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Review of Front Contact for CdTe Solar Cells

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Abstract- *CdTe thin film cells at present have achieved 22.1% efficiency as revealed by First Solar. However, that rate appears to be prepared to increment. While these cells have been restricted by their low efficiency, late advancements have extraordinarily enhanced their operational effectiveness. If this improvement continues, CdTe thin-film solar cells could soon rival crystalline silicon both in cost and performance. Specialists are working constantly to enhance the current conditions. This paper audits a few methods, for the most part, to take care of the issue related to the front contact of CdTe solar cells.*

Keywords: CdS/CdTe solar cells, TCO layer, Bilayer CdS Thin film, HRT layer and Anti Reflection Coating layer.

1. INTRODUCTION

Energy is key to the nature of our lives. These days, we are absolutely reliant on a bottomless and continuous supply of energy for living and working. It is a key fixing in all parts of present day economies. Worldwide sustainable power source capacity and output have expanded quickly and keep on growing at a remarkable pace, especially in the power area. Among different sustainable power source, sunlight based energy is the cleanest and most bottomless sustainable power source accessible. Thus, photovoltaic research groups from over the world are emphasizing on development in the PV conversion technology. This work has been coordinated to grow superior CdTe (Cadmium Telluride) solar cells, a potential possibility for thin-film cells and make commitment to the improvement of photovoltaic innovation, besides, it might give course of action against future energy crisis.

Cadmium Telluride is a polycrystalline material, which is a good absorber material has wide acceptance in thin film technology. Because it has a good band gap energy about 1.45 eV which is close to solar cells optimum band gap about (1.5 eV). It has better absorption coefficient, which is greater than 5×10^5 cm^{-1}. Due to better absorption coefficient, large number of incident photons whose energy is greater than the band gap energy will be absorbed in few microns of the absorber layer. So, required amount of absorber layer is smaller than other materials. Because of this, it is cost effective. Due to thin layer, material is saved, again recombination loss is reduced. Moreover, it has better performance in AM1.5 illumination.

For CdTe based solar cells, CdS is the most suitable hetero junction partner [1]. It consists about 2.45 eV band gap and used as window layer. CdTe solar cells are generally manufactured in superstrate configuration. The basic structure is shown in Fig. 1.

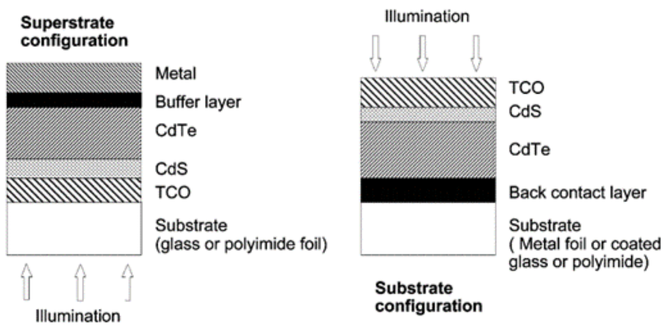

Fig. 1: Schematics of the CdTe solar cells in conventional ‘superstrate’ and ‘substrate’ configurations

The performance of CdTe solar cells was investigated on different front contact bi-layer combination. ZnSnO films seem to offer the best option for lessening the CdS thickness without reduction in *Voc* and FF [2]. Additionally a numerical examination was directed using AMPS simulator to investigate the likelihood of higher efficiency and stable CdS/CdTe cell among seven distinctive cell structures with tin oxide (SnO_2) and cadmium stannate (Cd_2SnO_4) as front contact layer, zinc oxide (ZnO) and zinc stannate (Zn_2SnO_4) as buffer layer and Ag or antimony telluride (Sb_2Te_3) with Mo as back contact material. This examination has demonstrated that Cd_2SnO_4 front contact, Zn2SnO4 buffer layer and Sb2Te3 back Contact materials are appropriate for high efficiency ,greater than 15.5% and stable CdTe based cells [3]. A 14.5% efficient CdTe thin-film solar cell with a mono-grained CdS window layer was created in 2014 [4]. Utilizing distinctive dyes in LDS strategy it is discovered 26.3% relative increment in conversion efficiency for CdTe cells under the AM 1.5G range [5]. Multi-junction layers containing CdTe/CdS/ZnO photovoltaic cells were fabricated and found that efficiency fluctuates with the thickness of the absorber layer [6]. Strategies coming up lately are mainly focused on short minority carrier lifetime because of recombination of EHP at the defect centers in CdTe layers. A few adjustments to conventional strategies and new systems have been investigated to move forward. Efficiency as high as 15%-15.8% has been achieved by Bosio et al. [7] by utilizing R.F. sputtering procedure in the atmosphere of Ar (argon) containing around 3% of CHF_3. The light intensity through the air–glass interface can be increased using multi-layer anti reflection (MAR) coating [8]. Researchers mainly focus on following fields: (1)Boosting efficiencies by, among other things, exploring innovative transparent conducting oxides that allow more light into the cell to be absorbed and that collect more efficiently the electrical current generated by the cell, (2) studying mechanisms such as grain boundaries that can limit the voltage of the cell, (3) understanding the degradation that some CdTe devices exhibit at contacts and then redesigning devices to minimize this phenomenon and (4) designing module packages that minimize any outdoor exposure to moisture. So there are many scopes of research regarding to CdTe based solar cells. This paper intends to review the possibility of advancement of CdS/CdTe photovoltaic by structural modification of front contact of CdTe solar cells.

