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Performance Analysis of Cu2O/TiO2 solar cell with V2O5 BSF layer using SCAPS 1D

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ABSTRACT

In this article, we have tried to simulated the performance of Cu_2O/TiO_2heterojunction solar cell with V_2O_5 back surface filed (BSF) layer. We have used SCPAS 1D software for simulation of the solar cell. This solar cell has shown the efficiency ~7.33% with initial set of parameters. Further, we have tried to optimize the performance of this solar cell by varying absorber layer thickness, defect concentration and absorber layer carrier concentration. Later, we have tried to understand the impact of thickness variation of buffer layer (TiO_2), electron affinity of buffer layer and its carrier concentration to understand its impact on the efficiency of the solar cell. We have also varied the thickness of BSF layer to optimize the performance of the proposed solar cell.

Keywords: Cu_2O, Solar Cell, Efficiency, SCAPS 1D

INTRODUCTION

The increasing demand of energy has triggered the use of renewable energy sources to bridge the gap between demand and supply. Solar energy is one such material which is available abundantly and can be harnessed to end the energy crisis of the world[1]. Photovoltaics solar cells are devices which is used to convert solar energy into electricity. Various materials have been investigated to be used as solar cells out of which silicon is investigated prominently. However, these solar cells suffer from high production cost. Hence, materials which are abundantly available on earth has been investigated over the years to replace the silicon solar cells. Metal oxide semiconductors have been topic of interest to the researchers for solar cell applications.

Copper oxide (Cu_2O) is one such metal oxide which offers direct band gap of 2.1 eV and is intrinsically p-type semiconductor[2][3][4]. It also offers high carrier mobility and absorption coefficient[5].

However, synthesizing n-type Cu_2O is difficult and hence it imposes restriction on construction of homojunction Cu_2O based solar cells. The various reports available in literature has investigated Cu_2O based heterojunction solar cells. Various buffer layers such as ZnO, CdS and ZnSe has been investigated with Cu_2O absorber layer.

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Back surface filed layer is used along with the absorbing materials to increase the performance of the solar cells. V_2O_5 is one such transition oxide which has been used as BSF layer[6][7]. It is chemically and thermally stable and offers reasonable electrical and optical properties. The burden of experimental work can be reduced by using simulation approach where we can see the performance of solar cells by varying various parameters in reduced time span. SCPAS 1D is one such open source software which is developed by University of Ghent, Belgium and offers the ease of parameter variation to understand its impact on performance of solar cell.

In this paper, we have analyze the performance of $V_2O_5/Cu_2O/TiO_2$ solar cells. We have tried to understand the impact of change in absorber layer thickness, carrier concentration and defect concentration on the performance of solar cell. Further, we have varied the thickness of buffer layer, electron affinity of buffer layer and the interface defect to understand the impact on solar cell.

MATERIAL'S PARAMETERS

The various parameters required for simulation is listed in table 1. The initial thickness of absorber layer is 2 μm and for buffer layer is 100 nm. The thickness of BSF layer is kept constant at 200 nm. The observed defects are considered donor type in absorber layer and neutral at the interface.

Table 1. Parameters of used materials

Parameters	**V_2O_5**[8]	**Cu_2O**[9]	**TiO_2**[10]
Thickness (μm)	0.2	2	0.1
Band gap (eV)	2.2	2.2	3.2
Electron affinity (eV)	3.4	3.2	4.2
Dielectric permittivity (relative)	8	7.1	10
CB effective density of states (cm^{-3})	$9.2x10^{19}$	$2x10^{17}$	$2.2x10^{17}$
VB effective density of states (cm^{-3})	$5x10^{20}$	$1.1x10^{19}$	$6x10^{17}$
Electron thermal velocity (cm/s)	$1x10^7$	$1x10^7$	$1x10^7$
Hole thermal velocity (cm/s)	$1x10^7$	$1x10^7$	$1x10^7$
Electron mobility (cm^2/V s)	150	200	100
Hole mobility (cm^2/V s)	100	8	250
Shallow uniform donor density ND (cm^{-3})	0	0	10^{17}
Shallow uniform acceptor density NA (cm^{-3})	10^{18}	10^{18}	0

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Absorber Defect (cm^{-3})	-	10^{11}	10^{11}
Interface Defect (cm^{-3})	-	10^{11}	10^{11}
Defect type at bulk/interface		Donor/Neutral	

RESULT AND ANALYSIS

Initially, we have simulated the basic solar cell with the parameters listed in table 1. The observed current-voltage (I-V) characteristics is shown in figure 1(a). The observed efficiency is ~7.33%. The quantum efficiency curve is shown in figure 1(b). Here, it is evident that the material covers the wavelength of spectrum ~600 nm. Hence, it explains the reason for observed low efficiency. Th interface defects plays an important role in changing the performance of solar cells. Hence, we have varied the interface defect concentration from 10^8 cm^{-3} to 10^{14} cm^{-3}. We can analyze from the curve that with increase in interface defect, the efficiency of the solar cells decreases drastically. Hence, we can conclude from here that the interface defect should be lower for enhanced performance of solar cells. The graph of this study is shown in figure 1(c).

