DEVELOPMENT OF A NEW 550X CONCENTRATOR MODULE WITH 3J CELLS _ PERFORMACE AND RELIABILITY –

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ABSTRACT

. The status of the development of a new concentrator module in Japan is discussed based on three arguments, performance, reliability and cost. The peak uncorrected efficiency in 7,056 cm2 400 X module with 36 solar cells connected in series was 26.6 % was measured by us. The peak uncorrected efficiencies of the same type of the module with 6 solar cells connected in series and 1,176 cm2 area measured by Fraunhofer ISE and NREL were 27.4 % and 24.8 %. The peak uncorrected efficiency of 550X and 5,445 cm2 module with 20 solar cells connected in series was 28.9 %. The temperature corrected efficiency in clear day in Japan of that 550X module was 31.5 ±2 %. In reliability, new degradation modes inherent to high concentration III-V solar cell system were discussed and proved 20 year's lifetime under concentrated flux exposure. The fail-safe issues of the concentrated sunlight are also discussed. In cost, overall scenario in the reduction of material cost was discussed.

INTRODUCTION

Concentrator modules using high efficiency multi-junction solar cells are expected to reduce the cost of PV significantly[1]. The cost of the module drops as the increase of the concentration ratio. This paper discusses on the performance and reliability issues of 550 X of concentration (equivalent to 1100 X circle to circle concentration), almost the maximum limit to Fresnel lens concentrator from a square lens to a square cell.

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550X CONCENTRATOR MODULE WITH RELIABILITY ENHANCED DESIGN

The newly developed 550X concentrator module is an improved model from the 400X concentrator module [2][3][4] (see Fig. 1).

From the 400X concentrator module, two major improvements were done. First, a new 550X dome-shaped Fresnel lens made by injection molding technology was developed (see Fig. 2).

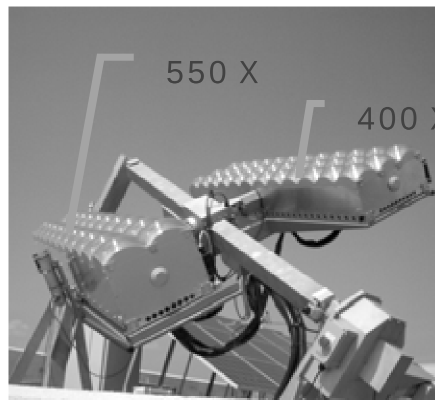

Fig. 1. 400X and 550X concentrator module on the same tracker in Toyohashi Site operated by Toyohashi University of Technology

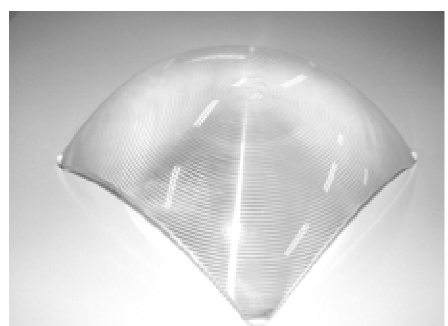

Fig. 2. 550X concentrator Fresnel lens made by injection molding. The size is 165 mm square.

The 550X lens have two improvements from the previous design. First, the facet size was significantly enlarged after improvement of injection molding technique by keeping uniformity in polymer fluid in the overall area. The loss from rounded prism peak and valley was significantly reduced. Second, durability against freezing cycle was improved. The previous 400 X injection-molded Fresnel lens had a problem in degradation by fine cracks caused by freezing [3]. The new 550X lens

