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Modelling and Simulation of the Temperature Effect in Dye Sensitized Solar Cells

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ABSTRACT

The effect of temperature on Dye Sensitized Solar Cells (DSSCs) is an important parameter, as temperature effect on the performance of solar cells. In our work we have studied this effect based on a diffusion model defined in the literature. This model is based on the electron diffusion in a porous semiconductor (TiO_2) thin film. Our results show that temperature has an effect on the open circuit voltage, the power and the energy conversion efficiency.

Keywords: Dye sensitized solar cells, TiO_2, Diffusion, Simulation, Temperature

INTRODUCTION

Solar energy is one of the solutions for a sustainable and ecological development; it helps to brake massive exploitation of fossil fuels [1]. Traditional solar cells are performing efficiency but the method of production is laborious and expensive, therefore their application is limited [2,3]. While many studies have been achieved to produce solar cells with low cost and high efficiency such as Dye Sensitized Solar Cells (DSSCs) [4]. The first DSSCs was produced by O'Regan and Grätzel [5], a record energy conversion efficiency of DSSCs is 14.7% [6]. Over the past two decades, many research focus in new DSSCs materials and theoretical modeling for understanding the basic working mechanisms [7-22].

A mathematical model has developed in the steady-state based on the electron diffusion in a porous semiconductor (TiO_2) thin film to obtain an explicit expression for the photocurrent [23], this model allowed to understand the mechanism of DSSCs. Many authors have used this model [24,25], to study the variation of open-circuit photo voltage with the film thickness and the light intensity; and the effect of electrode thickness on maximum power point. The effect of temperature has not cited in the literature based on the diffusion model, some studies have made experimental research to determine the effect of temperature and found that the conversion efficiency increases with increasing of the temperature [26], other research indicated that that the energy conversion of cell remains practically constant with a small variation [27]. In this study, we present a simple theoretical modeling of the temperature effect in dye sensitized solar cells based on the differential equation [23-25].

The model

We did this study under a steady-state condition of an irradiated DSSCs, the injected electron in the excited dye molecules, flows in the porous semiconductor (TiO_2) thin film, and recombines with the electrolyte at the TiO_2/electrolyte interface. The processus is described by the following diffusion differential equation [23,24,28]:

$$D\frac{\partial^2 n(x)}{\partial x^2} - \frac{n(x)-n_0}{\tau} + \phi\alpha e^{-\alpha x} = 0 \quad (1)$$

Where, n(x) is the excess concentration of the photo generated electrons at position within the film measured from the TiO_2/transparent conducting oxide (TCO) interface, n_0 is the concentration of electrons under equilibrium conditions in dark ($n_0=10^{16}$ cm^{-3}) [29,30], τ is the conduction band free electrons life time (τ=10 ms) [24,31], D is the diffusion coefficient of electrons ($D=5 \times 10^{-4}$ $cm^2.s^{-1}$) [25], Φ is the light intensity($\Phi=1 \times 10^{17}$ $cm^{-2}.s^{-1}$) [24,32] and α is the light absorption coefficient of the porous film (α=5000 cm^{-1}) [24,32].

The possibility of trapping-detrapping of electrons was not taken into consideration in equation (1) because it is only important under non-steady-state conditions [33]. Under short-circuit conditions, electrons are easily extracted as photocurrent and none of the electrons are drawn directly on the counter electrode. Therefore, the two boundary conditions are:

$$n(0) = n_0 \qquad (2)$$

$$\left(\frac{dn}{dx}\right)_{x=d} = 0 \qquad (3)$$

Where, d is the thin film electrode thickness. The short-circuit current density J_{SC} can thus be obtained as:

$$J_{SC} = \frac{q\phi L\alpha}{1 - L^2\alpha^2}\left[-L\alpha + \tanh\left(\frac{d}{L}\right) + \frac{L\alpha e^{-d\alpha}}{\cosh\left(\frac{d}{L}\right)}\right] \qquad (4)$$

Where, q is the charge of an electron equal to 1.60218×10^{-19} C and L is the electron diffusion length given by:

$$L = \sqrt{D\tau} \qquad (5)$$

If the DSSCs operates under a potential difference V between the Fermi level of the (TiO_2) and the redox potential of the electrolyte, the density of the electrons at the TiO_2/T CO interface (x = 0) increases to n giving a new boundary condition:

$$n(0) = n \qquad (6)$$

Another boundary condition at x=d remains unchanged as shown in (3). Solving (1) yields give us the relationship between J and V.

$$V = \frac{KTm}{q}\ln\left[\frac{L(J_{SC} - J)}{qDn_0 \tanh\left(\frac{d}{L}\right)} + 1\right] \qquad (7)$$

Where K is the Boltzmann constant equal to 1.38066×10^{-23} $J.K^{-1}$; m is the ideality factor equal to 4.5 [24,32].

