TEST OF HIGH CONCENTRATION SOLAR CELLS FOR APPLICATIONS ON FLUXMETERS FOR SOLAR CONCENTRATORS

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ABSTRACT: Solar concentration cells of the type SunPower HECO252 have been tested as photodetectors in fluxmeters for trough solar thermal concentrators. Two types of fluxmeters have been investigated, both realized with a collar-shaped sensor head wrapping round the glass tube protecting the cylindrical thermal receiver. The first fluxmeter has a sensor head mounting a single cell directly exposed to the concentrated solar radiation and provided with an optical screen. The second fluxmeter was realized with a polygonal frame over which eleven cells, protected by diffusive windows, are distributed at regular intervals in order to cover the full angular range involved with the concentrated light irradiation. The two fluxmeters were tested in a long campaign in the field, mounted on the PCS solar thermal concentrator of ENEA-Casaccia (Rome). No appreciable current degradation was observed for the single HECO252 cell of the first fluxmeter within two months of direct exposition, whereas a long term stability was observed for the eleven HECO252 cells of the second fluxmeter. The monitoring of both temperature and photocurrent of cells allowed us, for both fluxmeters, to calculate the flux density incident on the receiver.
Keywords: Fluxmeter, Concentration Cells, Concentrators.

1 INTRODUCTION

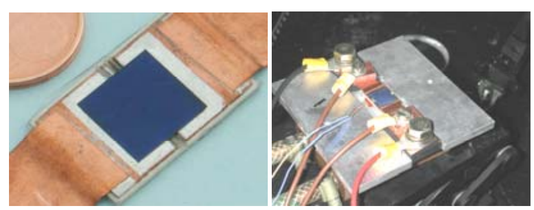
The widespread use of solar concentration for the photovoltaic or thermal solar energy conversion demands the development of new radiometers, or fluxmeters, for measurement of total flux or flux density distribution of the concentrated beam over the receiver surface. Besides to be suitable to sustain the high flux densities, these fluxmeters are to be designed to match the actual geometry of the receiver, which changes with the dimension of concentration (2D or 3D) and type of application.

For planar receivers, typical of photovoltaic applications, absolute flux measurements can be carried out by using fluxmeters based on one integrating sphere (ISR), such that developed by Ferriere [1], or two integrating spheres (DISR), such that developed by Parretta [2, 3]. The matching between fluxmeter and cylindrical receiver of a linear concentrator for thermal applications is a more arduous task. Riffelmann [4] has developed a fluxmeter (PARASCAN) with a sensor head provided with an array of photodiodes, moved along the receiver axis to record a two-dimensional flux map. The fluxmeter has been realized with two sensor heads, one for measuring the total flux incident on the receiver, the other for measuring the flux lost by reflection; the difference between them giving the effective flux absorbed by the receiver.

In this paper we present two types of fluxmeters, one with a single cell, the other with multiple cells, of similar geometry to that of PARASCAN, but operating in a different way concerning the selection of the flux effectively absorbed by the receiver. The two fluxmeters use SunPower HECO252 concentration cells as photodetectors. These cells were preliminary calibrated then tested outdoor on the solar thermal concentration plant PCS of the Archimede project of ENEA-Casaccia (Rome), operating at ~40-50 suns [5]. In this paper we investigate the degradation effects produced on the electrical and optical properties of the cells after long exposition at high concentration levels of solar radiation.

2 HIGH CONCENTRATION SOLAR CELLS AS HIGH FLUX DENSITY PHOTODETECTORS

In this paper we will refer exclusively to the SunPower HECO252 cell (see Fig. 1), a high efficiency concentration Silicon cell, realized with the advanced back contacts technology and suitable for high flux irradiation measurements of the order of two hundred suns. A summary of the main characteristics of the cell is reported in Table 1.



a) b)

Figure 1: Solar concentration cell SunPower HECO252. a) Cell welded on a copper-coated AlN substrate; b) cell mounted on a support for tests at high concentration illumination.

