A COMPARATIVE STUDY OF CDTE SOLAR CELL STRUCTURE FOR EFFICIENCY ANALYSIS

[1]Saket Kumar, [2]Rajesh Mehra, [3]Harshleen Kaur
[1]ME Scholar, [2]Associate Professor, [3]ME Scholar
[1] Department of Electronics & Communication Engineering,
[1] National Institute of Technical Teachers Training & Research, Chandigarh, India

Abstract: An alternative structure (Glass/SnO2/ZTO/CdS:O/$CdTe_{1-x}S_x$/CdTe) of a reference solar cell is presented. Cadmium Telluride (CdTe) solar cells are widely used because of various advantages such as better stability, low cost, high efficiency. Back Surface Reflector (BSR) is introduced between absorber layer and back metal contact. The BSR layer with distinct band gap material has been used to decrement the minority carrier recombination at the back contact. Based on the new model, this paper has shown improved fabrication parameters by using Cu_2Te material as BSR layer. Various other parameters like bandgap, open-circuit (Voc), short-circuit current density (Jsc), Fill-factor (FF) and quantum efficiency (E_{ff}) has been analysed. The traditional structure of solar cell has been modified by introducing CdS: O window layer (thickness-25nm) having varying wide range of band gaps. This layer influence the parameters of reference model, which is easily observed after the simulation. Several J-V characteristics and efficiency has been found quite better and high compared to the reference cell. Cu_2Te material as BSR layer shown impressive improvement in conversion efficiency of 3.671% as compared to the reference model having no BSR layer. Which indicates the possibilities of future enhancement of properties of Cds/CdTe solar cell.

IndexTerms **- CdTe, Solar cell, CdS, Semiconductor, Simulation, Cu_2Te**

I. INTRODUCTION

A device used to convert solar energy into electrical energy directly. It operates as a transducer, which translate the renewable source of energy to efficient form. A renewable energy source can be bank on for the long-term. Renewable energy is cost-effective and efficient. The confrontation of climate change has prompt many nations to set a renewable energy target. Solar power is non- polluting green electric supply that is created from sunlight, or heat from the sun. Installing solar power systems in a residential setting generally means setting up a solar panels or a solar thermal system on the roof. It is also a non-polluting source of energy and it does not discharge any greenhouse gases when generating electricity [1, 2]. Energy reaping is the phenomena in which the energy is originated from extrinsic sources like solar energy, wind energy, rain, tides, waves, geothermal heat and many more and it is captured & stored for a small autonomous device. It is also called as energy scavenging, power reaping or ambient energy/power. Various Energy generating devices used for transform the ambient energy into electrical energy. These devices can power cellphones, mobile computers, radio communication equipment, etc. All of these devices must be very efficient to meet long-term exposure to adverse surroundings and have a long range of dynamic sensitivity to affect the whole spectrum of wave motions [3].

Polycrystalline based solar cell are quite promising in order to achieve impressive conversion efficiency and several other counterparts. CdTe based solar cell are quite attractive to the world due to its reliable energy conversion, highly cost effective outputs and stability [4]. A new model for this device has been formulated based on the combination of graded band gap of various junctions formed between the solar cell structures at the interface [5, 6]. The long-term stability of CdTe solar cell is due to the presence of some copper material at the back metal contact. However, the invariability of CdTe solar cells is a complicated issue, which depends to a great degree on cell structure. The main stability issue for CdTe solar cells is the non-ohmic back contact and stability improvements have focused primarily on finding stable contacts without sacrificing efficiency [7, 8]. The main role of Cu_2Te is to provide confinement for the photo-generated minority carriers and keep them within the reach of the p-n junction to be efficiently collected. Photon characteristics is interesting to observe ancillary properties of BSR layer [9].

This paper summarizes the new model and the new way of developing the device with the latest achieved results. A BSR layer between the absorber layer and back metal contact in order to reduce the possible recombination at the back contact. An increased absorption coefficient >5 × 105/cm, which means that ~99% of light photons with energy higher than the band gap (having Eg of around 1.45 eV) can be captivated within 2μm of CdTe film [10]. Using guidelines based on this new model, the fabrication of improved device cell structure discussed in the next section of modelling.