was improv ed a stable
outdoor ope
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concentrate by UV [5].
Even thoug nsparency,
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typical env ng hot-wet
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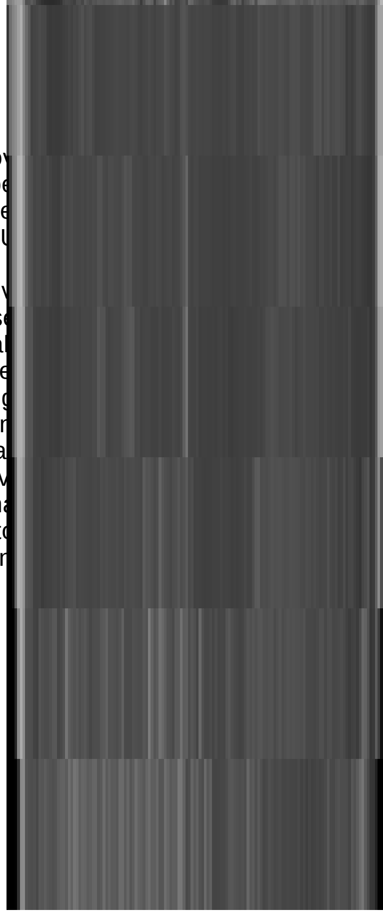

Fig. 3. Damaged solar cell by water invasion after degradation of sealing polymer by concentrated UV flux

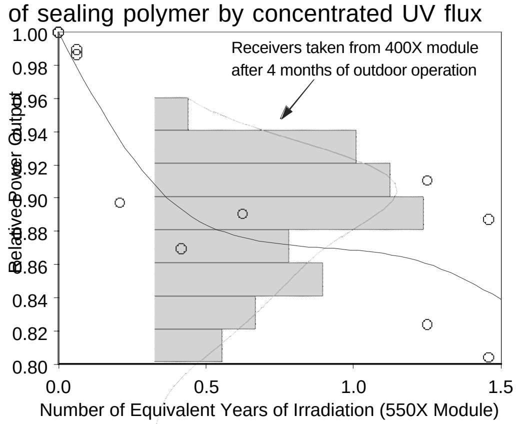

Fig. 4. Comparison between the acceleration test and outside exposure test

A good method is to expose concentrated UV in wet environment while the receiver is cooled and collects water condensation [3] by water-cooled Fe-Metalhalide lamp [5]. The acceleration ratio was examined by the comparison with outdoor exposure test of 400 X module (see Fig.4). After 4 month of outdoor operation, all the receivers were removed and measured by superlatively. The relative output to from the initial stage lied from 0.96 to 0.80 and most frequently 10 % degradation was found. At the same time, the same kinds of receivers were examined by the concentrated UV exposure test with water condensation. The trend was plotted in the circle symbols and solid line. Although they are scattered, the base line meet well.

Various kinds of sealing polymers were examined. Most of the polymers did not survive in 20 year's of accumulated concentrated UV, but we found one polymer that exhibited more than 20 year's of lifetime (see Fig. 5).

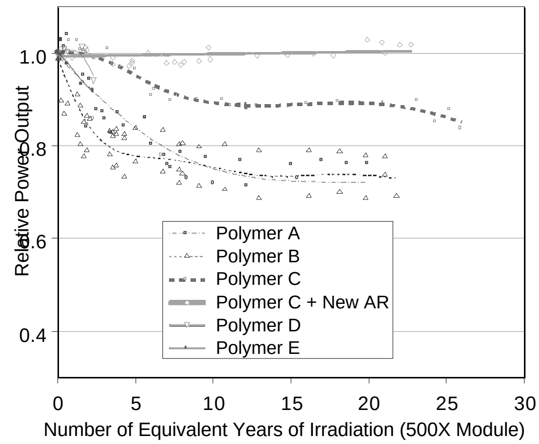

Fig. 5. Acceleration test by compound stress of simultaneous concentrated UV irradiation and water condensation.

UNCORRECTED MODULE EFFICIENCY

Both 400X and 550X modules were evaluated by 4 test sites. 3 sites were operated by independent organization. Table 1 lists an evaluated results. All the results were "UNCORRECTED". Different from flat-plate modules, the corrected procedure is not agreed internationally.

