



A REVIEW OF THIN FILM SOLAR CELLS

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ABSTRACT:

Researchers have tried their best to find an alternative supply of energy to replace fossil fuels, which is crucial for environmental needs. One of the best candidates is solar energy, which is clean, abundant and sustainable. To convert this energy directly into electricity, photovoltaic (PV) solar cells are used, so these PV solar cells have attracted researchers to explore various methods of their development and possibilities to increase their efficiency. These solar cells go through several stages of development to achieve low cost and high efficiency, from the first generation using wafer crystalline silicon to the second generation which is based on thin films such as amorphous silicon (a-Si), cadmium telluride (cadmium telluride). CdTe), and copper indium gallium diselenide (CIGS), reach the third generation based on perovskite materials. Second generation solar cells today compete with crystalline silicon solar cells because they use less material to produce a lower cost module resulting in higher efficiency compared to first generation cells. This work reviews thin film solar cells regarding aspects of development methods, design, advantages and disadvantages.

KEYWORDS: Thin film solar cells, a-Si, CIGS, and CdTe.

I. INTRODUCTION

The sun is a source of light and heat that is a clean, inexpensive and sustainable source of energy for generating electricity. Solar cells can be used to convert light from sunlight into electrical energy that must achieve cost-effectiveness (i.e. high efficiency using less material) and reliability. These solar cells can be classified into two types

- (i) Conventional solar cells (Silicon wafers based solar cells or crystalline silicon based solar cells)
- (ii) Thin film solar cells which can be divided into two types first type based on silicon such as (amorphous silicon a-c, polycrystalline silicon and nano -crystalline silicon) The second type is based on elements from group six of the periodic table such as cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS) [1, 2].

In previous years, silicon wafers solar cells participated with a large percentage in the market of the photovoltaic industry but this technology did not achieve cost-effective results due to the high cost of silicon wafers leading to high module costs. To overcome this challenge the world was directed to use thin film technology as these technologies achieved cost effectiveness as they used less amount of material resulting in lower module cost [3].

Thin film solar cells have advantages such as using less material and can be deposited by various deposition techniques such as vacuum-based techniques (sputtering and thermal evaporation) as well as liquid-based techniques (chemical bath). deposition CBD). These thin films can be deposited on

substrates that provide mechanical protection, these substrates can be rigid (soda lime glass SLG) and flexible (polymer, metallic foil, plastic, paper, etc.), these flexible substrates enable thin films to be formed. . (Building Integrated Photovoltaics BIPV) is used in many applications such as [3, 4].

A-si is used for many mini-applications such as power sources for calculators, clocks as reported in the late 1980s, but a-Si faced a challenge because its efficiency decreases over time called Wronski-effect. This led to the attraction of exploring alternatives such as CdTe and CIGS. Although CdTe offers high performance and stability, it still contains Cd which is a toxic material and harmful to humans and the environment. On the other hand, CIGS offers high efficiency at low cost but contains elements (gallium Ga and indium In) that are not abundant. These challenges facing CdTe and CIGS are behind c-Si technology in the PV market [3, 5].

This work focuses on the comparison between three major types of thin film solar cells (a-Si, CIGS and CdTe). The history, composition, deposition techniques, advantages and challenges of these three types will be presented in Sections II, III and IV respectively. Section V will summarize the findings.

II. AMORPHOUS SILICON SOLAR CELL

Due to the low need of silicon material and the possibility of using deposition techniques with low temperature, a-Si based solar cells have attracted researchers to improve their efficiency. This section will present the challenges including history, deposition technique, design and solution [6].

