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A High Efficiency Ultrathin CdTe Solar Cell for Nano-Area Applications

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Abstract

Due to limited availability and the rising price of telluride, the biggest challenge in solar Photovoltaic (PV) is to successfully design and fabricate optimized CdTe solar cells with reducing the cell thickness that show simultaneously high efficiency and current density. A novel structure of ultrathin CdTe solar cells is proposed in this paper that focuses on conversion efficiency. This structure achieved by rotating 90° in the base line structure that suggests high efficiency due to the high current density. The result showed a considerable improvement over the 15% efficiency of the reference solar cell. The proposed structure is quite noteworthy in reducing the amount of material used and associated losses. Under global air mass (AM) 1.5 conditions, an open-circuit voltage (V_{oc}) of 866 mV, a short-circuit current density (J_{sc}) of 74.84 mA/cm^2, and a fill factor (FF) of 48.2% were obtained corresponding to a conversion efficiency of 31.2%.

Keywords

CdS/CdTe Solar Cell, Conversion Efficiency, Nano-Area Applications

1. Introduction

Because of greater potential in low cost, high efficiency and stable solar cell fabrication, thin film polycrystalline CdS/CdTe solar cells are one of the most promising candidates for photovoltaic energy conversion in recent years. The CdTe has long been a leading material in thin film solar cell fabrication due to high optical absorption coefficient and ideal band gap of 1.45 eV. The most important parameter that affects photon absorption is

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thickness of the CdTe layer [1]-[4]. Due to limited availability and the rising price of Te with regards to very high volume photovoltaic module manufacture in the future, reducing the CdTe absorber layer thickness is an attractive prospect. Another advantage is that overall material consumption will decrease along with module production costs. Avoiding pin-hole formation and maintaining the photocurrent generation are the challenges in using ultrathin absorber layers. One of suitable materials for window layer of CdS/CdTe solar cells is CdS film. Thinner CdS films cause higher J_{sc} [3]-[6]. 28% - 30% are the maximum theoretical efficiency for CdTe solar cells [7] [8]. In the last 17 years, cell efficiency of CdTe solar cells has been increased by only 1.5% [9]-[13]. The reported maximum cell efficiencies for the CdTe solar cells were between 16% and 16.5% [14]-[17]. The NREL verified cell efficiency of 20.4% and a module efficiency of 14% were reported by First Solar [18]. One of the current hot research topic and the challenge facing the researchers in the CdS/CdTe thin film solar cells is increasing efficiency and decreasing the gap between the actual efficiency and the theoretical limit.

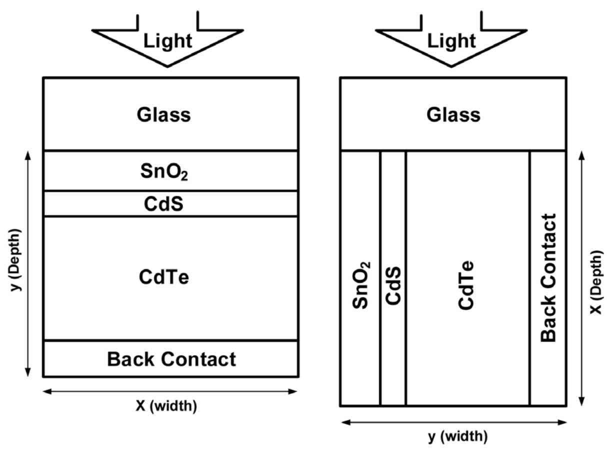
In this paper, an ultrathin structure of CdTe solar cells has been proposed with high conversion efficiency for nano-area applications [19]-[30]. This new structure has achieved by rotating in the base line structure. The paper is organized as follows: Section 2 describes the analysis of conventional and proposed structures; and its validation. Section 3 presents the obtained numerical results and discussion. Finally, in Section 4, we conclude.

2. Analysis of Conventional and Proposed Structures, and Its Validation

The useful tool to analyze the solar cell performances is numerical modeling. The mechanism of such structures could be evaluated by numerical simulations enabling the design of new structures with better efficiency and stability. The starting point of this work was the baseline case as reported in [16]. In brief, the CdTe device model in the base line case consists of a 4 µm-thick CdTe absorber layer, a 100-nm thick CdS window layer, and a 500-nm-thick SnO_2 buffer layer. Most of the important electronic parameters are listed in **Table 1**. The values have been chosen on the basis of theoretical considerations, experimental data and existing literature.

