Review Article

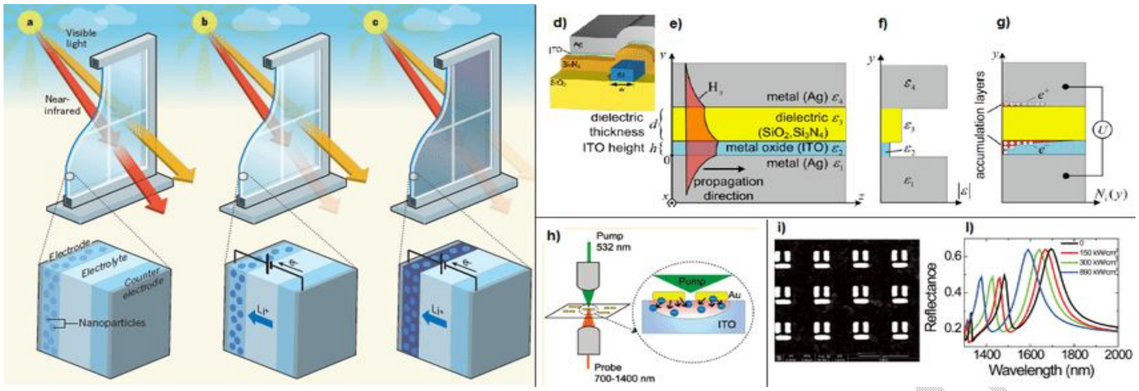
CdTe-Based Thin Film Solar Cells, Application, Semiconductor,Current Opinion in Materials and Treatment Science

Abstract :

Due to the manufacturing process, silicon-based solar cells have conquered the marketplace, but their cost is not economic.As a result, thin-film manufacturing was done with low-cost, appealing materials generated using less expensive, scalable, and manufacturable procedures. The motivation behind this work is to develop low-cost, high-efficiency solar cells using chemical and electrochemical techniques. Thin film solar cell structure could be presented as glass,Cu structure, CdS window material, TCO,and CdTe absorber material. The absorber and window materials include layers such as CdS and CdTe, while Cu and TCO are the back and front contacts. By using CSS and chemical bath deposition (CBD), The usual method of making this structure is to grow window (CdS) and absorber (CdTe) materials. CBD is a batch method that generates enormous quantities of Cd-containing waste solutions each time, adding to the production process's high cost. .Sputtering or PVD, including high vacuum conditions,is performed with back and front contacts. This research program focuses on developing an "all chemical-solar cell" structure. This study showed that CdS and CdTe materials may be employed and electrodeposited in thin-film solar cell systems,CBD and electroless techniques. Furthermore, the back and front contacts can be coated using the CdS electrolytic bath, which is utilized for seven months without being discarded, but the CBD bath lasts 2-3 days. The deposition rate of the thin films was about 50-100 times greater than reported values in the literature. The efficiency of the manufactured cells was between 1 and 6%,which was reduced by the duration of time. Twenty days aftermanufacturing a TCO,CdS, CDTe,the short-circuit current,Cu-Ag solar cell, and open-circuit voltage deposited by all chemical and electrochemical deposition techniques were 0.8 mA/cm^2 and 8.8 mV, respectively. However, consistency and reproducibility remain unresolved. The growth of CdTe nanocrystalline thin film is one of the reasons it has been identified as having nanosized tracks. High-quality CdTe layers should be developed, or the CdS window layer could be put on top of a ZnO buffer layer to increase the consistency of the solar cell efficiency.

Key Words: Cadmium telluride, Solar cell, Thin film, Nanostructure, Electro-deposition, buffer layer

Graphical abstract



1. Introduction:

Solar energy

Itis generally stored in non-renewable energies such as fossil fuels and nuclear power or utilized through renewable energies such as wind, waves, photovoltaics, heat, biomass, and hydropower. Energy sources are generally divided into two categories, each with advantages and disadvantages [3].

One of the outstanding features of renewable energies is their purity, compatibility with the environment, and inexhaustibility. Generally, renewable energy sources are the cleanest and best power supply and generation sources.The solar cell is the tool thattransforms solar energy into ternary energy. Photovoltaic technology is one of the best renewable energies. Without moving the components of PV, solar energy directly enters the system or generates harmful radiation that converts electricity without moving the photovoltaic parts.[3].

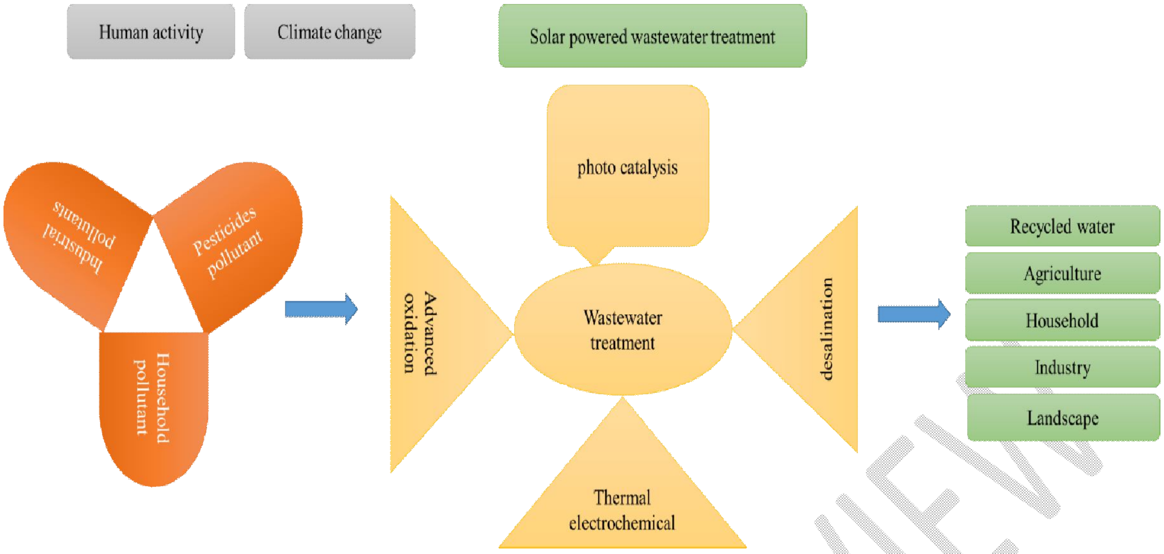
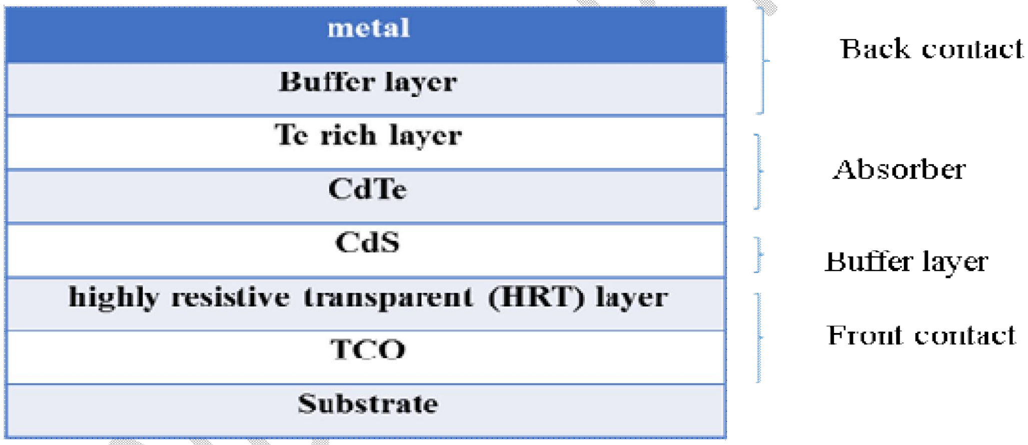


Figure 1. Utilization of solar energy[3]



Schematic 1: One solar cell structure[3].

Solar cells are divided into six categories based on their characteristics and importance.

