Universitat de Lleida

Document downloaded from:

<http://hdl.handle.net/10459.1/59448>

The final publication is available at:

<https://doi.org/10.1063/1.3658324>

Copyright

(c) AIP Publishing, 2011

Assessment And Comparison Of Concentrator Cell Carrier Efficiencies Under Very High Fluxes

Alain Dollet^{1*}, Osvaldo Arenas², Arnaud Perona¹, Alexis Vossier¹, Richard Ares², Vincent Aimez², Jérôme Barrau³, Daniel Chemisana³, Joan I. Rosell³

^{1*} *PROMES CNRS, rambla de la thermodynamique, Tecnosud, 66100 Perpignan, France*

Phone : +33 468682212, e-mail: dollet@univ-perp.fr

² *CRN², Université de Sherbrooke, Sherbrooke, 2500 Boulevard de l'Université, QC, Canada, J1K 2R1*

³ *Universitat de Lleida, Edifici CREA, C/Pere de Cabrera s/n, 25001 Lleida, Spain*

Abstract. The present work aimed at assessing and comparing the thermal performances of two different types of cell carriers exposed to natural sunlight beams concentrated up to 1,500 – 4,500 suns. Metallic and hybrid metal-ceramic carriers of various dimensions, or bonded to cells of different sizes, were considered. Temperature profiles inside the carriers exposed to concentrated beams were measured using temperature sensors placed at two different locations. 3D heat transfer simulations of a carrier bonded either to the real Ge-based solar cell or to the dummy cell instrumented for our temperature measurements showed that the measured temperatures differed by less than a couple of degrees from the real solar cell surface temperatures within a large range of concentration. Experimental results and thermal simulations confirmed the need to select a high-conductivity carrier combined with a very efficient active device for cooling the solar cells under very high concentration. In addition, the key role played by thermal constriction in the heat transfer process was highlighted, demonstrating the importance of carefully optimizing the carrier design.

Keywords: High concentration, cell carrier, temperature measurement, thermal simulation, concentrator cell

PACS: 88.40.fc, 88.40.hj, 44.05.+e, 65.40.-b

INTRODUCTION AND GOAL

Solar cell receiver assemblies are essential components of High Concentration Photovoltaics (HCPV) modules. In addition to provide electrical connections to the cells and insure their protection through bypass diodes, receiver assemblies must behave as efficient conductors and spreaders of the incoming solar energy fraction converted into heat inside the solar cells. Most concentrator cell carriers are plates made of copper or alternatively of high thermal conductivity ceramic material, which are both supposed to meet the requirements of current commercial HCPV systems operating typically at 500 suns (1sun = 1mW/mm²). However, it is not straightforward to assess the relative importance of the carrier design in the whole cell cooling device and the exact working temperature of the cell junctions for a given concentration ratio is usually unknown.

For sake of simplification, heat transfer through the conducting plate can be considered as a one dimensional problem in order to estimate the carrier thermal conduction resistance and then the cell

temperature; however, this may turn out to be a too crude approximation when thermal constriction effects are important. In particular, when a small area solar cell fixed to a larger size receiver is exposed to highly concentrated solar radiation, thermal constriction resistance may become much higher than ordinary conduction and convection resistances, resulting in large temperature gradients inside the receiver conducting plate.

The present investigation aimed at assessing the performances of various cell carriers exposed to natural sunlight beams concentrated up to 1,500 and even 4,500 suns. Dummy (instrumented) cells of either 1 cm² or 0.25 cm² were considered (fig. 1). Copper and Al₂O₃-based conductive (26 W.m⁻¹°C⁻¹) ceramic carriers of various dimensions were first instrumented for temperature measurements, then characterized under concentration and finally compared. 3D heat transfer simulations were also performed to check that the temperature measured was representative of the real cell surface temperature and also to study the temperature field variations in the carrier resulting from changing concentration, carrier material, carrier dimensions and cooling device efficiency.

EXPERIMENTAL

Selection And Preparation Of Carriers

Direct temperature measurements on solar cell surface exposed to concentrated sunlight are extremely difficult to perform. Cell carriers were especially instrumented for that purpose, as explained below. Instead of real solar cells, brass blocks coated with high temperature black paint were carefully bonded - using thermally conductive epoxy - to the carriers studied. A wire wound RTD (resistance temperature detector) element made of glass-coated ceramic was inserted inside the block in order to measure the temperature (T_2) representative of the real cell temperature (see simulations later). A second temperature (T_1) was measured at the carrier surface, at 3 mm from the block edge (fig. 1), using Al_2O_3 glass-coated thin film RTD.