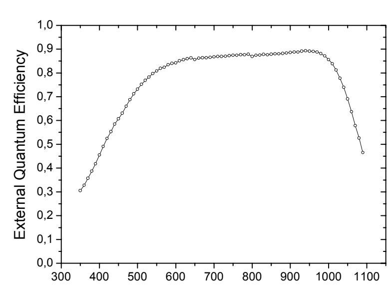
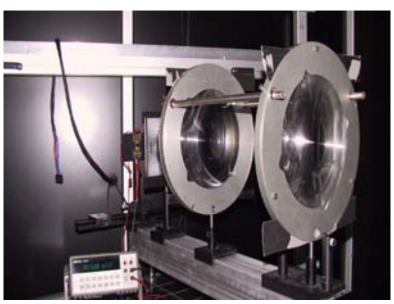


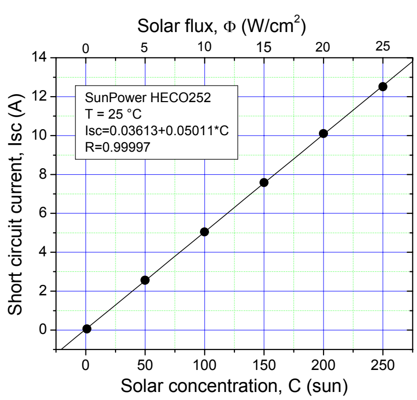
Figure 2: External quantum efficiency of the unexposed SunPower HECO252 cell.

Table I: Summary of HECO252 cell parameters.

Dimensions: 12x12 mm^2; active area: 11x11 mm^2; thickness: 120 mm.
Concentration range: up to 250 suns; Bulk material: FZ n-type; ρ (bulk): 200 Ω cm; lifetime (bulk): 3 ms.
ARC: TiO_2/SiO_2. Average reflectance (AM1.5): 0.6%.
Substrate: AlN; window: (5%)Ce-doped glass sheet.
Efficiency: 20.5 % (AM 1.5 D, 25°C); 25% at 100 suns (P=3W); 23.5% at 250 suns (P= 7.1W).
Efficiency peak at 5-10 W/cm^2: 25%
Efficiency (typical) at 25 W/cm^2: 23.5%.
I_{sc} at 25 W/cm^2: 11.3 A.
V_{oc} at 25 W/cm^2: 820 mV.
FF at 25 W/cm^2: 0.77.
I_{mp} at 25 W/cm^2: 10.3 A.
V_{mp} at 25 W/cm^2: 690 mV.
Maximum operating T: 100 °C.

The SunPower HECO252 cells are being massively used for the PV solar concentration Project PhoCUS of ENEA. Several of these cells were then available for tests as photodetectors in radiometers for high flux solar radiation measurements.
The cell is shown in Fig. 1a with the strip for the electric contacts and in Fig. 1b mounted on a support for the electrical characterization under illumination.
Fig. 2 shows the external Quantum Efficiency measured on an unexposed cell. To be used as photodetector in fluxmeters for solar radiation measurement, the HECO252 cells were calibrated at the PASAN mod. 3B pulsed solar simulator, equipped with Fresnel lens for concentration measurements (see Fig. 3a).

a) 



b)
Figure 3: a) Test of the cell at the PASAN solar simulator. b) Calibration curve of the SunPower HECO252 cell (1 sun = 0.1 W/cm^2).

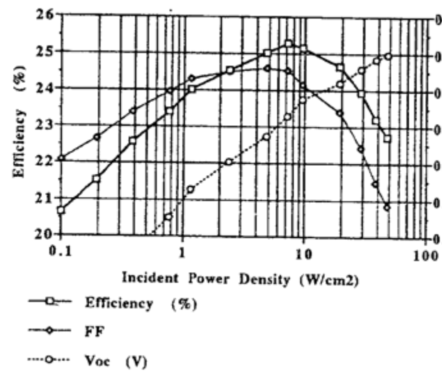
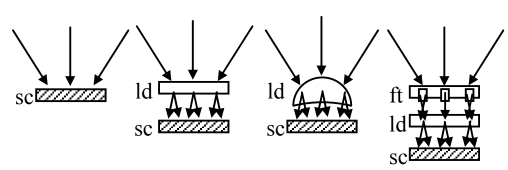


Figure 4: Typical efficiency, Voc and FF of the SunPower cell as function of the incident power density.