Emergence and progress of a-Si solar cells

In 1976 David Carlson and Wronsky fabricated the first amorphous silicon thin film solar cell of 1 μm thickness and gave an efficiency of 2.4% using silane gas (SiH_4) and glow discharge process as shown in Figure 1 [7]. Later in the 1980s RCA laboratories fabricated an a-Si based solar cell using (P-I-N) structure, 1.9 cm² area and glow discharge deposition, with an overall efficiency of 6.1% [8]. Kim et al used the photo-CVD technique to deposit an uncoated a-Si:H layer in a separate chamber, this cell yielded an efficiency of 11.2% [9]. In 1993 Katsuya et al optimized an a-Si solar cell using zinc oxide (ZnO) transparent conductive oxide (TCO), pre-annealing technique and ZnO/Ag/Al as back reflector, this cell achieved 11.9% efficiency. [10]. Yang et al obtained a stable conversion efficiency of 13% after 1000 hours of light exposure time in which (a-Si top cell) , (a-SiGe) is composed of an intermediate and a bottom cell as shown in Figure 2. [11]. In 2002 Jensen et al fabricated a hetero-junction solar cell with 14.1% efficiency from (a-Si/c-Si), as deposited by an a-Si layer (PECVD plasma enhanced chemical vapor deposition technique) [12]. Later, Yan et al in 2010 achieved a stable efficiency of 12.5% using a triple junction made from (a-Si:H/nc-Si:H/ nc-Si:H) [13]. Hairen et al in 2016 reported 11.6% efficiency of tandem solar cell from (a-Si:H/polymer) and 13.2% efficiency of triple solar cell from (a-Si:H/a-Si:H/polymer) [14]. In 2019, Wei lie et al achieved an efficiency improvement of 18.45% using a-Si based solar cell (NIP) structure using nano-pillar arrays and CdS quantum dots [15].

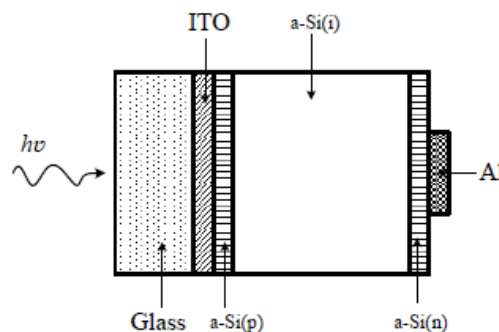


Fig (1): First structure of a-Si solar cell [7].

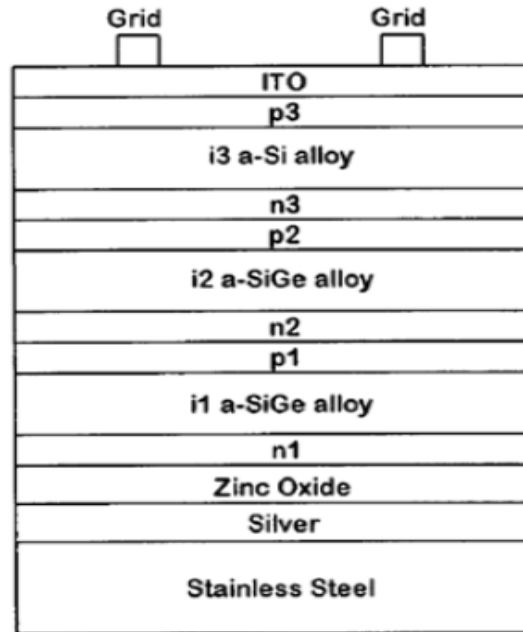


Fig (2): Triple junction structure a-Si solar cell [11]

B. Theory of operation and the structure of a-Si solar cell:

An amorphous silicon solar cell (a-Si) is called a drift device because it uses a drift mechanism for the transport of photo-generated carriers. Figure 3 which illustrates the principle of operation of an a-Si solar cell, typically consists of (p,i,n layers) such that the i-layer which increases the internal electric field, exists between the p and n layers. When light reaches the inner layer (i-a-Si), electron-hole pairs will form, these photo-generated carriers will be separated by an internal electric field, then electrons will move up (n-type layer) but holes will. (p-type layer), then the electrodes will collect these charge carriers [16].

