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Air mass effect on the performance of organic solar cells

A. Guechi[1*], M. Chegaar[2] and M. Aillerie[3,4, #]

[1]*Institute of Optics and Precision Mechanics, Ferhat Abbas University, 19000, Setif, Algeria*
[2]*L.O.C, Department of Physics, Faculty of Sciences, Ferhat Abbas University, 19000, Setif, Algeria*
Email : ab_guechi@yahoo.fr, chegaar@yahoo.fr
[3]*Lorraine University, LMOPS-EA 4423, 57070 Metz, France*
[4]*Supelec, LMOPS, 57070 Metz, France*
[#]*Email: aillerie@metz.supelec.fr*

Abstract

The objective of this study is to evaluate the effect of variations in global and diffuse solar spectral distribution due to the variation of air mass on the performance of two types of solar cells, DPB (etraphenyl–dibenzo–periflanthene) and CuPc (Copper-Phthalocyanine) using the spectral irradiance model for clear skies, SMARTS2, over typical rural environment in Setif. Air mass can reduce the sunlight reaching a solar cell and thereby cause a reduction in the electrical current, fill factor, open circuit voltage and efficiency. The results indicate that this atmospheric parameter causes different effects on the electrical current produced by DPB and CuPc solar cells. In addition, air mass reduces the current of the DPB and CuPc cells by 82.34% and 83.07 % respectively under global radiation. However these reductions are 37.85 % and 38.06%, for DPB and CuPc cells respectively under diffuse solar radiation. The efficiency decreases with increasing air mass for both DPB and CuPc solar cells.

Keywords: Organic solar cells, efficiency, air mass, solar irradiance, SMARTS model.

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1. Introduction

Thin film solar cells using inorganic and organic active layers are of increasing interest for solar energy researchers. The development of organic photovoltaics in the beginning of the 21st century succeeded to date in power conversion efficiencies for organic solar cells of 4–6% [1]. Organic solar cells based on low molecular weight and polymeric semiconducting materials have received considerable attention due

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[*] Corresponding author. *E-mail address:* ab_guechi@yahoo.fr.

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to their attractive advantages such as flexibility and large-area and less material usage and thus can be of potentially low cost and roll-to-roll techniques that are applied to produce the organic photovoltaic devices in large area [2-3]. The choice of organic semiconductors materials [4], organic film morphology [5], and film thickness [6] is critical to improve organic photovoltaic cells performance. However, in organic photovoltaic devices, the contact between the organic materials and the electrodes is also a challenge since it strongly affects the charge-collection properties of the devices. Contrary to the case of silicon semiconductor, it is difficult to realize a good ohmic contact between an electrode and an organic semiconductor by heavy doping and their contact usually forms a direct electrode-semiconductor junction if organic semiconductor is not doped [5].

Nomenclature

Albd	albedo
AM	air mass
$E(\lambda)$	diffuse or global irradiance
FF	fill factor
I_s	saturation current (A)
I_{sc}	short circuit current (mA)
J_{sc}	short circuit density (mA/cm^2)
n	ideality factor
P_i	incident irradiation (W/m^2)
S	area (cm^2)
SMARTS	Simple Model of Atmospheric Radiative Transfer of Sunshine
$SR(\lambda)$	spectral response
STC	standard testing conditions
Turb	turbidity
V_{oc}	open circuit voltage (V)
WV	water vapor (cm)
η	conversion efficiency

Organic devices are still in a research phase and they exhibit a better response at low irradiance levels, under diffuse radiation conditions [7] and also seem to have sensitivity to the solar spectral variation. It is well known that the solar spectrum varies according to the time of the day, the season and the weather conditions.

Manufacturers report photovoltaic module power output at standard testing conditions (STC), which correspond to 1000W/m^2, 25°C, air mass 1.5 and normal incidence. In real operating conditions however, the module output is strongly affected by various environmental conditions such as irradiance, temperature, spectral effects. Furthermore the impact of each climatic factor on the energy production varies according to the module technology in use [8].

The performance of solar cells is influenced by the solar radiation at ground level that is not only place and time dependent but also varies in intensity and spectrum due to varying atmospheric parameters as turbidity, water vapor and air mass. Due to natural spectral sensitivity of solar cell devices, the solar spectrum is one of those factors that may strongly influence the module's performance since the solar spectrum depends on the Sun's actual altitude and declination.