1- Thin Film
2- Amorphous Silicon
3- Cadmium Telluride
4- Cadmium Sulfide
5- Copper Indium diSelenide
6- Copper Indium Gallium di Selenide

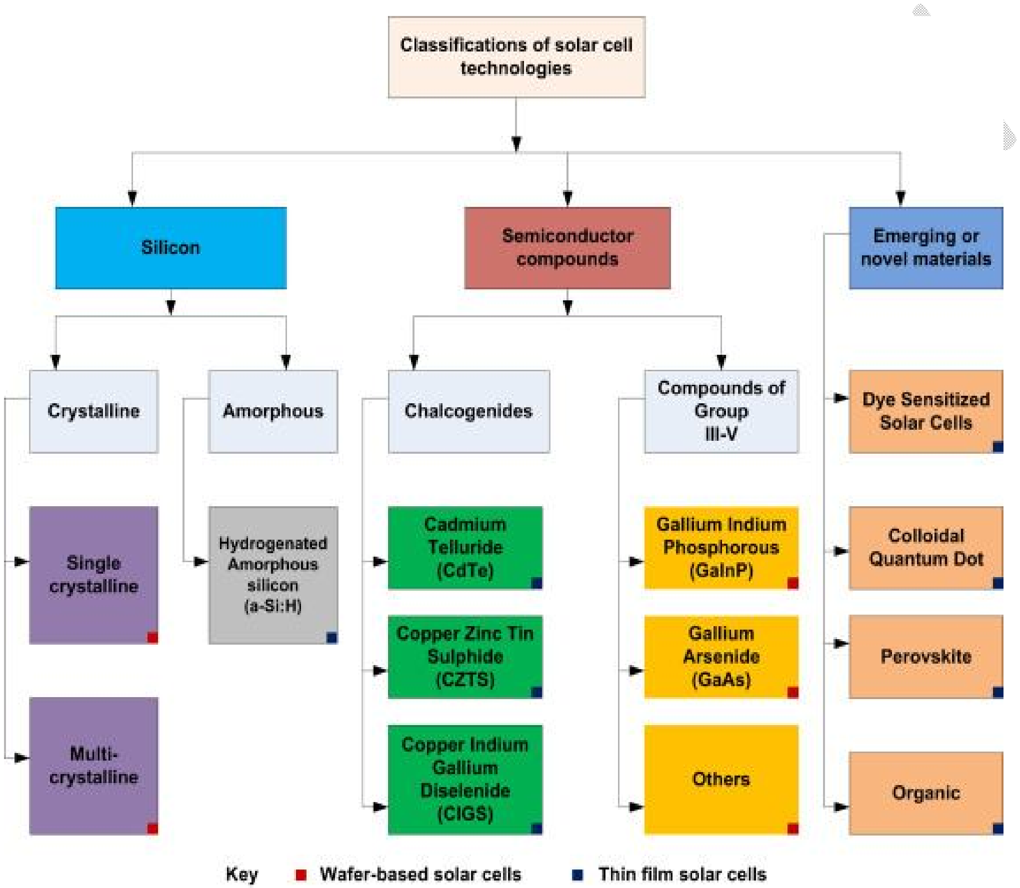


Figure 2. Type of solar cells[6]

Solar Cell Fabrication Summary

Substrate and superstrate configurations are the two common forms of thin-film solar cells, in contrast to silicon-based solar cells. The layers in a substrate arrangement are deposited from bottom to top, meaning that the topmost transparent electrode layer (TE), which is on the side that is exposed to light, is deposited last, starting with the back contact.Thus, opaque substrates like commercially available thin metal foils that are stiff or flexible, ceramics, and polymers can be used in this configuration. The layers are deposited top to bottom in a superstrate configuration, starting with the light-exposed side, or the uppermost TE layer, and ending with the metallic back contact's deposition. As a result, only exceptionally transparent substrates are required for this design, as light must travel through the substrate to reach the absorber layer. Solar cells in the superstrate arrangement, which is more frequent with Sb2Se3, work as follows: The photons are transferred to the Sb2Se3 layer via the n-type TE and CdS layers, which might lead to the creation of electron-hole pairs.

Higher energy photons (>2.4 eV) are not involved in this process because they are absorbed in the CdS (Eg = 2.4 eV) and TE (Eg> 3 eV) layers [22]. Due to the creation of an internal electric field at the p-n heterojunction between the Sb2Se3/CdS interface, minority charge carriers (electrons) produced by light migrate from the p-type Sb2Se3 to the n-type CdS, where they eventually enter the TE layer. Conversely, the p-type hole-transport layer attracts holes, which are then caught by the back contact. High-efficiency solar cells consist of multiple layers and interfaces, each contributing to the device's PCE. The quality of these layers and interfaces, such as absorber/BC, buffer/absorber, and TE/buffer, significantly influences PV performance.[23]. The influence of crystal orientation (in the Sb2Se3 bulk), sputtering damage, and rollover effects (at the interface and surface of Sb2Se3), in particular, needs to be investigated further at the nanoscale, as nanoscale materials (nanomaterials or nanostructures) typically have unique physical properties [22,23].

CdTe is utilized to create the most technologically advanced thin film with the shortest return time. Various methods have been suggested to enhance the efficiency of solar cells made of cadmium chloride. Thin film photovoltaic technology uses CdTe because it is a chemically stable and solid material. These days, the top ten manufacturers only employ this thin-film technology. These days, the top ten manufacturers only employ this thin-film technology. CdTe has an excellent bandgap for the Shockley queisser limit, with an open circuit voltage of 1V and a short circuit current density of more than 30 mA/cm2. As a single junction device, it may achieve very high efficiencies of more than 32%. Since their debut in the early 1970s, CdTe solar cells have mostly been researched and used for the preceding 30 years. Over the last five years, a new redesign of the CdTe solar cell device has produced notable efficiency gains, with single solar cell efficiency reaching 22.1% and module efficiency reaching 19%.In this study, we outline the manufacturing process and trace the history of the solar cell from its beginnings to contemporary improvements and adjustments. Furthermore, we provide potential alternative absorbers and explore this amazing technology's only contentious environmental impact [23].

Because of its strength, chemical stability, and ease of deposition through many methods, CdTe is a highly suitable material for a vast array of purposes and a large manufacturing domain. Increased conversion factors of more than 15% were the consequence of a number of innovations, including high substrate temperature during CdTe deposition, CdCl2 activation treatment, and copper doping. A 15.8% efficiency was shown in [1], and the National Renewable Energy Laboratories (NREL) recorded a 16.5% efficiency [2]. Over the past five years, efficiency has grown dramatically thanks to a new redesign of the CdTe solar cell device that eliminated the CdS and included new features like bandgap gradation, copper embedding, and a more transparent n-layer. The solar cell first reached an efficiency of 21.5% [3] and then improved to 22.1% [4] with these modifications; the astounding thing is that these results were accomplished using components from the production line. This demonstrates that this technology has a significant scalability potential. An area modulus of 19% was obtained [4]. The following sections explain the classic and modern designs of CdTe solar cells.

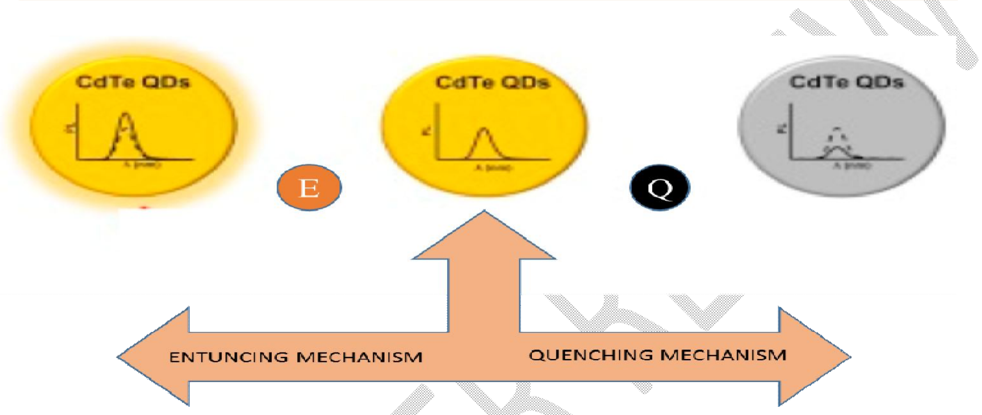


Figure 3. CdTe quenching and quantum dots[3]

Silicon solar cells:

Silicon solar cells have a significant market share, but their production costs are very high. Thin-film solar cells are cheaper and lighter and can be produced in large quantities using inexpensive and simple techniques; they are an excellent alternative to Silicon Solar Cells. The metal can represent a thin-film solar cell's general structure as a cadmium adsorbent.The standard method for producing cadmium is CBD. The CSS (close space sublimation) method involvesmetal and (tri-clamp) TC fittings. Copper and silver were electroless laminated by TC and chemically labeled by CdS glass material and cadmium chloride gravityelectro-deposition [5].