Regarding Figure 3, which shows the structure of (a- Al Si:H) solar cell, it includes (substrate, TCO transparent conductive oxide, p-type layer, intrinsic layer, n-type layer, back reflector layer and back contact). . These layers will be discussed in terms of requirements, materials, and deposition techniques.

Materials Various materials are used as substrate layers such as glass, sheet steel, polyamide foil, polyethylene terephthalate (PET), polyethylene (PE) and graphene paper [17]. It is known that transparent conductive oxide (TCO) is used as the front contact in case of p-i-n thin film solar cells [18]. A TCO must meet certain requirements: (1) it must be sufficiently transparent (i.e., its optical absorption should be low for the ultraviolet to infrared range) [18, 19], (2) its lateral electrical conductivity should be high, (3) its near-surface The contact resistance should be low [19], (4) it should be inert in the case of hydrogen plasma [20], and (5) it should be able to achieve light trapping to increase and decrease absorption in absorbent layers. thickness which is important for reducing light-induced degradation (Stabler-Wronsky effect) [18].

Various materials and deposition techniques are used to prepare TCO such as: zinc oxide (ZnO) which is more favorable because of its lower deposition temperature and material cost, fluorine doped tin oxide SnO₂ (SnO₂:F) [18, 20], hydrogen - doped In₂O₃ (IO:H) films [19], aluminum doped zinc oxide (AZO) [21], oxide-metal-oxide (OMO) structures such as AZO-Ag-AZO [22], amorphous indium zinc oxide (a- IZO) thin films [19]. Deposition techniques used to produce TCO layers such as: low pressure chemical vapor deposition (LP-CVD) technique to produce ZnO [18], extension of thermal plasma CVD technique to deposit textured ZnO and atmospheric pressure chemical vapor deposition (APCVD) to

produce fluorine doped zinc oxide ZnO:F and SnO₂:F [20], aluminum doped zinc oxide (AZO) also (a-IZO) by RF magnetron sputtering for thin films [19, 21].

Because the role of the p-type layer is very important because it is used as a window layer, some essential requirements must be met: (1) its band gap is wide, (2) it is dark and the photo-conductivity is high, and (3) the activation energy is low. [23]. Various materials and deposition techniques can be used to produce p-type materials such as amorphous silicon oxide (SiO_x), hydrogenated amorphous silicon carbide (a-SiC:H) and p-type hydrogenated amorphous silicon oxide (p-a-SiO:H). Layer produced by plasma enhanced chemical vapor deposition technique (PECVD) [23]. $\mu\text{-Si}_{1-x}\text{C}_x$ films that can be deposited using the hot wire chemical vapor deposition (HWCVD) method [24], radio frequency plasma enhanced chemical vapor deposition technique (RF-PECVD) using p-type hydrogenated nano-crystalline silicon nc-Si:H fabricated with wide band gap and high conductivity and can be used as a window layer [25], as well as (filtered cathodic vacuum arc deposition technique) (FCVA), boron doped tetrahedral amorphous carbon (ta-C:b) is prepared can [26], also wide optical band gap and high work function transition metal oxide (TMO) layers can be used as thermally evaporated dopant-free MOOCs because they have a high band-gap, low absorption coefficient, and are a-Si: Compared to H(p) and $\mu\text{-SiO}_x\text{:H(p)}$ layers are more transparent materials [27].

Absorber layer can be fabricated by using various

Materials and deposition techniques such as (a-Si:H) and (a-SiGe:H) which can be deposited using (RF-PECVD) [28], $\mu\text{-Si:H}$ can be deposited using 13.56MHz PECVD as high [29], hydrogenated amorphous silicon films (a-Si:H) that can be fabricated using hot-wire chemical vapor deposition (HWCVD) [30], as well as (a-Si:H) films can be fabricated using atmospheric pressure. Plasma chemical vapor deposition (AP-PECVD) technique [31], hydrogenated polymorphous and nano-crystalline silicon films (pm-Si:H,nc-Si:H) deposited by HW- and RF-PECVD [32], i-a-SiC:H films can be deposited using the (VHF-PECVD) technique [6], proto-crystalline silicon (pc-Si:H) can be prepared using medium pressure and radio frequency (RF, 13.56 MHz) [33].

