

DESIGN AND FABRICATION OF HIGH PERFORMANCE FOLDABLE SOLAR CELLS

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in Mechanical Engineering

By

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DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade “A++” by NAAC

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APRIL 2024



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **SARATHI R (40150043)** who have done the project work and carried out the project entitled **"DESIGN AND FABRICATION OF HIGH PERFORMANCE FOLDABLE SOLAR CELLS"** under our supervision from November 2023 to April 2024.

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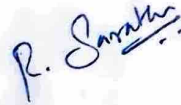
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DECLARATION

I, **SARATHI R (40150043)** hereby declare that the Project Report entitled "**DESIGN AND FABRICATION OF HIGH PERFORMANCE FOLDABLE SOLAR CELLS**" was done by me under the guidance of **Dr. V. SIVAPRAKASH, M.E., Ph.D.,** (Internal Guide) is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering.

DATE: 06-04-2024

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A handwritten signature in blue ink, appearing to read 'R. Sarathi', with a horizontal line underneath.

SIGNATURE OF THE CANDIDATE

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ABSTRACT

A heterojunction device was fabricated via oxidation of a thin film and sputtering technique. In this work, the sputtering process was used, the non-conductive glass slide was covered with Al to make it a conducting substrate. After that, copper oxide (CuO) film was fabricated via magnetron sputtering of conductive Copper film deposited, and subsequent oxidation at 450 °C in air to form a Copper oxide film. X-ray diffraction analysis revealed the formation of monoclinic CuO film. Scanning electron microscopy images characterization showed agglomerated grains for both films with Al grains larger than CuO grains. I-V characteristic of the Al-CuO exhibited a rectifying behavior with a turn-on voltage of around 1.3 V and an ideality factor of around 1.96. The heterojunction revealed an open circuit voltage of around 0.59 V and a short circuit current of 0.3 mA under 100 mW/cm² Spectral radiant power of the light-curing units solar light irradiation.

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LIST OF SYMBOLS AND ABBREVIATIONS

PV	Photovoltaic
CO₂	Carbon dioxide
DC	Direct current
AC	Alternating current
TFSCs	Thin film solar cells
CIGS	Copper indium gallium selenide
CdTe	Cadmium telluride
CZTS	Copper zinc tin sulphide
CIS	Copper Indium
DSSCs	Dye-sensitized solar cells
OPVs	Organic photovoltaics
FTO	Fluorine-doped tin oxide
ITO	Indium-tin oxide
ETL	Electron transport layers
HTL	Hole transport layers
CH₃NH₃PbI₃	Methylammonium lead iodide

CHAPTER 1

INTRODUCTION

To generate solar energy effectively and sustainably, photovoltaics has seen an increase in research and development due to a growing need for renewable energy sources. Thin film solar cells are one of the more promising photovoltaic technologies because of their flexibility, affordability, and ability to be produced on a wide scale. This effect, which occurs when light using the sun creates combinations of holes and electrons in materials known as electronic components, is what allows solar cells made of thin films to generate electricity using sunlight. Thin film solar cells, which offer advantages in terms of resource consumption and manufacturing processes, use small amounts of semiconductor materials which solar cells, placed onto substrates, in contrast to typical silicon-based solar cells. Thin film solar cells consume only a fraction of the semiconductor material compared to silicon-based cells. An overview of thin-film solar cell design and development is provided in this introduction, along with an emphasis on the technology's importance in the shift to sustainable energy sources.

Each of these materials has specific benefits regarding scalability, stability, and efficiency. Despite the active material's decreased thickness, the thin film architecture enables effective light absorption, reducing material costs while preserving competitive performance. Semiconductor materials like amorphous silicon, copper indium gallium selenide, cadmium telluride, and copper zinc tin sulfide enable solar cells to convert sunlight into electricity efficiently, with benefits in scalability, stability, and cost-effectiveness due to their thin film architecture and specific material properties.

Few notable commands must be resolved in the development and design of thin-film solar cells, such as increasing light absorption, maximizing the rate of charge transport, To improve light trapping or charge extraction efficiency, researchers are concentrating on the fabrication of innovative substances, such as nanostructured matter absorber films and transparent conductive oxides. In addition, novel device topologies are investigated to boost total efficiency and extend the spectral sensitivity of thin film solar cells, including tandem and multi-junction setups.