The absorber layer thickness affects the performance of solar cells. But we must keep in mind that increased thickness results in large material requirement and it leads to increased cost of production. Hence an optimized thickness is required in order to understand result in higher efficiency along with reasonable cost. Here the thickness of Cu_2O is changed from 1μm to 6 μm. The resulting graph is shown in figure 2(a), We can see from the graph that with increase in thickness the efficiency is initially increasing abruptly and then it saturates.

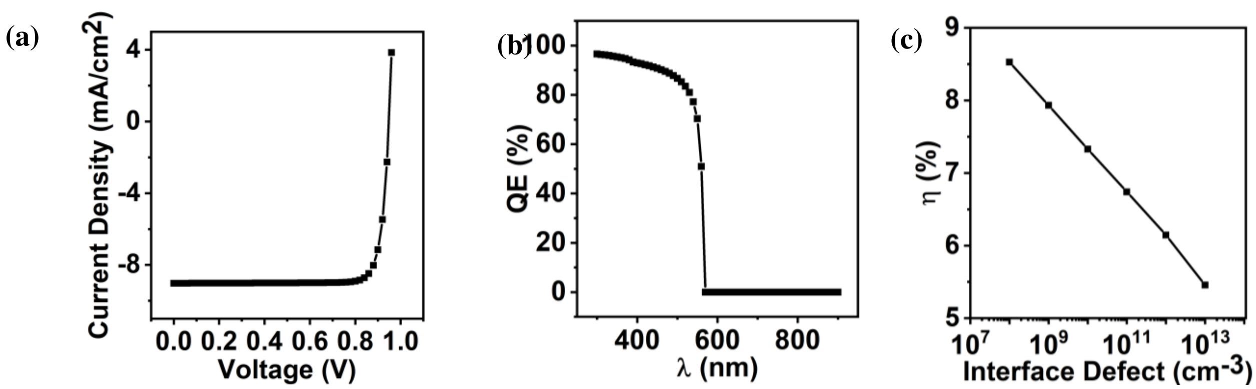

Fig. 1. (a) I-V characteristics, (b) QE curve of solar cell and (c) Impact of interface defects on the efficiency

The thickness up to 3 μm results in increased efficiency and after that the change in efficiency is lower. Hence, we can conclude from here that the optimum thickness should be 3 μm. The absorber layer is full of defects and the most prominent is donor type defect which reduces the number of active holes. Hence, understanding its impact on the solar cell performance is important. Here, we have the donor type defects of the absorber layer in a range of 10^{10} cm^{-3} to 10^{15} cm^{-3}. We can see that the with increase in defect concentration the efficiency is decreasing. The graph is shown in figure 2(b). The decrease the relatively slow up to 10^{13} and after that it decreases drastically. Hence,

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we can conclude that the optimum defect concentration should be less that 10^{13} cm^{-3}.

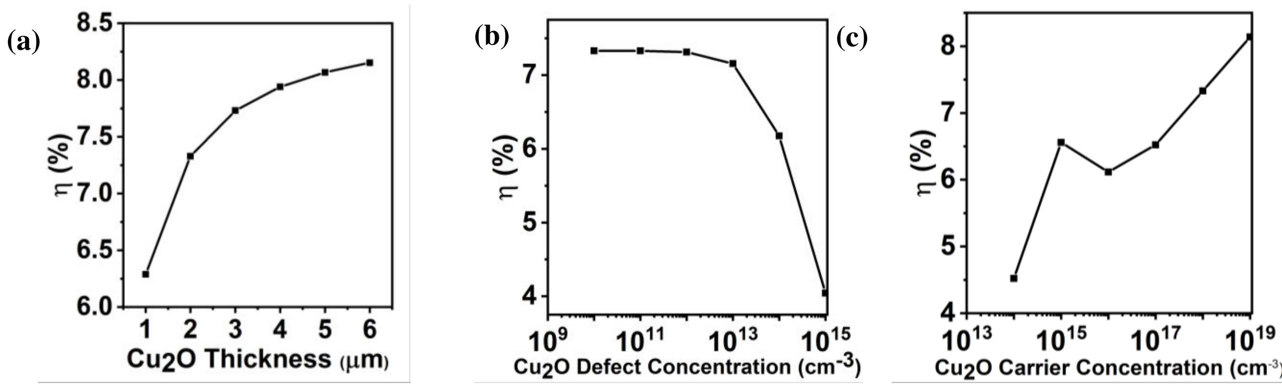

Fig.2. (a) Impact of absorber layer thickness on efficiency, (b) Influence of defect concentration of absorber layer on efficiency and (c) Impact of carrier concentration of absorber layer on efficiency

We have also varied the carrier concentration of the Cu_2O layer. We changed the concentration from 10^{14} cm^{-3} to 10^{19} cm^{-3} in order to understand its impact on the efficiency of the proposed solar cell. We can see from the graph figure 2(c), that efficiency is increasing with increased carrier concentration. The highest carrier concentration results in highest efficiency.