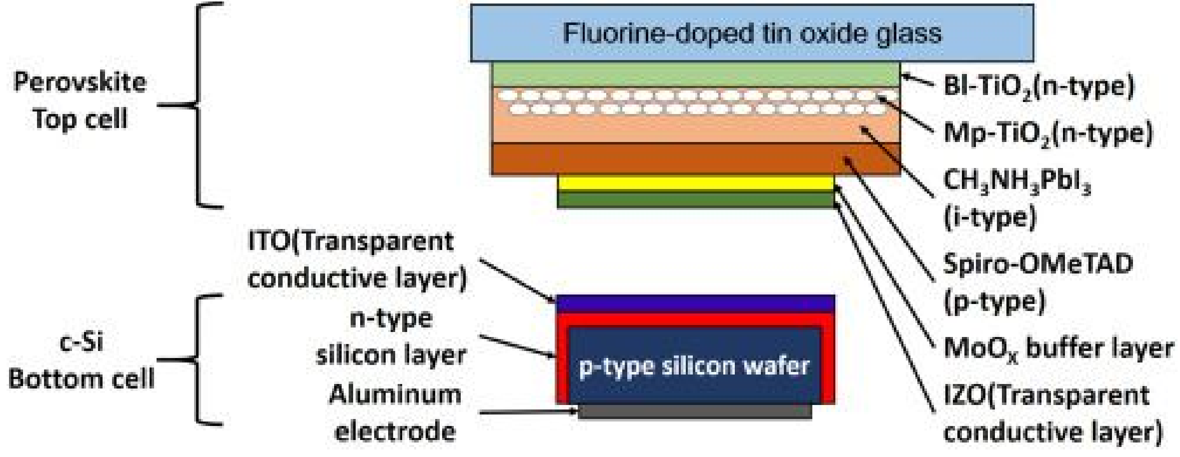


Figure 4. silicon solar cells[5]

Utilizing a spewed, oxygen-containing CdS window layer to increase CdTe thin-film solar cells' efficiency

The CdS window layer absorbs light but not converts it into electric current, resulting in a significant loss in cadmium sulfide/cadmium-telluride(CdS/CdTe). By adding oxygen during sputter deposition at room temperature, this film can be made more transparent. Before this work, no high-efficiency devices were made from this material on industrially utilized tin oxide-coated fizzy drink-lime-glass substrates. Several instruments were manufactured under various process circumstances to generate an optimum device. Although the material's bandgap does not rise consistently with oxygenation soin this layer absorption can be nearly reduced over the relevant spectrum, increasing the short-circuit current.

Meanwhile, the fill factor remains constant while the open-circuit voltage rises compared to baseline devices with sublimation CdS. With increasing conduction band offset at the window/CdTe interface, the tendency of device factors with oxygenation and thickness is constant. Optimizing for initial efficiency and stability on a 3.2mm fizzy drink lime glass resulted in a 15.2% National Renewable Energy Laboratory-verified efficient cell.This window material proved resistant to in-line consistent processes and compatible with clear conducting oxide based of SnO2. Using a window material with a larger band gap can also reduce the loss from window layer absorption. Testing on alloys like Cd and Zn revealed low open-circuit voltage and phase dispersion issues [3, 4]. By applying Zn to the window layer, Kartopu et al. increased the voltage and current of the devices in a MOCVD process; however, the open-circuit voltage stayed low at 710 mV. High-frequency sputter deposition of cadmium sulfide in the presence of oxygen has been shown to produce an alloy material with a significantly widened band gap; [5] was the first to develop this material and define its structural, optical, and electrical properties. The addition of oxygen reduced grain size, resulting in a nanocrystalline (NC) or amorphous film. The resistivity rose considerably with increasing oxygenation[7,8]. An X-ray absorption structure investigation of this material revealed that most of the oxygen is coupled to sulfur in SO3 and SO4. Yet, oxygen-free CdS nanocrystals are claimed to exist [6].

SO3 and SO4 peaks can be seen in XPS measurements. CdSO4, CdO2, and CdS have been assigned to amorphous films and peaks in X-ray photoemission spectra[8], and the peaks disappear with increasing oxygen supply using smooth angle X-ray diffraction (GAXRD) [8Peaks in the GAXRD diminish when the oxygen concentration is increased, and no peaks form when the films were heated to 500°C [8], which is in line with previous work by others. Using oxygenated CdS and a cadmium stannate/zinc stannate TCO/HRT stack on borosilicate glass, an AM1.5G conversion efficiency of 15.5% was attained. CTO/ZTO layers provide less stable devices than tin-oxide-based front contacts [9]. These investigations provide information about the film's characteristics and indicate the viability of creating high-efficiency CdTe solar cells using this window layer. The first attempt to use this material on commercial-type substrates failed to boost current density without lowering open-circuit voltage and fill factor [10].

There has been little data published. It is concerning the important factors for including this material into a device structure. The current work, which is based on earlier research utilizing commercially relevant substrates, attempts to investigate reproducible device performance thoroughly. To retain field performance, a cell must not only display great effectiveness in the laboratory but endure environmental stress. Enhanced period testing mimics years of field stress due to higher temperatures, light exposure, and bias scenarios. The electric field ofthe device was decreased by open circuit and illumination, and high temperature enhanced diffusion [8].

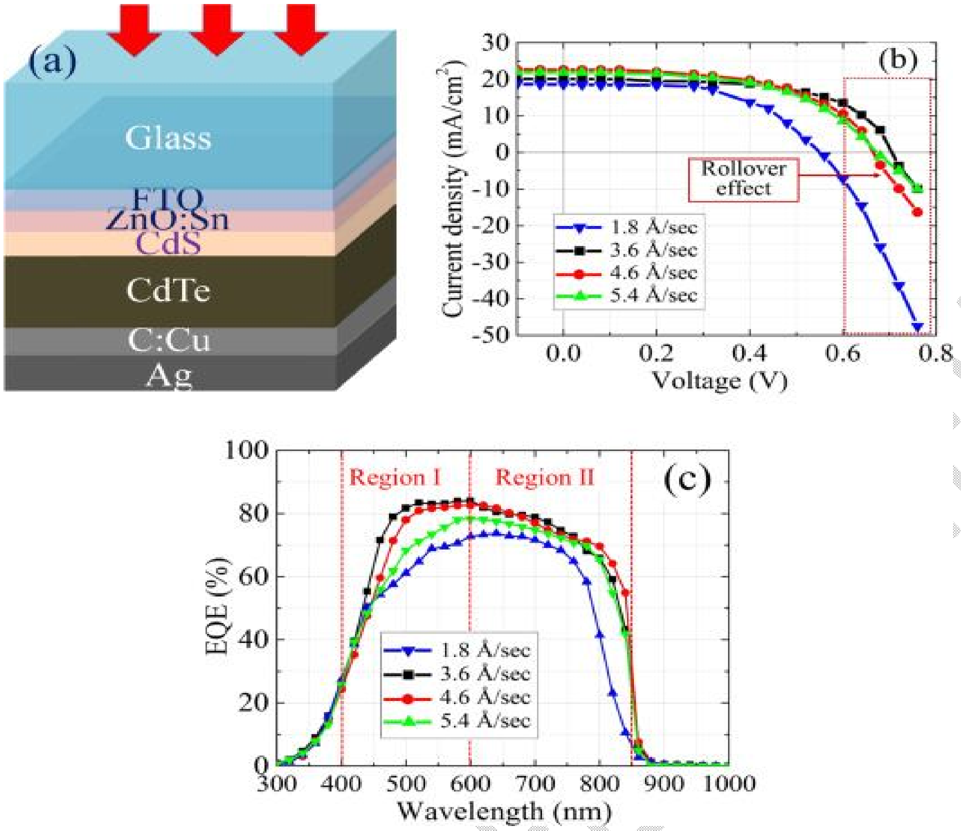


Figure 5. Oxygenated CdS window layer[8]

We examined the structural and morphological properties of CdTe solar cells in various deposition temperatures. High-performance cells are related with films that lost their (111) growth roughness, according to the findings. The (111) growth orientation is related with the development of a substantial concentration of planar defects caused by stacking faults and twin boundaries, which impair the electronic bulk properties. Consequently, interface orientation may be a critical issue [10]. At low sample temperatures, compact layers with advantageous structural and electrical properties are discovered to form. The data show that activation treatment has a considerable impact on structural faults within the bulk of CdTe grains. However, at high temperatures, non-oriented 3D grains have a significant tendency to form as the thermodynamically stable form of compounds with a fcc cubic lattice. Due to pinholes, unattractive grain boundaries, and weak diodes, this propensity may result in low shunt resistances in the cell, which are significant degradation in thin cells of 1 m thickness.