Deposition methods are techniques used in materials science and engineering to deposit thin films or coatings onto a substrate. These methods are crucial for

fabricating various electronic, optical, and functional materials used in a wide range of applications. Deposition processes can be categorized into physical vapor deposition (PVD) and chemical vapor deposition (CVD), each with its own sub-techniques. PVD methods involve the physical transfer of material from a source to a substrate through processes such as evaporation or sputtering, while CVD methods involve chemical reactions to deposit thin films from precursor gases onto a substrate surface.

Deposition methods play a vital role in the manufacturing of semiconductor devices, solar cells, optical coatings, and many other advanced materials and technologies, developments in deposition methods, including chemical vapor deposition (CVD), sputtering, or electrodeposition, are critical in allowing for exact control over the shape, content, and thickness of films, which in turn affects the scalability and performance of devices. Furthermore, current research initiatives seek to address environmental issues related to certain thin-film materials such example cadmium in CdTe solar cells by creating sustainable substitutes and recycling plans. Surface modification techniques encompass a diverse array of methods aimed at altering the physical, chemical, or biological properties of a material's surface. These techniques are crucial in tailoring surface characteristics to meet specific requirements in various applications, ranging from electronics to biomedical devices. Physical methods include mechanical abrasion, laser ablation, ion implantation, and plasma treatment, which modify surface topography or chemistry through mechanical, thermal, or ion bombardment processes. Chemical techniques, such as chemical vapor deposition, etching, functionalization, and coating, enable precise control over surface chemistry and functionality by introducing or modifying chemical groups or thin films. Biological methods involve biomimetic coatings, bioconjugation, and cell-surface engineering, leveraging biological molecules or processes to impart specific functionalities or interactions with biological systems. Advanced techniques like atomic layer deposition, layer-by-layer assembly, self-assembly, nanopatterning, and surface grafting offer unparalleled control over surface properties at the atomic or nanoscale level, enabling the fabrication of sophisticated surface structures and devices with tailored functionalities. These techniques play a pivotal role in advancing materials science, enabling the development of innovative materials and technologies with enhanced performance and functionality.

Thin film solar cell design and development is an interdisciplinary effort involving engineering, physics, materials science, and sustainability. Thin film solar cells offer a feasible way to fulfill the growing energy demands while reducing environmental impact. By overcoming technological hurdles and maximizing performance of the device, thin film solar cells have significant promise in helping to an overall transition toward renewable energy sources.

1.1. SOLAR PANELS

A wide range of solutions have grown within the solar energy production sector to specifically acquire clean energy. By heating the materials, standard power producing resources like coal or fossil fuels generate energy through steam. Uncommon electrical power resources such as wind, solar, tidal, and biomass power garner significant attention due to their renewable nature and potential to reduce reliance on fossil fuels. To increase solar panel performance by using different ways to cool like air, water, or a mixture of the two, phase-changing substances, fins, heatsinks, small particles, or wicks made of cotton with sunlight was provided along with an explanation of various kinds of sunlight-generating sections and their ability to cool plans.

Overall, solar energy systems will be divided into three generations based on their generation. First generation silicon solar panels using wafers, the second generation of silicon cell depending upon thin-film technology, or third generation solar cells depending on nanoscale crystals, polymers, dye-sensitized solar panels, or solar cells made from perovskite, which are examples of early emerging technologies. (Parthiban et al., 2022) In a time when solar power and sustainable development are more important than ever, solar energy systems have become the cutting edge of advances in technology and awareness of the environment. By utilizing the sun's strength, these solar cells provide a fresh, environmentally friendly, and essentially limitless source of energy.