The energy of back barrier in CdTe layer was low about 0.3 eV. It is assumed that 5% of the incident light was reflected at the front contact. The electron lifetime of 0.5 ns was used in the CdTe absorber layer of the baseline case. Using the mentioned parameters, the baseline solar cell parameters were V_{oc} = 0.865V, J_{sc} = 25 mA/cm^2, FF = 73%, and η = 15.7%. At the next step, this structure was modified by rotating 90˚ of the structure without dimension variation. **Figure 1** illustrates the CdTe baseline case structure and the modified structures investigated in this study.

The proposed structure has many advantages such as high photogeneration and low recombination rate. The J_{sc} of the cell can be improved by reducing the carrier recombination losses at the back contact or increasing the photogeneration rate in the absorber layer. Because the light inters to layers independently, the photogeneration rate is high in each layer. **Figure 2** shows the comparison the photogeneration rate between conventional and proposed structure.



(a) (b)

Figure 1. Structures of the CdTe solar cells: (a) baseline case structure and (b) modified cell structure for higher efficiency.

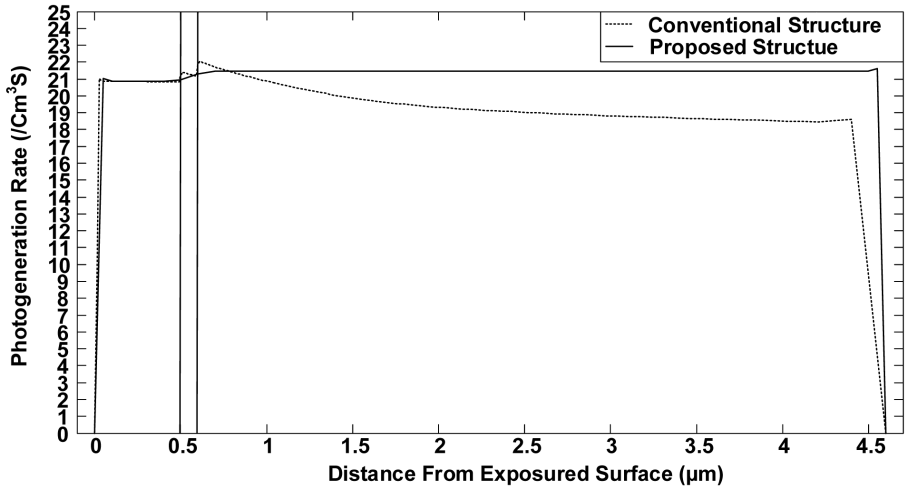


Figure 2. Photogeneration rate for the conventional and proposed structure.

Table 1. Best cell parameters including layer properties and defect states.

Parameters Unit	CdS	SnO_2	CdTe
Layer Width D [nm]	100	500	4000
Dielectric Constant $\varepsilon/\varepsilon_0$	10	9	9.4
Electron Mobility μ_e [cm^2/Vs]	100	100	320
Hole Mobility μ_h [cm^2/Vs]	25	25	40
Electron/Hole Density n, p [cm^{-3}]	n: 10^{17}	n: 10^{18}	p: 2×10^{14}
Band Gap Energy E_g [eV]	2.4	3.6	1.5
Effective Density of States N_C [cm^{-3}]	2.2×10^{18}	2.2×10^{18}	8×10^{17}
Effective Density of States N_V [cm^{-3}]	1.8×10^{19}	1.8×10^{19}	1.8×10^{18}
Acceptor/Donor Defect Density N_{DG}, N_{AG} [cm^{-3}]	A: 10^{17}	A: 10^{15}	D: 2×10^{14}
Defect Peak Energy E_A, E_D [eV]	Midgap	Midgap	Midgap
Distribution Width W_G [eV]	0.1	0.1	0.1
Electron Capture Cross Sectionσ_e [cm^2]	10^{-17}	10^{-15}	10^{-12}
Hole Capture Cross Sectionσ_h [cm^2]	10^{-12}	10^{-12}	10^{-15}