Fig. 3b shows the linear correlation (correlation coefficient R=0.99997) found between the short circuit current (in A) and the simulated solar flux density (in W/cm^2 and in suns) at 25° temperature:

$$I_{sc}(A) = 0.036 + 0.501 \cdot \Phi(W/cm^2) \quad (1)$$

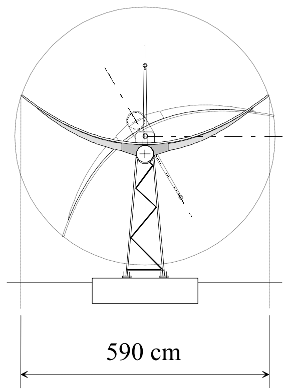
Eq. (1), joined to the cell operating temperature measured inside the fluxmeter and the temperature coefficient for the Isc (0.04 % / °C), allows to obtain the actual flux density incident on the cell for a homogeneous distribution of radiation. Fig. 4 shows the dependence of efficiency, V_{oc} and FF on the incident power density.
The exposition of the cell to radiation inside the fluxmeter can be realized in different ways. The simple direct exposition of the cell (sc) to concentrated radiation (Fig. 5a) has the disadvantage to produce a current response dependent on the spatial and angle distribution of incident beam, which affects the reflectance and quantum efficiency of the cell. To reduce these effects, the cell can be covered by a suitable diffuser (ld), preferably of Lambertian transmission properties, with planar (Fig. 5b) or convex geometry (Fig. 5c). A forth solution (Fig. 5d) is the use of a neutral filter (ft), i.e. a metallic sheet with a calibrated density of holes, or a very thin metallic layer, for attenuating the radiation, followed by the planar diffuser (ld) described before.



a) b) c) d)
Figure 5: Different ways of exposing the SunPower HECO252 cell photodetector to the concentrated light inside the fluxmeter.

3 THE FLUXMETERS

The fluxmeters described in this paper were designed [6, 7] to be used on the solar thermal concentration plant located at the ENEA-Casaccia laboratories of Rome. This is characterized by a trough geometry with 590 cm aperture and 181 cm focal length (see Fig. 6). The mirror panels are of 120 cm length, assembled in modules of 12 m length. The sensor head of the fluxmeter is collar shaped, in such a way to be easily wrapped round the 125-mm diameter glass tube protecting the 70-mm diameter stainless steel receiver, placed under vacuum.



a)

b)

Figure 6: a) Schematic section view of the parabolic trough solar collector of PCS plant. b) Photo of the PCS solar collector.

The first realized prototype FVC1 (Photo Voltaic Collar 1) is characterized by a sensor head characterized by a single solar cell (sc) as photodetector, directly exposed to the concentrated solar radiation (csr) (see Fig. 7). The sensor has been realized by joining two anticorodal half cylinders for the assembling on the glass tube. The sensor operates with an optical stainless steel screen (os) with large view (aperture angle a) whose main function is to select the radiation impinging on the receiver tube (rt) [9]; it improves, indirectly, the cooling of the cell.

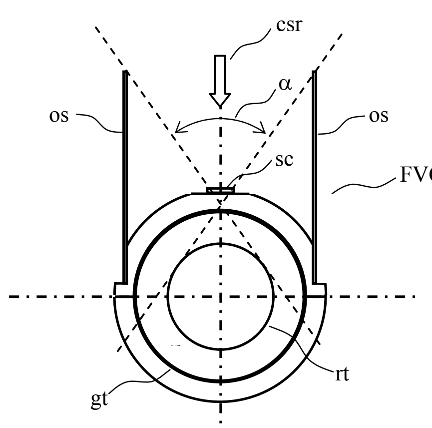


Figure 7: Schematic section view of the FVC1 prototype of fluxmeter.

To explore the angular sector interested to the solar irradiation (~210°), the sensor head has to be manually oriented towards different directions (azimuthal angle). The cell temperature is measured by an Iron-Constantan (type J) thermocouple welded directly under the cell substrate. The cell used with the CFV1 sensor was calibrated with a class A solar simulator, producing 48.2 mA under 1000 W/m^2 irradiation (AM1.5G). We measured 0.71 mV at AM1.5G on a shunt resistance of 0.015 W, and this value was used to convert the voltage drop on the cell to irradiance values.

