ISSN Online: 2756-3898, ISSN Print: 2714-500X https://doi.org/10.47514/phyaccess.2024.4.1.006

# The Effect of Work Function of Back Contact Metals on the Performance of CdTe Solar Cells

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Received 18-03-2024
Accepted for publication 15-04-2024
Published 17-05-2024

## Abstract

The CdTe thin film solar cells suffer power losses at the back contact due to charge losses due to poor mismatch of the work function of interfacing back contact materials. Thus, there is a need to find appropriate back contact materials that do not reduce cell performance by creating large Schottky barriers. One of the established strategies employed to reduce the barrier height is depositing metal(s) with high work function to the CdTe back surface. In this study, we used the average of the commonly reported values of the work function of metals, to investigate the effects of various metals, when used as back contacts, on the performance of CdTe solar cells. Without any other strategy employed to overcome the Schottky contacts, the solar cells' efficiency is gravely diminished when metals with work functions lower than 5.0 eV are used. While metals like Pt, Pd, and Au with very high work functions produce cells with efficiencies of up to 18.6%, lower work functions metals like Al almost completely diminished the efficiency to less than 0.5%. our findings indicate that the Schottky barrier affects mainly Voc and FF, as Jsc showed only a slight reduction. When subjected to extreme operating temperatures, the efficiencies largely decreased with temperature. Temperature coefficients of -0.3 to -0.45/$^{o}$C have been obtained, for the highest-performing metals.

Keywords: CdTe; Back contact; Schottky barrier; work function; efficiency.

## I. INTRODUCTION

The second generation solar cells have attained high attention as a possible replacement for the first generation, silicon crystalline solar cells due to several production and cost advantages they enjoy. These thin film solar cells are fast taking strategic relevance in the renewable energy sector due to their strong potential for low-cost, clean energy supply sources. Even amongst the thin film cells, CdTe has been recognized as a strong candidate for future photovoltaic devices [1]. This is due to its ideal and direct bandgap of 1.5 $V$ with high optical absorption, and easy and multiple fabrication processes [2], [3]. Solar cells based on CdTe absorber have been developed using more than 14 methodologies with close-spaced sublimation producing the highest cell efficiency [3], [4]. Cadmium telluride (CdTe) thin-film PV modules are the primary thin-film product on the global market, with more than 30 GW peak (GWp) generating capacity [5]. Currently, industrial production has started by First Solar, reaching a production of about 1GW in 2009, the highest PV production by any single manufacturer [6]. CdTe thin-film solar cells have achieved impressive conversion efficiencies greater than 22% [5], [7]. Despite the success recorded by this PV technology, there are still areas of serious concern in CdTe solar cells. Among the most important of them is the problem of producing ohmic back contact, for better cell performance [3], [5], [7], [8]. CdTe semiconductor with a bandgap of 1.5 eV, has a high electron affinity of 4.28 eV, thus, to form a non-rectifying metallic contact, a metal with a high work function is required to form such back contacts [9]. Most metals do not have a work functions that is sufficiently high, resulting in an energy barrier known as the Schottky barrier, created at the interface, which results in a rectifying, non-ohmic contact. Thus, back contacts on CdTe/CdS solar cells often show this non-ohmic behaviour in their J-V characteristics which is attributed to the Schottky barrier. This Schottky barrier acts as a diode reverse biased to the CdTe/CdS junction diode and increases the contact resistance, thereby reducing the solar cell performance [8], [10]. The resultant series resistance affects the fill factor (FF) and eventually open-circuit voltage (Voc). Although other strategies, such as heavy p-doping and use of back contact interlayer are usually employed to reduce this effect, using an appropriate metal with high work function is basic. Thus, this study investigates the potential outcome of using various metals in this regard. Five metals have been studied by simulating each in a typical simple CdTe solar cell and their effects on the cell performance were analyzed. The metals studied in this study were, in descending order Platinum (Pt), palladium (Pd), gold (Au), nickel (Ni), and silver (Ag). These were the metals with the highest work function. The efficiency of cells with these metals varied from around 7 to 18.64%. The thermal stability of the best cells was also simulated and found that their performance largely decreases with temperature.

The Analysis of Microelectronic and Photonic System 1-D software was used for the simulation of all the proposed solar cell structures. The choice of this software was due to its availability as well as its good performance in the simulation of thin film solar cells, as reported in [11]. This study aimed to investigate and compare the performance of the CdTe solar cell with different metals used as back contact. This could enable a better understanding of the significant effects of the work function of these metals on the performance of the devices and widen the choices available in selecting suitable and cost-effective back contact structures. From the several output parameters produced by this software, the following were used for this study: short circuit current (Jsc), open circuit voltage (Voc), fill factor (FF), and efficiency (η), while the J-V characteristics output was also used in the analysis of the simulated cells.