Sunlight is attenuated as it passes through the Earth's atmosphere toward its surface because gas molecules and aerosol particles in the atmosphere absorb and scatter some of the Sun's rays. Since there are virtually no gas molecules or aerosols in space between the Sun and the top of the Earth's atmosphere, there is essentially no attenuation of sunlight above the top of the atmosphere. The path a sunray travels through the atmosphere, i.e. the air mass, directly affects the amount of attenuation.

The aim of this study is to evaluate the effect of changes in spectral distribution of global and diffuse irradiation due to the variation of the air mass on the performance of two kinds of organic solar cells (DPB and CuPc). The components of the solar irradiance striking these solar cells are estimated using the spectral irradiance model for clear skies SMARTS2. The variation of the common parameters namely short circuit current, fill factor, open circuit voltage and efficiency are shown and discussed.

2. Calculation Procedure

Accurate predictions of incident solar radiation are necessary in many different disciplines, not just solar energy applications. Even though it is relatively easy to evaluate irradiances with appropriate broadband radiation models, spectral models provide considerably more flexibility, and normally better accuracy because of the more physical nature of their modeling. In many spectrum dependent applications, they even are the only resource. A number of spectral radiative models have been described or used in the literature, and some of them are reviewed elsewhere [9-11]. However, most of the existing models are designed to perform specific tasks and can hardly be tailored for completely different applications. One of the purposes of the SMARTS code [11] is precisely to be as versatile as possible and therefore to address a variety of both spectra and broadband applications, through the use of its different options. More specialized tasks are obviously possible by further manipulating the spectral output of the code. This irradiance details many possible applications for which a spectral model can provide the necessary information.

The model adopted here is the widely used SMARTS2 model for clear skies developed by Gueymard [12]. In the last few years SMARTS model [12-14] has gained acceptance in both the atmospheric and engineering fields due to its versatility, execution speed, low number of inputs and ease of use. This model can advantageously be used to predict clear-sky irradiance spectra on surfaces of any tilt and orientation. It can calculate punctual estimations of spectral irradiances using as input parameters local geographic coordinates, atmospheric pressure, atmospheric water vapor content, and aerosol optical thickness. Provided that the most important inputs are known with sufficient accuracy, it is concluded that the model performance is very high when compared to reference model [15]. SMARTS2 is used here to generate the different component solar spectra for the site of Setif (36.11° N, 5.41°E and 1081m) under different conditions.

The short circuit current density *Jsc* of a device, is directly related to the irradiation can be calculated as:

$$J_{sc} = \int E(\lambda)\, SR(\lambda)\, d\lambda \qquad (1)$$

Where E (λ) is the energy of the incident light and SR (λ) is the spectral response at the given wavelength. FF is the fill factor and is determined as [16]:

$$FF = \frac{v_{oc} - \ln\left(v_{oc} + 0.72\right)}{v_{oc} + 1} \tag{2}$$

Where: $$v_{oc} = \frac{V_{oc}}{n\left(\frac{kT}{q}\right)} \tag{3}$$

The open circuit voltage is calculated using:

$$V_{oc} = n\frac{kT}{q}\ln\left(\frac{I_{ph}}{I_{s}} + 1\right) \tag{4}$$

The ideality factor "n ", and the saturation current, Is, are computed from the I-V characteristics [17]. The fill factor and the conversion efficiency η of the solar cell are linked through:

$$\eta = FF\,\frac{V_{oc}\,I_{sc}}{P_i\;S} \tag{5}$$

Where: V_{oc} is the open circuit voltage, I_{sc} is the short circuit current, S is the solar cell area, and P_i is the total irradiance in W/m^2 and is given by:

$$P_i = \int_0^{\infty} E(\lambda)\,d\lambda \tag{6}$$

E (λ) is the spectral irradiance.

Fig.1 shows the measured spectral response of DPB and CuPc solar cells considered in this work.

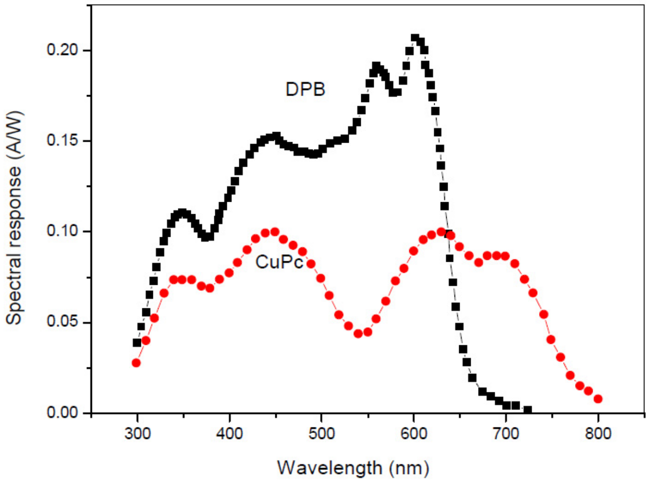

Fig.1. Spectral response of and CuPc and DPB solar cells [18]

3. Results and discussion

The components of the spectral solar irradiance are calculated at Setif on horizontal surface by varying one environmental parameter and maintaining the others fixed, using SMARTS. Then for each component of the solar irradiation, we calculate the short circuit current, the open circuit voltage, the fill factor and the conversion efficiency of the DPB and CuPc solar cells.