The buffer layer parameters also change the efficiency of the solar cell. To understand this phenomenon, we have changed the thickness of buffer layer. The observed graph is shown in figure 3(a). We can see that with efficiency is decreasing with increased thickness of buffer layer. increased thickness results in higher depletion width in buffer layer which reduces the efficiency. The maximum efficiency can be achieved by keeping the thickness of buffer layer minimum and thickness of absorber layer maximum. Electron affinity of buffer layers are another important parameter which affects the efficiency adversely. If the difference of electron affinity between buffer layer and absorber layer is large then the efficiency is the lowest. Hence, an optimized electron affinity of buffer layer is required. To understand this, we have varied the electron affinity of buffer layer from 3.4 eV to 4.2 eV and the resulting graph is shown in figure 3(b). We can see that the highest efficiency is observed when the electron affinity of buffer layer is 3.4 eV which is equal to absorber layer. Further, with increase in electron affinity, the efficiency decreases. Hence, the lower the electron affinity, more will be the efficiency of the solar cell.

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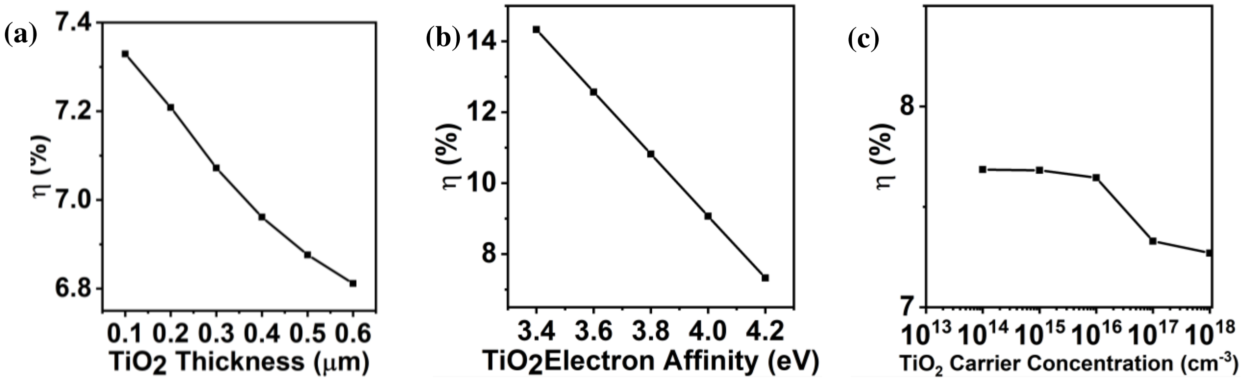

Fig. 3. (a) Curve of buffer layer thickness on efficiency, (b) Impact of buffer layer electron affinity on efficiency and (c) Impact of buffer layer carrier concentration on efficiency

We have further tried to understand the buffer layer carrier concentration chnage and have analyzed the performance of the proposed solar cells. We have varied the value from 10^{14} cm^{-3} to 10^{18} cm^{-3}. It can be seen from the graph, figure 3(c), that the efficiency is constant from 10^{14} to 10^{16} cm^{-3}. Further increase in buffer layer carrier concentration results in lower efficiency. Hence, to have the maximum efficiency, the carrier concentration of TiO_2 should be below 10^{16} cm^{-3}. Hence, overall, we have optimized the solar cell so that this can result in maximum efficiency of ~10.6%.

CONCLUSIONS

In summary, we have investigated the performance of V_2O_5/ Cu_2O/TiO_2 solar cell using SCAPS 1D. Here, initially the solar cell showed and efficiency of ~7.3% with initial set of chosen parameters. Further, we have varied the thickness of Cu_2O and we concluded that the optimized thickness should be 3 μm. The defect concentration of the absorber layer should be ~10^{11} cm^{-3}. The Cu_2O layer should have highest carrier concentration to obtain the high performance from the solar cell. The interface defect of the solar cell should be minimum as the increased concentration leads to reduction in efficiency. The thickness of buffer layer should be minimum thickness and the optimized value is 100 nm. It gaps between electron affinity of the buffer layer and absorber layer should be maximum. The analyzed results also showed that the optimized carrier concentration of buffer layer should be $10^{15}$$cm^{-3}$. The observed efficiency of the solar cells with optimized parameters has increased from 7.33% to 10.6%. Hence, the proposed solar cell has potential to be acting as a low-cost solar cell with reasonable performance.

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