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Effect of Dust Deposition on the Performance of Thin Film Solar Cell

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***Abstract*—The effect of dust on the performances of the thin-film solar cell CZTS (Cu_2ZnSnS_4) was investigated. With the use of the spectrophotometric measuring instrument, an experimental study was made on one piece of glass of 10X10 cm^2 with different levels of deposited dust (soil) , it will allow to estimate the resulting solar spectrum affected by the dust deposed on the piece of the glass, the affected spectrum by the dust deposition is used as an input spectrum for solar cell simulator SCAPS-1D (Solar Capacitance simulator in one dimension), the obtained results showed that when the accumulation of the dust increased on the solar cells surface, the short current density and the maximum power of the solar cells was affected strongly.**

***Index Terms*—Dust; SCAPS-1D; Solar cells; CZTS.**

I. INTRODUCTION

The importance of the energy in our society became obvious during the last years. Among the different alternative energies, the solar energy has the very desirable property to be essentially unlimited and not to be polluting nor physically dangerous [1]. With the various applications of the photovoltaic solar energy in the terrestrial and spatial fields, the improvement of the conversion efficiency of the cells solar becomes indispensable with their outdoor work environment.

The main parameters affecting the energy production of the photovoltaic (PV) module during its operation in outdoor installations are: Humidity rate, wind speed, Intensity of illumination, operating temperature and the soiling [2].

Recently, the study of the dust effect on the energy yield of PV modules is becoming one of the topical issue in field of renewable energy [3]–[5] due to the evolution of the PV module manufacturing technology (Si monocrystalline, Si amorphous, thin layer). Also, the need to make installation in various sites which implies different deposited dust types.

The adaptation between the various types of PV modules technologies and the environments of their installation sites requires making pilot installations in the desired site in order to be able to choose the best type of modules that it fits well with this site, this will take a long time of examination and will imply an increase in the rate of investment. The study of the dust effect with numerical simulation will save time and minimize the investment rate of PV central.

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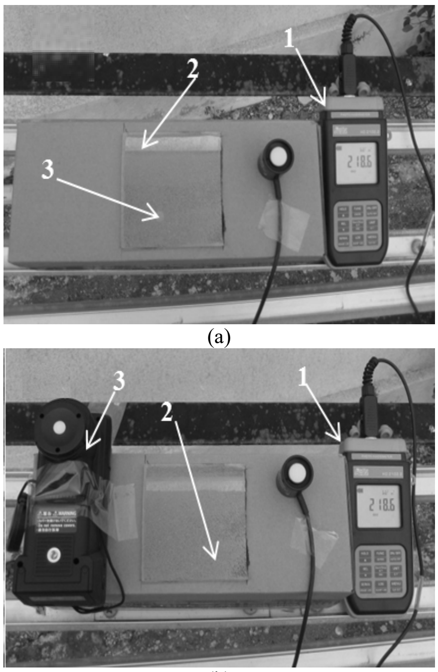
In this paper, we propose a numerical simulation based on experimental results of calculated solar spectrum allowing us to study the effect of dust on the solar cells, from calculated solar spectrum resulting from the forced dust deposition on a piece of glass, a numerical simulation is done on CZTS solar cell and other solar cells like CIGS and a-Si to choose the best technology adapted to the dusty environment.

II. EXPERIMENTS

In order to simulated the effect of the dust on the solar cells, a preliminary experimental study must be done to calculate the solar spectrum under a dusty glass, A piece of glass with surface of 10x10 cm^2 and 3 mm of thickness is used as sample bearer of the dust studied. The solar spectrum is calculated for different densities of deposited dust, the experimentally calculated spectrum is introduced as an input solar spectrum for SCAPS-1D solar simulator.

The outdoor test bench used for this experiment is shown in Fig. 1.



