



THIN FILM TECHNOLOGIES FOR IMPROVING THE EFFICIENCY OF SOLAR CELLS

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Abstract: Solar energy is one of the most promising renewable sources of energy, and solar cells are the key components for converting sunlight into electricity. However, traditional silicon-based solar cells are limited by their relatively low efficiency and high manufacturing costs. Thin film technologies offer a potential solution to these problems by providing a more efficient and cost-effective alternative to traditional solar cells. In this report, we review recent developments in thin film technologies for improving the efficiency of solar cells. We discuss different types of thin film materials, including cadmium telluride, copper indium gallium selenide, and perovskites, and their potential for improving the efficiency of solar cells. We also review different manufacturing techniques for thin film solar cells, including physical vapor deposition, chemical vapor deposition, and solution-based methods. Finally, we discuss the challenges and opportunities associated with thin film technologies and their potential to revolutionize the solar energy industry. Overall, thin film technologies have the potential to significantly improve the efficiency of solar cells and reduce the cost of solar energy, making it a more viable and sustainable source of energy for the future.

I. INTRODUCTION

Thin film technologies have emerged as a promising solution to improve the efficiency of solar cells[3] These technologies involve the use of thin layers of materials to capture sunlight and convert it into electrical energy. Thin film solar cells offer a range of advantages over traditional solar cells, such as reduced material usage, lower manufacturing costs, and greater flexibility in design and installation. As a result, thin film technologies have gained widespread attention in the field of photovoltaics and are rapidly advancing towards commercialization[1],[2].

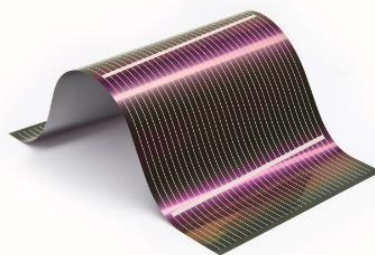


Fig 1 : Thin-film solar cell[1].

Thin-film solar cell technology is one approach to improving the efficiency of solar cells. This technology is based on the use of thin layers of semiconducting materials to absorb sunlight and generate electricity [fig1],[3] Thin-film solar cells offer several advantages over traditional silicon-based solar cells, including lower cost, improved flexibility, and the ability to be integrated into a wide range of applications[1].

In recent years, significant progress has been made in developing and commercializing thin-film solar cell technologies. These technologies include cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and organic photovoltaics (OPVs). These technologies have shown promising results in terms of improving the efficiency of solar[2].

This paper aims to provide an overview of the current state of thin-film solar cell technology and its potential to improve the efficiency of solar cells. The report will cover the different types of thin-film solar cell technologies, their working principles, advantages, and challenges, as well as recent advances and future prospects.



II. TECHNOLOGY

1. Nano technology

Nanotechnology is the manipulation and engineering of materials and devices on the nanoscale level, typically between 1 to 100 nanometers. It involves the creation and control of materials, structures, and devices with unique and often improved properties compared to their bulk counterparts. The field of nanotechnology is multidisciplinary, bringing together expertise in physics, chemistry, materials science, and engineering, among other fields[4].

The steps involved in nanotechnology can be broadly divided into five stages:

- Synthesis
- Characterization
- Processing
- Integration
- Testing.

□ Synthesis:

The first step in nanotechnology involves the synthesis of the nanomaterials. There are two approaches to the synthesis of nanomaterials: top-down and bottom-up. Top-down involves breaking down bulk materials into smaller structures, while bottom-up involves building up from individual molecules or atom[4].

□ Characterization:

After the nanomaterials are synthesized, they need to be characterized to determine their size, shape, composition, and other physical and chemical properties. Characterization techniques such as microscopy, spectroscopy, and X-ray diffraction are used to analyze the nanomaterials. This step is important in ensuring that the desired properties of the nanomaterials are achieved[4].

➤ Processing:

Once the nanomaterials are synthesized and characterized, they are processed to create the desired nanoscale devices or structures. This step involves the manipulation and assembly of the nanomaterials to create the desired structures or devices. Techniques such as chemical vapor deposition, sputtering, and spin coating are used to deposit the nanomaterials onto a substrate or template[4].

➤ Integration:

After the nanoscale devices or structures are fabricated, they are integrated into larger systems or devices to achieve the desired functionality. Integration involves the connection of the nanoscale components to electrical or mechanical systems to enable their operation[4].

➤ Testing:

Finally, the nanoscale devices or systems are tested to ensure that they function as intended and meet the desired performance specifications. Testing involves a range of techniques such as electrical testing, mechanical testing, and imaging to evaluate the performance of the nanoscale components. The testing step is critical in ensuring that the nanoscale components meet the desired performance specifications and can be deployed in real-world applications[4].