RESULTS AND DISCUSSION

Photovoltaic conversion is a highly energy dependent application of temperature. In terrestrial applications, solar cells are generally exposed to temperatures of operation ranging from 283.15 K to 328.15 K. The parameters characteristic of the solar cell, namely the short-circuit current density J_{SC}, the open circuit voltage V_{OC} and the energy conversion efficiency η are influenced by the temperature. To study the dependence of these parameters with temperature, we use the value of light intensity 1×10^{17} $cm^{-2}.s^{-1}$ represents 1 sun condition 1000 Wm^{-2} [24-32].

The J-V characteristics of the DSSCs under different temperature and various thin film electrode thicknesses are plotted in Figure 1, the variation of the temperature affect the photocurrent density J and the voltage V.

As presented the temperature increase causes an increase in the photocurrent density J and the voltage V, different thicknesses provide different values, the thickness 1 µm provide a maximum value of voltage V of a temperature corresponding to 343.15 K. The thickness 10 µm has the maximum value of the short-circuit current density. The simulation result also shows that the voltage V increases with the decrease of the thin film electrode thicknesses of the cell, this effect could be due to the concentration of electrons [24].

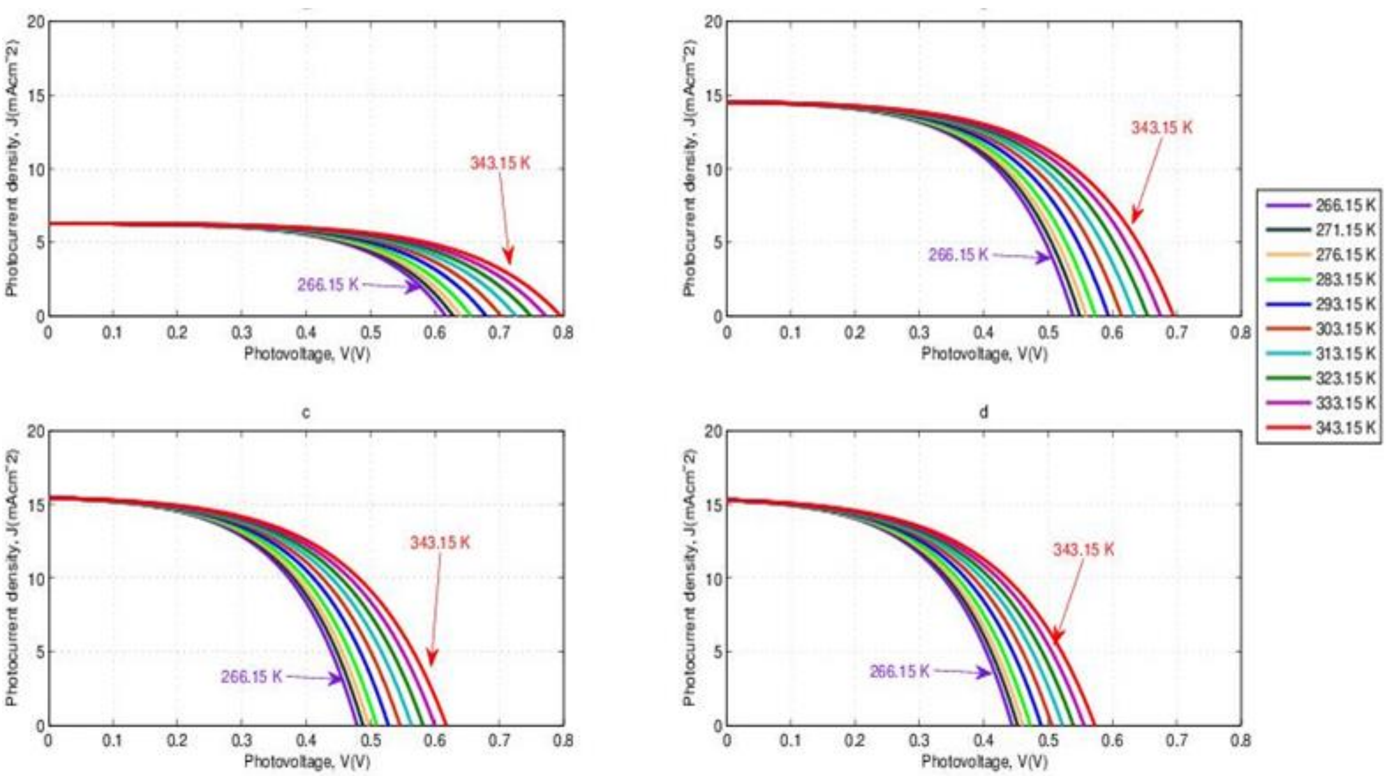

Figure 1: Variation of the DSSCs J-V characteristics under different temperature and various thin film electrode thicknesses: (a) 1 µm, (b) 5 µm, (c) 10 µm and (d) 15 µm

Power characteristics in function of the voltage are shown in the Figure 2, the results show that when the temperature increases the power also increases.