But materials like (a-Si:H, $\mu\text{-Si:H}$) are used for the n-layer which can be fabricated using (PECVD) [29]. A common back reflector layer is ZnO/Ag which can be fabricated using the sputtering method [34]. Silver Ag and aluminum Al are common materials used as back contact materials [28].

C. Advantages and Challenges of a-Si Solar Cells: Hydrogenated amorphous silicon (a-Si:H) solar cells offer some advantages such as:

- It uses a direct band gap material (a-Si:H) with a bandgap energy of about 1.75 eV and has a high absorption coefficient. This helps to effectively absorb the solar spectrum using a small amount of Si material [35, 36].
- It can be deposited using low temperature processes that allow low cost flexible substrates such as stainless steel, metal foil and plastic [35, 36].
- It uses abundant materials like silicon and does not use rare metals like (Cd) or (In, or Te) [36].
- It can be deposited on large area substrates allowing the fabrication of (a-Si:H) module solar panels [36].
- Due to its homogeneous nature, it can be used in building-integrated photovoltaic (BIPV) applications [36].

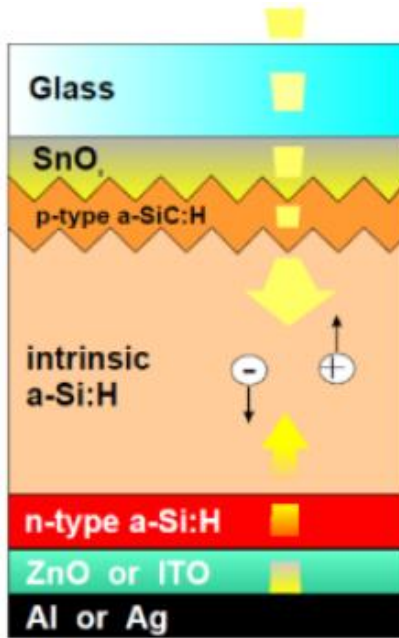


Fig (3): structure of a-Si solar cell [16].

On the other hand, this solar cell faces some challenges:

- As a result of the high density of states of the band gap of the (a-Si:H) material, this material has a low ability to transport carriers efficiently and a very short diffusion length [37].
- Exposure to light leads to reduced performance and reduced efficiency, called the (Stabler-Wronsky) effect [38].

III. COPPER INDIUM GALLIUM DISELENIDE(CIGS) SOLAR CELL

A. History of CIGS(Cu(In,Ga)Se₂)

In 2001, Y.Hagiwara et al achieved an efficiency of 18% for CIGS based solar cells, this was achieved using a composition of (MgF₂/ZnO:B/i-ZnO/CdS/CIGS/Mo). Because the use of ZnO:B as a window layer helped to increase the light transmission in the near infrared region [39]. On the other hand, in 2004, M.Kaelin et al achieved only 13.6% efficiency using paste coating technique which is a non-vacuum technique used to deposit CIGS layer [40]. Akira et al in 2006 used ZnS(O,OH) as a buffer layer that could be deposited by ultra-sonic chemical bath deposition (US-CBD) to improve the performance of CIGS solar cells [41]. An efficiency of 12.8% was achieved for a CIGS based solar cell using chromium free steel as a substrate because it was stable to the high temperature process of CIGS deposition, a work done by R. Wuerz et al in 2009 [42]. In 2010 Sunghun Jung et al reached a CIGS based solar cell efficiency of 15.56% using a Ga/(In+Ga) ratio of 0.27 value, which was the best ratio achieved at that time [43]. R. Wuerz in 2012 studied the effect of using enameled steel as substrate on the performance of CIGS based solar cells. They reported a cell efficiency of 17.6% for cells and a module efficiency of 15% for modules [44]. In 2014 Fabian Pianeszi et al proposed a CIGS based solar cell with 20% efficiency using alkaline components for doping absorber layer using (post deposition treatment PDT). They used NaF and KF for this purpose [45]. In 2018 Tim Kodale et al used rubidium fluoride post deposition treatment RF-PDT to increase the efficiency of CIGS solar cells by 0.8%. In 2019 Seongyeon kim et al obtained an efficiency of 14.52% using In₂S₃ as a buffer layer and doping with 3% tin (Sn⁴⁺) [47].