In contrast, the superstrate arrangement is the most efficient alternative for CdTe devices, owing to the ability to perform essential post-deposition treatment at this structure. The front contact, a degenerately doped semiconductor, typically an oxide layer called as transparent conducting oxide (TCO), is where the window and absorber layers (CdS and CdTe) are created. When the growth occurs at substrate temperatures below 450 °C, a low-cost soda-lime glass is preferable;

when the growth occurs at substrate temperatures above 500 °C, a more expensive alkali-free glass is required. In substrate arrangement, the very first layer that coats the substrate is often molybdenum. This stable metal serves as an efficient back contact, reducing impurity migration in subsequent layers. One notable advantage of this construction is the ability to employ opaque substrates rather than glass, enabling flexible materials such as thin metal foils or polymers to be used to create a flexible device [8].The current record efficiency for flexible CdTe cells in substrate configuration is 13.6% on a Mo/MoOx coated glass substrate [9], while on flexible polymer foils with a MoOx/Te back contact when deposited on steel substrates is 11.5% with copper and 10.9% without it [9]. A special flexible polymer or ultra-thin flexible glass can also be used to create flexible CdTe solar cells in a superstrate arrangement [10].

Substrate and window layer

The study uses 3.2-mm soda-lime glass coated with ten fluorinated tin oxide to create small-area devices. The glass was cleaned using a float-compatible technique and thermally cleaned before sputter deposition. Oxygenated CdS window layers were used to create the devices. CdS was deposited using radio-frequency sputtering on a 10-cm diameter planar magnetron CdS target, with two mass flow controls controlling oxygen flow as a fraction of argon flow during deposition. This process ensures the device's durability and resistance to delamination.The substrate was not heated during deposition. As a result, the sample was delivered directly to the ARDS without any intermediate storage. Because the sublimation CdS production stage is bypassed, the substrate is heated to the average CdTe entrance temperature of 480-500°C. Aside from that, the processing cells that contain sublimation CdS and oxygenated CdS are identical [18].

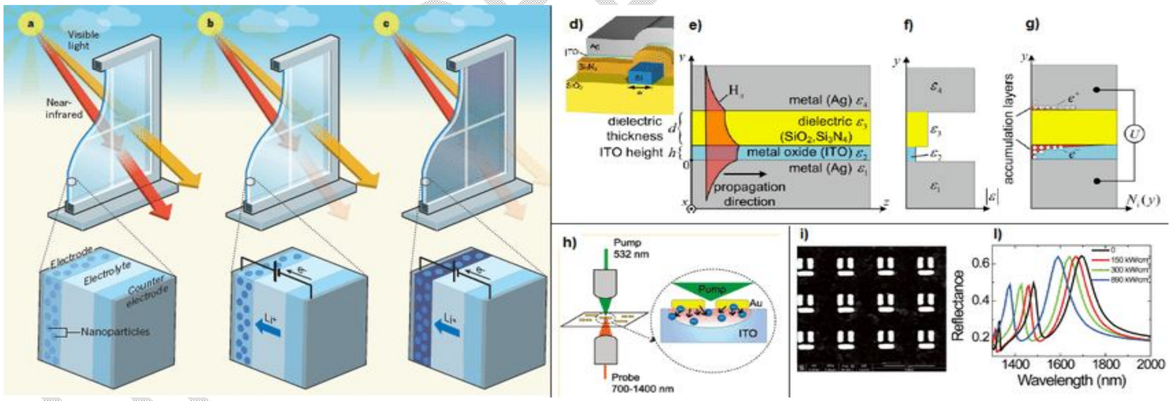


Figure 6. Substrate and window layer[18]

The past and present of CdTe/CdS solar cell configuration

CdTe solar cells were formerly constructed in superstrate configuration by depositing a clear conductive oxide, a CdS layer, the CdTe absorber layer, and finally the back contact on a glass substrate. Because the substrate accounts for more than 98% of the material in thin films, a low-cost material such as soda lime glass is required to keep costs low. However, deteriorating the glass at temperatures above 500 degrees Celsius softens the gadget. We now go over all of the layers that make up the conventional configuration, the majority of which are still there in the revised configuration presented in Section[11].

Thin-Film solar cells

A thin-film solar cell is formed by depositing one or more thin layers of PV material on a supporting material such as glass, plastic, or metal. Nowadays there are two primary types of thin-film PV semiconductors: cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS). Both supplies can be applied directly to the front or back surface of the module. CdTe is the second most common PV material after silicon, and CdTe cells may be manufactured using low-cost manufacturing methods. While this makes them a more economical option, their efficiency levels are still inferior to silicon's. Although CIGS cells have good PV material attributes and lab efficiency, the complexity required to assemble four pieces makes the transition from lab to manufacturing more difficult. CdTe and CIGS require greater shielding than silicon for long-term outdoor operation[20].

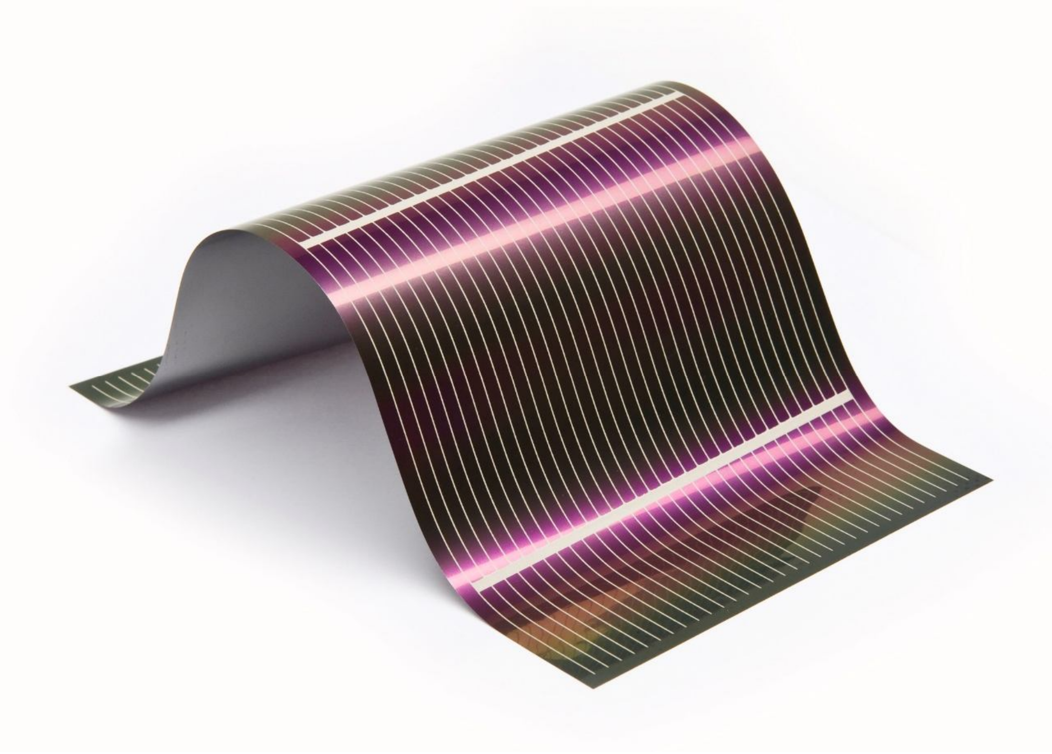
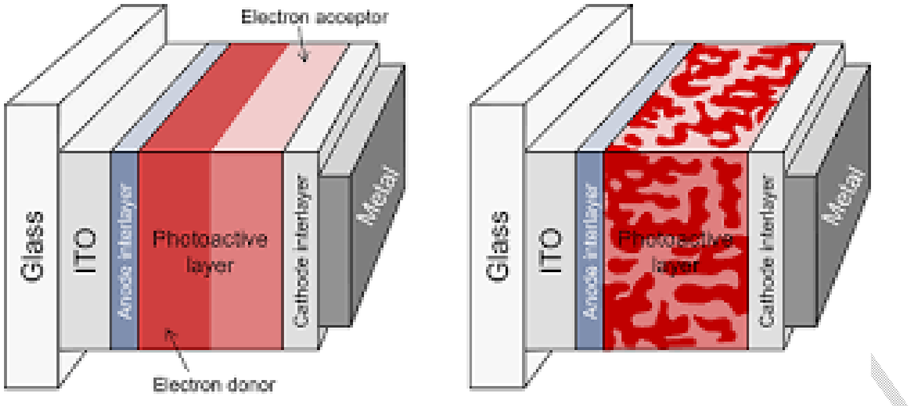