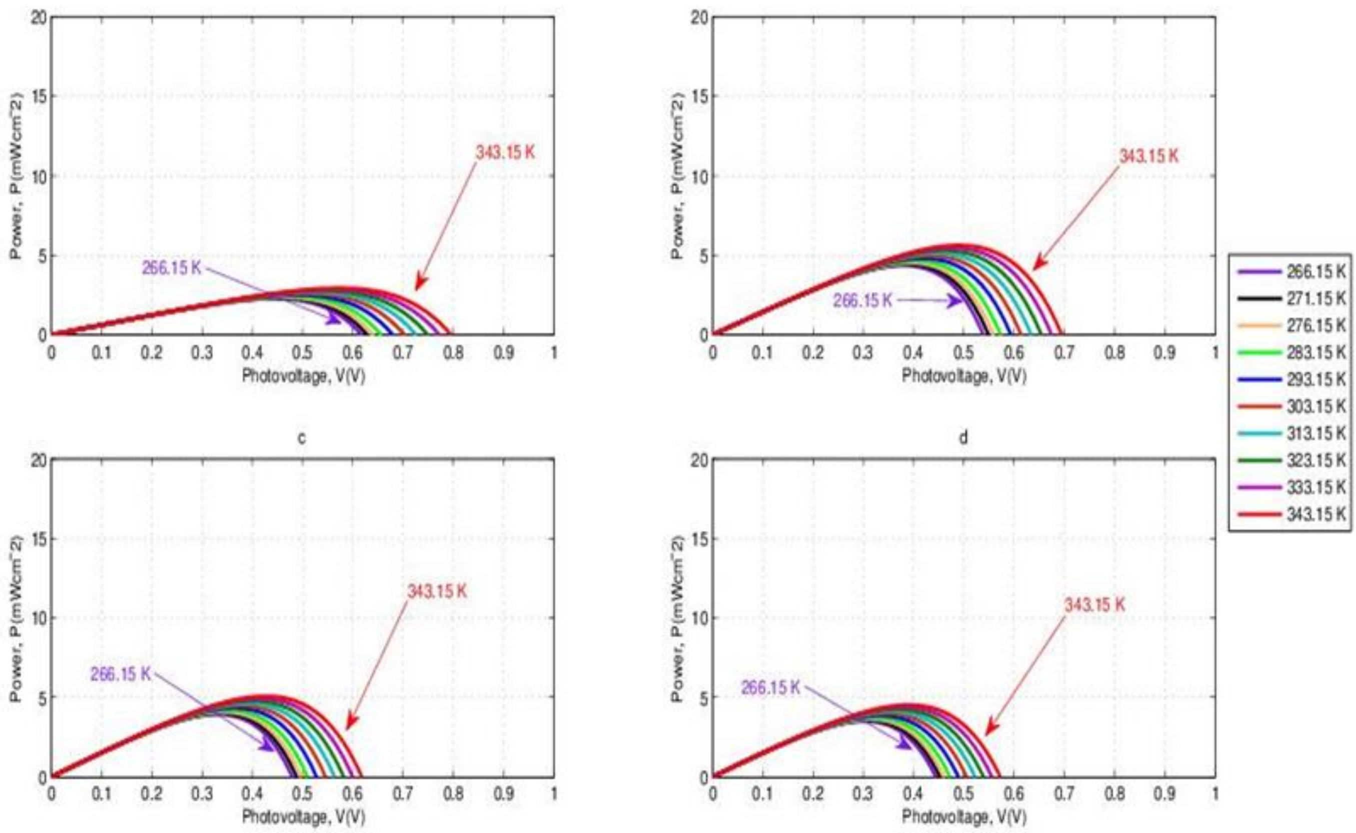

Figure 2: Variation of the power under different temperature and various thin film electrode thicknesses: (a) 1 µm, (b) 5 µm, (c) 10 µm and (d) 15 µm

As presented in the Figure 2, the thicknesses of the electrode effect the variation of the voltage and the power. For a maximum temperature T=343.15 K, the thickness of the electrode 1 µm gives a maximum value 2.94 $mW.cm^{-2}$, the thickness 5 µm gives a maximum value 5.63 $mW.cm^{-2}$, the thickness 10 µm has the value 5.07 $mW.cm^{-2}$ and the thickness 15 µm gives 4.51 $mW.cm^{-2}$. From these results we find that the optimum power obtained by this model is convenient for the value of the thickness of the electrode 5 µm and depending on the increase in the thickness of the electrode, the value of the power is decreased confirming that the thickness of the electrode 5 µm remains the most convenient thickness.