## II. SIMULATIONS RESULTS

Simulations of the effects of metallic back contacts were carried out using AMPS-1D, by establishing a simple CdTe cell structure with tin oxide ($SnO_2$) as front contact in the form of glass/$SnO_2$/CdS/CdTe/Metal. Both $SnO_2$ and CdS thicknesses were fixed at 100 nm, while the CdTe absorber was fixed at 1000 nm. The ambient temperature was set at 25 ℃. The parameter values of materials used in the simulations were obtained from the results of experiments, literature, established theory, and reasonable estimates, based on previous works. The most general values of these parameters are presented in Table I.

In this study, the device output parameters were Jsc, Voc, FF, and efficiency. The results of the simulations are presented as plots of these parameters with metal/work function, as in Fig. 1. It was observed that the efficiency of the cells was between 7 and 18.6%.

To determine the temperature stability of the cells with various metal contacts, the operating temperature of each cell was varied from 20 to 100 ℃, and the cell's outputs were studied. The results of these are presented in Fig. 3. Similarly, the J-V characteristics of these cells were analyzed with the results shown in Fig. 4.

Table I. Material parameters used in the simulations

| Parameter | $W$ $(nm)$ | $\varepsilon/\varepsilon_0$ | $\mu_e$ $(cm^2/Vs)$ | $\mu_p$ $(cm^2/Vs)$ | $n,p$ $(cm^{-3})$ | $E_g(eV)$ | $N_C$ $(cm^{-3})$ | $N_V$ $(cm^{-3})$ | $\chi$ $(eV)$ |
|---|---|---|---|---|---|---|---|---|---|
| n-SnO2 | 100 | 9.0 | 100 | 25 | $10^{17}$ | 3.6 | $2.2\times10^{18}$ | $1.8\times10^{19}$ | 4.5 |
| n-CdS | 100 | 10.0 | 100 | 25 | $10^{17}$ | 2.42 | $2.2\times10^{18}$ | $1.8\times10^{19}$ | 4.5 |
| p-CdTe | 1000 | 10.2 | 320 | 40 | $5\times10^{15}$ | 1.45 | $7.5\times10^{17}$ | $1.8\times10^{19}$ | 4.28 |

## III. DISCUSSION AND ANALYSIS

From the plots of the cell output parameters of Fig. 1 and 2, all the parameters, Jsc, Voc, FF, and efficiency increased with the work function of metals used. However, a careful observation indicates that while the Jsc showed a uniform rise with an increase in work function, the Voc response appeared stratified into about four stages. This could be attributed to the sensitivity of Voc to the barrier height as proposed in [10]. In this study, aluminium, which has the smallest work function (4.2 eV) produced cells with a Jsc of 18.75 mA/cm$^2$, which is 75% of that of platinum, which has the highest work function of metals, with a Jsc of 24.92 mA/cm$^2$. However, their corresponding differential in Voc and FF ratios were 5.7% and 4.6% respectively.

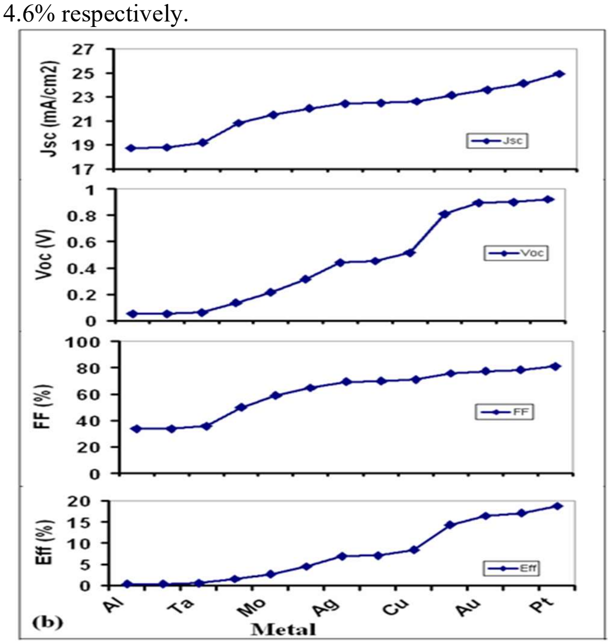


Fig. 1 Dependence of cell performance on Metal.

