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VARIATION OF THE DYE THICKNESS AND THE ANODE THICKNESS WITH TIME OWING TO ELECTRON TRANSPORT THROUGH THE ANODE OF A DYE-SENSITIZED SOLAR CELL – A REVIEW OF EFURUMIBE *ET AL*'S WORK

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ABSTRACT: *It is believed that the anode thickness and the dye thickness vary in some way over time. In this study we investigated how these variations take place, by considering the portion of the cell between the dye and the anode. The dynamical system technique was applied here where the dye and the anode thicknesses were considered to be changing with time. As a result two systems of ordinary differential equations were obtained. These equations were solved using Runge-Kutta method of solving system of differential equations. The result obtained showed that the dye thickness decreases by some small amounts over time, whereas the anode thickness increases by some small amounts over time.*

KEYWORD: Dye, Anode, Thickness, Differential equations

INTRODUCTION

It is believed that some form of changes occur within the anode and dye of a dye-sensitized solar cell as they function in a solar cell (Glazier *et al*, 2003). These changes are investigated in this study. In studying the rate at which bodies change with time, ordinary differential equations are usually called to play (Karris, 2007). In real life, the anode of a standard dye-sensitized (Grätzel's) cell made of titanium dioxide, while the dye is usually Ruthenium dye. Titanium dioxide is whitish in colour while ruthenium dye is dark purple in colour. It is believed that this study will give insight on what changes that occur within the anode of a standard dye-sensitized solar cell and what changes that occur within the sensitized dye. The scope of the study stretches from the anode to the sensitized dye.

THE DYNAMICS OF THE PORTION OF THE CELL UNDER INVESTIGATION

The dynamics of the portion of the cell under investigation is presented by the system of differential equation below:

$$\frac{ds}{dt} = p\,s(t) - \alpha s(t) - \beta\,T(t)s(t) - \gamma T(t)s(t) \qquad 1$$

$$\frac{dT}{dt} = \beta\, T(t)s(t) - \gamma T(t)s(t) \qquad 2$$

Equations 1 and 2 reduce to:

$$\frac{ds}{dt} = (p - \alpha)s(t) - (\beta - \gamma)T(t)s(t) \qquad 3$$

$$\frac{dT}{dt} = (\beta - \gamma)T(t)s(t) \qquad 4$$

Let q = p – α and r = β - γ. Equations 3 and 4 reduces to:

$$\frac{ds}{dt} = qs(t) - rT(t)s(t) \qquad 5$$

$$\frac{dT}{dt} = rT(t)s(t) \qquad 6$$

Let: s(t) = thickness of the sensitized dye (which depends on time, t)

T(t) = thickness of TiO_2 (which depends on time, t)

p = rate of photon absorption by the dye

α = rate of electron emission by the sensitized dye

β = rate of electron trapping by the TiO_2 anode

γ = rate of electron transmission/diffusion by TiO_2 anode

Next we try to solve the system of differential equations given by equations 5 and 6. This is a form of initial value problem since we have assumed that the sensitized dye is a perfect one. If this is the case it shows that the dye needs little photon to produce more electrons.

Thus the difference (q) between the rate (p) of photon absorption by the dye and the rate of electron emission by the dye will be negative. That is $q = p - \alpha < 0$. This implies that, $q < 0$. Here -3 was chosen as the value of q.

Next we make another assumption. For the cell to be inefficient (owing to electron trapping by the anode) it means $\beta > \gamma$. This implies that the difference (r) between the rate (β) of electron trapping by TiO_2 anode and the rate (γ) of electron diffusion through the anode will be greater than zero. Mathematically we write $r = \beta - \gamma > 0$. We have assumed that the sensitized dye is a perfect one such that, its rate of electron emission is equal to 1. This implies that if electrons did not pass through any other substance or channel, but only through the anode, then, $\beta + \gamma \approx 1$.

This implies that, $\beta \approx 1 - \gamma$. Thus $r = 1 - 2\gamma > 0$. This implies that: $\gamma < 0.5$. So in this work the value of γ was taken to be 0.4 and that of r = 0.2. First of all we try to find out how the thickness of TiO_2 varies over time.

The system of differential equations (equations 5 and 6) were re-written as shown in equations 3 and 4.

$$\frac{dy(1)}{dt} = qy(1) - ry(2)y(1) \quad 7$$

$$\frac{dy(2)}{dt} = ry(2)y(1) \quad 8$$

Where

y(1) stands for 's' (the dye thickness) while y(2) stands for 'T' (the anode thickness) in the work.

q = the difference between the rate (p) of photon absorption by the dye and the rate of electron emission by the dye.

r = the difference between the rate (β) of electron trapping by TiO_2 anode and the rate (γ) of electron diffusion through the anode

A matlab programme was afterwards written to solve equations 7 and 8 using Runge-Kutta method.