Table. 1 Uncorrected peak efficiency measurement

Type	Area (cm^2)	Site	Ambient	Uncorrected Efficiency
400 X	7,056	Inuyama, Japan Manufacturer	35 C	26.6 %
400 X	7,056	Toyohashi, Japan Independent	23 C	26.8±1.5 %
400 X	1,176	Fraunhofer ISE, Germany Independent	19.3 C	27.4 %
400 X	1,176	NREL, USA Ind ependent	29 C	24.9 %
550 X	5,445	Inuyama, Japan Manufacturer	33.4 C	28.9 %
550 X	5,445	Toyohashi, Japan Independent	31 C	> 27 %

Table 1 summarizes measured efficiency in three different sites. The Inuyama Site locates North of Aichi Prefecture, Japan in N35.4 deg of latitude and E137.1 deg of longitude, 30 km from seashore and 3 km from a major river and operated by Daido Metal Co., Ltd. (One of the manufacturer of the concentrator system). The tested system was constructed on the ground. The Inuyama Site also located in Aichi Prefectrue, Japan in N34.7 deg of latitude and E137.4 deg of longitude, 3 km from seashore, and operated by Toyohashi University of Technology, an independent organization. The tested system was constructed on the rooftop of the building. The reason of relatively lower efficiency in NREL is now clear now. Considering that the module was adjusted the direct beam in the atmosphere in Japan, one of the possible reason is the difference of spectrum [6].

CORRECTED MODULE EFFICIENCY

For the purpose of fair comparison to the flat-plate module, the efficiency at 25 C cell temperature in the spectrum closed to AM1.5G was tried.

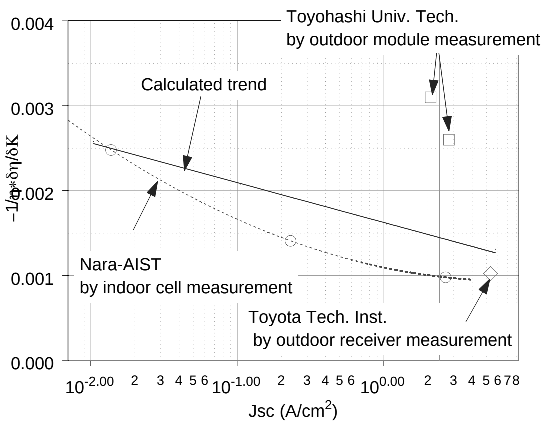

Fig. 6. Temperature coefficients in different concentration ratio by both indoor and outdoor measurements

First, the temperature coefficient was often evaluated by non-concentration measurements. However, with the increase of the concentration ratio and short-circuit current, the influence of the dark current is supposed to be logarithmically decreased and thus leads to less temperature coefficient. Fig. 6 indicates the normalised temperature coefficient with different levels of short-circuit current. The values measured by Nara-AIST [7] were obtained by the bare cell on the temperature-controlled stage. The values from Toyohashi University of Technology [8] were the results from statistical analysis of one-year field operation of the 400 X flat Fresnel lens concentrator module with 32 concentrator cells. The temperature correction was done with the coefficient given by the equation listed in the Fig. 6 as a function of the short-circuit current density at that instance [8][9-13] with theoretical calculation of the temperature coefficient. Obviously, the absolute value of the coefficient logarithmically drops with the increase of the current density per dark current density. There were gaps among the calculated trend, measurement by the cell, measurement by the receiver and measurement by the module. For the purpose of estimation of the temperature coefficient, we adopted a simple logarithmic calculated trend.

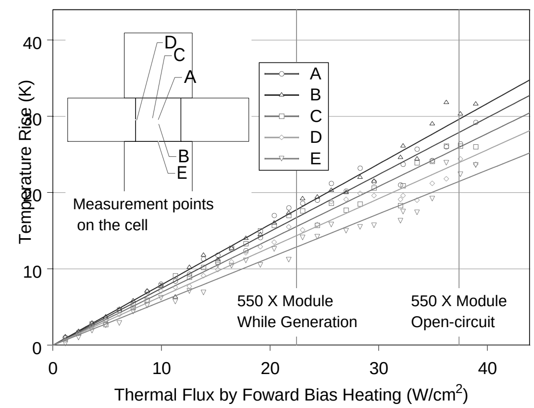

Fig. 7. Cell temperature relative to module temperature with given thermal flux

Next, the cell temperature of the concentrator module is not always the module temperature. Most of the cases, the concentrator solar cells are electrically isolated from the module body. Different from the flat-plate module, the concentrated heat flux flows in the relatively high heat resistance insulation layer to the module body. The cell temperature is raised by the product of heat flux and heat resistance. The cell temperature with given direct beam irradiance was anticipated by the temperature measurement with forward bias heating (see Fig. 7). The additional temperature correction result from the temperature gap between the module and the cell was done in proportion to the direct normal irradiance given by Fig. 7.