Fig.1.1: Mass Power Production using Solar panel

1.2. SOLAR PHOTOVOLTAIC SYSTEMS

Photovoltaic or PV, panels use the photovoltaic panel to turn light and generate energy. It refers to the method by whereby light exposure causes semiconductors to produce voltages or current. A photovoltaic component, also known as a photovoltaic panel, is a collection of photovoltaic cells arranged within a structure of metal. The solar cells with the photovoltaic system collect light or transform its photons into electrical power. Solar photovoltaic (PV) systems come in a range of sizes, including compact roof-mounted units having just a few cells with only a few kilowatts of power to enormous facilities that use multiple megawatt many cells. An inverter converts direct current (DC) electricity from solar panels into alternating current (AC), making it suitable for powering homes and businesses, ensuring compatibility with electrical grids and appliances. Photovoltaic (PV) panels are crucial components in harnessing solar energy to generate electricity. Operating on the principle of the photovoltaic effect, these panels utilize semiconductor materials to convert sunlight into electric current. Comprising multiple photovoltaic cells within a metallic framework, solar panels capture sunlight and transform its photons into usable electrical power. PV systems vary in size and application, ranging from small rooftop units for residential use to large-scale solar farms generating multiple megawatts of electricity. To ensure compatibility with electrical grids and appliances, inverters are employed to convert the direct current (DC) electricity generated by the panels into alternating current (AC). This makes PV panels versatile and applicable in diverse settings, providing clean and

renewable energy for homes, businesses, remote areas, and utility-scale power generation, thereby contributing to sustainability and reducing dependence on fossil fuels. (Vodapally et al.,2016)

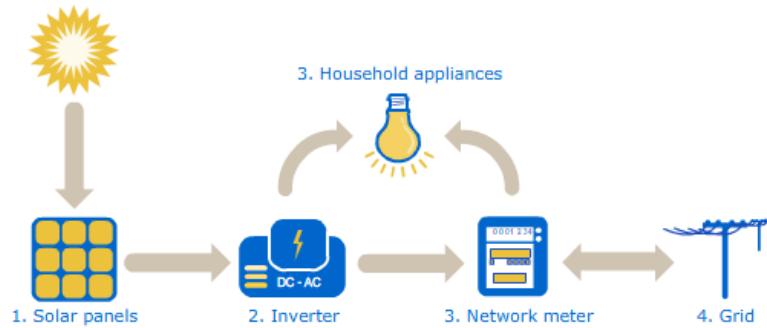


Fig.1.2: Grid-tied photovoltaic system for a home.

1.3. SOLAR CELLS

Alexandre-Edmond Becquerel made the first observation of the photovoltaic (PV) phenomenon in 1839. Russell Oh went on to create the first silicon solar cell of the modern era in 1946. Thin silicon wafers used in previous photovoltaic solar cells convert light from the sun into electrical power. The foundation of contemporary photovoltaic technology is the idea that every semiconductor material cell, consisting of two distinct layers (p-type & n-type materials), creates an electron hole. When a photon with enough energy strikes the p-type or n-type junction in this configuration of the structure, an electron is released from one layer to the next by absorbing energy emitted by the striking photon. In the process, an electron while a hole are created, and electrical power is produced. Mostly silicon (single crystal, multi-crystalline, amorphous silicon), cadmium telluride, copper-indium-gallium-selenide, and copper-indium-gallium-sulfide are among the several materials used in photovoltaic solar cells. All solar solar cells are divided into different classes according to these materials, as covered in the parts that follow. (Sharma.,et.2015).

1.4. GENERATION OF SOLAR CELLS

1.4.1. FIRST GENERATION SOLAR CELLS

The development of first-generation solar panels in the first half of the twentieth century established the groundwork for current solar power technology. Crystallized silicon serves as the main semiconductors used in those cells. They use p-n junctions and single-junction layouts to transform solar energy into electrical energy. While the first versions claimed performance levels of 10% to 20%, continuous improvements in production procedures have led to a steady improvement in performance indicators. First-generation solar panels are now widely used in the commercial, industrial, or residential industries to supply electricity to anything from massive solar power plants to rooftops installations. (Pastuszak., et.2022). Their stable nature and well-established production procedures have strengthened their place in the world energy scene. There are still issues, such as expensive costs for manufacturing and few efficiency improvements. First-generation cells for solar power continue to dominate the market irrespective of these obstacles, supporting the widespread application of solar power.