II. Structure And Modelling

Figure 1 depicts the basic schematic of a solar cell structure. A grid is a topmost part consist of solar panels of required thickness, where light incidents [11]. CdTe is an II–VI compound semiconductor with a direct optical band gap of ~1.5 eV, which is used for energy conversion [12]. CdTe have zinc blend structure and is known as chalcogenide semiconductor. Thin film CdTe produced remarkable results. Gold (Au) is used as cathode (electron transport layer). Glass serve as substrate and protect other layers. Other chemical layers like TCO are deposited over glass [13]. The polycrystalline layers of CdTe solar cells can be synthesized using a variety of different low cost techniques such as Close-Space Sublimation (CSS), Chemical Vapour Deposition (CVD), Chemical Bath Deposition (CBD), or Sputtering [4, 14]. Numerical modelling is used to predict the precise physical parameters on cell performance [15].

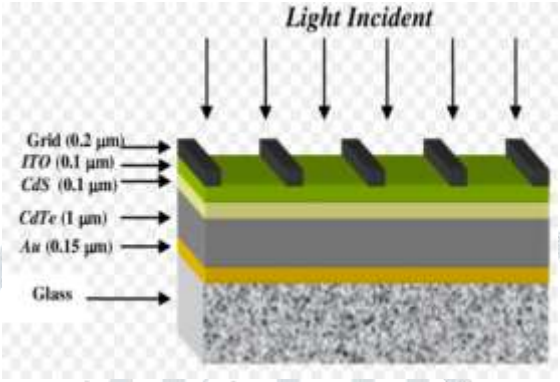
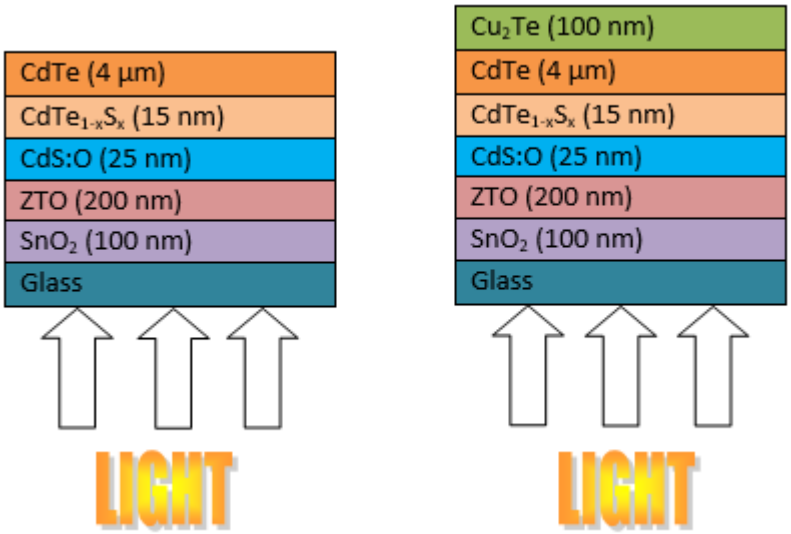


Figure 1: Basic structure of CdTe Solar Cell

Figure 2(a) depicts the schematic of reference model. BSR layer is introduced in the proposed model with Cu_2Te material and corresponding layer structure of cell is obtained as shown in figure 2(b).



(a) (b)

Figure 2: (a) Reference structure of solar cell; (b) Proposed solar cell structure

CdS is the window layer and it is introduced between front and back layers to reduce leakage current and to achieve morphology by thinning the layers. Oxygenated CdS is used to suppress the Te interdiffusion from CdTe to the CdS film and the formation of a $CdS_{1-y}Te_y$ alloy, which has a lower band gap and provides poor quantum efficiency in the short wavelength region [9]. $CdTe_{1-x}S_x$ developed by CSS growth process and it's thickness can be reduced during fabrication [16]. All the material parameters used in this work for numerical simulation are listed in Table I. These values are taken from literature survey and some of them are estimated. Various parameters taken under consideration for estimations are layer thickness, doping concentration, band gap, etc. Some of the other parameters include dielectric constant, electron mobility, hole mobility, electron and hole concentration, density of conduction band, density of valence band and electron affinity.

