c-Si PV cells emissivity characterization at low operating temperatures for efficiency management

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Abstract. Efficiency is a critical parameter for a solar cell to be successful and is closely related to the working temperature of the cell. In turn, the temperature can be related to the infrared emissivity, the parameter that governs the thermal radiative properties of a body. In particular, the importance of infrared emissivity in a solar cell is essential in passive cooling applications, where controlled radiative thermal losses could let the cell operate at lower temperatures, the range where they present higher efficiency. In this presentation, the emissivity of c-Si solar cells in the low temperature range (around 50 ºC) is discussed. Traditionally, it has been determined by indirect reflectivity measurements at ambient temperature and extrapolated to working temperatures, but here, a direct measurement is proposed. For an accurate value the measurements are performed in the high accuracy radiometer of the University of the Basque Country, which allows spectral directional emissivity measurements as a function of temperature.

1 Introduction

Efficiency is known to be a critical parameter for a solar cell to be successful and is closely related to its temperature and the infrared emissivity. The emissivity is a radiative property of materials that shows how much radiation is emitted by a given body as compared to a blackbody at the same temperature. It describes the capability of a real material surface to emit electromagnetic radiation, mainly in the infrared part of the spectrum. Thus, it is a decisive parameter in the calculation of the radiative thermal losses.

The relevance of infrared emissivity in a solar cell may be considered in multiple applications. On the one side, a high emissivity could be interesting in passive cooling applications, which let the cell operate at lower temperatures, the range where they present higher efficiency [1-3]. On the other side, hybrid systems could require a low emissivity so as to use the heat in the thermal system [4,5]. Both cases involve a precise study of the infrared emissivity value at the operating temperature.

Traditionally, the emissivity has been determined by indirect reflectivity measurements at ambient temperature and then it has been considered constant or extrapolated to working temperatures [6-10], but in addition to this, a direct measurement is here proposed and results are compared.

2 Experimental

The emissivity of a silicon PV cell emissivity is characterized by two methods: the usual reflectivity indirect method and a direct emissivity method. The usual reflectivity method considers the emissivity as 1 minus reflectivity (as transmission in the cell is 0), so that reflectivity is measured at room temperature by means of a commercial integrating sphere and then the emissivity is inferred from it [9]. The direct method, explained below, allows temperature, atmosphere and angular control in the emissivity measurement process.

Our laboratory in the University of the Basque Country in Spain developed a few years ago a hand-made radiometer, HAIRL radiometer, in order to perform direct emissivity measurements at high temperatures [11]. The set up, schemed in Figure 1, allows measuring between 40 and 1000 degrees Celsius in the 0.83-25 µm range and is also capable of doing directional measurements at different angles between 0 and 80 degrees. The samples are heated by radiation and can be measured at vacuum, air or any controlled atmospheres.

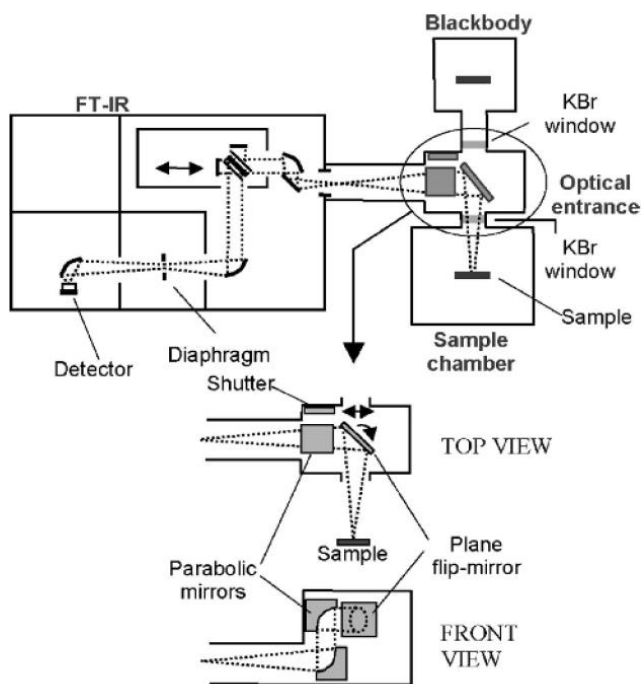* Corresponding author: raquel.fuente@ehu.eus