2. Multifunction solar cells:

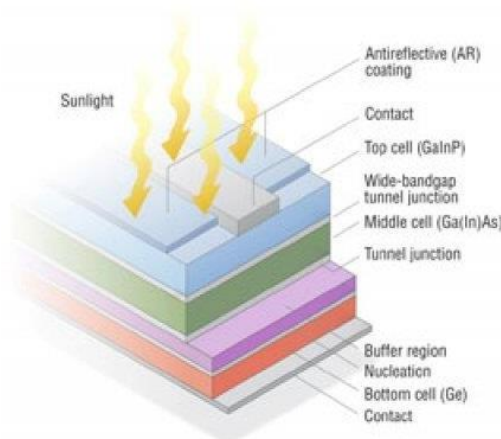


Fig 2 : Multifunction solar cells[6].



Multifunction solar cells are a type of solar cell that can convert not only sunlight but also other forms of energy, such as heat or mechanical vibration, into electrical energy. These cells offer a potential solution for increasing the efficiency and versatility of solar energy conversion systems.[6] One example of a multifunction solar cell is a thermophotovoltaic (TPV) cell shown in fig 2 .TPV cells can convert both sunlight and heat into electricity. These cells use a combination of materials that can absorb sunlight and heat radiation to produce a voltage across a semiconductor junction. The heat energy can come from a variety of sources, including concentrated solar power systems, waste heat from industrial processes, or even the human body. TPV cells have the potential to achieve high conversion efficiencies due to their ability to harvest energy from two sources[7].

There are also challenges associated with the development and implementation of multifunction solar cells. One challenge is the integration of multiple energy conversion processes into a single device. This requires careful selection and optimization of materials, as well as engineering of the device structure and interfaces between the different materials[7]. Another challenge is the trade-off between efficiency and complexity. Multifunction solar cells may require additional components or processing steps, which can increase the cost and complexity of the device. It is important to balance these factors with the potential benefits of increased efficiency and versatility[9].

II. WORKING PRINCIPLE

Multijunction solar cells based on III-V materials (gallium arsenide (GaAs), aluminum indium phosphide (AlInP), aluminum gallium indium phosphide (AlGaInP), gallium indium phosphide (GaInP), and indium phosphide (InP), etc.) show high efficiency, exceeding 35%, but due to the high production cost and low availability of their constituents, these solar cells are not considered suitable for cost- effective terrestrial applications though they are still very important for space PV applications.

Possible solar cell structures

Multijunction solar cells are solar cells with multiple p– n junctions made of different semiconductor materials. In response to different wavelengths of light, the p–n junction of each material will produce electrical current. The use of many semiconducting materials allows for the absorption of a wider range of wavelengths, enhancing the cell's absorption of sunlight to convert to electrical energy.

Techniques of existing tandem manufacturing designs were used to enhance the performance. In fact, unlike conventional crystalline silicon, a-Si can be used to reduce the cost of thin-film solar cells to generate cells with a lightweight and versatile capacity of about 10% fig3.

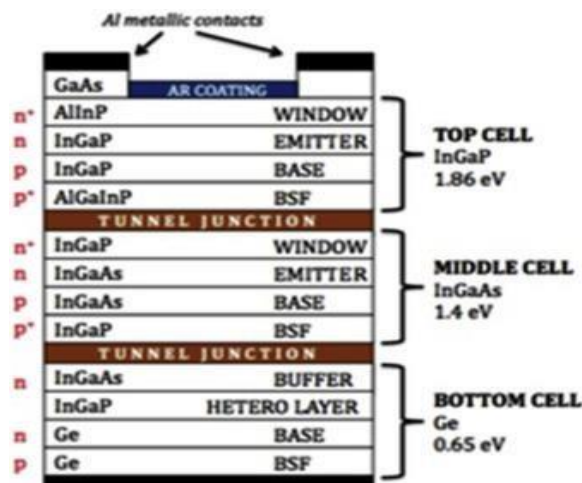


Fig 3:Possible multijunction solar cell structure. Back surface field.

➤ Tunnel diodes

Most monolithic multijunction solar cells use subcells, which are composed of a thin n-doped emitter on a thick p-doped base layer. Stacking such n-on-p junctions on top of each other would lead to p-on-n diodes between the subcells and these reverse diodes would block current flow. Thus solutions for the interconnection of the subcells need to be implemented.



A suitable interconnector must have a low-electrical resistivity, a high optical transmissivity and has to be integrated into the structure. Esaki interband tunnel diodes [49] have become standard for this purpose. They are realized through thin highly doped p-on-n diodes between the subcells. Fig. 5A shows the band diagram of an exemplary GaAs/GaAs tunnel diode. Due to the high doping levels the quasi-Fermi level (E_F) on each side of the pn-junction moves into the valence (E_V) and conduction (E_C) band, respectively. If a small positive voltage is applied to the junction, full states on the n-side become aligned with empty states on the p-side.