III. Design And Simulation

In this section, the simulation result for both the structure discussed above and shown in figure 2 are compared one-by-one through various waveforms by considering the basic parameters like thickness, voltage, band gap, current density, carrier density, quantum efficiency, etc.

Table I: Material parameters used in the numerical analysis for the nano-CdS:O/CdTe cell

Parameter	n- SnO_2	n-ZTO	n-CdS:O	p-$CdTe_{1-x}S_x$	p-CdTe	Cu_2Te
Thickness(μm)	0.1	0.2	0.01-0.1	0.0-0.3	0.6-2	0.1
Dielectric constant	9.0	9.0	10.0	9.4	9.4	10
Electron mobility (cm^2/Vs)	100	52	100	320	320	500
Hole mobility (cm^2/Vs)	25	3	25	40	40	100
Electron and hole concentration (cm^{-3})	10^{17}	10^{19}	$1.1x10^{18}$	$2x10^{14}$	$10^{16}/10^{17}$	10^{21}
Band gap, E_g (eV)	3.60	3.35	2.80	1.47	1.50	1.18
Density of conduction band (cm^{-3})	$2.2x10^{18}$	$2.1x10^{18}$	$2.2x10^{18}$	$7.9x10^{17}$	$7.9x10^{17}$	$7.8x10^{17}$
Density of valence band (cm^{-3})	$1.8x10^{19}$	$1.5x10^{19}$	$1.8x10^{19}$	$1.8x10^{19}$	$1.8x10^{19}$	$1.6x10^{18}$
Electron affinity (eV)	4.55	4.50	4.50	4.26	4.26	4.20

3.1 Reference Model

In this model five layers are used viz; window layer, electron transport layer (ETL), buffer layer, hole transport layer (HTL) & absorbing layer. Thickness varies between 0.1-2μm, dielectric constant is around 9-10, electron mobility ranges between 52-320 cm^2/Vs, hole mobility shows large variation (3-40cm^2/Vs), electron & hole concentration is on an average to $10^{17}cm^{-3}$, band gap have narrow changes between 1.47-3.60 eV, density of valence band is smaller than that of density conduction band by around 10 times, whereas electron affinity shows very minute differences. The exact values of all the material parameters can be verified from the Table I. The respective layers performance analysis of the reference model with no BSR layer is shown in various output waveforms obtained from the simulation. Figure 3 depicts the variation in the considered parameters. In Figure 3(a) electrons, holes, total charge & total current density all are showing almost similar variation but have multiple spikes towards the end as thickness increases. Figure 3(b) shows that the electron carrier density remain low initially but it increases with the thickness suddenly & then decreases again. Carrier density of hole is almost opposite to that of electron. While total charge carrier density goes through multiple variations. in Figure 3(c) shows that current density of electron remain constant unto 1.4 μm thickness and then there is a sudden fall to -29 mA/cm^2 at 1.5 μm thickness, whereas holes are behaving exactly opposite to that of electrons. While total current density remain constant at -29 mA/cm^2 for all the thickness variation. Figure 3(d) shows the variation following the positive exponential standard as the voltage values increases. Figure 4 showing the quantum efficiency curve as a function of wavelength for different values of defect density. The curve is spanned over almost entire visible range of solar spectrum. The quantum efficiency decreases for increase in defect density. The quantum efficiency is constant in the region 350 nm to 800 nm and then it decreases and has an onset even up to 900 nm.