One of the main goals of today's solar cell research is using less semiconductor material by making the cells thinner. The thinning saves material and reduces the recombination loss as well as lower production time and the energy need to produce them. Therefore, all of these factors will decrease the production cost. Hence, it is possible to reduce the dimension of proposed structure considerably and achieve better base line results, simultaneously. **Figure 3** shows the current-voltage and power-voltage curves for comparison with the base line case. As can be seen from **Figure 3**, the conversion efficiency can be increased to 31.2% mostly due to improvement of J_{sc} compared to the base line case. Although FF is smaller than base line case because of the high difference between J_{sc} and maximum current of the cell, the important parameters of the solar cell are much more than base line case. **Figure 4** and **Figure 5** show the characteristics of the proposed cell by decreasing the cell depth.

It is clear from **Figure 3**, the J_{sc} decreases and V_{oc} increases by reducing the depth. Therefore, cell has a lower FF. Moreover, the variation of the J_{sc} in the lower depth is higher than large depth. **Figure 6** shows the cell efficiency and FF of the proposed structure as a function of depth. Because of reducing the depth corresponding to a thinner cell, photogeneration rate decreases. As a result, the efficiency of the cell is decreased. It can be seen from **Figure 5** by decreasing the depth up to 0.1, the cell efficiency is still better than base line case.

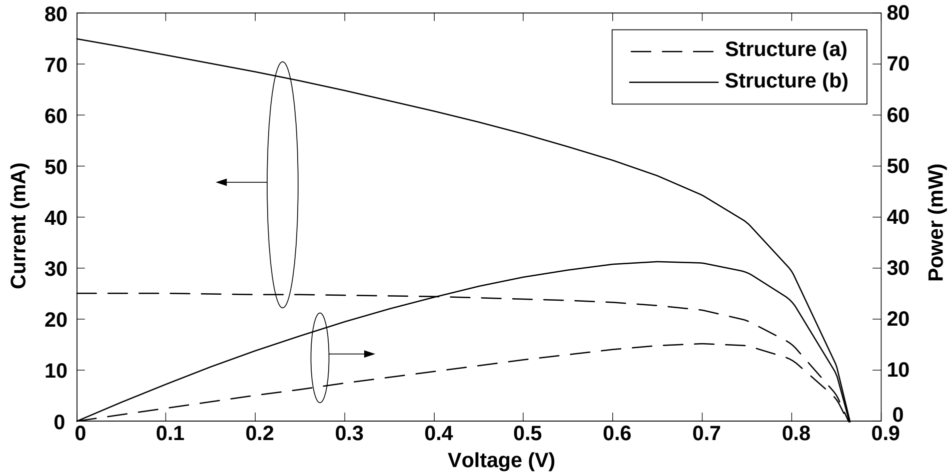


Figure 3. Characteristics of the (a) baseline case structure and (b) modified cell structure for higher efficiency.

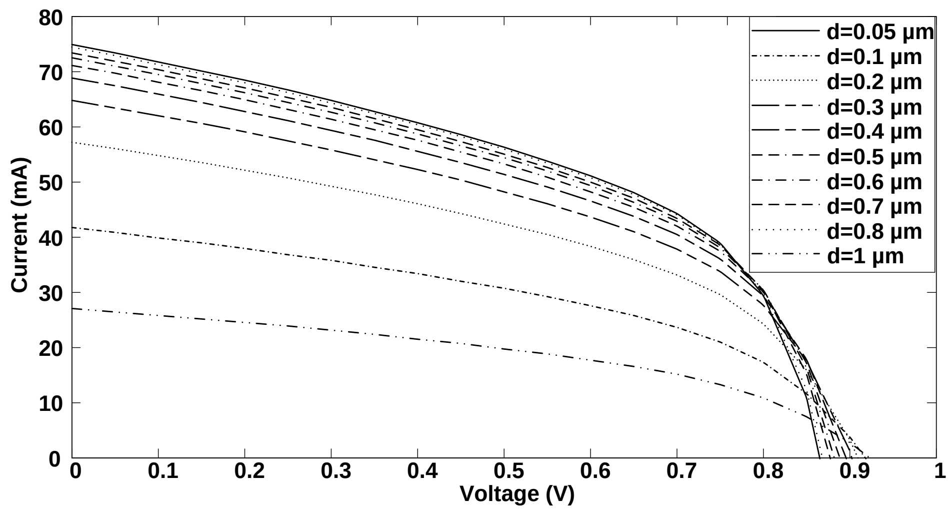


Figure 4. Light J-V curves of the cell with the lower depth (d).