Figure 7. Thin-Film Photovoltaics [20].

Organic Photovoltaics

Organic PV cells, also known as OPV cells, are made of carbon-rich (organic) molecules and can be tuned to increase an particular PV cell function such as bandgap, transparency, or color. OPV cells have half the working lifespan of crystalline silicon cells and are half as efficient, but manufacturing them in large volumes can be less expensive. The source [21] states that these coatings can be applied to diverse supporting materials, including flexible plastic.



(a) (b)

Figure 8. Organic Photovoltaics [21]

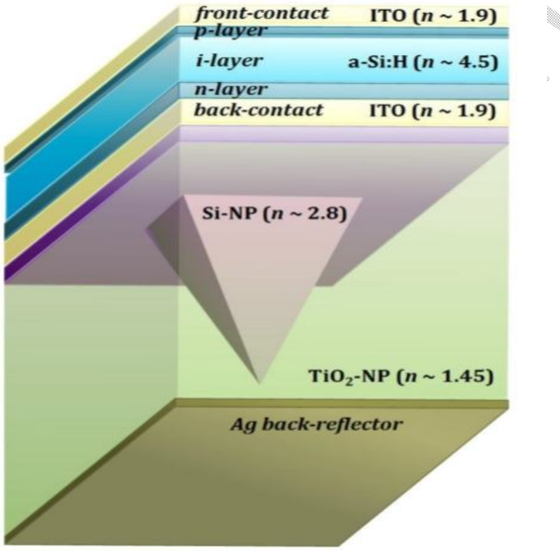


Fig 9 :**Buffer layer**

Buffer layers are critical for enhancing thin-film solar cells. In CuInSe2- and CdTe-based solar cells, multilayered transparent conductors (TCOs) such as ZnO or SnO2 are frequently utilized in conjunction with a CdS heterojunction layer. The cell functions best when the TCO layer in contact with the CdS is very resistant or almost insulating. Buffer layers influence not only the open-circuit voltage of a cell, but also stress-induced degradation and transient events in CdTe- and CuInSe2-based solar cells. Light-induced deterioration in amorphous silicon solar cells has both a recoverable and nonrecoverable elements and the mechanism's complexities may be dependent on the p-type contact layer.Carriers, rather than diffusing atomic species, are thought to cause degradation and recovery, and more carriers may improve conductance in isolated sections or "filaments." By limiting current flow into filaments, buffer layers can control the rate and quantity of damage or recovery. Understanding why species diffuse and atomic configurations relax differently in surplus carriers is more important than understanding how this happens. Furthermore, a cell's operational conditions may impact carrier transport qualities, emphasizing the significance of buffer layers.

The front contact

Transparent conducting oxides (TCO) are extremely degenerative conductive semiconductors that are both transparent (high bandgap) and conductive (highly doped). However, oxides are often intrinsic materials; donor elements were utilized to replace the higher valence cation with donor impurities in order to promote nonconductivity. TCOs are thus degenerate semiconductors with carrier concentrations ranging from 1018 cm3 to 1020 cm3. TCOs for CdTe solar cells are numerous; however, the most common are SnO2: F (FTO), ZnO: Al (AZO), and In2O3: Sn (ITO).TCOs with higher conductivity, transparency, and efficiency, such as Cd2SnO4 (CTO) [5,], have been used.

Because of its long-term stability, FTO is extensively employed in large-scale production. Intrinsic oxides (HRT) can be put on TCO and CdS layers to minimize device shunting and maximize energy band alignment. This enables further thinning of the CdS layer, resulting in decreased parasitic absorbance and more energy in the wavelength area below 500 nm. TO and ZnO are the most often used HRTs12].

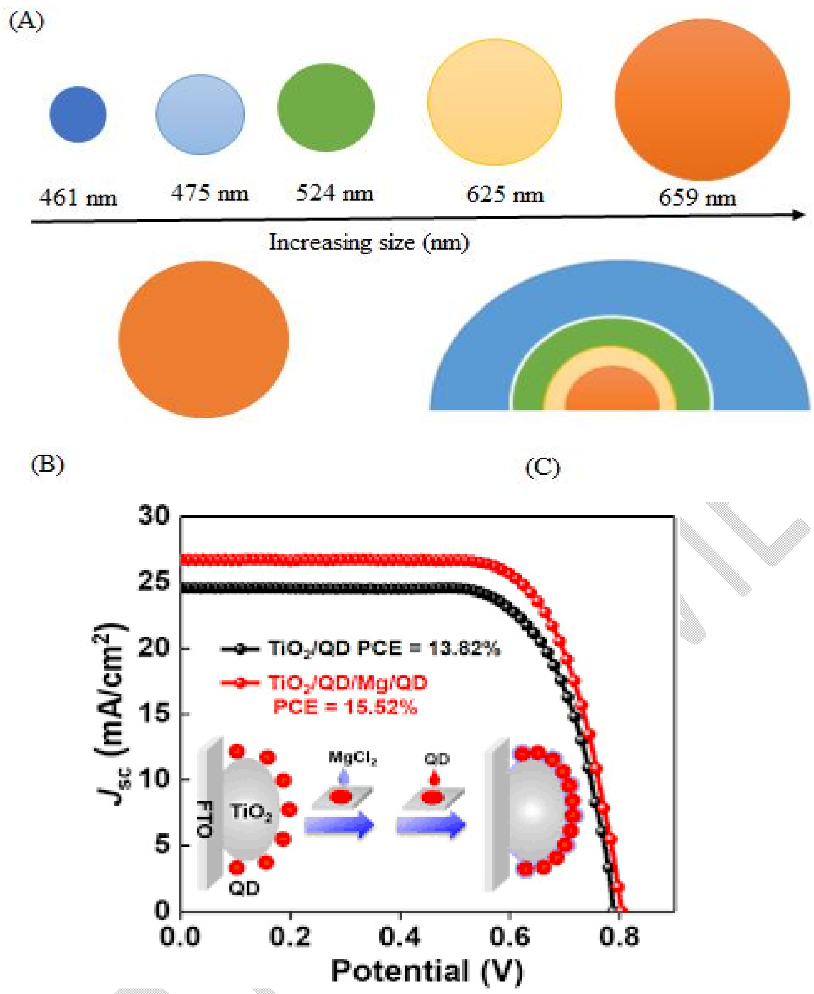


Figure 10. CdTe/CdS solar cell configuration [12]

The TCO is the initial layer formed on glass in a superstrate configuration and can affect the shape and form of subsequent films. Controlling potential contaminants that may diffuse from the TCO at the connection is critical.Because the TCO structure influences both the CdS and CdTe grain structures and their electrical properties [12], it can be argued that TCO criteria must also include chemical and physical durability [13].

Indium thin Oxide

Indium tin oxide (ITO) is the most commonly used type of TCO in the In2O3 (IO)-based thin film family. Its band gap changes with deposition parameters, ranging from 3.55 to 3.75 eV, with transparency ranging from visible to near-infrared, reaching 80%. The layers of growing polycrystalline form a cubic shape, and the grains range from 10 to 50 nm in size depending on the deposition technique and substrate temperature. IO layers are typically deposited utilizing reactive radio frequency. Some of the processes employed include sputtering, induced reactive evaporation, chemical vapor deposition, and spray pyrolysis[14].