3.2 Proposed Model

In this model six layers are used viz; window layer, electron transport layer (ETL), buffer layer, hole transport layer (HTL), absorbing layer & an extra sixth layer is added as BSR layer i.e. a band gap material Cu_2Te. Thickness varies between 0.1-2μm, dielectric constant is around 9-10, electron mobility ranges between 52-500 cm^2/Vs, hole mobility shows large variation (3-100 cm^2/Vs), electron & hole concentration is equal to 10^{21} cm^{-3}, band gap have narrow changes between 1.47-3.60 eV, density of valence band is smaller than that of density conduction band by around 10 times, whereas electron affinity shows very minute differences. The exact values of all the material parameters can be verified from the Table I.

The respective layer performance analysis of Cu_2Te as BSR layer is shown in various output waveforms obtained from the simulation. Figure 5 depicts the variation in the considered parameters. In Figure 5(a) electrons, holes, total charge & total current density all are showing almost similar variation but have multiple spikes towards the end as thickness increases. The structure exhibits higher values of parameters, when the defect density is kept high. Further increase in the defect density does not affect the band gap much. Carrier becomes dominant in the absorption layer and quality decreased. Figure 5(b) shows that electrons have two vibrant changes but remain constant for a range of distance in between. Hole behavior is quite opposite, while total charge shows multiple variations & spikes towards the end as thickness increases. Figure 5(c) shows that current density of electron remain constant unto 1.4 μm thickness and there is a sudden fall to -29 mA/cm^2 at 1.6 μm, whereas holes are behaving exactly opposite to that of electrons. While total current density remain constant at -29 mA/cm^2 . Figure 5(d) shows the variation following the positive exponential curve with the increment in the voltage. Electrons having higher values in compared to the total charge density present in the cell. Figure 6 showing the quantum efficiency curve as a function of wavelength for different values of defect density. The curve is spanned over almost entire visible range of solar spectrum. The quantum efficiency decreases for increase in defect density. The quantum efficiency is constant in the region 350 nm to 800 nm for both electron & hole and then it decreases and has an onset even up to 900 nm for both electron & hole, while electron shows the same variation at higher wavelength then hole.