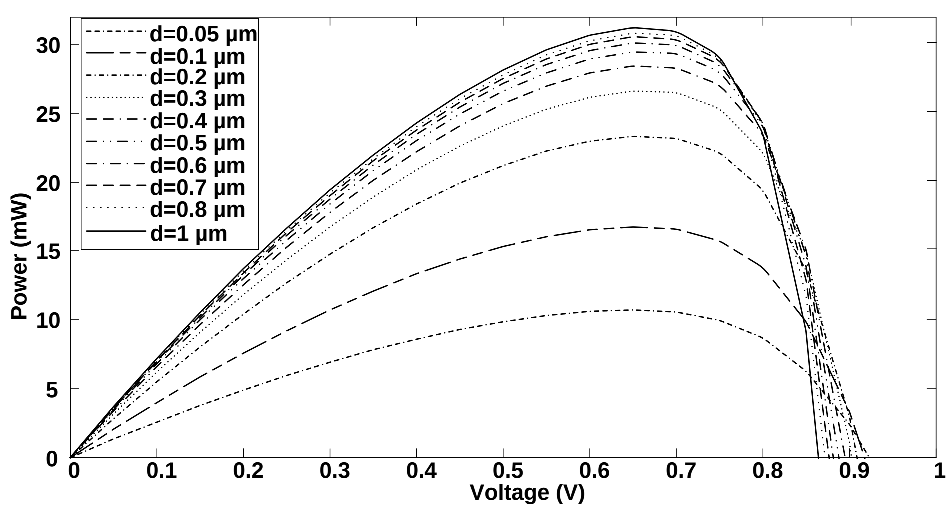


Figure 5. Power curves of the cell with the lower depth (d).

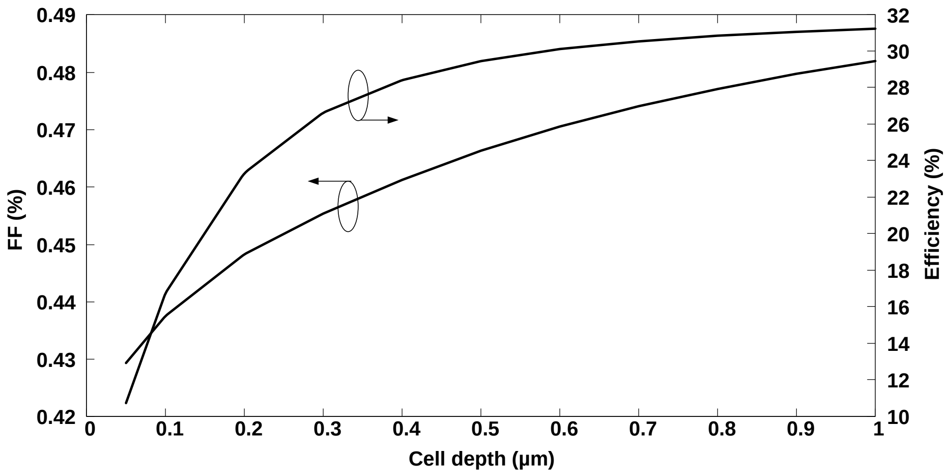


Figure 6. Efficiency and FF of the cell as a function of the cell depth.

3. Results and Discussion

The CdTe absorber thickness have to decreases below the absorption limit of 1 μm in order to reduce material usage and to address carrier recombination loss throughout the absorber layer. Generally, the absorber layer thickness in thin film CdTe solar cells is between 2 and 10 μm. In order to avoid pinholes reaching through to the window layer, thicker absorber layers are used that may lead to shorting from the back contact. Cell performance depends on CdTe thickness and the magnitude of photocurrent generation loss, especially for the very thin CdTe layers. Decreasing the CdTe thickness would minimize series resistance as well as cost of the material. As mentioned above, if the absorber layer is reduced, the carrier generation relative to less absorption would be low and vice versa.