3.1. Diffuse solar irradiance

Fig.2 presents the diffuse spectral irradiance at Setif as a function of air mass. When the air mass increases, the solar irradiance peak shifts toward longer wavelengths because more radiation of shorter wavelengths is attenuated due to Rayleigh scattering.

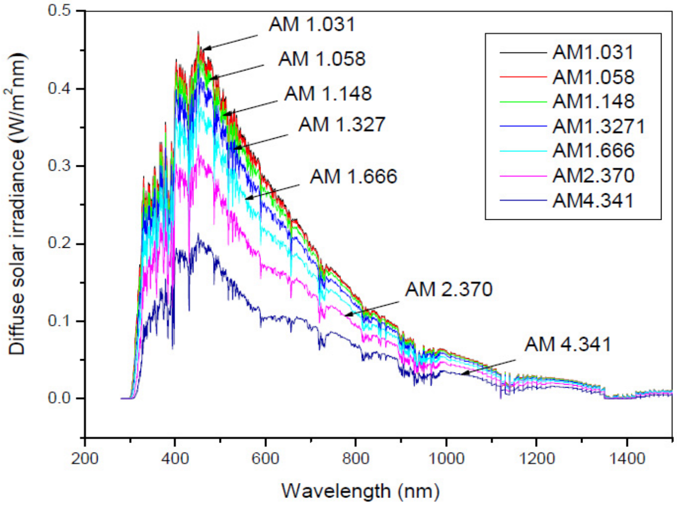

Fig.2. Diffuse spectral irradiance as function of wavelength for different values of the air mass

Increasing air mass reduces the available irradiance and consequently the short circuit current. These reductions are 82.34% and 83.07 % respectively for DPB and CuPc cells when the air mass increases from AM= 1.031 to AM = 4.431. A general summary of the variation of the short current, open circuit voltage and fill factor as function of the air mass are illustrated in Table 1. Fig.3 illustrates the effect of air mass variation on the efficiency of the solar cell. The efficiency decreases with increasing air mass.

Table 1. Effect of the air mass on the DPB and CuPc solar cells parameters under diffuse solar irradiance

AIR MASS	J_{SC} (mA/cm²)		V_{OC} (V)		FF	
	DPB	CuPc	DPB	CuPc	DPB	CuPc
1.031	1.481	1.020	0.746	0.445	0.592	0.668
1.058	1.466	1.090	0.744	0.444	0.591	0.667
1.148	1.418	0.975	0.740	0.442	0.590	0.666
1.327	1.332	0.914	0.733	0.439	0.588	0.664
1.666	1.197	0.881	0.720	0.433	0.584	0.662
2.370	0.984	0.668	0.696	0.423	0.576	0.657

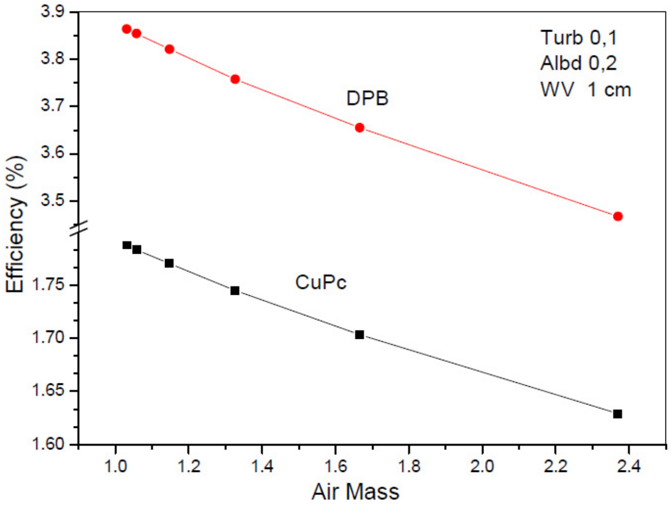

Fig.3. Conversion efficiency of the DPB and CuPc solar cells as function of air mass under diffuse solar irradiance

3.2. Global solar irradiance

The global spectral irradiance as function of different values of air mass is shown in Fig.4. In this figure an increase in air mass reduces the global solar irradiance.