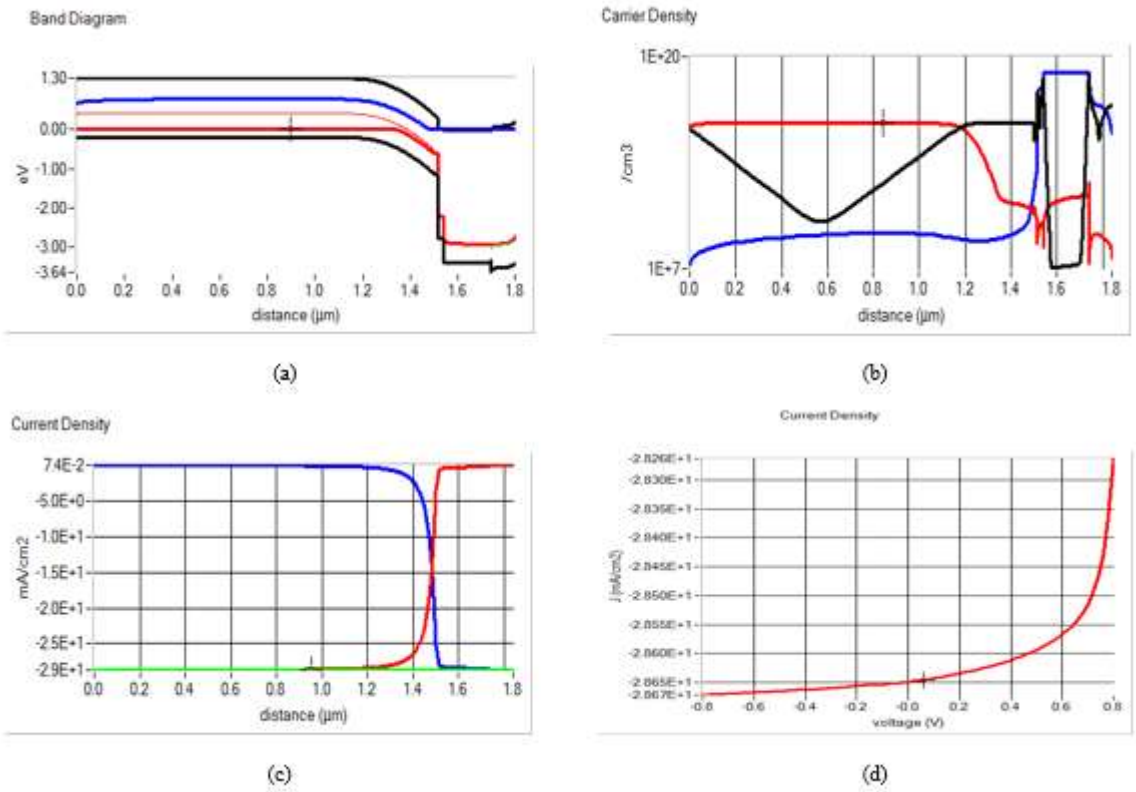


Figure 3: (a) Band diagram Vs Distance; (b) Carrier density Vs Distance; (c) Current density Vs Distance; (d) Current density Vs Voltage