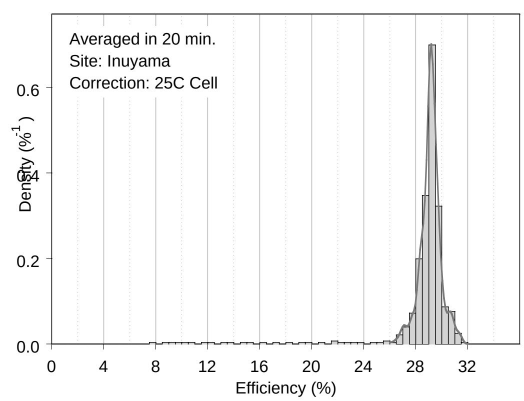

Fig. 7. Histogram of the corrected module efficiency in a clear summer day

Finally, the output power calculated I-V curve in one minute interval, the module temperature, and the direct normal irradiance was smoothed by moving average method in 20 minutes. This procedure was done to compensate the difference of time constants between the solar cells and the pyrheliometers. Without the smoothing, the module efficiency will be overestimated by a relatively larger time constant of the pyrheliometers, in case the direct beam abruptly increases by removal of small clouds. The corrected efficiency was categorized by the level of the direct normal irradiance and the histogram was made (Fig. 7). The most frequent corrected efficiency in summer time under a good sky condition (high direct normal irradiance and low scattering) was 32 %. Considering possible an error in measurements, the peak efficiency value in the best sunshine condition with error was 31.5 ±2 % and the most frequent efficiency was 28.6±2 %.

Again, this was for comparison to the flat-plate module. Considering the fact that it is difficult to control the cell temperature under illumination of concentrated sunlight, a realistic rating method may be a histogram in uncorrected efficiency [13]

FAIL-SAFE

One of the concerns to the reliability of concentrator modules is safety in some accidents. For example, the concentrated solar beam may burn the inside of the module components including internal cables, when the tracker has some problems and off-axis beam hits outside the solar cell. It was true in the early history of the concentrators [14][15]. The current non-imaging concentrator Fresnel lens maintains beam intensity within plus or minus 0.9 degree of tracking error, but the beam intensity substantially drops out of that acceptance angle. These characteristics help to reduce the thermal flux from off-axis beam to unwanted components. The homogenizer glass rod shifts the focal surface from the cell area and thus reduces intensity of the off-axis beam. The temperature rise by off-axis beam from 850 W/m2 direct normal irradiance was typically 15 K (See Fig.8).

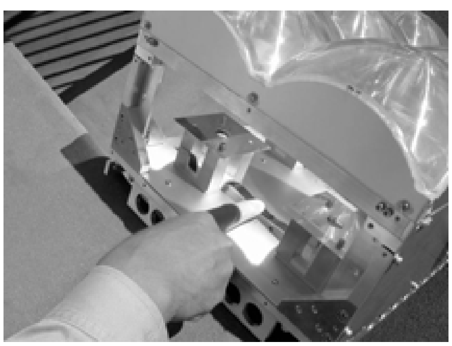

Fig. 8. Off-axis beam test : Thanks to the optical characteristics of the non-imaging Fresnel lens etc, fingers will not be burnt by off-axis beam

CONCLUSIONS

A new 550X module was developed after the 28 % efficient 400 X concentrator module. It is shown that degradation by concentrated UV is important and the new 550X module showed 20 year's of accelerated lifetime. Both 400 X and 550 X modules were evaluated by independent organizations and showed more than 27 % of uncorrected outdoor efficiency. The corrected peak efficiency was supposed to 31.5±2 %. Additionally, the fail-safe by off-beam axis was examined and the non-imaging Fresnel lens with the homogenizer succeeded to suppress temperature rise less than 15 K by the off-axis beam.

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