(a) Monocrystalline Silicon Cells:

The cells that we commonly refer to as silicon cells are monocrystalline silicon cells. As the name suggests, a single silicon crystal makes up the whole volume of the cell. These days, the commercial utilization of these cells is more common. Single-crystal silicon is a common term used to describe this element. It is composed all silicon, where the crystal's lattice is continuous throughout the solid, uninterrupted at the edges, and devoid of grain boundaries. Since monocrystalline silicon is made entirely of extremely pure silicon, it can be regarded as an inherent semiconductor. By adding additional elements to the silicon, it can also become p-type or n-type. Monocrystalline silicon is carefully cultivated in an extremely controlled atmosphere after being cut from big single crystals for use in solar cell fabrication. Usually a few millimeters thick, the cells are grid-arranged to create a panel. Efficiency levels of up to 24.4% can be achieved using monocrystalline silicon cells. (Baghel.,et.2022)

Among the several silicon-based semiconductor devices is the crystalline silicon photovoltaic cell. In the initial stages of solar cell manufacture, numerous approaches

of crystalline silicon cells have been suggested based on silicon semiconductor devices. The photovoltaic cell consists of a diode having a semiconductor structure. Progress in both domains was aided by the synergy between technologies and equipment created for PV cells and those created for additional silicon-based semiconductor devices, including large-scale integrated circuits or the numerous varieties of silicon semiconductor applications. Power conversion efficiency of solar cells was improved by process technologies like photolithography, and mass-production techniques like wire-saw slicing of silicon ingots created for the PV industry were also easily transferred to different silicon-based semiconductor devices. (Saga.,et,2010).

(b) Polycrystalline Silicon Cells:

One of the most important elements of contemporary photovoltaic systems are polycrystalline silicon cells, also known called polycrystalline solar cells. These cells are essential parts of solar panels and are responsible for turning light into power. Polycrystalline devices are constructed from numerous silicon crystals, in contrast with their monocrystalline substitutes, that are built from one silicon crystal. In order to create a substance with numerous structures of crystals, raw silicone is melted before being cast in rectangular molds during the process of production. Massive solar energy installations are known to benefit greatly from the cost-effectiveness of polycrystalline silicon cells, which are easily identified by their characteristic blue colour. Although their efficiency is usually a little lower than that of monocrystalline cells, technological developments have greatly reduced this difference in efficiency.

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developments have greatly reduced this difference in efficiency. Organic solar cells are manufactured through solution-based processes, beginning with the preparation of donor and acceptor materials dissolved in solvents. These solutions are then deposited onto a substrate, often coated with a conductive layer, using techniques like spin-coating or inkjet printing. After deposition, annealing may be performed to optimize the film's properties. Subsequently, a second electrode material is deposited to complete the device structure.

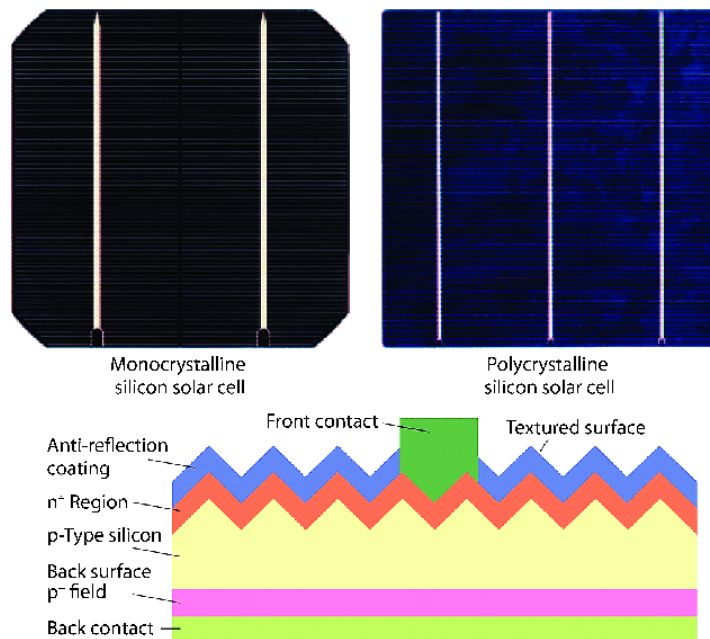


Fig.1.4.1.b: Typical polycrystalline silicon solar cells (top), and simplified cross-section of a commercial monocrystalline silicon solar cell.

