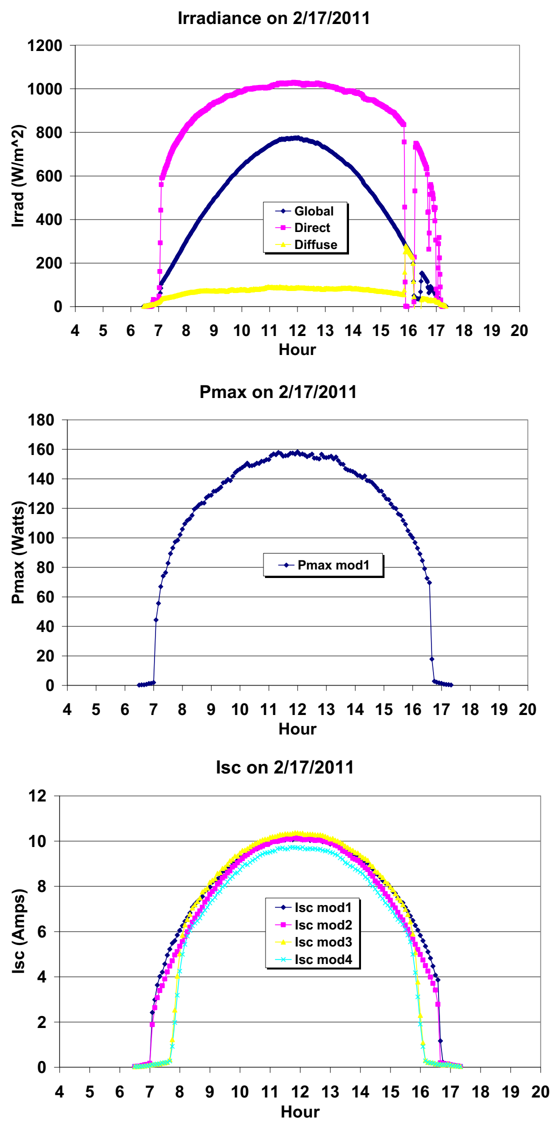

FIGURE 4: On a cold day in February of 2011 for a direct solar flux near 1 kW/m2, the module maximum power output peaks at 160 W with a module peak current near 10 A.

Comparing the Isc data in figures 3 and 4 shows that the carousel has continued to operate and that the generic 3-sun mirror performance has not changed. This is significant because nothing was changed in the carousel over this 3 year period and two of the module mirror sets have remained unchanged over that 3 year period. However, in April of 2010, two mirror sets were changed out not because of any failure but simply because we wanted to start testing 3M cool mirrors [5] as potentially lower cost options for the previous Alanod -brand aluminum based mirrors. .

Figure 5 shows a comparison of the performances for these two different mirror types over the period from April 2010 to July 2010. While this data shows that the 3M brand cool mirrors slightly outperform the Alanod brand aluminum based mirrors, it should be noted that the 3M brand cool mirrors are slightly longer. Figure 5 also illustrates the need for easy clean or dirt repellant coatings on mirror films. In addition to accelerated weathering studies, experiments are planned to continue testing of the 3M cool mirrors in larger numbers at various sites for longer periods of time.

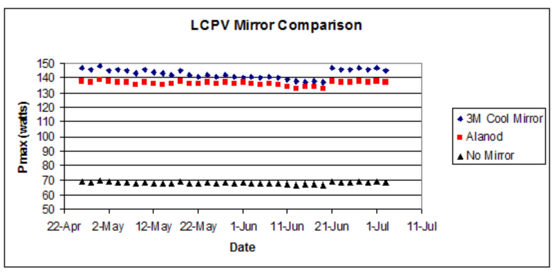

FIGURE 5: 3-sun module power output from April through July of 2010 for two alternate mirror types. The mirrors were cleaned in late June 2010.

The data presented in figures 3 and 4 show 3-sun mirror module performance throughout the day for sunny days in the summer and late winter respectively. Figure 6 shows daily average data from 10am to 2pm through the spring and summer in 2010. Some interesting trends are notable. Of course, while most days in Las Vegas during this period are sunny, not all days are sunny and the module power and current follow the sun.

Note also in figure 6 the record of the module temperature over this period. The module temperature ranges from about 40 C to about 70 C. In fact, the module temperature runs about 25 to 30 degrees C above the ambient temperature. This is similar to the temperature increase above ambient for standard Si planar modules and this is by design for the 3-sun modules [2, 3] because of the addition of a thin aluminum heat spreader at the back side of the glass circuit lamination.

Also note in figure 6 that as the ambient and module temperature increase in the summer, the module power decreases accordingly. The module peak current around noon also decreases slightly in the summer because the sun is higher than the fixed module tilt at 30 degrees on the tracker (see figure 3).