As we have discussed in the previous paragraph, the fluxmeter can operate also with cells not directly exposed to the concentrated radiation, but protected by diffusive windows. This allows to reduce cells temperature and to have a more uniform distribution of flux on the cell surface. With this concept in mind, we have developed a second, more sophisticated prototype, FVC2 (see Figs. 8 and 9), operating with eleven SunPower cells (sc) protected by as many translucent targets (ld) with quasi-Lambertian transmission properties [6, 7]. The eleven cells are distributed over an angular interval of ~210°. The concentrated light impinges on the diffusive translucent window (ld), is reflected by the optical guide (og) walls and is absorbed by the cell (sc). This arrangement allows to have a quite homogeneous radiation on the cell, independent of the impinging direction of radiation on the window (ld). To improve the dissipation of heat from the cells, an electric fan is used to extract air from the sensor body. Signals of photocurrent and temperature of the cells are brought to electrical connectors and measured by remote instrumentation for both fluxmeters.

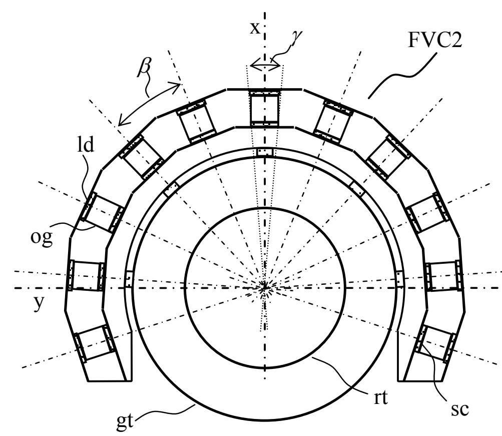


Figure 8: Schematic section view of the CFV2 sensor head.

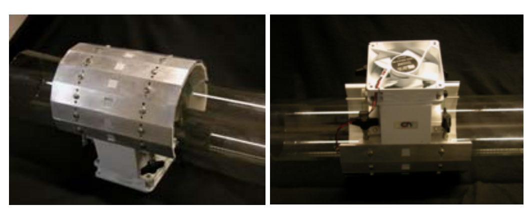


Figure 9: Top of the FVC2 sensor head with visible the diffusive windows (ld) (left); back of the sensor head with visible the electric fan (right).

4 RESULTS AND DISCUSSION

The FVC1 sensor was tested in a long test campaign in the field, with continuous monitoring of the cell photocurrent and temperature and for different orientations with respect to the solar collector. Fig. 10 shows the sensor mounted on the PCS receiver.

Figure 10: The FVC1 sensor head mounted on the PCS receiver during a test campaign.

We report here some results obtained at the beginning of the test campaign. In Fig. 11 the intensity of direct solar radiation is compared to that of concentrated radiation on the cell in a day of measurements. The simultaneously measured temperature is reported in Fig. 12.

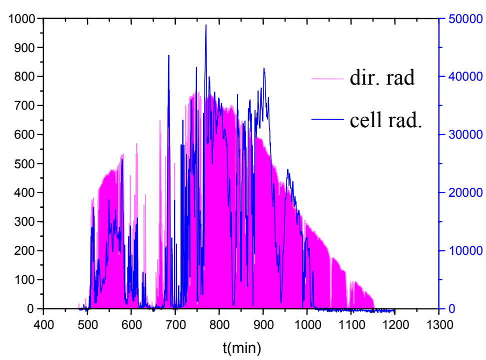


Figure 11: Intensity (in W/m^2) of direct radiation measured by the pyranometer and of concentrated radiation measured on the cell, as function of time (in min) in the first day of test.

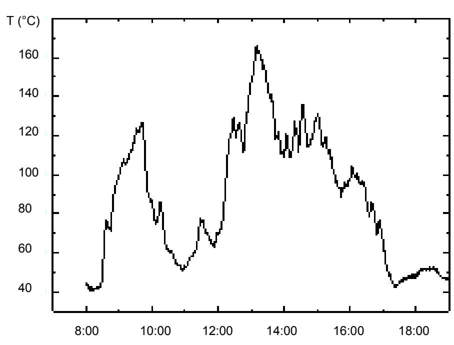


Figure 12: Temperature of the cell during the first day of measurements.