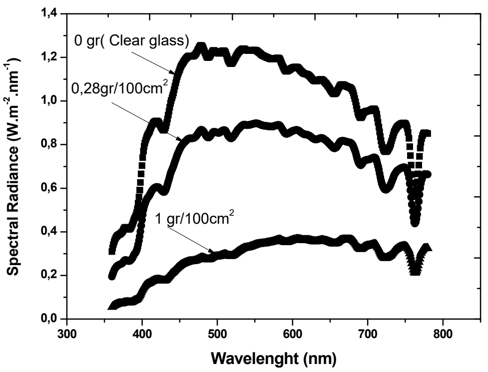
(b)

Fig. 1. Outdoor test bench for solar spectrum measurement of dusty glass: (a) spectrophotometer after the glass; (b) spectrophotometer before the glass. 1 – radiometer LP 471 RAD; 2 – dusty glass CL500A; 3 – spectrophotometer.

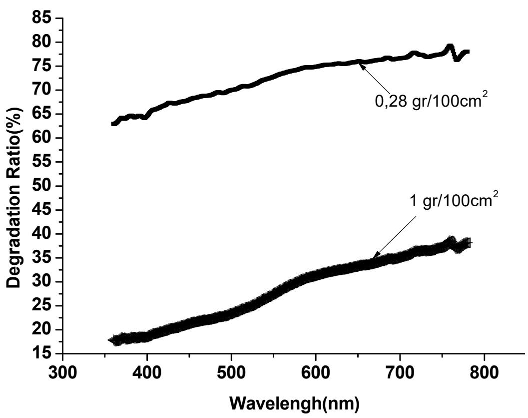
It consists of a mechanical structure bearing the sample of glass to be tested oriented to the south and tilted 37° to obtain maximum irradiation of the solar spectrum with respect to our position's latitude (Tipaza-Algeria), a spectrophotometer CL500A is used to plot the solar spectrum resulting from the deposited dust on the glass (measured light spectrum varies from 360 to 780 nm). In addition, a Radiometer LP 471 is used to calculate the solar irradiation of the solar spectrum (number of watt by meter square; W/m^2). The dust is deposited uniformly on the glass by an air compressor. The type of dust deposited is soil, it is characterized by its grain size there varies between [100-300 µm] [6], [7].

A. Result and Discussion

Figure 2(a) shows the results of the experimental measurements representing the variation of the solar spectrum in function of the dust density. The dust density is defined as the ratio between the dust's weight and the glass area, and Fig. 2(b) demonstrates that the degradation of solar spectrum increases in accordance to the wavelength. Figure 2(c) shows the variation of solar spectrum irradiation (W/m^2) as a function of dust density, the decrease in solar irradiance became linear with the increase in the deposited dust density, a losses coefficient of (-87.81) is calculated. Figure 3 presents the transmission coefficient of the clean glass used in this experiment; it is calculated by the ratio between the solar spectrum on the backside of the glass and the solar spectrum on the front side of the glass, this coefficient permitted to estimate the reflection losses by 7%. The sets of these results obtained in this section are used as input data file in the simulation part with SCAPS-1D solar simulator.



(a)



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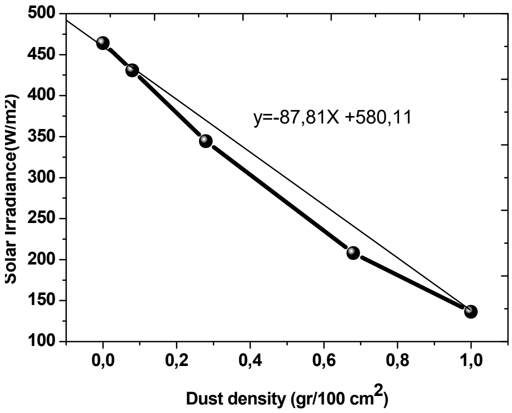


(c)

Fig. 2. Effect of dust density on the solar spectrum and irradiance: (a) effect of dust on the solar spectrum; (b) rate of solar spectrum degradation due dust deposition variation; (c) effect of dust on the solar irradiance.