Based on quantum mechanical principles charge carriers can tunnel through the barrier if energy and momentum are conserved. The right handside graph in Fig. 5 shows an exemplary current–voltage curve of a tunnel diode. High current densities flow at low voltages. However, the current flow falls off sharply after a characteristic peak tunneling current density has been reached. Fig 4 This happens as occupied states on the n-side are no longer aligned energetically with empty states on the p-side. At higher voltages the tunnel diode behaves like a conventional pn-junction leading to another increase in current. As the targeted operating range of the tunnel diode is between 0 V and the voltage at which the peak tunneling current density is reached, tunnel diodes in a multijunction solar cell need to have a sufficiently high peak tunneling current density. This is especially challenging for concentrator cells, which are operating at current densities of several A/cm^2 . Realizing such tunnel diodes is a key challenge in the development process of monolithic multijunction cells.

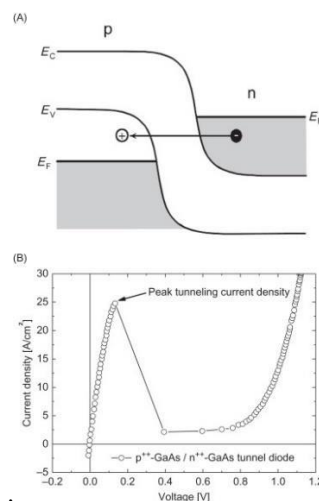


Fig 4:. Schematic band diagram of a tunnel diode (A).

Measured I - V curve of a GaAs/GaAs tunnel diode with a peak tunneling current density of above 25 A/cm^2 (B)

➤ Use of quantum dots in building solar cells

Quantum dots are three-dimensionally confined semiconductor nanocrystals. These are 0D particles in which, due to quantization effects, the band structure is dependent on the particle size. Therefore, in theory, one can engineer an optimal bandgap for high efficiency solar cells by varying the particle size appropriately. QDs provide new techniques for efficient photoexcitation and charge separation by combining novel nanoscale properties with low cost and processability to improve solar energy conversion. Three general strategies have been proposed to incorporate QDs in solar cells. The first strategy is to use the QDs to sensitize wide-bandgap semiconductors. The second strategy is to place the QDs in intimate contact with electron or hole conducting polymers. The third strategy is to form QD arrays where the QDs are electronically coupled to allow for efficient electron/hole conductivity. The first two strategies are based on the close contact of the QDs with other materials to achieve charge separation and transport with the QDs acting as the light-absorbing component. The third strategy requires highly coupled QD-array for light absorption.

The use of Quantum Dots to build highly efficient solar cells is primarily based on the following two facts.

First, additional current or voltage can be generated by employing hot carriers generated by absorbing photons of greater energy than bandgap energy. And second, carriers generated from photons having energy lower than the bandgap energy can be trapped by the energy states in the energy bandgap.

➤ Tandem Solar Cells

The conventional solar cells use single energy bandgap materials. These materials cannot efficiently absorb the full solar spectrum. To enhance the solar cell efficiency, the use of layers of different bandgap materials has been suggested [18]. The perfect combinations of materials to absorb the entire solar spectrum have been researched upon extensively.



Application of low-dimensional nanostructures, such as QDs, as an absorber layer in these solar cells, has been under consideration. A research group has shown an efficiency of 10.6% by embedding 3nm quantum dots in 2nm SiO₂ layers [19]. The efficiency obtained by the use of QDs in tandem solar cells is much lower than the efficiency of commercially available single junction silicon solar cells. Also, there are fundamental issues of reliability and heat removal that are associated with the use of QDs [20]. The complexity with the use of QDs in solar cells is further aggravated by the fact that for a silicon wafer of size 150mm, QDs in the order of quadrillion (10^{15}) will be required [21]. Another challenge is imposed by the control on the size distribution of QDs. When the size distribution is large, the interactions between the QDs increases resulting in reduced mobility and short circuit current. This happens due to charge carrier hopping between adjacent QDs [22].

➤ Hot Carriers to Increase Solar Cell Efficiency

Solar Cells using hot carriers convert excess photon energies into stable form before the excited states can reach to an equilibrium state with the environment. This excess photon energy appears as kinetic energy of the carriers, in the case of semiconductors, and phonon that is dissipated as heat, in the case of molecules. When a photon having energy greater than the bandgap energy is incident on the cell, the electrons get excited, and thermalization occurs through phonon-carrier scattering (Fig. 5). This excess photon energy must be delivered to the bands sustaining the hot carriers for achieving high efficiency of the solar cell [13].