B. Structure and deposition techniques for CIGS solar cell:

Figure 4 shows the simple structure of a solar cell, which basically consists of (substrate, back contact, absorber layer, buffer layer and window layer). These layers and their materials and deposition techniques will be discussed hereafter. First, the substrate layer can be made of different materials with different deposition methods such as soda-lime glass [39], flexible substrates such as metallic foils and polymers [4]. Soda lime glass is commonly used because it is less expensive and thermally stable. In addition, it contains sodium Na which diffuses from it into the absorbent layer so it will improve the structure of the absorbent layer [48]. Second, metal foils (such as stainless steel, titanium and Kovar® (Fe/Ni/Co alloys)) or ceramic sheets can be made from flexible materials such as zirconia or polymers (polyimide). These flexible substrates are very useful because they can be used .In many applications and allow roll-to-roll processing that helps reduce costs, metal foils have shown their potential to be an alternative to rigid glass substrates, so an absorbent layer can be deposited with high temperatures. Metallic foil stainless steel is a promising flexible substrate because of its low thermal and chemical stability, and flexible substrates have advantages, but they also have some disadvantages because it is detrimental at high temperatures , 49, 50] requires an additional layer to provide

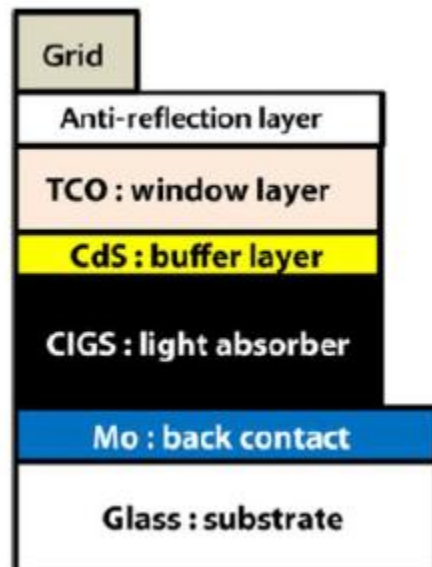


Fig (4): simple structure of CIGS solar cell [48]

There are certain requirements for the back contact layer such as its low electrical resistivity, high optical reflectivity, good adhesion with the substrate layer, high stability against the corrosive selenization process used to form the absorbent layer, and it should make ohmic contact with the absorbent layer [51]. Several materials were investigated to obtain materials that meet these requirements, such as molybdenum (Mo) films, Al₂O₃-doped ZnO ceramics, F doped tin oxide (SnO₂:F) and indium tin oxide (ITO) that can be fabricated using DC. -Sputtering RF-Magnetron sputtering also Ni, Au,Au/Be, Pt,Al, Ag, Cu also molybdenum bilayer thin film with seed and bulk layers, but commonly used back contact is sputtered Mo because it has high conductivity, There is good ohmic contact with the absorber layer through the Mo₂Se layer which is formed between the Mo layer and the absorber layer. It facilitates the diffusion of Na from the glass substrate into the absorbent layer and has high chemical and thermal stability (inertness) such as selenization of the absorbent layer [48, 50, 51, 52, 53, 54, 55, 56].