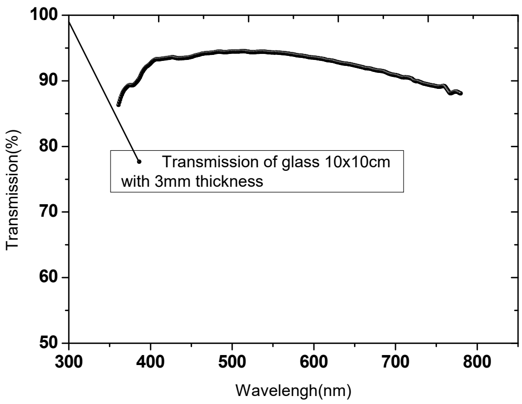


Fig. 3. Transmission coefficient of clean glass sample.

III. SIMULATION

The cell is composed with a Window layer represented by Transparent Conductive Oxide (ZnO), Buffer layer represented by (CdS) material and finally the absorber layer represented with CZTS material. The main parameters of CZTS/CdS/ZnO solar cell used in the simulation are shown in Tables 1. Solar cell characteristics were assessed using the one dimensional numerical simulator SCAPS1-D Edition 2.9.4, it is developed for modelling solar cell structures of the CIGS, $CuInSe_2$ and the CdTe family [8], with this simulator the user have the possibility to change or modify the input solar spectrum.

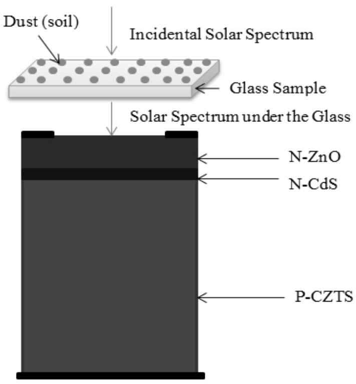


Fig. 4. Structure of the CZTS/CdS/ZnO solar cell used in simulation with dusty glass.

TABLE I. MAIN PARAMETERS OF THE CZTS/CDS/ZNO SOLAR CELL USED IN THE SIMULATION [9], [10].

Semiconductor parameter's	ZnO	CdS	CZTS
Layer thickness (μm)	0.2	0.05	2.68
Band gap (eV)	3.3	2.4 [4, 2]	1.5
Dielectric permittivity (relative)	9	10[4], 9[2]	10
Electron mobility (cm²/Vs)	100	100[4], 350[2]	100
Hole mobility (cm²/Vs)	25	25[4], 50[2]	25
N_C effective density of states (1/cm^3)	2.2E18	2.2E18[4], 1.8E19[2]	2.2E18
N_V effective density of states (1/cm^3)	1.8E19	1.8E19 [4], 2.4E18[2]	1.8E19
Absorption coefficient (cm-1)	SCAPS data	SCAPS data	2.5E4

The mathematical model of solar cell is given by the following equations

$$J_{SC} = J_L - J_{01}\left[exp\left(\frac{q(V+JR_S)}{AK_BT}\right)-1\right] - $$

$$-J_{02}\left[exp\left(\frac{q(V+JR_S)}{A'K_BT}\right)-1\right]-\left(\frac{(V+JR_S)}{R_{Sh}}\right), \quad (1)$$

where J_{SC} is the short circuit current, T is the absolute temperature in Kelvin, J_L is the light-generated current, J_{01} and J_{02} are the two saturation current densities, A and A' are the ideality factors of these diodes, R_s and R_{sh} are respectively a series and some shunt resistances.

The open circuit voltage is given by

$$V_{OC} = \frac{AK_BT}{q} ln\left[1 + {}^{J_L}/_{J_0}\right], \quad (2)$$

where J_0 is the dark current density.

The efficiency of a photovoltaic solar cell is defined as the ratio of the maximum electrical power output P_{MAX}, compared to the solar optical power input

$$\eta = {}^{Pmax}/_{Pin}, \quad (3)$$

where P_{in} is taken as the product of the irradiance of the incident light and the surface area of the solar cell, measured in W/m^2 or in suns (1000 W/m^2),

$$P_{max} = FF \times Voc \times Jsc, \quad (4)$$

where FF represents the file factor; it determines losses within the solar cell. This factor allows optimization of the solar cells performances.

