Direct sunlight facility for testing and research in HCPV

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Direct Sunlight Facility For Testing And Research In HCPV

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Abstract. A facility for testing different components for HCPV application has been developed in the framework of "Fotovoltaico ad Alta Efficienza" (FAE) project funded by the Sicilian Regional Authority (PO FESR Sicilia 2007/2013 4.1.1.1). The testing facility is equipped with an heliostat providing a wide solar beam inside the lab, an optical bench for mounting and aligning the HCPV components, electronic equipments to characterize the I-V curves of multijunction cells operated up to 2000 suns, a system to circulate a fluid in the heat sink at controlled temperature and flow-rate, a data logging system with sensors to measure temperatures in several locations and fluid pressures at the inlet and outlet of the heat sink, and a climatic chamber with large test volume to test assembled HCPV modules.

Keywords: heliostat, High Concentrated PhotoVoltaic module, multijunction cell.
PACS: 88.40.hj

INTRODUCTION

The research activity aimed at optimizing the performances of HCPV (High Concentrated PhotoVoltaic) modules requires to perform a wide variety of measurements, characterizations, and ageing tests of individual components and assembled systems. Doubtless most tests for an HCPV components demand a radiation source as similar as possible to the solar spectrum. In this regard some solar simulators for HCPV, using Xenon flash light, are available on the market with prohibitive costs for a small scale project budget [1]. Furthermore, the simulated light, due to the short time duration of the flash pulses, barely allows to proper reproduce the thermal conditions that the tested components would undergo under real high concentration sunlight. On the other hand, our system, relying on direct sunlight, provides a continuous beam allowing to test HCPV components and prototypes at operating temperature, that is especially essential for cogenerating systems. Moreover, the employment of real sunlight allows for prototypes characterization in conditions different from the ideal clear sky illumination, i.e. in the presence of clouds or scattered light.

Our sunlight facility concept is surely adequate for laboratories located in sunny sites and provides more working hours in the sunny seasons; indeed our apparatus installed in Sicily at about 38° of latitude, provides a number of operating hours ranging from 6 to 10 along the year.

Within the framework of the FAE "Fotovoltaico ad Alta Efficienza" (FAE) project, these circumstances suggested us to develop in house an apparatus, based on a low cost heliostat, that provides continuously a large size Sun beam in the lab for testing both refractive and reflective concentrators, multijunction cells, as well as different materials and components (frusta, encapsulants, etc...) for HCPV applications. Several activities can largely benefit from the availability of the real sunlight inside a laboratory for many hours. The system consists of a heliostat that reflects the actual solar light in a dedicated laboratory.

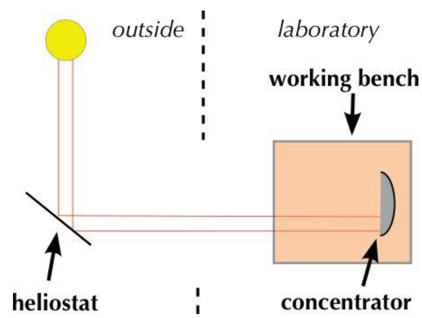

FIGURE 1. Sketch of the reflection of solar light in the dedicated laboratory.

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Beside the heliostat, the set-up testing facility is equipped with: an optical bench for mounting and aligning the HCPV module components; an electronic equipment to characterize the I-V curves of high efficiency multijunction cells operated at high sunlight concentration up to 2000 suns; a system circulating a cooling fluid in a heat sink at controlled temperature and flow-rate for thermal characterization of hybrid CPV components; and a climatic chamber with large test volume (≈ 500 liters) to test fully assembled HCPV modules.

DIRECT SUN-BEAM IN THE LAB

The heliostat aimed to provide a large size (> 60 cm diameter) sunbeam, consists of a commercially available Sun-mirror device modified by the addition of a large format high flatness extra clear glass mirror (with very low content of iron), coated with silver on the back side. The additional mirror is a regular octagon circumscribed to a circle with diameter 120 cm (figure 2) and reflecting area of 11950 cm^2. The mirror has a high reflectivity over the full solar spectrum including ultraviolet, visible and infrared bands.