In general, an absorbent layer with a high absorption coefficient is preferred as a direct band gap material. In addition, the diffusion length should be high but the recombination speed should be low

[50]. For CIGS based solar cells, the absorber layer is CIGS whose band gap can be controlled by changing the content of Ga or S. It is a direct band gap material with a high absorption coefficient that enables the use of thinner materials and lowers energy. fabrication [48, 54, 57, 58] in addition to being chemically stable. There are various deposition techniques to prepare this layer such as (in-line evaporation process, basic co-evaporation, flash evaporation, chemical bath deposition, single-source evaporation, RF sputtering, electro-deposition, molecular beam epitaxy (MBE) system, a. reactive co-sputtering) [52, 59, 60, 61].

The buffer layer plays an important role in CIGS based solar as it helps the absorber layer to be chemically and mechanically stable. This allows for reduced interface recombination and helps in better band alignment between the absorber and the window layer [49, 62, 63]. This layer should be an n-type material and have a wide band gap to form a hetero-junction and reduce losses due to light absorption in this layer, respectively [62, 63]. Non-Cd buffer materials such as [cadmium sulfide (CdS) and [SnO₂, In(OH)₃, In₂S₃, Sn(S,O)₂, ZnSe, Zn(Se,OH)] are used to form this layer. , in(OH,S), ZrO₂, ZnS, ZnO , Zn(OH)₂, ZnInSe, Zn(O,S,OH) and Mg-doped ZnO thin films (Zn, Mg)O [39, 40, 62 64,65]. [These materials can be produced using different techniques such as chemical bath deposition (CBD), chemical bath deposition (US-CBD), atomic layer deposition (ALD), electro-deposition (ED) and ion layer gas reaction (ILGAR). 58, 62]. Different materials used as buffer layers are mentioned but one commonly used is CDS. However, it has some problems such as parasitic absorption of light due to small band gap (eg = 2.4 eV) and harmful elements like Cd existing in this layer, thus, using a free-Cd layer with wide band gap material is preferred. such as zinc oxide (ZnO) or ZnS. They have band gaps of 3.3 and 3.7 eV, respectively. This leads to an increase in external quantum efficiency in the short wavelength range [62, 63, 64, 66].

The window layer or transparent conductive oxide (TCO) must meet certain requirements to maximize solar cell performance: (1) it must be highly transparent to minimize light absorption in the layer, (2) it must have high conductivity. to be able to effectively collect photo generated carriers [65, 67]. [Boron-doped ZnO (ZnO:B) layer, Al-doped ZnO (ZnO:Al) Fluorine doped tin oxide (SnO₂:F), Mg doped ZnO (ZMO) film] [39, 64, 68]. These layers can be deposited by RF magnetron sputtering, DC-magnetron sputtering MOCVD atmospheric pressure chemical vapor deposition (APCVD) deposition techniques [39, 64, 65, 69]. (ZnO:B) has high optical transmittance while Al-doped ZnO (ZnO:Al) suffers from optical absorption of light in the near infrared region [39, 69].

C. Advantages of CIGS based solar cell:

- (i) This solar cell presents higher efficiency compared to other solar cells.
- (ii) Due to high absorption coefficient it consumes less CIGS absorbent layer material, hence, its manufacturing process is cost-effective.
- (iii) It has long term stability.
- (iv) The band gap of its absorbing layer can be tuned to match the solar spectrum. This increases the absorption of light.
- (v) This is consistent with flexible substrates [56, 57, 67, 70, 71, 72].

IV. CADMIUM TELLURIDE SOLAR CELL

A. Birth and progress of cadmium telluride(CdTe) solar cells

In 1980, Nobuo Nakayama et al achieved an efficiency of 6.3% for a solar cell based on CdS/CdTe, with an area of 4*4 cm² using borosilicate glass as the substrate and using repetitive screen printing and heating CdS, CdTe and C paste [73]. Later in 1991 T.L.Chu et al made such a breakthrough that they fabricated a CdS/CdTe based solar cell with 13.4% efficiency by depositing CdS and CdTe layers using aqueous solution and close spaced sublimation (CSS) respectively [74]. J.Britt and C.Ferekides announced 15.8% efficiency of CdS/CdTe based solar cell in 1993. This was achieved using CdS/CdTe