SOLUTIONS TO EQUATIONS 7 AND 8

The numeric solutions are displayed as column vectors below:

y(1) =

1.0000

0.9014

0.8124

0.7322

0.6599

0.5948

0.5360

0.4830

0.4353

0.3923

0.3535

y(2) =

1.0000

1.0062

1.0118

1.0169

1.0215

1.0257

1.0294

1.0328

1.0359

1.0387

1.0412

The above solutions were obtained by simulation over a small time range (0 to 0.5 s) in step of 0.05s. After this another Matlab sub-program was written to plot the graph of y(2) against time, t and that of y(1) against time, t, for time 0 to 1 second, in step of 0.05 second. The plot of y(2) against time was varied for other lengths of time (that is from 0 to 3 seconds, from 0 to 5 seconds and from 0 to 10 seconds).

PLOT OF y(1) and y(2) AGAINST TIME

The results of the plot y(1) and y(2) against time are shown in figures 1, 2, 3, 4 and 5.

Fig.1: Graph of s against time (t) plotted for time 0 to 1 second in time step of 0.05s

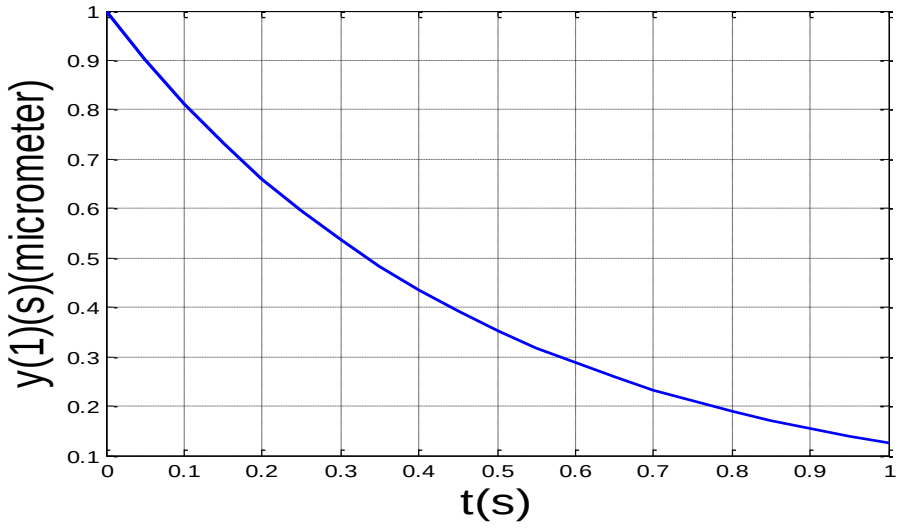


Fig.2: Graph of T against time (t) plotted for time 0 to 1 second in time step of 0.05s

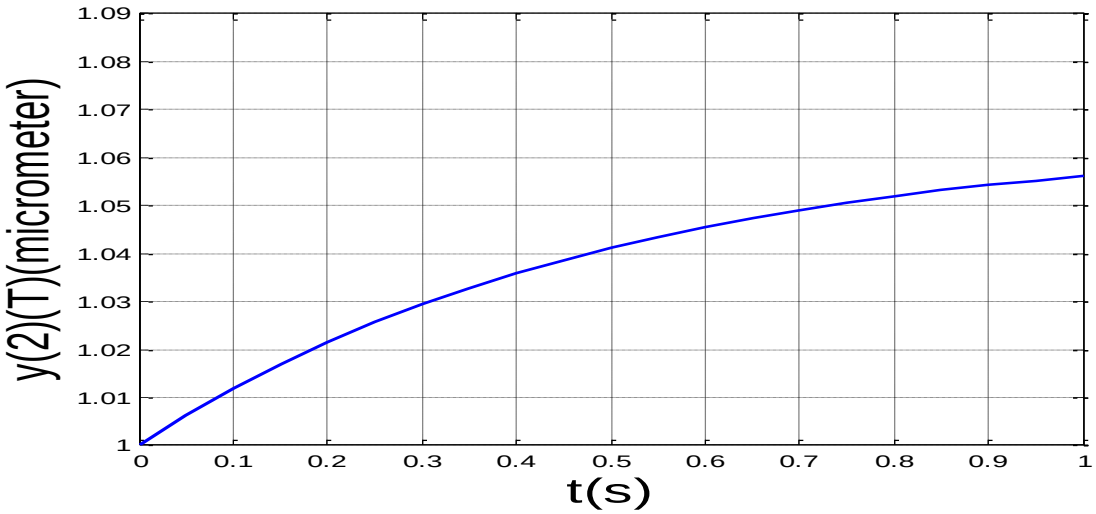


Fig. 3: Graph of T against time (t) plotted for time 0 to 3 seconds in time step of 0.05s