Under condition of a different illumination, caused with a uniform shadow represented by uniformed distribution of the dust on the solar panel or by Cloudy skies, the short circuit current of the solar cell J_{SC} is varied proportionally with the illumination (J_{SC} = k×F) (where k is a constant and F the luminous flux). In this paper we present the case of the uniform deposition of the dust on the solar cell which is the objective of this paper.

A. Result and Discussion

First, CZTS solar cell is simulated under Standard Test Condition (STC); ambient temperature of 300°K and solar irradiance of 1000 W/m^2 (AM1.5G spectrum), Fig. 5 presents the simulation curves of J-V and PV for CZTS solar cell under standard test conditions. To study the behavior of CZTS solar cells in a dusty environment, we use the obtained results of local solar spectrum calculated in the experimental part, this data is used as an input spectrum in Scaps-1D simulator. The obtained simulation result with varied dust density are shown in Fig. 6.

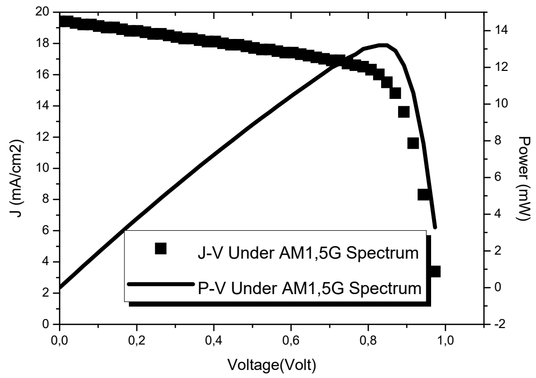
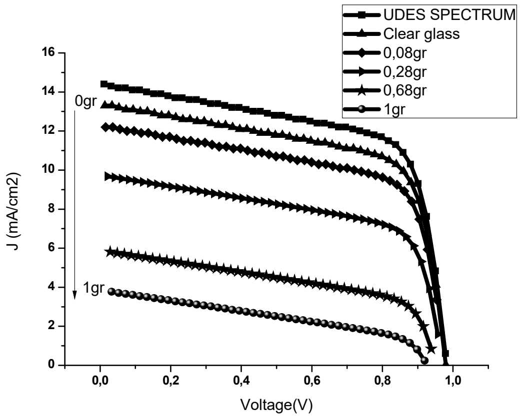
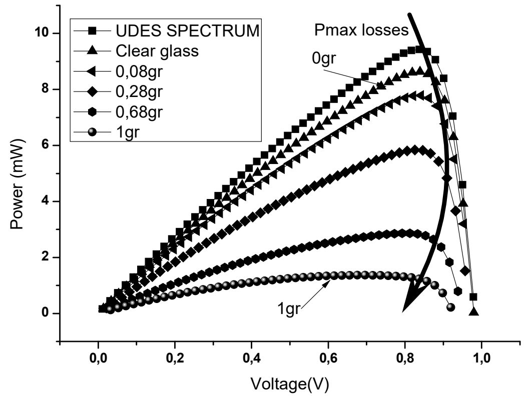


Fig. 5. J-V and P-V characteristics of CZTS/CdS/ZnO solar cell in standard test condition.



(a)



(b)

Fig. 6. SCAPS-1D Simulation results of CZTS/CdS/ZnO solar cell with different dust density levels: (a) J-V characteristic; (b) P-V characteristic.

Figure 6 shows, that with the increase of dust density levels the short circuit-current and the maximum power of the CZTS solar cell are affected strongly, on the other hand, the voltage is affected slightly by the variation of the dust density, these results are explained by the diminution of the solar spectrum due to the uniform deposition of the dust which is in accordance with the results obtained in Fig 2 and the experimental works done on the PV module refereed in [11]–[13].