FIGURE 1. Metallic carrier MC2 (25x25x0.78 mm) with dummy (instrumented) cell bonded at the center (measurement of cell temperature T_2) and RT detector on the right side (measurement of carrier temperature T_1)

Cell carriers of different materials and dimensions, as well as instrumented cells of different sizes were considered. Hybrid Carrier (HC1) consisting of 0.78 mm thick copper layer plus 0.635 mm thick Al_2O_3 layer (table 1) was used to evaluate the effect of a dielectric layer on heat transfer. Two metallic carriers (MC1 and MC2) having only a copper layer in order to maximize heat transfer were considered to evaluate heat spreader size effect on cell temperature.

TABLE 1. Carrier characteristics

Carrier Name/n° Material	dimensions in mm (Cell or Carrier)
Hybrid Carrier 1: HC1	12x10x1.8 (Cell)
Cu+ Al_2O_3	40x40x0.78 + 42x42x0.635 (Carrier)
Metallic Carrier 1: MC1	12x10x1.8 (Cell)
Cu	40x40x0.78 (Carrier)
Metallic Carrier 2: MC2	10x10x1.5 (Cell)
Cu	25x25x0.78 (Carrier)
Metallic Carrier 3: MC3	5x5x1.75 (Cell)
Cu	25x25x0.78 (Carrier)

Finally, two similar metallic carriers with cells of different areas (MC2 and MC3) were prepared to evaluate cell size effect on cell temperature.

Experimental Set-up For Carrier Characterization Under Concentration

The experimental set-up is schematically depicted in figure 2. A large parabolic mirror concentrated the solar radiation reflected from an outdoor heliostat tracking the sun to the focus where the dummy cell (optionally surmounted by an optical guide) was positioned. A cooled mask with an aperture precisely matched to the cell area was placed just above the instrumented carrier itself actively cooled by water flow. This set up allows irradiating cells of area as large as 1cm^2 up to 10,000 suns. Directional shutters shown in fig. 2 can be precisely tilted in order to adjust the solar flux intensity. Direct solar irradiation (DNI) was measured by using a pyrheliometer. The power transmitted through the cooled mask was measured by using a thermal head (spectrum neutral pyranometer).

FIGURE 2. Schematic view of the experimental concentration system with cell carrier at the focus of the dish

Carrier temperatures vs concentration ratio were recorded according to a four-step procedure as follows: i) thermal head placed under the mask aperture, ii) DNI and power transmitted through the mask aperture measured for various shutter tilt angles (calibration), iii) thermal head replaced by cell carrier, iv) carrier temperatures recorded for increasing shutter tilt angles while recording DNI (variations may occur).

EXPERIMENTAL RESULTS

Carrier Material influence

Plotted in figure 3 vs concentration ratio (X) are temperatures T_1 and T_2 recorded for metallic carrier 1

(MC1) and hybrid carrier 1(HC1) respectively. Carrier and cell areas were similar in both cases; hence fig. 3 illustrates the influence of material on carrier performances. The temperature increase as a function of X is slower for the metallic carrier which not surprisingly turns out to be more efficient than the hybrid carrier because of its higher thermal conductivity. Cell temperature T_2 reaches 109°C at 1,300 suns with the hybrid carrier whereas it remains lower than 80°C with the metallic carrier at the same concentration level.

FIGURE 3. Temperatures T_1 (carrier surface) and T_2 (instrumented cell) measured at different concentration ratios using metallic carrier 1 (gray) and hybrid carrier 1 (dark). See complete carrier characteristics in table 1.

Carrier size and cell size influence

Summarized in table 2 are temperatures T_2 recorded at high concentration for the various carriers considered. Both T_2 and T_1 were found to vary linearly with X in the concentration range investigated. Table 2 illustrates the effect of either changing carrier material, carrier area (cell size $\approx$ fixed) or cell size (other carrier characteristics fixed).

TABLE 2. Comparison between cell temperatures (T_2) measured at high X on the various carriers considered.

Name (carrier/cell dimensions in mm)	X (suns)	T_2 ($^\circ\text{C}$)
HC 1 (40x40x0.78/12x10x1.8)	1308	109.7
MC 1 (40x40x0.78/12x10x1.8)	1411	88
MC 2 (25x25x0.78/10x10x1.5)	1573	153
MC 3 (25x25x0.78/5x5x1.75)	1415	35.6
-	4208	67.7

Increasing carrier area increases the surface available for cooling, leading to lower values of T_2 and T_1 . Dividing cell surface by a factor of 4 (from 1cm^2 to 0.25cm^2) leads to a significant decrease of cell temperature at fixed power density (i.e. concentration ratio); indeed, in this case, the total heat flux absorbed by the carrier and to be removed by cooling is also

divided by a factor of 4. A 0.25cm^2 cell mounted on a $25\times 25\times 0.78\text{mm}$ metallic carrier turns out to operate at temperature less than 70°C at 4,200 suns.

SIMULATION RESULTS

Finite element thermal simulations of the irradiated cell mounted on a cooled carrier were performed in 3D. Simulations first aimed at estimating the difference between the measured temperature, i.e. in the core (at the center) of the instrumented cell, and the temperature at the center of the real cell surface (considered as pure Germanium in the simulations).