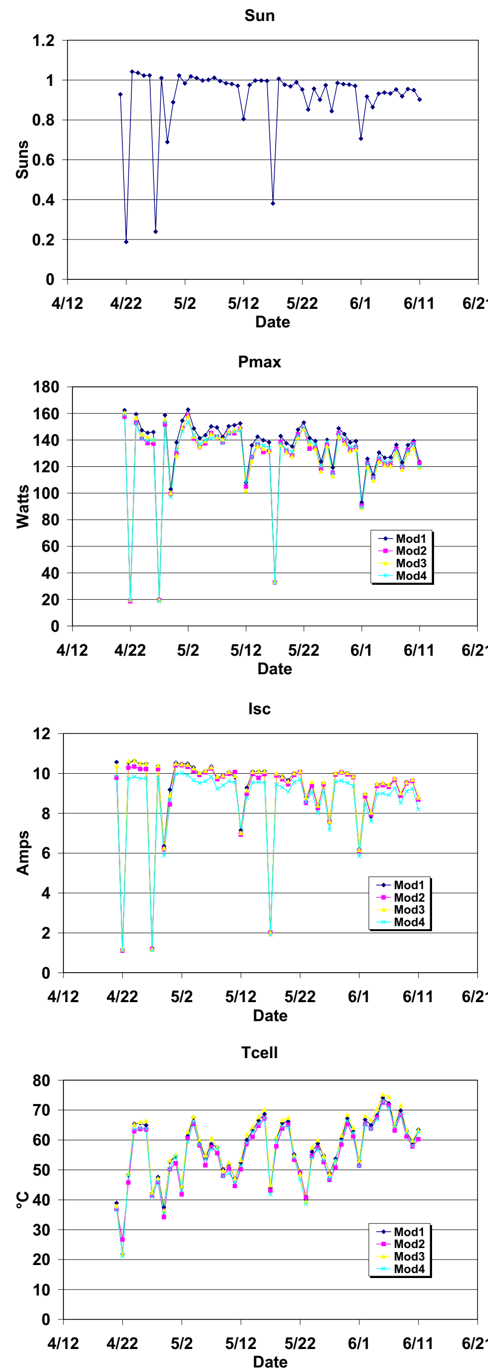

FIGURE 6: The day to day 3-sun module performance data is shown for the spring and summer of 2010.

POTENTIAL IMPROVEMENTS

The 3-sun module testing at UNLV has also revealed opportunities for improvements. Referring to figure 7, it is evident that the fill factor in the illuminated I vs V cell power curve can be improved. The data from figures 4 and 7 were taken on the same day. Comparing the current data from figure 4 with the fill factor data from figure 7 shows that when the current is at 5 A in the morning and late afternoon, the fill factor is high at over 0.75 but when the current rises to 10 A, the fill factor falls to 0.65. The module temperature curve in figure 7 shows that this drop in fill factor is not just the result of a very high module temperature.

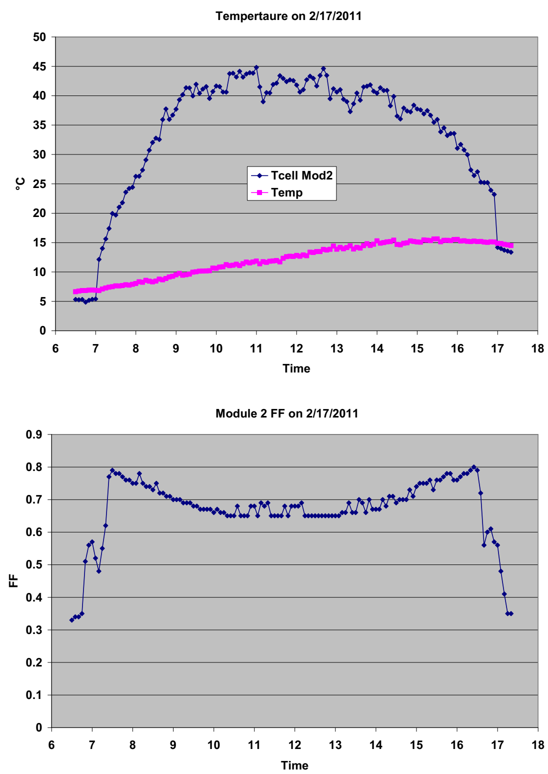

FIGURE 7: The 3-sun module fill factor drops from 0.75 to 0.65 as the module current rises from 5 A to 10 A.

This drop in fill factor is attributable to the use of SunPower brand interdigitated back contact 1-sun cells without modification and results from high grid line resistance because the grid lines run the full length of the 125 mm cell. However, a redesign of the grid pattern can resolve this problem by running the grid lines across the narrow 40 mm long cell dimension as is shown in figure 8. Alternately, standard screen printed Si cells with a custom grid line design can be used. In either case, improving the module fill factor will increase system performance.

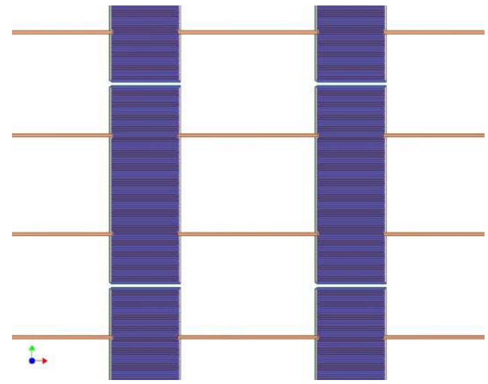

FIGURE 8: Back side view of interdigitated back contact Si cells with custom grid pattern running across the cell in the short dimension. A possible cell interconnect wiring scheme is also shown.

CONCLUSIONS

Solar trackers are now used regularly in large PV fields because tracking the sun produces more kWh reducing the cost of solar electricity but they are still not used on flat building rooftops. Herein, it is shown that solar 1-axis azimuth tracking carousels work reliably and can be used on commercial building flat rooftops. Also, in the past, the durability of mirrors has been questioned by the solar PV community even though mirrors are much cheaper than single crystal Si cells and can potentially reduce PV module cost. The test data presented here shows no degradation for aluminum based Alanod mirrors over a three year test period.

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