Heterojunction in which CdS and CdTe layers were deposited by chemical vapor deposition and close-gap sublimation, respectively [75]. In 1997, Tetsuga et al fabricated a CdS/CdTe based 16% solar cell (metal organic chemical vapor deposition) for CdS with a thickness of 5 nm and close spaced sublimation to deposit CdTe, using indium tin glacide (ITO) as the substrate [76]. Xuanzhi Wu in 2004 increased the efficiency of a CdTe based solar cell to 16.5% using a composition of (cadmium stannate CTO/zinc tin oxide ZTO/CdS/CdTe) [77]. The efficiency of CdS/CdTe based solar cells reached 17.5% by the work of Arturo morales-Acevedo in 2006 by improving F.F and Vo.c, controlling the doping of CdS and CdTe and achieving better ohmic contact. CdTe [78]. Naba R. Poudel and Yanfa Yan in 2013 fabricated a CdTe based solar cell with 15.5% efficiency using radio frequency sputtering to form CdS layers in a low oxygen environment, coating soda-lime glass (fluoride doped tin oxide FTO). Space sublimation to deposit CdTe [79]. In 2018, Tom Baines et al achieved an efficiency of 13.5% using a composition of SnO₂ /CdSe/CdTe/ and replacing CdS with CdSe due to the presence of Se, the CdTe_{1-x} species was formed due to the diffusion of Se into the CdTe layer. This led to band-gap grading which increased the lifetime of charge carriers and Voc [80].

B. Basic structure with fabrication method of CdTe solar cell:

In this section the basic structure of CdTe based solar cell will be presented and different deposition techniques for the layers forming this cell will also be studied. Figure 5 shows the simple structure of a CdTe based solar cell consisting of (substrate, front contact, window layer, absorber layer and finally back contact). Common materials first used as substrate layers in the literature are soda lime glass, borosilicate glass which are rigid substrates as well as metal foils and polymers which are flexible substrates [81, 82,83].

Later, the front contact or TCO plays an important role as it is used as an electrode to collect the carriers (i.e. current collection). To be used in CdTe based solar cells this layer must meet certain requirements: (1) it must be made of a highly transparent material to transmit light efficiently, (2) the sheet resistance must be low, (3) it must be thermally and chemically stable, and (4) Good adhesion with glass substrates is essential [81, 84, 85, 86, 87]. TCOs can be made from different materials by different deposition methods such as: tin oxide (SnOx) or indium–tin oxide In₂O₃ (ITO). It is well known that ITO has a sheet resistance that is lower than that of SnOx, but ITO is not stable during other layer deposition processes [84].

Cadmium stannate (Cd₂SnO₄, or CTO) which can be deposited by RF magnetron sputtering retains high mobility with high carrier concentration. Moreover, it has high conductivity and high optical transmission [85, 88, 89, 90]. The F-doped SnO₂ film prepared using the pyrosol technique is highly transparent with low-resistance properties [91]. Al-doped ZnO (ZnO:Al) which can be prepared using radio-frequency (RF) - sputtering has the advantages of high transparency to visible light, high electron mobility and large capacity to transport carriers [86].

The next layer for TCO is the window layer, this layer plays an important role in CdTe based solar cells as it allows high energy photons to pass through. In addition, it forms a junction with an absorbent layer that creates an electric field to separate the minority carriers before recombination [87, 92]. A window layer must meet certain conditions to make a solar cell with high efficiency: (1) the layer must match the absorber layer, (2) its resistivity should be low, (3) it should be highly transparent to light, (4) it should be thick enough to prevent absorption of light. should not be and should not be too thin to avoid short circuiting and (5) It is preferred for this layer to have an optical band gap [87, 93]. Regarding materials and deposition techniques, CdS can be deposited by physical vapor deposition (PVD) or chemical bath deposition (CBD) and close space sublimation (CSS) [84, 94]. An oxygenated amorphous CdS layer (a-CdS:O) can be prepared by RF sputtering. This layer offers some advantages such as its amorphous structure and higher optical band gap compared to CdS materials thus this layer helps to increase Jsc [77, 95]. Cadmium zinc sulfide (Cd_{1-x}Zn_xS) can be prepared using chemical bath deposition