FIGURE 4. Simulated temperature profiles obtained at 450 suns with a 1cm^2 cell mounted on Metallic Carrier 2 : a) top, dummy (instrumented) cell, b) actual Ge cell

Figures 4a and 4b show the simulated temperature profiles obtained in both cases for a concentration ratio of 450 suns. Cooling water temperature was 9.5°C , all surfaces were assumed adiabatic except cell surface (energy input) and carrier bottom surface where an exchange coefficient $h = 4,500\text{Wm}^{-2}\text{C}^{-1}$ was considered. The difference ΔT_c between the calculated temperature at the surface of the real cell and at the center of the dummy cell (measured by the sensor) is only 0.2°C at this concentration level, and ΔT_c remains $< 1^\circ\text{C}$ at 2,000 suns. In the worst case, a theoretical value of $\Delta T_c = 2.8^\circ\text{C}$ was found at 2,000 suns when considering $1\text{cm}^2/6.25\text{cm}^2$ cell/carrier

areas instead of 0.25 cm²/16 cm². These results confirm that the experimental temperatures obtained from the instrumented cell were excellent estimates of the real cell surface temperatures.

DISCUSSION

Thermal constriction and carrier cooling

When cell area is much smaller than carrier area, the deviation of heat flow lines at the constriction point (fig. 5) adds a thermal resistance R_{constr} to the "usual" convective and conductive components of thermal resistance R_{th} :

$$R_{th} = R_{conv} + R_{cond} = \frac{1}{hS} + \frac{e}{kS} \quad (1)$$

FIGURE 5. Heat flow lines without (left) or with constriction (right)

In the above equation, h is the convection heat transfer coefficient, k the thermal conductivity of the heat spreader, e and S are respectively the thickness and area of the spreader. Thermal constriction has been extensively studied, e.g. in heat spreader optimization problems for power electronics [1]. Non-trivial semi-empirical correlations can usually be found in the literature to calculate the thermal constriction resistance without the need to perform numerical simulations, for instance in [1]. In this work, analysis of the influence of thermal constriction was conducted in order to highlight the importance of the heat spreader geometry on the overall cooling device performance; this analysis will be only very briefly summarized here. In the case of Metallic Carrier 2 (size: 25x25x0.78 mm) with 1cm² cell the total thermal resistance R_{th} was about 1.4 °C/W, with a major contribution of the convection resistance and a very low contribution of the constriction. By increasing the carrier size, i.e. by selecting Metallic Carrier 1 (size: 40x40x0.78 mm) instead of MC2, the convection resistance decreases down to 0.56 °C/W so does the total thermal resistance R_{th} = 0.7 °C/W (figure 6); the conduction resistance remains negligible but the constriction resistance increases significantly (R_{th} = 0.14 °C/W). The above results as well as experimental results (see table 2) confirm that carrier MC1 is more efficient than Carrier MC2. Further increasing carrier area keeping cell area unchanged will decrease the convection resistance, but, in turn, will increase the contribution of constriction and on the whole, R_{th} will

be unchanged or even increased. The best way to further increase the overall efficiency of cell cooling is then to use a much more efficient device capable of producing high values of h , e.g. combining jet impingement and micro-channels [2]. Experiments using such a cooling device are currently in progress.

FIGURE 6: Contributions to overall thermal resistance R_{th} in the case of a 40x40x0.78 mm metallic carrier as a function of carrier thickness ($e=0.78$ mm in the case of MC2). Convective coefficient: $h=4,500 \text{ Wm}^{-2}\text{°C}^{-1}$.

CONCLUSIONS

Temperature measurements on dummy cells exposed to concentrated solar radiation were performed to evaluate and compare the efficiency of various cell carriers. Thermal simulations confirmed that the temperature measured should be equal to the real solar cell surface temperature. The magnitude of thermal constriction effects confirm the major importance of the heat spreader design in addition to the selection of very efficient cooling devices when solar cells are exposed to very high concentration.

ACKNOWLEDGMENTS

Financial support from the CNRS "Energy" program (FORCO-PV project) is acknowledged. J.J. Huc and E. Hernandez (PROMES) are particularly thanked for their invaluable help in preparing the experimental devices. L-M Collin (CRN²) is also thanked for his support with 3D simulations.

REFERENCES

1. G. Maranzana, I. Perry, D. Maillet, S. Rael, *Int. J. Therm. Sci.* **43**, 21-29 (2004).
2. J. Barrau, J. Rosell, M. Ibanez, "Design of a hybrid jet impingement/microchannel cooling device for densely packed PV cells under high concentration", *6th Int. Conf. on Concentrating Photovoltaic Systems*, AIP Conf. Proc. Vol. 1277 (2010) pp 74-77