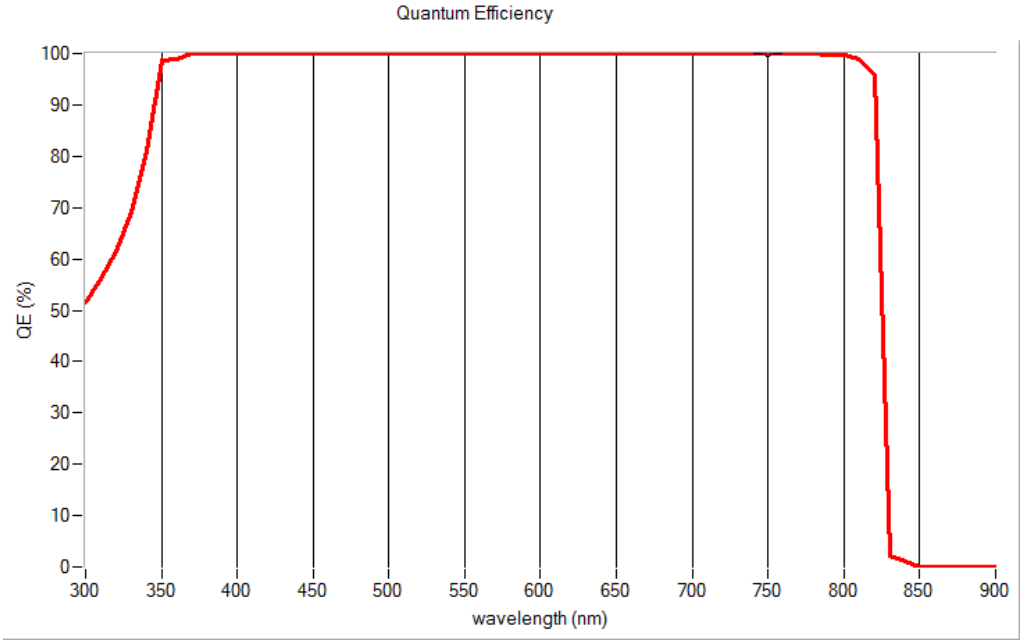


Figure 4: Plot of Quantum efficiency Vs Wavelength for the Reference Model

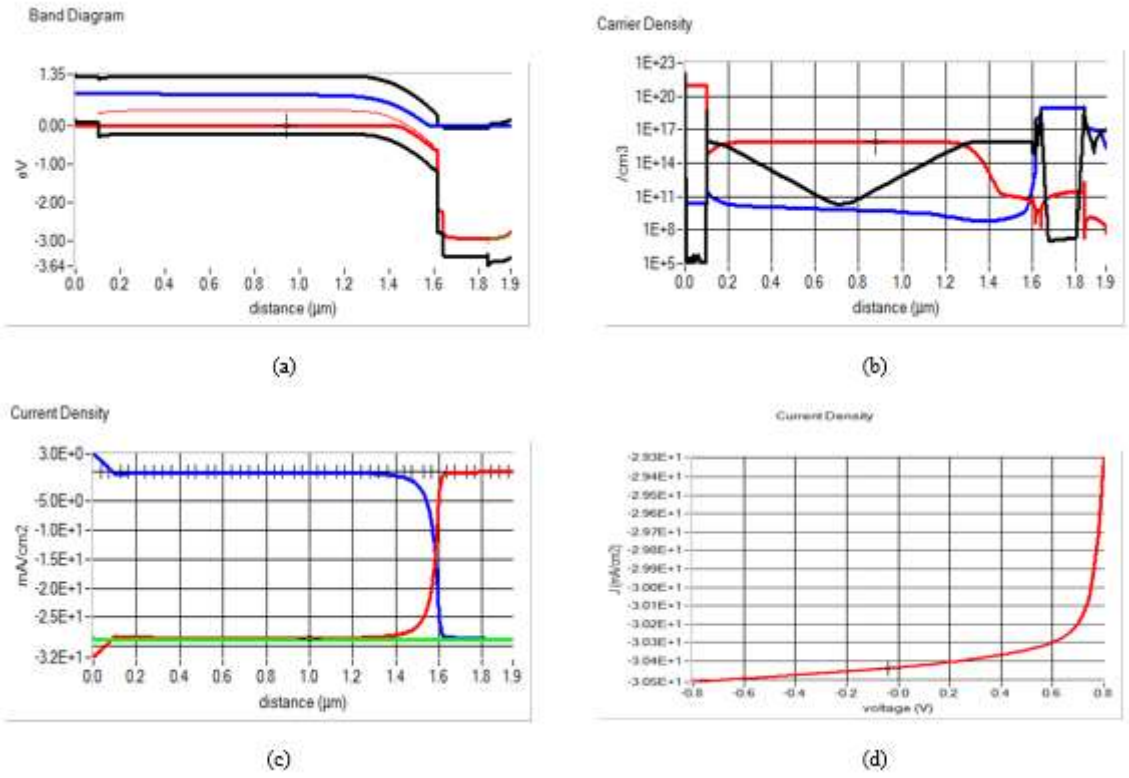


Figure 5: (a) Band diagram Vs Distance; (b) Carrier density Vs Distance; (c) Current density Vs Distance; (d) Current density Vs Voltage