(c) Amorphous silicon cells:

An important development in solar power technological devices, amorphous silicon cells offer multiple benefits over conventional crystalline silicon semiconductors. Amorphous silicon cells consist of non-crystalline, disorganized silicon atomic particles, as opposed to the crystalline equivalents directed atomic structure. This makes these individuals lighter, thinner, and more flexible, which makes them perfect for uses where adaptability and thinness are crucial. The amorphous silicon cells may be placed onto a variety of materials, which includes adaptable plastic bottles, allowing for the manufacture of thin and bendable solar power panels. Although formerly these

cells have performed less efficiently than crystalline silicon, continuing developments within the development of materials and manufacturing. (Kabir., et.2012)

1.4.2. SECOND GENERATION SOLAR CELLS

Photovoltaic cells of the second generation: thin-film solar cells (TFSCs) The thickness of many film layers varies between several nanometers(nm) for tens many micrometers(μm). The primary benefit of this method is in its low production and material expenses, as every cell only requires a little bit of semiconductor material to function. In comparison to first-generation PV, TFSC are more flexible, lighter, and generate less drag because of their thinness. Using sputter techniques, tiny layers of substances are deposited on plastic, glass, and stainless-steel substrates to create TFSCs. A few of these technologies aren't on the market just yet.

(a) Copper indium gallium selenide (CIGS):

A new kind of solar cell known as the copper indium gallium selenide (CIGS) thin-film solar cells was created in the last years of the 1980s, and testing in the lab has verified that it can achieve a theoretical photovoltaic the conversion rate of over 20 percent. This kind of photovoltaic cell has become one of the most widely available thin-film solar cells on the market right now. It has recently been produced and has good stability & photovoltaic absorption characteristics possess discontinuity and device features that are visible in the p-n a heterojunction band chart. This type of junction illustrates the potential for energy barriers to emerge in the context of charged particle transit. By creating buried intersections, the transformation for minority carriers within the p-type absorbers layer can separate both physical and electrical junctions, making most carriers on the nearby interface zone. This decreases the likelihood of recombination.(Zhou et al.,2021)

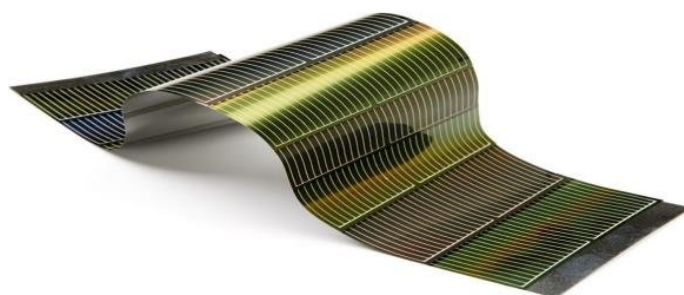


Fig.1.4.2.a: Copper-Indium-Selenide (CIS) cells

(b) Cadmium telluride (CdTe):

An outstanding compound semiconductor with a wide range of uses is cadmium telluride (CdTe), especially in detection of radiation & solar power. With its special set of characteristics, CdTe has a lot of potential for sunlight conversion. It is extremely effective at turning sunlight to energy because of its immediate band gap and substantial absorbing coefficient. CdTe exhibits an ideal balance between reflection of light & carrier transport, which boosts the effectiveness in solar energy sources. The band gap measures approximately 1.5 volts of electrons. Its semiconductor's large number of atoms and effective conversion of photons with high energies into electrical impulses make it useful in X-ray or gamma-ray sensors, demonstrating its adaptability across solar cell applications. Due to its abundant supply, cheap cost of production, and capacity for large-scale manufacture, CdTe is becoming increasingly important for application in clean energy and medicine.(Kapadnis.,et.2020).

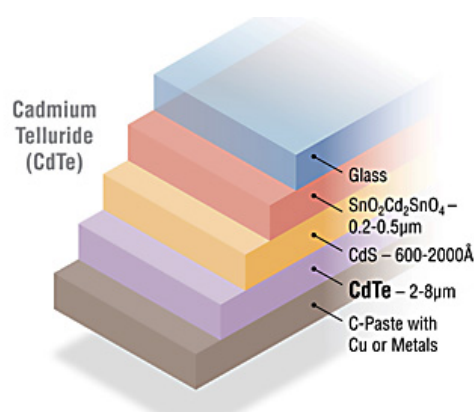


Fig.1.4.2.b: Cadmium Telluride Solar cells

(c) Copper zinc tin sulphide (CZTS):

Compound semiconductors CZTS is composed on zinc, copper, tin, and sulphur—elements that are now sufficiently available to be environmentally hazardous when employed in the levels required. Despite being a relatively new substance, preliminary findings suggest that CZTS may find application as a material for absorption for solar cells. An interesting semiconductor substance known for its possible uses in electronic gadgets and thin-film solar power cells is copper zinc tin sulfide, or CZTS. Composed of zinc, copper, tin, and sulfur, CZTS has favorable properties such a large amount of

component elements, non-toxicity, and inexpensive manufacturing methods. This quaternary combination is a strong contender to replace conventional solar energy sources like silicon since it has a straight bandgap appropriate for solar conversion.(islam et al.,2021) The electrical and optical characteristics of CZTS can be adjusted, providing versatile gadget design opportunities for effective absorbing light or charge carrier transfer. To obtain comparable solar converting efficiencies, studies concentrate on improving CZTS's efficiency using materials fabrication techniques, defects management and interaction engineering.