Despite the high temperatures reached (>160 °C), the cell has been operating correctly during the day. We note, as expected, that the cell temperature follows the concentrated irradiance (cell current) measured on the cell. We note also the smoothing of temperature curve respect to that of concentrated irradiance, as expected due to heat capacity of the sensor body. Both temperature and concentrated irradiance (cell current), however, show a behaviour not perfectly correlated with that of the direct radiation. Differences can take origin on geometrical factors (existence of separation zones between mirrors), or temporal factors (temporal phase difference between measurement of pyreliometer and of solar cell). In the case of Fig. 11, the relevant differences are due to panel and module separations.

The cells were periodically tested in the lab for measuring the light I/V curve. No detectable degradation was observed after about two weeks of exposition, whereas a sensible degradation was observed only after two months of direct exposition, which had little effect however on photocurrent measurements (see Fig. 13). During this period the cell worked at an average temperature near the maximum recommended by the manufacturer, with peaks 50% above.

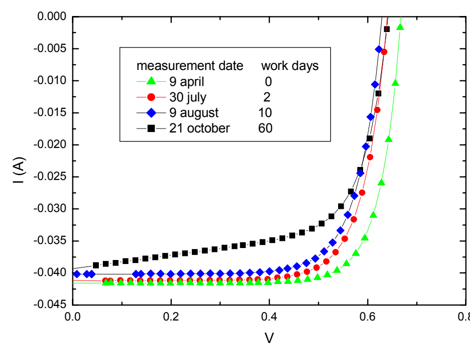


Figure 13: One sun light I/V curves of the HECO252 cell after different periods of exposition at concentrated radiation.

The test campaign carried out on the FVC2 fluxmeter (see Fig. 14) proved the suitability of the sensor to sustain the maximum radiation flux densities (around 50 suns). All the tests in the field, in fact, showed that the cells temperature maintained always at around 60-80 °C, well below the maximum temperature (100°C) recommended by the manufacturer. The light I/V curve tests made in the lab after a long period of exposition showed no electrical degradation of the eleven cells.

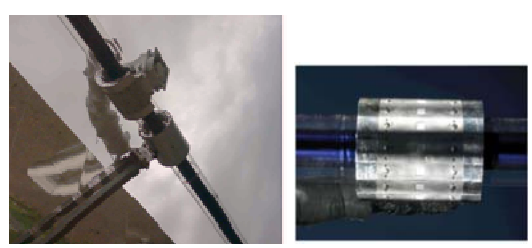


Figure 14: The FVC2 sensor head mounted on the PCS receiver during a test campaign (left). CCD image of the FVC2 sensor as it appears from the air space between the two half-parabola of the collector during sun tracking (right).

The flux distribution measurements were also in good agreement with simulations based on experimental data of the real optical profile of the collecting mirrors, as obtained by indoor laser measurements [8]. The diagram of Fig. 15 shows the measured flux by sensor (FVC2, square points), the simulated flux for the real mirrors (AC01, dotted line) and the simulated flux in the ideal case of perfectly parabolic mirrors (ideal, continuous line).

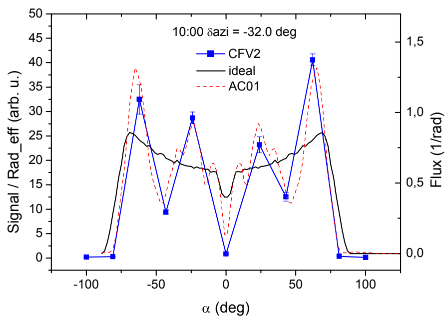


Figure 15: Measured flux by the CFV2 (CFV2) compared to that simulated for real mirrors (AC01) and for an ideal mirror of parabolic shape (ideal).

Fig. 14 (right) clearly shows the central dark zone produced on the sensor by the air space between two collecting half-parabola. Other grey regions are also present due to the modulation of flux distribution as consequence of mirror deformation (see the flux profile in the diagram of Fig. 15.

5 CONCLUSIONS

Solar concentration cells from SunPower have been tested as photodetectors in fluxmeters for trough solar thermal concentrators operating at 50 suns maximum. Cells directly exposed to the concentrated solar radiation reached temperatures in excess of 100°C and worked well without appreciable degradation for few months. Cells protected by diffusive windows and air cooled experienced, on the contrary, temperatures in the 60-80 °C interval with no appreciable degradation. The method for high flux density measurements in trough solar concentrators is also discussed.

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