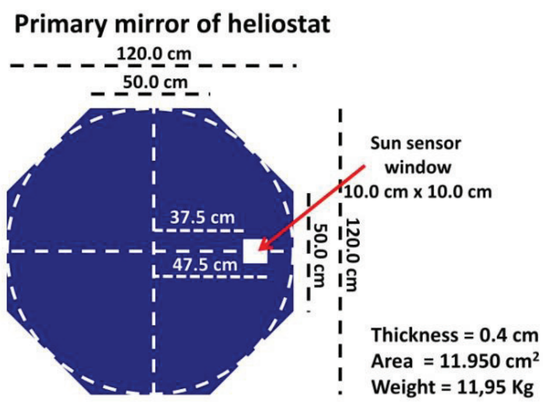

FIGURE 2. Sketch of the mirror of the heliostat.

The system is arranged to test both refractive (e.g. Fresnel lenses) and reflective optics (e.g. parabolic and paraboloid mirrors). The adopted configuration, constrained by the available laboratory space and building location, has been optimized to operate efficiently mainly in the a.m. hours with a beam flux up to 90% of the direct sunlight. Figure 3 shows the Direct Normal Irradiance (DNI, W/m^2) of the sun-beam recorded in the laboratory with a calibrated pyrheliometer in a mid-october day. As it is evident the heliostat provides a quite stable beam with small variations due to tracking alignment corrections, occurring at intervals of about 90 seconds on average, with a maximum range between 50 and 130 seconds.
In order to properly characterize the efficiency of HCPV modules based on multijunction cells it is crucial to know the flux and the DNI of the beam after the reflection from the primary mirror of the heliostat.

For these purposes, the DNI of the reflected beam is continuously monitored in the laboratory by the use of a pyrheliometer, which allows to normalize the small flux changes in between two subsequent tracking corrections. As shown the DNI average value evolves not only during months but also in a single day.

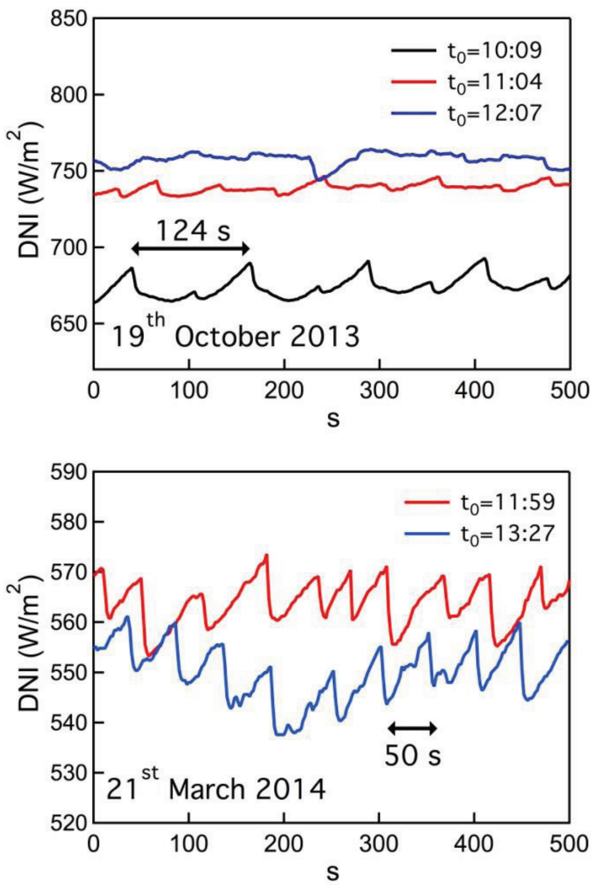

FIGURE 3. Time variation of measured DNI by a pyrheliometer measuring the reflected Sun-beam in the lab. Upper panel: the measurements were carried out in Sicily the morning of October 19th, 2013. Lower panel: the measurements were carried out in Sicily the morning of March 21st, 2014. For all data the initial time, t_0, of acquisition is reported.