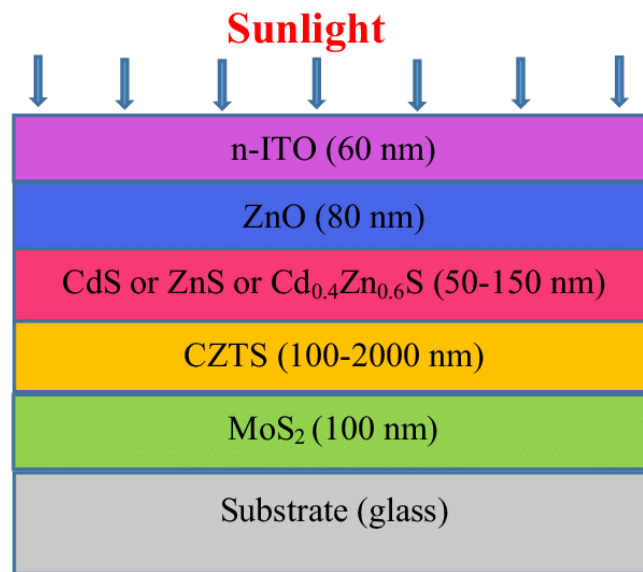


Fig.1.4.2.c: Structure of CZTS thin-film solar cells

(d) Copper indium selenium (CIS):

A semiconductors compound having exceptional qualities, copper indium selenium (CIS) has the greatest potential to thin-film solar cells. CIS, which is made from copper, indium, & selenium, has a straight bandgap, making it ideal for effective solar energy conversion. Strong coefficients of absorbing and superior charge-carrying mobility, which are critical for photovoltaic cell performance, are made possible by the way it is made. Sputtering, also and the use of chemical vapor deposition are two techniques that can be used to manufacture CIS thin films, making production processes scalable and reasonably priced. The material's adaptability to a variety of solar applications is further enhanced by its compatibility with flexible substrates. CIS-based solar cells are being optimized for increased stability and effectiveness through creative device

topologies and material engineering techniques. CIS has the potential to be a highly effective long-term treatment because of its non-toxic components.

1.4.3. THIRD GENERATION SOLAR CELLS

Third-generation photovoltaic cells have been developed to be inexpensive for production and to attain high efficiency in converting power. The Shockley–Queisser limit can be exceeded by these photovoltaic cells. This overview looks at various forms of third-generation solar panels, including line solar cells, which are made up of multiple materials placed together and use the full spectrum of the sun for high efficiency in converting electricity. Other kinds of third-generation solar panels include solar cells that are dye-sensitized, Perovskite-based cells, organic compounds solar power, and the quantum dot solar panels. Other third-generation methods, such as

Table 1.4.3 Third generation methods for photovoltaic

Photovoltaic Method	Description
Multiple Excitons	Generation of multiple electron-hole pairs (excitons) from a single photon through quantum dots or nanocrystals, increasing efficiency.
Hot Carrier	Utilization of high-energy charge carriers (electrons or holes) before thermalization to enhance efficiency in solar cells.
Down-Conversion	Process of converting high-energy photons into multiple lower-energy photons, thereby increasing absorption in solar cells.
Up-Conversion	Conversion of low-energy Photons into higher-energy photons, enabling absorption of previously unused wavelengths in solar cells.

are addressed as well in addition to these photovoltaic cells. It offers a guide to the technologies, covering their components and operating principles, as well as a summary of earlier research in the topic.