(CBD), vacuum evaporation, metal organic chemical vapor deposition, or spray pyrolysis, etc. The optical band gap of these materials can be tuned to be considered as an important advantage [96]. Furthermore, CdSe can be used as a window layer because the CdSe absorber layer has the ability to increase the photocurrent due to the diffusion of Se. In addition, chemical bath deposition (CBD), spray pyrolysis, pulsed laser deposition (PLD) and radio frequency magnetron sputtering can be used to deposit these materials [97].

Before introducing the deposition, the techniques used to create the absorber layer should introduce the characteristics of this layer. CdTe is a p-type material used to absorb light so it is called an absorber layer, it is a II-VI compound semiconductor material with a direct band gap of optimum value (~ 1.5 eV). It has a high absorption coefficient for visible light ($>10^5$ cm⁻¹), it can be deposited by a low-cost fabrication process [77, 82, 92, 94, 98, 99]. This layer can be deposited by close space sublimation (CSS), electrodeposition, metal-organic chemical vapor deposition (MOCVD), pulsed laser deposition (PLD), or vapor phase condensation [82, 84, 100, 101].

Investigating the back contact is very useful as this layer affects the performance of CdTe based solar cells. The back contact layer helps to improve the performance of the solar cell if it meets certain requirements as follows: (1) it should have a work function > 4.5 eV to form an ohmic contact with the absorber layer, (2) it should be capable of transmission reflection. Light returns to the absorbing layer and (3) it should be stable [87,102,103]. Materials used for the back contact are Cu-loaded graphite which can reduce series resistance and increase stability [84], molybdenum (Mo), which can be deposited by RF sputtering at room temperature [104], nano-crystalline (NC) with high thermal FeS₂ stability [105].

There are some challenges that face CdTe based solar cell like:

- (i) Loss due to recombination at the interface of CdTe/CdS.
- (ii) CdTe layer is difficult to dope.
- (iii) Making ohmic contact with back contact is difficult because CdTe has high electron affinity and there is no metal with work function higher than this value.
- (iv) Loss due to parasitic absorption in window layer (CdS).
- (v) Te is not an abundant element and Cd is also a toxic element [4, 94, 106, 107, 108].

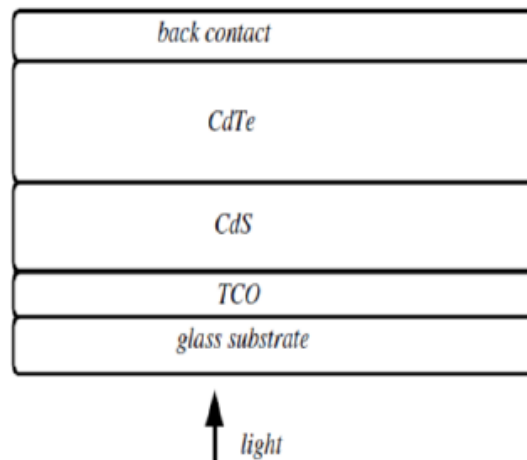


Fig (5): Basic structure of CdTe solar cell [81]

CONCLUSION

This review article presents a comparison between three types of thin film solar cells (a-Si, CIGS and CdTe), describing the various materials and fabrication methods in addition to the merits and issues

for each type. Although a-Si based solar cells offer some advantages, they degrade in efficiency when exposed to light, a problem that halts progress in the PV market. On the other hand, CIGS and CdTe based solar cells offer high efficiency with long term stability. In addition, they use less material due to their high absorption coefficient in the visible range. This makes these two types of cells promising candidates for crystalline silicon solar cells. Based on this article, extended work can be done on CIGS based solar cells because these types of challenges are faced compared to CdTe solar cells, therefore, it will motivate extensive research on CIGS based solar cells.

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