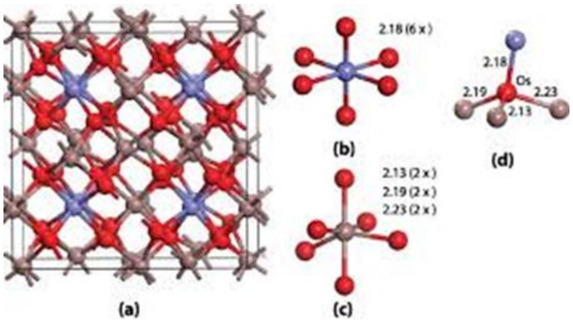


Figure 11. Indium thin Oxide [14]

Zinc Oxides

Zinc oxide, with a band gap of 3.2 eV, is generally used as a high resistive layer between ITO and CdS to increase the open circuit voltage. ZnO, on the other hand, can be doped with indium or aluminum to provide a highly conductive and transparent layer; aluminum doping, in particular, is well suited for high conductivity [12]. ZnO sheets are routinely deposited via radio frequency sputtering. Chemical vapor deposition (CVD) and chemical bath deposition (CBD) are two methods that are used. CVD is the formation of thin films by a gas reaction driven by organic or inorganic precursors, whereas CBD is the formation of nanostructured films by the reaction of precursors in a solution[12,13].

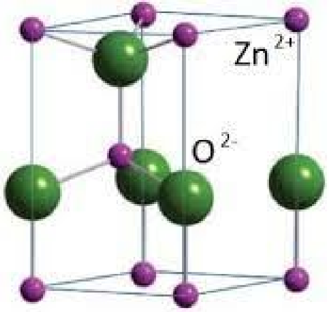


Figure 12. Zinc Oxides[14]

Tin Oxides

Tin Oxides SnO_2 (TO) are widely used in optical and photovoltaic applications due to their efficacy. CVD is used to deposit tin oxide thin films, with "in line CVD" being a possibility.[15]. CVD is used to deposit tin oxide thin films, with "in line CVD" being a possibility. A highly conductive layer is required for solar cell applications, and the structure contains both SnO and SnO_2. The layer is mildly conductive due to oxygen vacancies and Sn^{2+} atoms. However, to produce a degenerate semiconductor, fluorine is introduced to the process. Tin Tin-based compounds (Zn_2SnO_4 and Cd_2SnO_4) were produced using an Argon-oxygen reactive R.F. sputtering technique. These films have extremely high transparency, exceeding 90% in the 400-850 nm wavelength range. Zn_2SnO_4 films have high resistivity, while Cd_2SnO_4 thin films have a conductivity of 7-8 Ohm/sq, similar to FTO films but with higher transparency [13].

These two layers were critical in breaking a ten-year efficiency record [5]. Previously, the most often used buffer layer (sometimes referred to as window layer) in CdTe cells was CdS, which usually develops in hexagonal wurtzite structure. With a band gap of 2.4 eV, CdS exhibits apatitic absorbance at wavelengths shorter than 400nm.

As a result, a variety of buffer layers, such as Cd1xZnxS [12], were examined. Alternative Thinner CdS layers are another way to reduce the previously described parasitic optical absorption. A typical thickness for great efficiency should be less than 100 nm; decreasing it from 120 nm to 60 nm would increase efficiency by around 10% [14]. CdS has been deposited in a variety of techniques, but chemical bath deposition [15] produced the highest efficiency by reducing layer thickness. CSS (CdS: O) and sputtering (CdS: F) methods have also proven effective. The decrease in CdS thickness was required to add a HRT layer, which minimizes the number of shunts required. Chemical Bath Deposition CBD can be accomplished using a variety of methods, the most prevalent of which depends on the dissolution of thiourea and cadmium salts in an alkaline solution, as shown below:$Cd(NH_3)_{42}+ + SC(NH_2)_2 + 2OH- = CdS + CH_2N_2 + 4NH_3 + 2H_2O$

The reaction is generated by thiourea, water, and a variety of cadmium compounds, such as $CdSO_4$, $Cd(COOCH_3)_2$, $Cd(NO_3)_2$ or $Cd(NH_3)_4$.

The process of creating CBD-CdS involves three distinct steps: nucleation, growth, and final phase. Nucleation occurs on the substrate surface, generating initial monolayers. Growth occurs on top of the first monolayer, and final phase forms agglomerates that branch to the substrate. Ammonia is problematic for large-scale CBD-CdS due to its volatility, poisonous nature, and environmental hazards. As a result, numerous efforts to study ammonia-free CBD formulations have been attempted; for example, sodium citrate [15] or ethylenediaminetetraacetic acid (EDTA) [15] have been used to replace ammonia as the complexing agent[15]

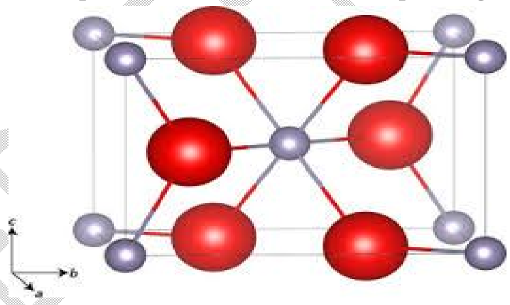


Figure 13. Tin Oxides[15]

Buffer Layer

Buffer layers are widely used in the optimization of thin-film solar cells. In CuInSe2- and CdTe-based solar cells, multilayer transparent conductors (TCOs) such as ZnO or SnO2 are generally utilized in conjunction with a CdS heterojunction layer. The cell functions best when the TCO layer in contact with the CdS is very resistant or almost insulating. Buffer layers influence stress-induced deterioration and transient events in CdTe- and CuInSe2-based solar cells, in addition to influencing open-circuit voltage. Light-induced degradation in amorphous silicon solar cells has a recoverable and a nonrecoverable component, with the details of the mechanism varying depending on the p-type contact layer. Because transients and degradation in all material systems are equivalent, it is claimed that degradation and recovery are driven by carriers instead of diffusing atomic entities. The question is why, not how, species spread and atomic configurations relax differently when extra carriers are present. It was claimed that the operational conditions of a cell could change the carrier transport properties.Excess carriers commonly enhance resistance in specific areas ("filaments") and buffer layers; consequently, controlling current flow into such filaments can influence the rate and amount of degradation (or recovery)[5].

In addition to influencing a cell's open-circuit voltage, buffer layers have been shown to influence stress-induced deterioration and transient phenomena in CdTe- and CuInSe2-based solar cells. Light-induced deterioration has a recoverable and nonrecoverable component in amorphous silicon solar cells, and the details of the mechanism may vary depending on the p-type contact layer. Because transients and degradation are identical in various material systems, it is proposed that degradation and recovery are driven by carriers rather than diffusing atomic entities. Multilayer transparent conductors (TCOs, such as ZnO or SnO2) are typically utilized in conjunction with a CdS heterojunction layer in CuInSe2- and CdTe-based solar cells.

Cadmium chloride treatment:

Cadmium chloride treatment was recognized as a vital method in the late 1970s for significantly enhancing the solar-to-electric conversion efficiency of CdS/CdTe thin film solar cells. Despite a substantial body of experimental evidence, even after three centuries of investigation, this mechanism is still not completely understood.This paper examines the accessible experimental results, provides some fresh insights that contribute to increased awareness, and presents essential research topics required to understand this critical processing phase properly. The increased performance will further increaseCdS/CdTe solar cell conversion efficiency above 20%.