Figure 7 and **Figure 8** show the characteristics of the proposed structure for the various thickness of the CdTe layer. As it is shown by **Figure 6**, J_{sc} is considerably decreased by decreasing the thickness of the CdTe layer due to reduced photon absorption resulting to a lower photocurrent and it is negligible by increasing the thickness. The V_{oc} is increased with absorber thickness, due to an increase in the photogenerated current as the absorption volume is increased. Because the generated carriers by incident photons must travel through the CdTe thickness and they experience a high series resistance to arrive to the back contact, CdTe thickness increment is limited. Thus, the current density is decreased resulting to low cell efficiency.

In the proposed structure, the simulation results showed that for a CdTe thickness more than a critical value, the efficiency was decreased. Thus, increase of efficiency by thickness is limited by a maximum value. **Figure 9** shows the variation of efficiency and FF as a function of CdTe thickness. As shown in **Figure 9**, the efficiency is decreased when the CdTe thickness is reduced. The reason is the carrier generation losses. The FF can be improved by reducing the thickness of CdTe absorber material. As a result, J_{sc} and V_{oc} are decreased and the FF is increased.

In this section the effect of CdTe doping on the important parameters of CdTe solar cell is studied. If the doping of the CdTe is decreased, the absorption and the percent of the light arriving to the CdTe layer converting to the current would be decreased. Therefore, current density is decreased resulting in a loss in efficiency. The V_{oc} of the cells can be improved by higher carrier density of CdTe (~10^{15} cm^{-3}) and higher absorber lifetime (>1 ns) and reducing the back contact barrier height. So, product of J_{sc} and V_{oc} becomes low resulting in a high FF. **Figure 10** and **Figure 11** show the characteristics of the proposed structure as a function of CdTe doping variation.

Figure 12 shows the FF and efficiency of the proposed structure as a function of CdTe doping. As mentioned above, CdTe decrement results in a lower efficiency and higher FF.

4. Conclusion

In this paper, a new structure of CdS/CdTe solar cell is proposed which is achieved by rotating 90˚ in the base line structure. The result showed a considerable improvement over the 15% efficiency of the reference solar cell.

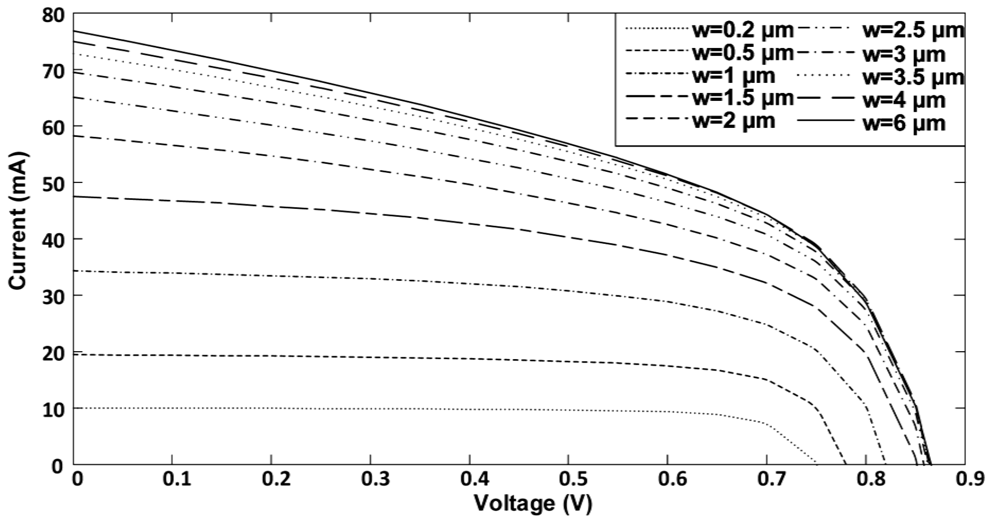


Figure 7. Light J-V curves of the cell with the lower CdTe thickness.