In order to characterize our apparatus, the reflectivity of the primary mirror has been measured. In the 400-500 nm range it is larger than 90% while it reaches up to 95% in the 500-1100 nm range [2]. The subcells of the monolithic multijunction are not measurable separately; hence, as a supplementary knowledge, the DNIs of the developed apparatus have to be monitored to analyze the irradiance in the interesting spectral regions.

The spectral distribution of the DNI for the flux reaching the multijunction cells is characterized by coupled use of a pyrheliometer and of longpass optical filters.

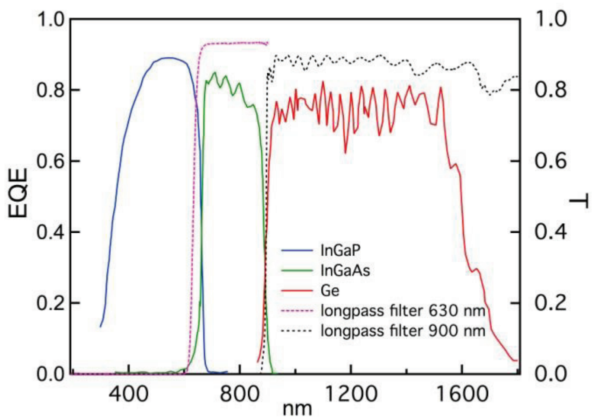

FIGURE 4. The EQE curves of a conventional III-V multijunction cell are compared to the transmissions of the two selected filters. On the vertical axes are reported the cell EQE and the filter transmission scale on the left and on the right, respectively.

In figure 4 the typical External Quantum Efficiency (EQE) curves of the materials that constitute a conventional III-V multijunction cell are compared to the edge of the two selected longpass filters, namely 630 nm and 900 nm, which turn out to be very close to the band gaps of InGaP and InGaAs, respectively.

The DNI measured with and without the longpass filters are reported in figure 5.

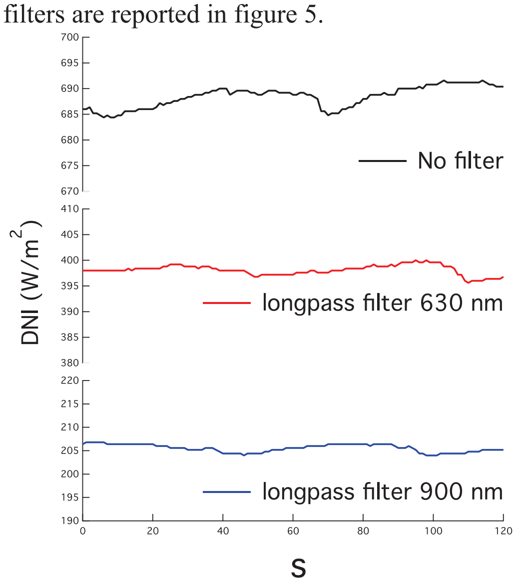

FIGURE 5. DNI acquired in absence (black line) and in presence of the longpass filters at 630 nm (red line) and at 900 nm (blue line).

Starting from these measurements we calculated as differences the DNI of the three spectral regions (<630 nm, 630-900 nm, and >900 nm) corresponding to the EQE curves of figure 4. The summarized results are collected in table 1.

TABLE 1. Measured distribution of DNI in the three spectral regions compared to the calculated distribution from the ASTM G173-03 reference solar spectrum [3]. The error of the measured DNI is ±5 W/m².

Spectral region (nm)	Measured DNI (W/m^2)	Measured DNI %	Reference DNI * %
< 630	288	42	39.4
630-900	192	28	31.3
> 900	206	30	29.3

*Calculated from the Direct and Circumsolar components of ASTM G173-03.

There is a strong dependence of I-V curves on the incident spectrum [4], for this reason it is crucial to compare our values of DNI with the reference spectrum ASTM G173-03 [3], that is customarily used to calibrate the cells.
Table 1 also shows the reference ASTM G173-03 DNI [3] measured at similar latitude and Sun height above the horizon of our facility for each spectral region; these values are customarily used to compare different cells. Since our spectral distribution in terms of DNI is very close to that of the reference spectrum, our system is suitable to perform HCPV components characterization comparable with standard in-lab measurements.