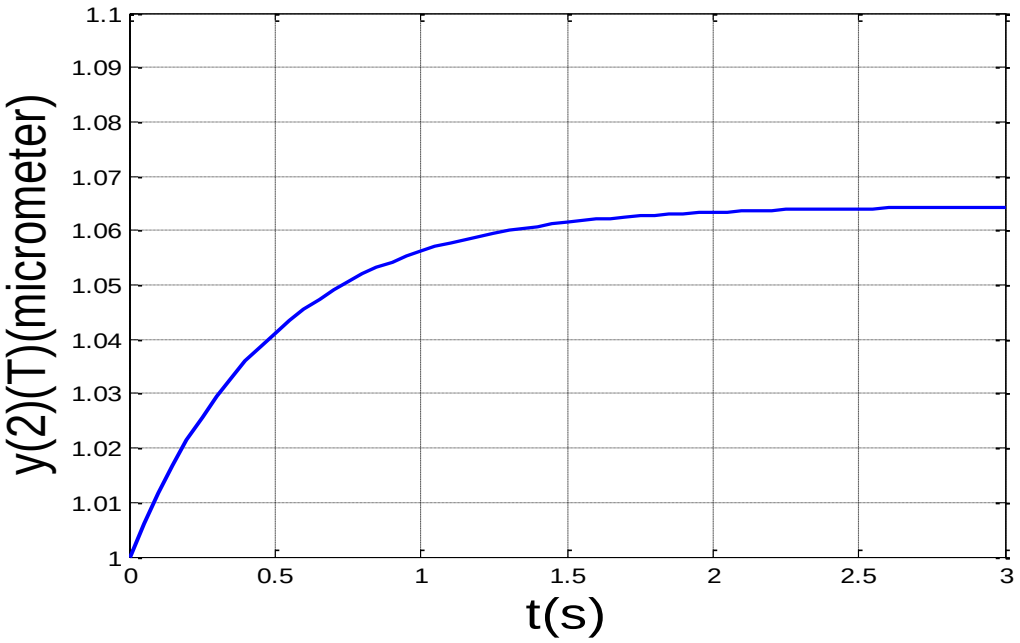


Fig. 4: Graph of T against time (t) plotted for time 0 to 5 seconds in time step of 0.05s

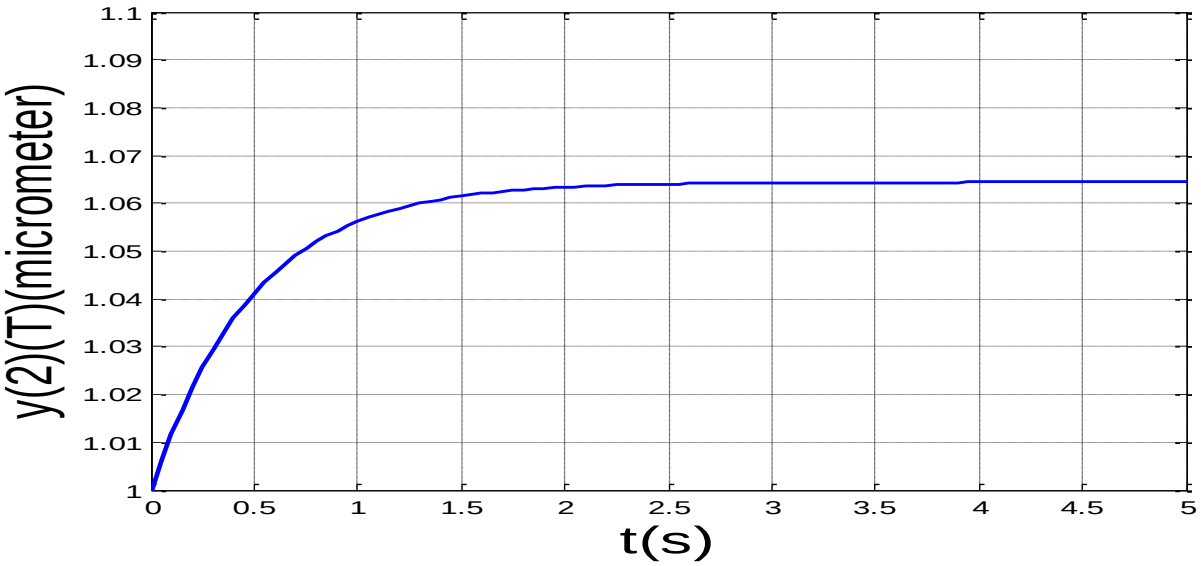
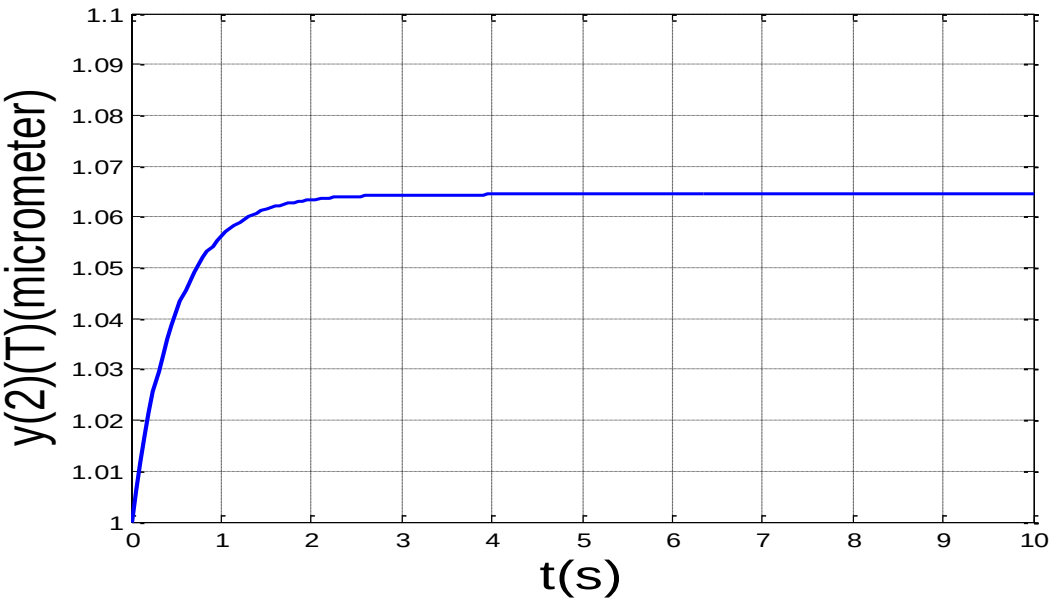