Table 2 summarize the effect of the dust deposition on open circuit voltage, short current and maximum power of CZTS solar cells with, it is noticed that with the increase of the dust density more than 0.28 gr/100cm^2, the variation in J_{sc} and P_{max} becomes noticeable, which a relative reduction in maximum power down to 60% is corresponding. This result is confirmed by experimental works done on photovoltaics panels; Appels et al., [14].

TABLE II. DUST EFFECT ON CZTS SOLAR CELL PERFORMANCES.

Dust weight	0gr	0.08gr	0.28gr	0.68gr	1gr
V_{OC}	0.980	0.977	0.969	0.949	0.925
J_{SC}	13.362	12.264	9.740	5.884	3.843
P_{MAX}	8.632	7.782	5.835	2.930	1.364

B. Comparative Study

In order to compare the behavior of CZTS solar cell with other existing solar cell under dusty environment, a comparative study is done between CZTS solar cell and two other cells CIGS and a-Si. Figure 7 presents the variation of normalized power as function of the deposited dust density.

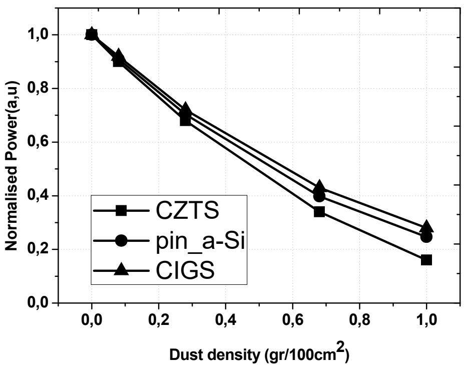


Fig. 7. Effect of dust on the normalized power of solar cells.

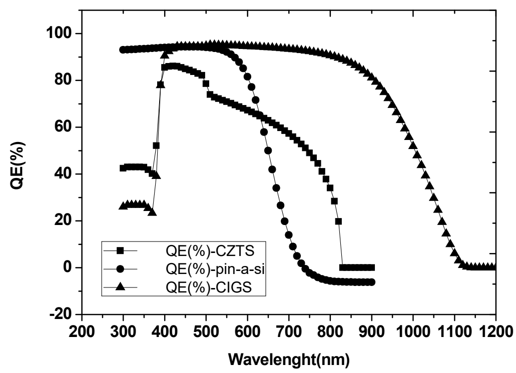


Fig. 8. Quantum Efficiency of CIGS, CZTS and a-Si solar cells.

The results show that the CZTS solar cell presents the lowest performances in comparison with a-Si and CIGS solar cells. For CIGS and a-Si solar cells the obtained results are in accordance with those obtained by Russell et al., [15], this team demonstrated experimentally that CIGS PV modules have good behavior in dusty environment in comparison with a-Si. This result is explained by the good crystallographic orientation of CIGS solar cell in comparison with the other cell. In addition, CIGS solar cells have large quantum efficiency in comparison with a-Si and CZTS solar cells, observed on the solar spectrum in the range between 380 and 780 nm (Fig. 8).

IV. CONCLUSIONS

In this work, a new method for study the effect of the dust on the solar cells was proposed, to estimate the effect of the dust on the solar spectrum an experimental study was done on a glass plate, the reflection losses of the glass plat is estimated by 7%. Also, the decrease in solar irradiance affected by the dust is calculated, it varied linear with the increase in the density of deposited dust, the losses coefficient of solar irradiance is estimated to (-87.81). The simulation of CZTS solar cell in dusty environment was done based on the obtained solar spectrum affected by dust deposition on the glass plate. The obtained results show a strong degradation in the density of the current and the maximum power of the CZTS solar cell, the increase of the dust density more than 0.28gr/100cm^2, makes the variation in J_{sc} and P_{max} noticeable, which gives a relative reduction in maximum power down to 60%. A comparative study demonstrates that the CZTS solar cell have lower performance with dusty environment in comparison with CIGS and a-Si.

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