The effect of temperature on the energy conversion efficiency is illustrated in Figure 3, with different thickness of the electrode. Therefore we conclude that when the temperature increases, the energy conversion efficiency of DSSCs increases, the thickness of the electrode 1 µm has the lowest energy conversion efficiency values, this is also explained in the power characteristic depending on the voltage and the thickness of the electrode 5 µm gives the most optimal values of the energy conversion efficiency depending on the temperature.

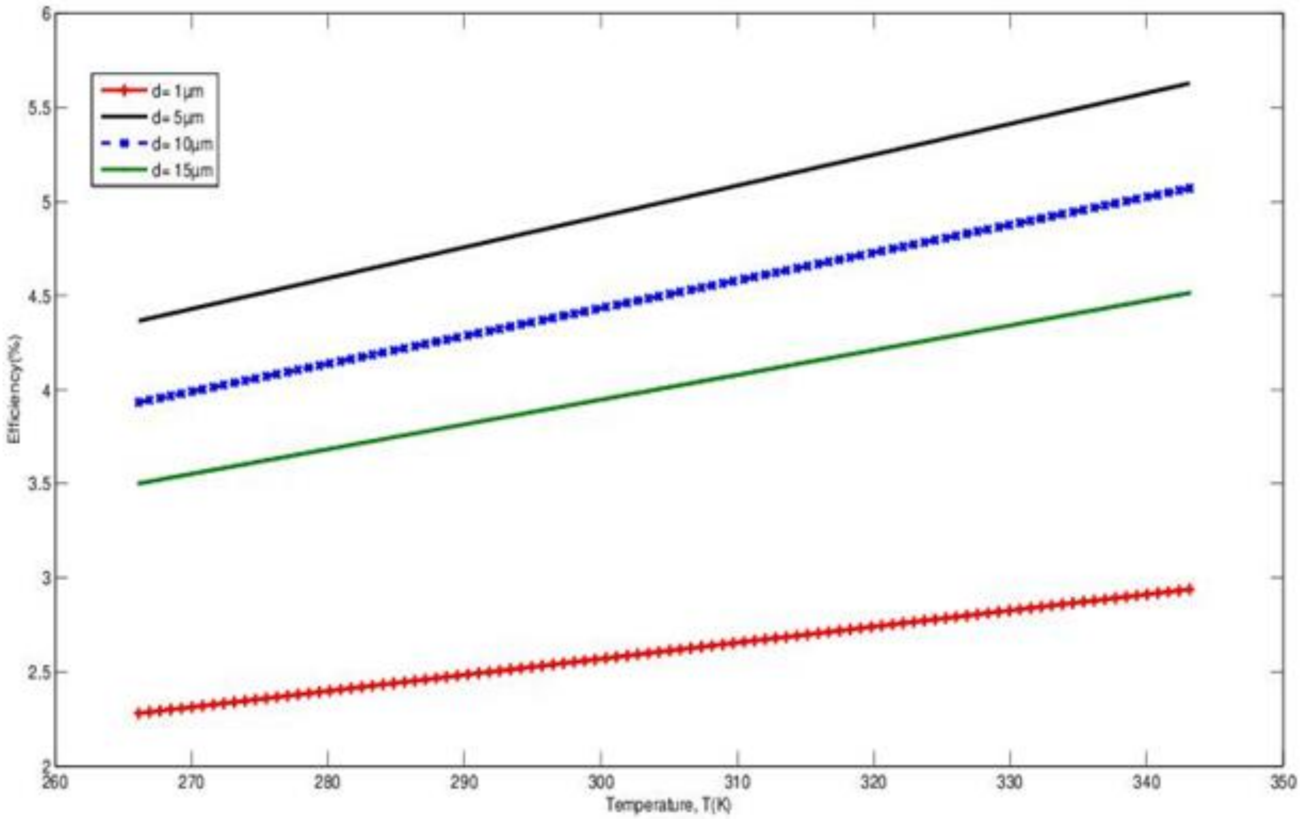

Figure 3: The effect of temperature on conversion efficiency with different thickness of the electrode

The results obtained by the differential equation [23,24,28] showed that the thickness of the electrode 5 µm gives optimum results [25].

CONCLUSION

We have achieved a simulation of differential equation to evaluate the effect of the temperature on J-V characteristics, the power and the energy conversion efficiency. According to the results achieved with this simulation; we find that with increasing of temperature, the open circuit voltage, the power and energy conversion efficiency of dye sensitized solar cells increases.

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