Solar and solar X-rays are electromagnetic radiation from the sun (including gamma-ray ion beam radiation) and non-ionic radiation (distribution of 1-1 and visible and infrared radiation devices). It is evident that the distribution of cover on the earth's surface shows the solar cell in terms of length, the type and amount of atmospheric compounds, as well as the length of the path of the rays through the earth's atmosphere (H_2O), and water (O_2), Absorbed Hydrogen and N_2. The main constituents of the earth's atmosphere are nitrogen (1%) and mineral substances (21% (O_2) and 78% (N_2). The percentages of these compounds are Carbon dioxide, 0.03% argon, and 0.93, including solar preparation in terms of length, is divided into three main parts[6]:

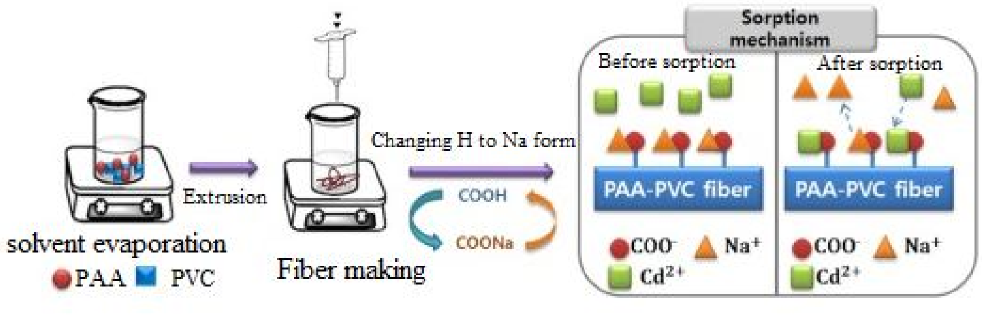


Figure 14. Cadmium chloride treatment[6]

Heat treatment

Heat treatment is an effective and simple way to immerse the layers in $CdCl_2$, treat them with a solution, and then dry and heat them. The temperature used was $CdCl_2$ methanol containing CdS treatment powder CdTeat400° C and 450° C for 15 and 20 min, respectively.

Treatment in saturated CdCl2 solution and reheat in the oven

According to what was explained at the beginning of the article, a methanol-saturated solution was prepared to repair the pinholes. In general, in cadmium sulfide and cadmium telluride thin films, there are small gaps between the grain boundaries that severely limit the efficiency of the solar cell by short-circuiting[24].

CdTe Adsorption Growth and Optimization

They need $CdCl_2$ / verification to fill in the gaps of each layer. For this reason, the treatment is heat. This treatment causes the layers to become intertwined or "mixed" and activate the cell. The heat also removes imperfections, establishes connections between the grains, and helps them to grow larger grains. In heat treatment to conventional towers 1, samples are heated quickly in conventional heat treatment, the specimens are rapidly heated and then slowly cooled to achieve their optimum growth by performing crystalline happy growth. [24] Chlorine to $CdCl_2$Many researchers have reported that during heat treatment with n, increasing the doping of the samples will help them become - and, at the same time, reduce the type resistance in the finished cell. The FF series of the solar cell series and eventually this will increase and improve. [25] Other effects of chlorophyll will increase the size of the grains and their proximity to gas. Compan[solution method] have reported that straw treatment with solution and co-solution is an effective and at the same time, simple way, which is reported that straw treats with a solution of CdTe and then drying and heat treatment. Treatment was performed on the structure of $CdCl_2$ in this solution. Then, the samples were washed with deionized water. They were exposed to an oven at 450 ° C for 15 minutes[25].

Close-Spaced Sublimation (CSS)

The CSS method is a highly effective method for deposition of CdS films, involving sublimation of Cd and S at high temperatures under inert gas pressure. The growth rate depends on source temperature and chamber pressure, while substrate temperature also influences CdS growth parameters. Sputtering CdS can be done using radio frequency.In a study by Gupta et al.[15], A 0.13 μm all-sputtered layer device was created using CdS fabricated using an unbalanced magnetron. Balanced magnetron RF sputtering is another method for CdS deposition. The layer, combining Argon with 3% CHF3, developed at 220 C, producing a crystalline, higher quality layer but a less conductive one [16].Thermal evaporation can deposit CdS grains, but substrate temperature must not exceed 200 C. CdS source typically ranges from 800-900 C. Re-evaporation is used to anneal films, improve grain development, and remove poorly bound Cd and S atoms [15]. The average grain size of thin CdS films is around 500 nm, typically 100 nm thick due to vacuum evaporation issues, with some films reaching 60 nm thickness[16].

The CdTe layer is the most critical portion of the device, and it is typically 4 to 8 m thick to ensure total light absorption. Because the crystal structure of the layer affects both the net carrier concentration and the carrier lifespan, the open circuit voltage and current density can alter dramatically. The vastity of deposition processes further reveals this material's excellent stability and resilience. CSS is perhaps the most extensively distributed technology providing high-speed deposition with high crystalline purity. The CSS on an industrial scale is known as vapor transport deposition (VTD). The size of the particles is directly proportional to the temperature of the substrate. The stronger the lowering of grain boundaries, the larger the grains.However, if a low substrate temperature deposition is used, a high grain size can be obtained using a post-deposition procedure called the CdCl2 treatment. This is about annealing the deposited at 360-440 degrees Celsius following CdCl2 deposition. This treatment can potentially change the grains and improve the quality of CdTe. Without this phase, the devices' conversion efficiency isless than 10%. CdTe has been grown using a variety of techniques, including atomic layer epitaxy (ALE) [30,31], electro-deposition [32,33], screen printing [15], and metal-organic chemical vapour deposition (MOCVD) [16], with CSS, DC, RF sputtering, and thermal evaporation being the most successful. Thermal evaporation under vacuum CdTe is evaporated from heated crucibles at pressures ranging from 105 to 108, and the Cd and Te condense on a heated substrate. The substrate temperature is regulated above 300 degrees Celsius. CdTe films with good crystal quality grow stoichiometrically. However, because re-evaporation of the substance at temperatures beyond 350 C is impossible. As a result, grain size is lowered, and the number of grain boundaries increases. A proper activation procedure can achieve efficiencies of more than 19%[17].

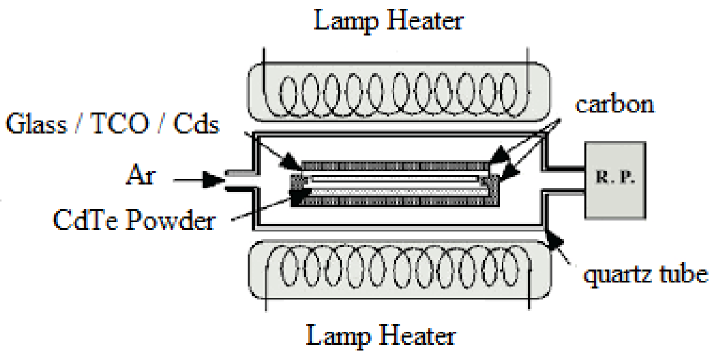


Figure 15. Close-Spaced Sublimation (CSS) [17]

Substrate Configuration

The configuration of substrates in solar cells offers a range of advantages, including the ability to select from a variety of substrates, operate at high temperatures, and utilize flexible substrates. Notably, the first CdTe solar cells were produced in the superstrate configuration, which has since maintained the highest efficiency. The freedom to choose a substrate is a key advantage of substrate configuration in solar cells. It allows for the use of high-temperature and flexible materials, which can significantly impact the efficiency of the cells. Furthermore, the superstrate configuration, in which the CdTe solar cells were produced initially, continues to be the most efficient structure.This is connected to the CdCl2 treatment, affecting junction quality and absorber activation. The compromise between robust recrystallization of the CdTe grains and regulated intermixing of CdS is lost by reversing the configuration activation procedure.Some argue that the preciseness of the statement is challenged as it suggests that the activation of the CdTe absorber can be split on the substrate configuration.

Furthermore, another significant constraint of the CdTe substrate architecture is the back contact construction, which normally performs best with the integration of copper. The back contact in an inverted structure would have to endure the high deposition temperatures, boosting the natural diffusion of copper into the device and deteriorating it. The superstrate configuration of CdTe solar cells holds tremendous potential for renewable energy applications. This configuration comprises five crucial components: buffer layer, front contact, glass substrate, absorber, and back contact. The composition of these components can vary in terms of layers and types, and the structure of the CdS (buffer layer) and CdTe (absorber) layers can differ depending on the deposition methods employed.A transparent substrate is essential for this configuration. Although a simple soda-lime glass is cost-effective, an alkali-free glass may be preferred to reduce impurity diffusion and enable larger grain growth at higher temperatures. It is worth noting that the substrate's cost significantly impacts the overall cost of the thin film device, as glass constitutes over 98% of the material used.