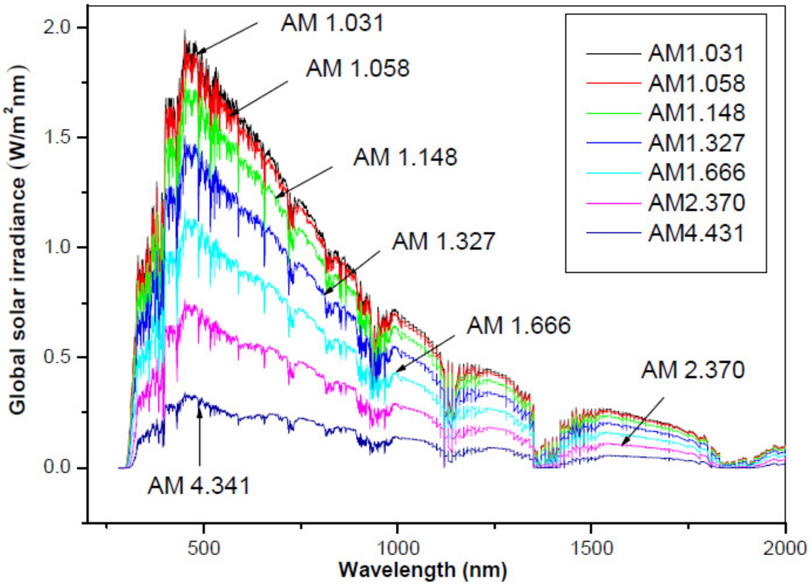

Fig.4. Global spectral irradiance as function of wavelength for different values of the air mass

The variation of the short current open circuit voltage and fill factor as function of the air mass are illustrated in Table 2. The short circuit current decreases with increasing the air mass. These reductions are 37.85 % and 38.06% respectively for DPB and CuPc cells when the air mass increases from AM=1.031 to AM=4.431. The efficiency decreases with increasing air mass. This is illustrated in Fig.5.

Table 2. Effect of the air mass on the DPB and CuPc solar cells parameters under global solar irradiance

AIR MASS	J_{SC} (mA/cm²)		V_{OC} (V)		FF	
	DPB	CuPc	DPB	CuPc	DPB	CuPc
1.031	6.325	4.340	0.920	0.518	0.6387	0.6977
1.058	6.145	4.215	0.917	0.516	0.6379	0.6972
1.148	5.611	3.846	0.906	0.512	0.6353	0.6954
1.327	4.760	3.258	0.886	0.503	0.6305	0.6922
1.666	3.649	2.491	0.854	0.490	0.6225	0.6869
2.370	2.365	1.605	0.802	0.467	0.6086	0.6777

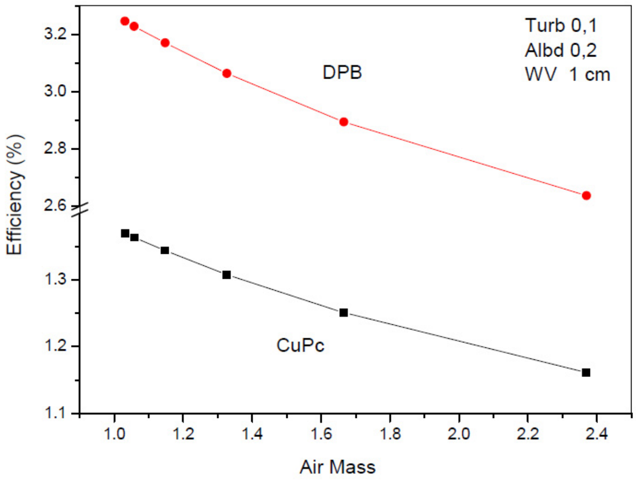

Fig.5. Conversion efficiency of the DPB and CuPc solar cells as function of air mass under global solar irradiance

4. Conclusion

The purpose of this work was to know how DPB and CuPc solar cells perform under possible diffuse and global solar spectrum variations due to the variation of the air mass using the spectral irradiance model for clear skies on the specified site. The results show that the short circuit current and the efficiency decrease with increasing air mass for both organic solar cells but to different extents. The open circuit voltage and the fill factor are slightly influenced. From this analysis, we conclude that the air mass has a significant influence on the overall performance of the examined solar cells and CuPc perform better than DPB solar cells under increasing air mass.

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