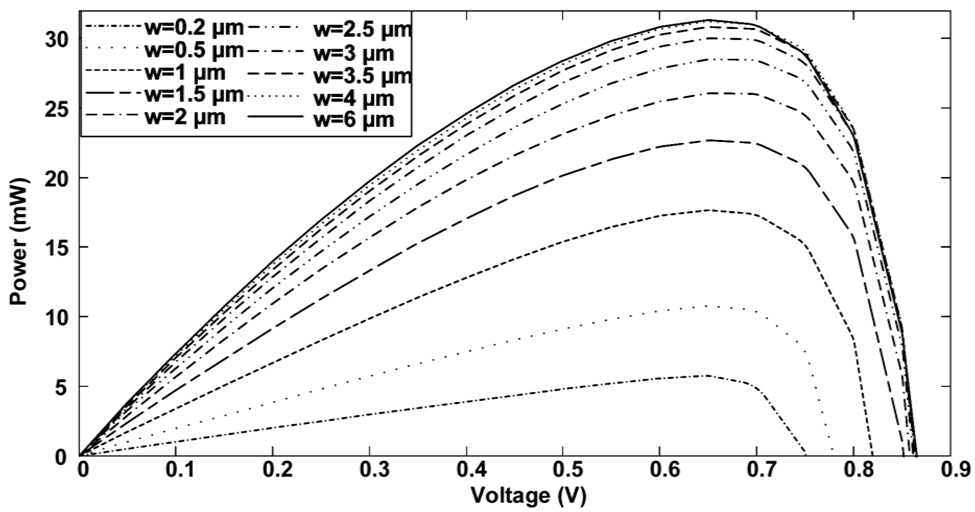


Figure 8. Power curves of the cell with the lower CdTe thickness.

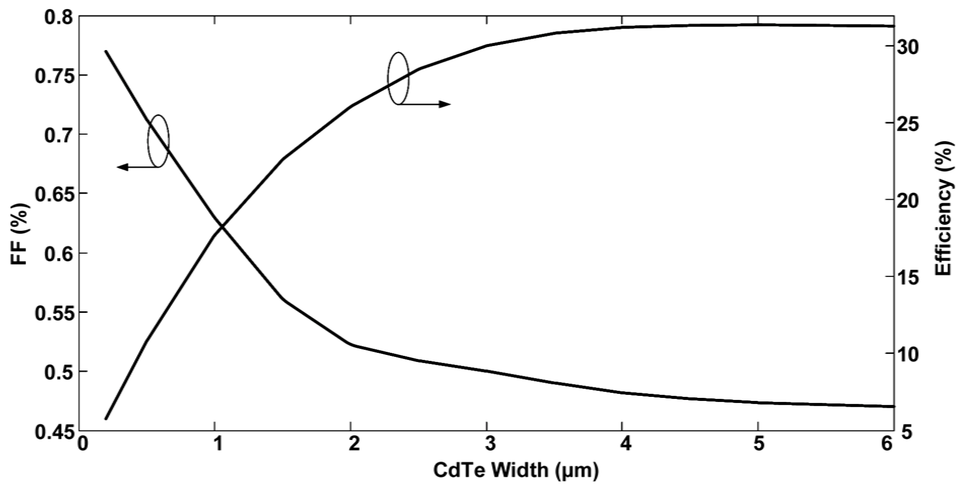


Figure 9. Efficiency and FF of the cell as a function of the CdTe thickness.

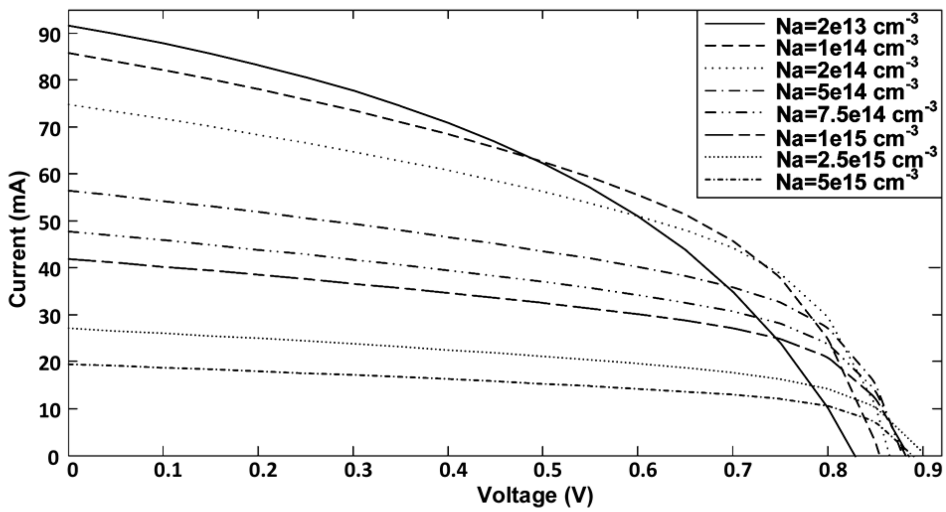


Figure 10. Light J-V curves of the cell with different CdTe doping.