This implies that the Schottky barrier especially affects the Voc and FF of cells. This is because metals of lower work function produce a higher Schottky barrier, leading to higher resistance and thus lower FF and Voc, as deduced by [12].

Nevertheless, Jsc was also slightly affected since the transfer of charges across the junction is limited by the barrier.

For the thermal stability, results of Fig. 3, showed that while Jsc increases slightly with temperature, Voc, FF, and efficiency show a more pronounced reduction. This is because, at higher operating temperatures, the bandgap of the semiconductors decreases, thus reducing the blue response of the cell as well as Voc and FF [13].

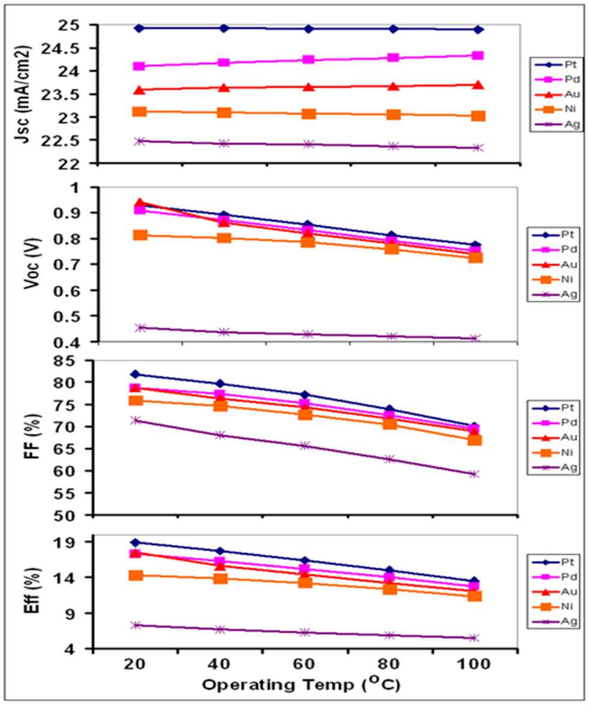


Fig. 2 Thermal stability of best cells.

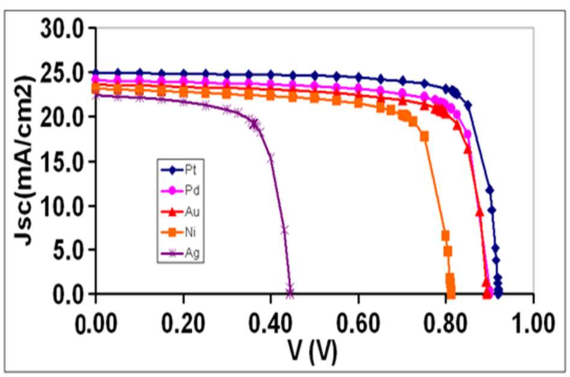


Fig. 3 J-V Characteristics of 5 best cells.

The temperature coefficient of the cells' efficiency was calculated as $-0.067\%/°C$ (Pd), $-0.057\%/°C$ (Pt), -0.068%/°C (Au), $-0.037\%/°C$ (Ni) and $-0.023\%/°C$ (Ag). This trend indicates that lower efficiency cells are more stable, thermally, with Ag-based cells exhibiting the best stability, even though the J-V characteristics of the cells show that Ag cells have the lowest performance of all the 5 best-performing cells. Here also, it is evident that the effect of the barrier is more pronounced on the Voc and FF than on Jsc.

Despite these results, the importance of lower work function metals in CdTe back contacts is still very important. This is because other strategies are usually employed, such as heavily doping p-CdTe and the use of interlayer helps in improving the metallic contact and cell performance, especially with the rare and high cost associated with metals with higher work function [12].

## IV. Conclusion

In this study, the performance of CdTe solar cells was investigated for different back contact metals, having varying work functions. Results indicated that the performance of the cells improved with a higher work function of the back contact metals, resulting in an efficiency variation from 7 to 18.6% between the lowest and highest work function metal back contact. This was because Voc, Jsc, and efficiency all improved with increasing work function of the metal used as back contact. This confirmed the idea that using back contact metals with higher work function produces better Ohmic contact which leads to more efficient solar cells. For temperature stability, it was found that there was a reduction in efficiency with an increase in temperature, with the cells with the highest efficiency exhibiting the highest temperature coefficient $-0.068\%/°C$. These results indicate that good ohmic contact, obtained from back contact metals with high work function produces more efficient cells. This is due to the reduction in the Schottky barrier formed at the back contact of these cells, indicating the significance of using high-work function metals in these back contact structures.

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