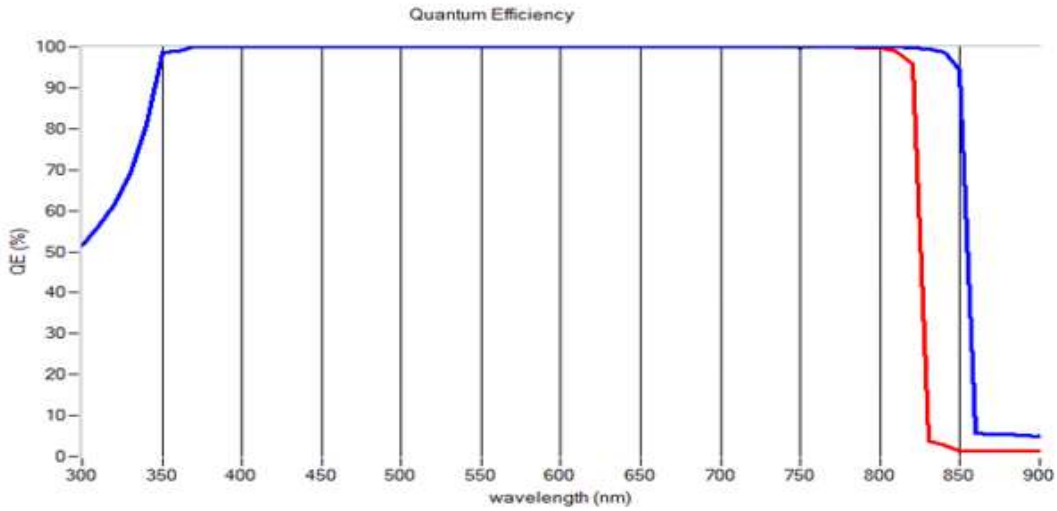


Figure 6: Plot of Quantum efficiency Vs Wavelength for the Proposed Model

IV. Comparison And Result

In this section, the comparison of the two simulated result are analyzed as per the performance of the solar cell structure mentioned in figure 2. Where figure 2(a) represent the reference model & figure 2(b) represent the proposed model. In proposed model, an extra layer of Cu_2Te as BSR is used. Which shown quite impressive improvement in the various parameters. The resulting performance parameters of the open-circuit voltage (Voc), short-current density (Jsc), fill factor (FF), and efficiency are determined and are shown in Table II. It can be observed that Cu_2Te in BSR layer, Voc reduced whereas Jsc, FF & E_{ff} increased in comparison to BSR less layer cell. Figure 7 showing the bar chart comparison of all four numerical parameters for the two case compared.

Table II: Comparative analysis of both cell structure

S. No.	Cell Structure	Voc (V)	Jsc (mA/cm^2)	FF (%)	η (%)
01.	Reference Model	6.38	28.64	12.37	22.61
02.	Proposed Model	2.22	30.43	34.63	23.44

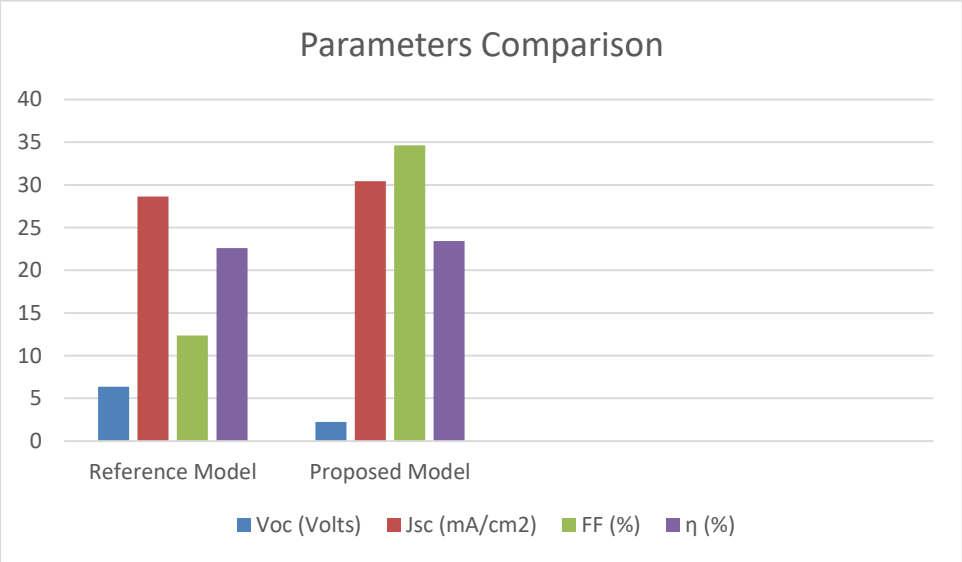


Figure 7: A bar chart comparison of parameters

V. Conclusion

A theoretical approach has been followed in this paper to study the comparison of the CdTe solar cell with & without BSR layer. To examine the performance of cadmium telluride solar cell structure various numerical analysis has been done. Qualitative as well as quantitative approach has been considered through various material parameters. A layer called BSR is mainly added and analysed by using a band gap material called Cu_2Te and corresponding effects on the parameters are observed as mentioned above. There is a quite impressive improvement in the efficiency of around 3.671% as compared to the reference model having no BSR layer. The presence of interface and absorber layer led to the formation of barrier, which leads to recombination of charge carrier, & hence it hamper the performance of the cell. Future work can be taken forward by analyzing the improvement of efficiency by replacing the BSR layer with different band gap materials such as ZnTe, p^+CdTe, etc.

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