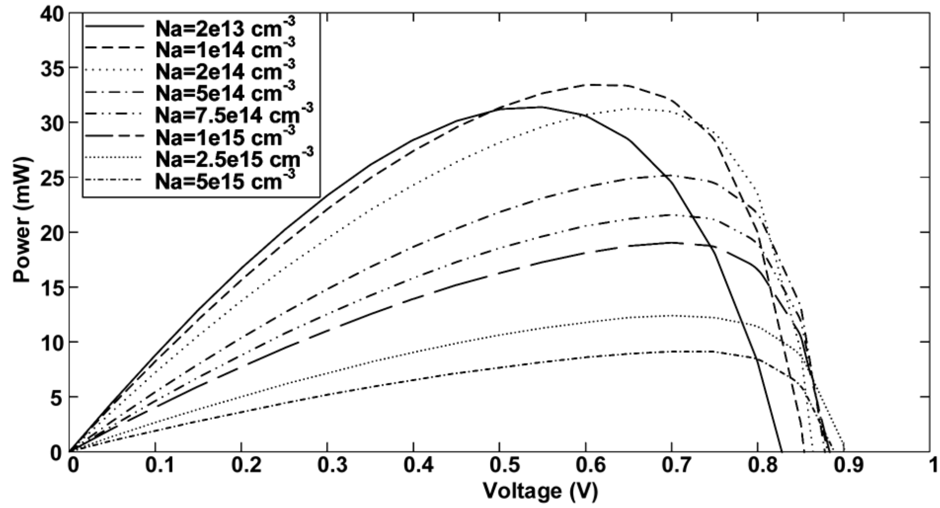


Figure 11. Power of the cell different CdTe doping.

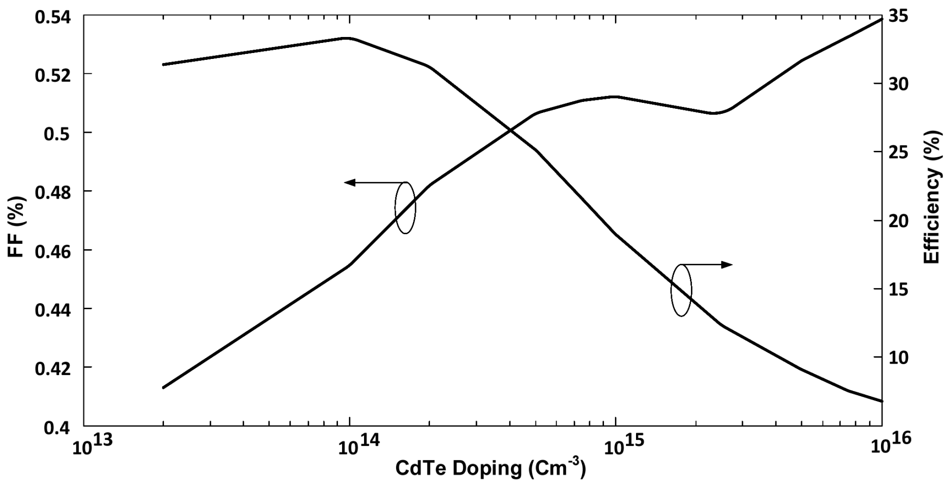


Figure 12. Efficiency and FF of the cell as a function of the CdTe doping.

This structure showed acceptable efficiency which is quite noteworthy in reducing the amount of material used and associated losses. It was shown that 0.1 µm of CdTe absorber layer was sufficient to produce conversion efficiency over 15%. The proposed cell had a V_{oc} of 866 mV, a J_{sc} of 74.84 mA/cm^2, and a FF of 48.2%, corresponding to a conversion efficiency of 31.2% under global AM 1.5 conditions.

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