2. STRUCTURAL MODIFICATION

One way to improve the performance of a CdS/CdTe solar cell is the modification of the configuration. Also fabrication technique should be carefully picked with the thought of excellent thin-film structure and cost effectiveness. There are several methods of fabrication including screen printing method [9], close spaced sublimation [10], metal organic chemical vapour deposition, chemical bath deposition and R.F. sputtering [11]. In this section, effects of different layer insertion in the front contact of CdTe solar cells are discussed.

2.1 Effect of Transparent Conductive Oxide layer

There is optical and recombinational loss due to the absorber layer thickness. For the CdTe layer of large thickness (about 2000 nm), the absorptivity of photons is higher but it reduces to ≈ 93% at a layer thickness of (below 1000 nm).

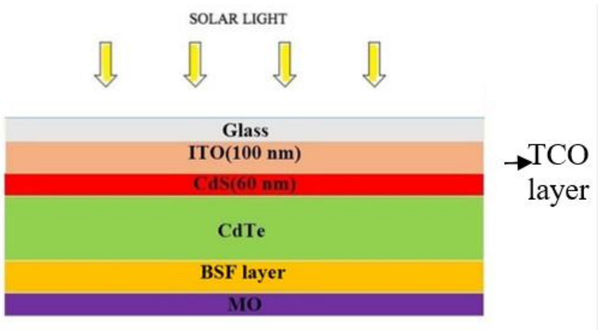

Fig. 2: Structure of standard TCO/CdS/CdTe thin film solar cells.

Transparent Conductive Oxide layer as commonly known as TCOs are utilized as transparent electrodes in solar cells as shown in Fig. 2[12]. TCO is used to converge light on solar cell. When Transparent Conductive Oxide (TCO) layer is used in optimized cell, then the performance of the cell is increasing, because it reduces the photon loss and increases short circuit current density. Due to use of TCO layer, number of photons striking on absorber layer increases, which produces more electron. So, short circuit current density and overall efficiency of the cell increase.
High electronic conductivity and good visible transparency should be ensured. In addition, another important factor is the energy band alignment with the CdS/CdTe layer [13]. Keeping in mind to choose the suitable thickness of the TCO layer, an inverse relationship between the TCO sheet resistivity and the TCO thickness is taken into account. For this reason, the optical and electrical properties of the TCO layer also should be considered. With the increase of conductivity, there may be an adverse effect on optical transparency of TCO films. A trade off must be done between resistivity, mobility and carrier concentration. It is suggested to use HMTCO layer, since the reduction in resistivity of TCO films is possible by increasing mobility instead of carrier density. These relations are expressed in the following equation (1), where Carrier density N, resistivity , mobility and electron charge e.

$$\frac{1}{\rho} = N\mu e \qquad (1)$$

It is recommend to use a TCO material of wide band gap (>3 eV) and high mobility, greater than 62.5 $cm^2V^{-1}S^{-1}$ and sheet resistivity less than 10^{-3} Ωcm. Based on electrical and optical properties ,Indium Tin Oxide (ITO) has been chosen as TCO layer. ITO has low reflectance and better band alignment with the Cadmium Sulphide. Again high mobility transparent conductive oxide layer is preferred. ITO has mobility of 103 cm2/V-sec [13].

2.2 Bilayer CdS Thin-Film

Smooth and uniform Cadmium Sulphide (CdS) layers can be obtained by the bilayer structure which in result may provide smaller grain size without any pinholes or weak diode problem. In CdTe thin film solar cells high efficiencies cannot be obtained by direct contact of the absorber (CdTe) with the TCO. Carefully fabricated bilayer CdS films could solve the non-uniformity problem. Bilayer CdS thin film configuration is shown in Fig. 3.

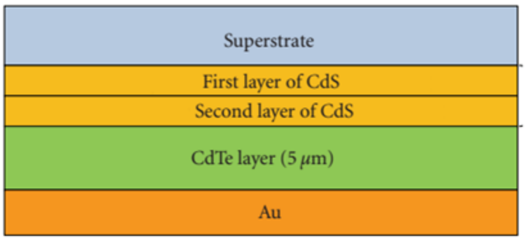

Fig. 3: Bilayer Structure of CdTe solar cells

Moreover, thinner CdS film in bilayer configuration provide high Short circuit current and better performance [7].