TESTING EQUIPMENT FOR HEAT SINK AND CELL CHARACTERIZATION

A critical parameter in the operation of HCPV modules is the temperature of the cell, which has to dissipate a large fraction of the concentrated power towards an efficient heat sink. We have set-up a testing equipment (fig.6) to characterize the performance of cells and liquid cooled heat sinks as a function of sun concentration, inlet fluid temperature, flow-rate, and pressure drop. Cells are operated under sun concentration (up to 2000 suns) with a circulating fluid (water) at controlled temperature and flow-rate. The cells can be tested using a constant fluid temperature in the range between 20÷90 °C and flow rate in the range 0.003÷0.03 L/s. The chiller is equipped with an on/off thermostat while the heater regulates the temperature of the water with a closed-loop algorithm. To check accurately the temperature of the cell a thin film temperature sensor is placed between the cell and the heat sink [5].

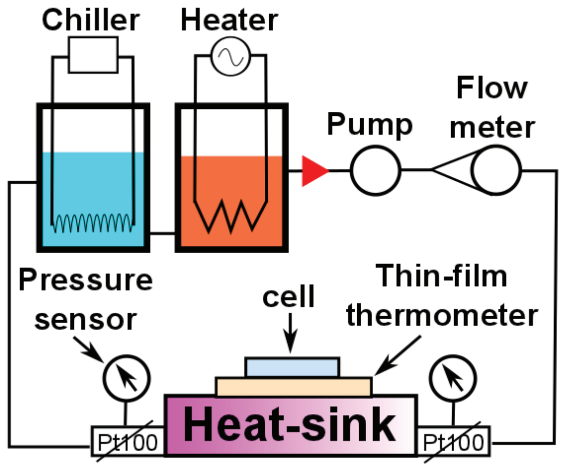

FIGURE 6. Sketch of the device set-up to control the temperature, and flow rate of the cooling liquid in the PV cell heat sink.

The use of this equipment allows to evaluate hybrid systems that recover part of the thermal energy dissipated onto the heat sink.

ELECTRONIC EQUIPMENT FOR CELL CHARACTERIZATION

The HCPV testing facility is also equipped with an electronic load used to analyze I-V curves [6], controlled by a computer, which is also interfaced with PT100 thermometers mounted on the cell and the heat sink, with the pressure sensors, as well as with the pyrheliometer.

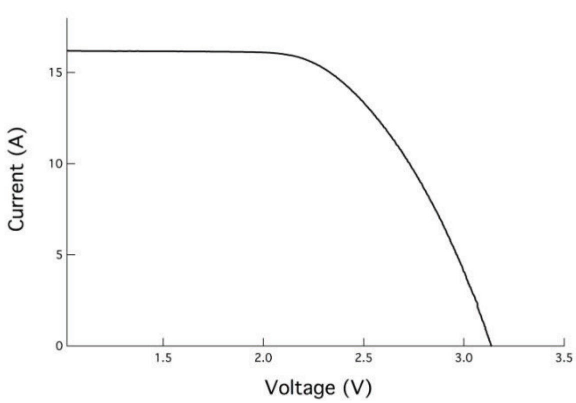

FIGURE 7. Typical I-V characteristic curve of a multijunction cell.

An I-V curve (fig.7) can be acquired using a 300 W programmable DC electronic load, that allows to acquire automatically an I-V curve scanning about 1000 data points in less than 10 ms, with a maximum measured current of 60 A. Figure 7 shows an example of an I-V curve of a III-V multijunction cell at the focus of a 2000 suns reflective concentration module operated with an average DNI of 700 W/m^2 inside our lab.

CLIMATIC CHAMBER

Finally, a climatic chamber Angelantoni model HYGROS - 50 with a test volume of 800mm × 700mm × 892mm, has been refurbished and its control interface upgraded to perform environmental tests on fully assembled HCPV modules. Tests can be performed in a temperature range between -40÷180°C with an uncertainty of ±0.25°C, with an increment of 4°C/min up to 100°C and of 3°C/min up to 180°C, furthermore for the range 5÷95°C the humidity percentage can be set from 10% to 98% with an uncertainty ranging from 1% to 3%.

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