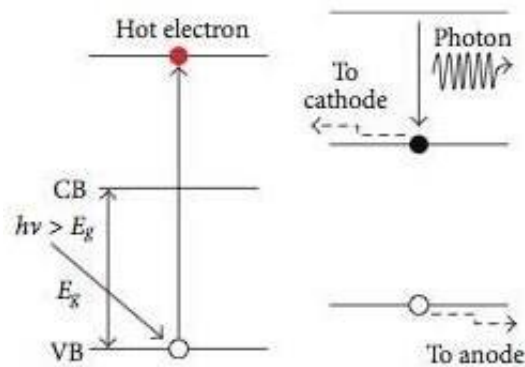


Fig. 8: Photon with energy ($h\nu$) greater than bandgap energy (E_g) strikes on a solar cell, excites an electron to conduction band (CB) from valence band (VB), and releases the extra energy ($h\nu - E_g$) as phonon [13].

There are two techniques to do the same. First, before the device cools down, remove the carrier from it thereby obtaining a higher energy electron and thus a higher voltage output (Fig. 8). To make this possible, the rate of hot carrier separation, transport, and collection at contacts must be greater than the rate of cooling hot electrons [13].

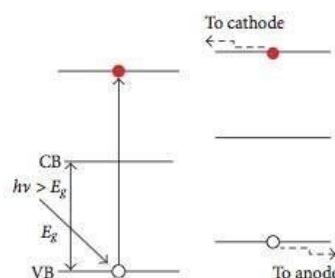


Fig. 9. Photon with energy ($h\nu$) greater than bandgap energy.

The second approach involves the energized electron spending its excess energy to excite another electron from the valence band thereby obtaining a higher output current (Fig. 9). This is also known as impact ionization. This occurs only when the rate of relaxation process is less than the rate of impact ionization [13]. The use of QDs for utilizing these hot carrier effects has been investigated by various groups [15, 17]. Till date, there has been no experimental evidence to support the fact that for QDs, the rate of thermal cooling of hot carriers is slower than the rate of multiple carrier excitations [13].

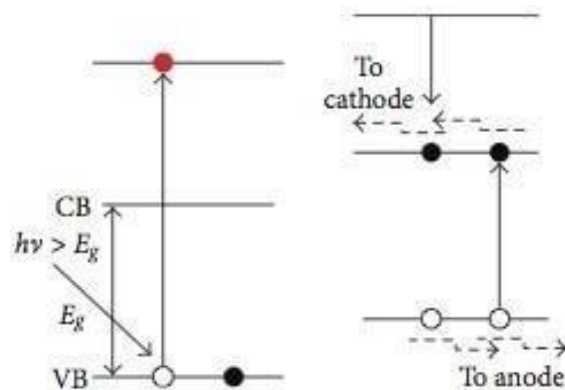


Fig. 10. Photon with energy ($h\nu$) greater than bandgap energy (E_g) strikes on a solar cell, excites an electron to conduction band (CB) from valence band (VB), and releases the extra energy ($h\nu - E_g$), which is used to excite another electron from VB to CB [13].

IV ADVANTAGES

1. Cost-effective: Thin film solar cells can be produced using less material than traditional silicon-based solar cells, which makes them less expensive to produce. They also require less energy to manufacture, which further reduces the cost of production.
 2. Lightweight and flexible: Thin film solar cells are much thinner and lighter than traditional solar cells, which makes them more flexible and easier to install. This also makes them ideal for use in portable and wearable applications.
 3. High efficiency: Thin film solar cells have the potential to achieve higher efficiencies than traditional solar cells.
 4. Versatile: Thin film solar cells can be deposited on a variety of substrates, including glass, metal, and plastic..
- Durable: Thin film solar cells are often more durable than traditional solar cells.

V APPLICATIONS

1. Building-integrated photovoltaics (BIPV):
2. Portable electronics:
3. Transportation:
4. Remote power:
5. Space applications:

VI CONCLUSION

In conclusion, thin film technologies have shown promise in improving the efficiency of solar cells by reducing the thickness of the absorber layer and optimizing the material composition. The most common types of thin-film solar cells are cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and amorphous silicon (a-Si). CdTe solar cells are relatively low cost and have achieved high efficiency levels of up to 22.1%. CIGS solar cells have also demonstrated high efficiency levels of up to 23.35%, but they are currently more expensive to produce than CdTe solar cells. Amorphous silicon (a-Si) solar cells are the most common type of thin-film solar cells but have lower efficiency levels compared to CdTe and CIGS solar cells. Overall, thin film technologies offer a promising avenue for improving the efficiency of solar cells, and further research and development in this field will likely lead to even greater advancements in the future.

VII. ACKNOWLEDGMENT

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