Fig.5: Graph of T against time (t) plotted for time 0 to 10 seconds in time step of 0.05s



ANALYSIS OF RESULTS

The result of the Matlab programme written to solve the system of differential equations that resulted from the model is shown in section 3. Those results were obtained for simulation over a time interval: 0 to 0.5 in step of 0.05. It can be noted that increasing the time interval beyond 0 to 0.5 will yield more numeric solutions. Nevertheless, the time interval used here

as said earlier was 0 to 0.5. The solutions (y(1) and y(2)) were displayed as column vectors in Matlab's command window. y(1) is seen to decrease as the time of simulation increases while on the other hand, y(2) is seen to increase as time of simulation increases. Also the plot of T against time, t using Runge-Kutta method in Matlab showed that within the short time period (0 to 1 seconds, see fig.2), the thickness of the anode increases exponentially with time. Fig.2 showed that within a short time period (0 to 1 second), the thickness of a particular anode increases exponentially with time by a small amount. As the time period increases (say from 0 to 3 seconds), the increase in thickness gets to a point (about 0.064μm) where it stops and remains steady all through the time of electron transport through the anode. This is shown in fig. 3. That amount of increase (that is 0.064μm) of the anode thickness can be called the elastic limit of the anode (FARLEX, 2012). Any amount of increase beyond the elastic limit must distort the anode's thickness and must only occur when an external force is added. This agrees with Hook's law of elasticity which invariably states that if the elastic limit of a spring is exceeded, the spring becomes deformed (Efuribe, 2007). Figures 4 and5 ascertained that over a little long period of time (up to 10 seconds) the elastic limit would not be exceeded. The numeric solution, y(1) obtained in section 3 also ascertained the above.

CONCLUSION

From the results obtained it can be noticed that the anode's thickness tends to increase by some small amount over short time, and afterwards remains constant. The initial increase could be in response to incoming electron's from the sensitized dye. The sensitized dye on its own tends to decrease by some small amount over a short time probably in response to its electron ejection. Since from the results, it is seen that the anode's thickness tends to increase by some small amount, it means that attention needs to be paid on the present size of the anode. It has been suggested that the anode size of the dye-sensitized solar cell be improved (Efurumibe et al, 2012). For this will help improve the efficiency of the cell. At the present micron size of the anode, low current values are being obtained. This could be due to the inability of the majority of the electrons to pass through the available pores in the anode, leading to losses. Assuming a thicker anode is used, more electrons would pass through thereby improving the efficiency of the anode. And when more electrons pass through at relatively low resistance, greater open circuit voltage would be obtained, since voltage is proportional to current following Ohm's law (Ndupu and Okeke, 2002). So the conclusion here is that the anode side of the dye-sensitized solar cell be increased rather than be reduced.

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