Fig. 1. Scheme of the HAIRL radiometer

Regarding the sample, a mono-crystalline silicon (mono c-Si) solar cell has been selected for preliminary characterization. It is a NSP NS6ML-1900 cell with an alkaline texturized surface with dark blue silicon nitride anti-reflection coating. Its efficiency is 19 % at standard test conditions (STC, 25 ºC), although the working temperatures are usually around 50ºC [12]. Therefore, measurements will be performed at real working conditions

3 Results and discussion

The c-Si cell mentioned above has been tested by the two cited methods. In Figure 2 the normal spectral emissivity is depicted in a range from 3 to 22 µm. Blue results represent the indirect measurement at room temperature tested by the integrating sphere, while red results correspond to the direct emissivity measurement at around the usual working temperature, 47 ºC.
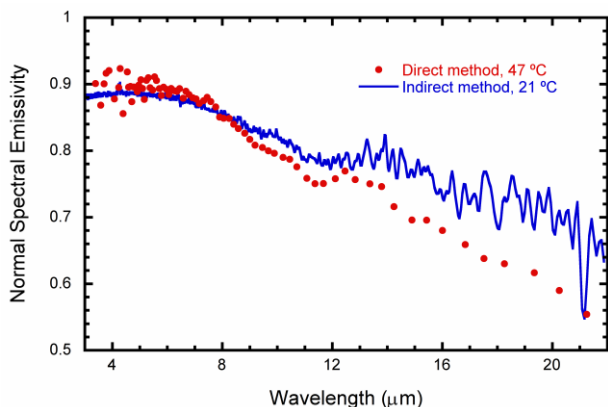

Fig. 2. Comparison between both methods for calculating the emissivity of a c-Si cell

As it can be observed, both methods are in agreement for most of the measured range, showing the differences in the long-wavelength range. Besides, their uncertainty level is different. While the integrating sphere shows a significant error above 12 µm, the direct measurement remains more accurate in the full range.

A significant advantage of the direct method is that it measures the emissivity at working temperature, and thus possible temperature dependences are taken into account. Furthermore, according to an investigation of the standard uncertainty of emissivity measurements [13], the effects of most sources of uncertainty vanish for samples of high emissivity. The only significant source that remains is the uncertainty due to the determination of the surface temperature, which is independent of the sample emissivity. That uncertainty decreases slowly with wavelength from 16% below 4 µm to 10% at 22 µm, which is exactly the opposite trend observed for the noise in the emissivity measured indirectly with an integrating sphere, which has not been quantified. This is especially relevant since most of the thermal radiation at 47 ºC is emitted in the long-wavelength range, with the peak at 9 µm. In particular, 14% of that radiation is emitted at wavelengths longer than those measured in this experiment, with only 0.05% at shorter ones. This means that extrapolations based on direct emissivity data at long wavelengths are intrinsically more precise than those obtained with an integrating sphere.

Finally, integrated total normal emissivity results obtained from these experiments are 0.68 ± 0.07 for the direct measurement and 0.71 ± 0.06 for the indirect one through the integrating sphere. It is worth considering the overestimation of the indirect method if efficiency needs to be controlled. It should be noted that the uncertainties above correspond only to the extrapolation procedure, and the low signal-to-noise ratio of the indirect method has not been taken into account in that calculation.

As a final note, one of the main advantages of the direct method is that it allows directional measurements of the emissivity, while the indirect method can only be used at an angle of 13º. As an approach to more accurate results, hemispherical emissivity measurements are planned to be performed in this sample, as some other works in solar selective coatings suggest the influence of directional emissivity on the total result [14].

4 Conclusions

Emissivity measurements have been performed on a mono-crystaline silicon solar cell at working temperature in order to assist in the radiative heat losses calculation and therefore managing the efficiency by radiative cooling of the cell.

A direct method has been used at working temperature and results have been compared to those obtained by an indirect method based on reflectivity measurements at room temperature.

An overall agreement between both methods has been found, but the difference in the uncertainty level should be noted. Direct emissivity measurements show greater signal-to-noise ratio and their uncertainty is mostly due to errors in sample temperature measurement. In the case of reflectance measurements, however, measurements at long wavelengths are much noisier and less repeatable. Besides, a slight overestimation in the total emissivity value has resulted from the indirect method.

It can be seen from this comparison that both methods are valid for measuring the emissivity of PV cells, although the direct method is intrinsically more precise. Besides, it allows directional measurements for proper calculation of the total hemispherical emissivity, which is the property that accounts for the thermal radiation emitted by the sample at all wavelengths and angles.

Although the error is not vital, if an accurate value is demanded for a precise determination of the efficiency, the direct emissivity measurement at real working temperature is recommended.

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