2.3 Effect of High Resistive Transparent Layer

To retain the maximum amount of photons on the absorber layer a thin CdS window layer is required. The window layer material (CdS) may have significance impact. CdS layer with thickness of above 125nm confirms high open circuit voltage (*Voc*) provided good properties of the remaining layers of the solar cell but limits a number of photons that could reach the p-n junction of the solar cells and results in poor collection of photocurrent. Then again, thin CdS layer allows more photons to reach the p-n junction, producing higher photocurrent but *Voc* of the device is decreased. This reduction of *Voc* is based on assuming that thin CdS films are full of imperfection and discontinuities that permits the development of parallel weak diodes called pinholes between the CdTe and the Transparent Conductive Oxide (TCO) layer [14]. The effects of non-uniformities mentioned above, can be reduced by introducing a thin, high resistivity transparent buffer layer between the conductive electrode and the semiconductor diode. It improves open circuit voltage and fill factor. A CdS/CdTe solar cell with HRT layer is shown in Fig. 4.
Due to shunt effect, a portion of the current will flow in inverse direction which results in decrease of net current flow through the load .As a result, efficiency is also reduced. If High Resistive Layer (HRT) is used then opposite direction current can be prevented. ZnO is explored as a high-resistivity transparent buffer layer for CdTe solar cells.

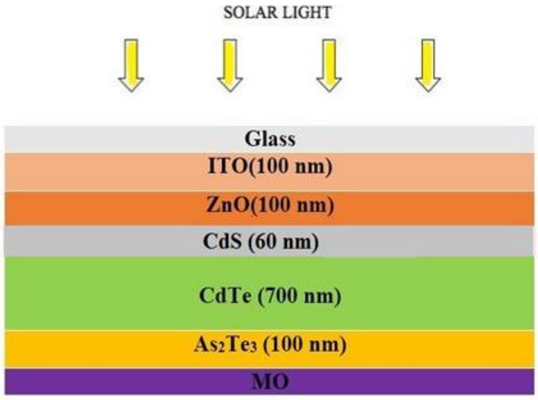

Fig. 4: CdS/CdTe Solar cell with HRT layer

Typically HRT layer is of 100 nm. ZnO can be considered as both TCO and HRT layer, so ZnO is processed to have the necessary resistivity that allow it to be used as a high-resistivity transparent layer.

2.4 Effect of Anti Reflection Coating Layer

Optical losses totally cannot be reduced due to reflectivity on the surface of the cell. The glasses which are on top contact are not 100% anti-reflective. They reflect some photons from the incident light. To solve this problem, an Anti-Reflection Coating, commonly known as ARC is used on top contact. It reduces reflectivity and increases transmittance of light.
Anti-reflection coating plays a vital role in solar cell device as it reduces optical losses due to spectral mismatch. Significant improvement in solar cell efficiency can be obtained using anti reflection coating (ARC). To cancel the reflection at a given wavelength, it is necessary that generation of two reflections which interfere destructively with each other taking into account the thickness of the layer [15]. The material used as the anti-reflection layer should be non-absorbing in the range of the solar spectrum.
Single layer antireflection coatings are generally calculated for a midrange wavelength like 550 nm (green). With the assumption of a coating thickness of a quarter wavelength in the medium, the reflection can be calculated by using the normal incidence reflection coefficient.
The general equation for reflection of light, considering no absorption, from a transparent surface coated with two superimposed films is given in the following relation [16].

$$RF = \left(\frac{n_1^2 - n_0 n_2}{n_1^2 + n_0 n_2} \right)^2 \quad (2)$$

Where,
n_0 = Surrounding air refractive index.
n_1 = Anti Reflection Coating (ARC) refractive index.
n_2 = Glass substrate on TCO layer refractive index.

But recently, researchers are working on multi-layer anti reflection coating (MAR) which provide better result than single layer antireflection coating. In case of MAR, it is found that pre-processed low cost soda lime glass with broadband antireflection coating is durable and can be used directly on module. Also some factor like temperature sustainability, cell structure whether it is superstrate or substrate, effect of coating materials must be kept in mind [17].

3. CONCLUSION

This paper has reviewed the most recent research and methods to tackle the performance issue in CdS/CdTe solar cells from aspects of modification in front contact. Although there is noteworthy advance for efficiency change these years, those procedures above discussed provide some thoughts for further improvement. In light of the past analysis, CdS/CdTe solar cell will be a crucial contender in PV market share

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6. NOMENCLATURE

Symbol	Meaning	Unit
Voc	Open Circuit Voltage	(V)
ρ	Sheet Resistance	Ωcm
N	Carrier Density	cm^{-3}
μ	Mobility	$cm^2V^{-1}S^{-1}$
e	Electron Charge	coulombs
RF	Reflectivity	Dimension - less