By utilizing CdTe solar cells in the superstrate configuration and carefully selecting the components, we can enhance the efficiency and affordability of renewable energy.

Photovoltaic panel (PV)t

Indium was infiltrated into cadmium telluride crystals of type p, and parameters such as open circuit voltage of 600 mV or short circuit of four and a half milliamperes per square centimeter had a filling factor of 55 percent, and in 1979, a group In France, a package that precipitated cadmium telluride films impregnated with arsenic by VDT method on bread-type crystals with a conversion efficiency of 7% of the open circuit voltage of 723. The connection current was 12 mA / cm^2 in light radiation, and a filling coefficient equal to 63 percent was extracted [6].

Perovskite Photovoltaics

Perovskite solar cells, which are named for theircrystal structure, are a type of thin-film cell. Perovskite cells are built by stacking materials over a fundamental support layer known as the substrate by printing, coating, or vacuum deposition.These cells are relatively simple to build and can achieve efficiency comparable to crystalline silicon. According to lab experiments, perovskite solar cells perform better than any other PV material, with a performance of 3% in 2009 and more than 25% in 2020. Perovskite PV cells must become robust enough to endure 20 years outdoors in order to be economically viable, , so researchers,through low-cost manufacturing techniques, aim to maketheir scales larger and more durable. The process of constructing perovskite cells involves the sequential layering of materials, achieved through printing, coating, or vacuum deposition methods, onto a foundational support layer referred to as the substrate. Photovoltaic (PV) cells, also known as solar cells, operate by generating electricity when exposed to light. The incoming light may be reflected, absorbed, or transmitted upon irradiation through the cell.

PV cells are made from semiconductor materials with intermediate electrical conductivity properties between perfect conductors and insulators. These materials absorb light energy and convert it into electrons, which are then used to power homes and the electric grid. The efficiency of a photovoltaic cell is determined by its ability to convert light energy into electrical power, measured as the ratio of the cell's electrical energy output to the incident light energy. The quantity of electricity produced by PV cells is determined by the qualities of available light and the cell's features. The bandgap of the semiconductor is crucial as it determines which light wavelengths the material can absorb and convert into electrical energy[19].

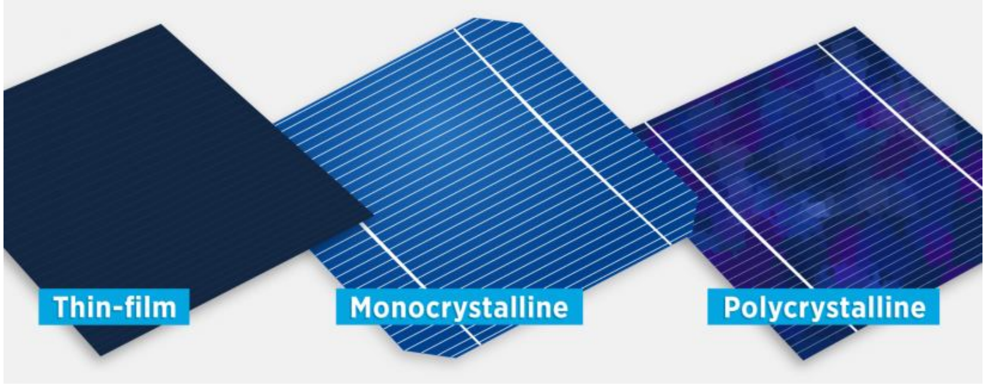


Figure 16. Perovskite Photovoltaics [19].

Efficiency Verification

NREL received a cell with improved settings for efficiency verification. This cell's initial efficiency will be balanced, and its AM1.5G efficiency is 15.2%. It was tested with an aperture smaller than half the cell's active area at 30°C, which may explain discrepancies in VOC and fill factor from the authors' data. Figure 6 displays the J-V, quantum efficiency, and device parameters. The quantum efficiency observed by Wu et al. owing to the window layer at roughly 500 nm has a distinct band edge[12]. The cells described here do not have a discernible band edge. The absorption edge for the 15.2% cell was 300-400 nm due to the company's anti-reflective coating. Lower voltage and fill factor might be attributed to lower temperature, high throughput CdTe and CdCl2 processes, and paint back contact. The existence of an optimized HRT layer is substantially more sensitive in devices with oxygenated window layers than in devices with sublimated CdS..In sublimated CdS, even without HRT, the open-circuit voltage and fill factor of oxygenated films, the thickness of 200 nm directly on a $SnO_{2:}$ F TCO did not produce a VOC of 800 mV, and the J-V kink is intensified by such thickness. With an improved HRT, high VOC may be achieved with minimal thickness (less than 15nm) and yet exhibit low thickness dependency. This effect is thought to be caused by the optimal band alignment of the HRT/window interface and the HRT's reduced work function [5]. The oxygenated window layer's lower carrier concentration prevents it from fixing a bad band alignment by increasing the thickness.

The impact of changing the conduction band offset of the window layer (called the "buffer layer" for Cu (In, Ga) Se2) thin-film solar cells has been investigated. Minamoto et al. demonstrated that interface defects are more damaging when the window layer electron affinity is greater than the absorber electron affinity, resulting in a negative conduction band offset or cliff. The size of the cliff also reduces the diode's activation energy [17]. Adding a small "spike" to the window layer conduction band reduces these effects and improves device efficiency; but, if the spike is too large, barrier effects reduce the fill factor [18]. Later, this was demonstrated experimentally by using (Zn, Mg) O layers in Cu (In, Ga) Se_2 devices, which were improved by increasing [Mg]/([Zn] + [Mg]) [14]. The observed CdS-CdTe conduction band offset is close to zero, and the CdS conduction band may be 0.1 eV lower (a "cliff") than the CdTe CBO [18]. This is undesirable in the presence of interface defects, and sites and pan show that this influence can be large at minimal contact recombination velocities while the CdTe carrier concentration is low [15]. As oxygenation increases, the sputtering conduction band offset for oxygenated CdS appears to increase. Using 1D modeling, this single modification may explain the J-Vkink and the modest rise in open-circuit voltage. As the conduction band offset goes from negative to positive, the activation energy of the diode approaches the band gap of the absorber. The window's conduction band shifts from the Fermi level, held by the CdTe conduction band, causing a decrease in electron concentration at the interface.Surface recombination lowers the effective recombination velocity.Another probable result is that oxygen has a direct role in passivating the CdTe interaction. It has been demonstrated that a few percent of oxygen in CdS can decrease interdiffusion and enhance devices [18]; these values are accessible for films with no deliberate oxygenation.

CONCLUSIONS

Window layer absorption, a key cause of efficiency loss in CdS/CdTe solar cells, can be significantly reduced by utilizing oxygenated CdS, which is compatible with float-line deposited, SnO2-based TCO, and HRT layers. The bandgap of oxygenated CdS can be much bigger than that of CdS, although it increases dramatically at a crucial oxygenation level.In combination with an adjusted HRT layer, oxygenation gives a more perfect, adjustable band alignment at the front contact, resulting in devices with VOC higher than 850 mV. The oxygen content and thickness of this layer must be carefully selected to prevent current loss, give more stability, and avoid detrimental consequences from a secondary barrier. The effect of varying the conduction band offset of the window layer (also known as the "buffer layer" in Cu (In, Ga) Se2 thin-film solar cells) has been studied. The substrates are 3.2-mm soda-lime glass coated with ten fluorinated tin oxide layers (PPG Industries, Inc.). At the glass plant, this coating was applied in-line. Using a float-compatible technique, PPG Industries used a laboratory coater to deposit a SnO2-based HRT layer. CSS deposition of CdS films requires the sublimation of Cd and S at high temperatures and pressures of an inert gas (i.e., Ar). During sublimation, the CdS source dissociates and recombines on the substrate. Indium Tin Oxide (ITO) is the most widely distributed kind of TCO in In_2O_3 (IO)-based thin films. A high grain size, on the other hand, can be achieved by a post-deposition treatment if lower substrate temperature deposition is used.

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Author links open overlay panelJaveedAkhtar1MuhammadAamir2MuhammadSher2 Materials Today Energy

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Author links open overlay panelNaeimehTorabiaAbbasBehjataYinhuaZhoubPabloDocampocRyanJ.StoddarddHughW.HillhousedTayebehAmeri

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