Third-generation solar power cells, which aim to surpass the constraints of conventional silicon-based or thin-film sun cells, are at the cutting edge of solar solar power. Such modern solar cells include dye-sensitized solar cells (DSSCs), perovskite solar cells, quantum dot solar cells, organic photovoltaics (OPVs), as well as other

cutting-edge technologies. Third-generation photovoltaic cells aim to achieve enhanced stability, reduced manufacturing costs, and increased efficiency through the adoption of novel materials and innovative device structures, paving the way for more sustainable and cost-effective solar energy solutions. By utilizing ideas from material science, quantum physics, and nanotechnology, researchers are looking for novel approaches to improve absorption of light, electron movement, and efficiency of conversion. These photovoltaic cells present the possibility of clear, lightweight, but adaptable designs, creating opportunities for well-thought-out combined solar energy systems.

(a) Dye-sensitized solar cells:

As an innovative method of converting sunlight into electricity, dye-sensitized solar cells (DSSCs) differ from conventional silicon-based photovoltaic technology. Light-absorbing pigments are employed for these cells' novel design, which draws inspiration from natural the process of photosynthesis to harvest solar energy. In contrast to traditional solar cells, dye-sensitized solar cells (DSSCs) use a permeable semiconductors layer that collects light and produces electric currents. After that, the charged particles are moved across the material called semiconductors to generate power. Due to their affordability, flexibility, and transparency, Dye-Sensitized Solar Cells (DSSCs) find practical applications in various fields, including handheld electronics and building-integrated solar power systems. To improve effectiveness or stability, studies are concentrated on improving molecules of dyes, materials for semiconductors, and electrolytes. Despite issues including leakage of electrolytes and dye deterioration, DSSCs show potential as a workable substitute. (O.I.Francis et al.,2021)

A standard Dye Sensitized Solar Cell (DSSC) has a variety of constituents, such as the backing material, the translucent conductive layer, the electrolyte, the dyes, the TiO_2 particles, the photovoltaic electrode, and the opposite electrode that are sealed with a gasket. The primary parts of dye-sensitized solar cells are the conductive substrate, counters the electrode, mesoporous TiO_2 layer, semiconductors films, dye sensitizers, the redox electrolytes. The electrode that operates consists of a mesoporous layer of nanoparticles of TiO_2 (approximately 20 nm in size) over a glass surface covered with fluorine-doped tin oxide, or FTO that has a thickness of roughly

10 μm . TiO_2 absorbs molecules of dye at its surface. The TiO_2 structure serves as a means of transportation and electrons receiver. This solution has certain chemicals that enhance the efficiency of solar cells in addition to an appropriate redox couple in high quantities. This makes sense in view of the gains in dye-loading and input photons to collected electron efficiency (IPCE) that have been documented for iodide/triiodide redox dependent electrolyte using standard 40–50 Mm concentration-based TiCl_4 treatment procedures. To successfully monitor the dispersion properties of bulk shuttles, an increase of concentrations within a TiCl_4 solutions was created. This method has been shown to be useful for lowering diffusing resistances in constructed DSSCs, leading to increased JSC levels. Applied using shuttle-based electrolytes in liquid form increasingly porphyrin sensitizers, such sophisticated increasingly thinner TiO_2 electrode have led to outstanding solar cells.

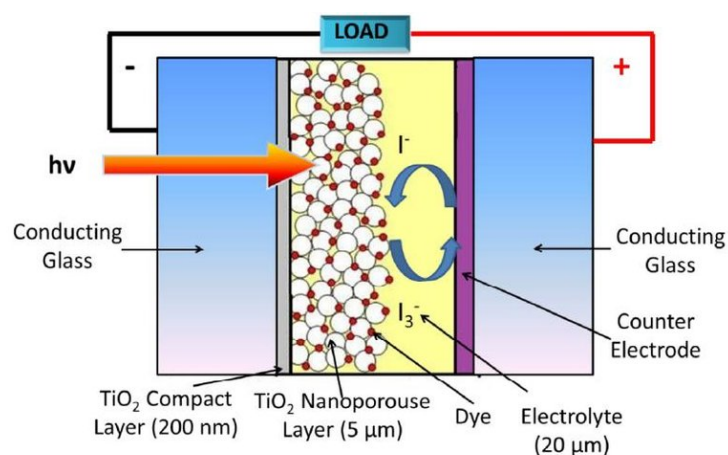


Fig.1.4.3.a: Structure of dye-sensitized solar cells

(b) Perovskite solar cells:

From the field of solar energy systems, perovskite solar panels have become an innovative technology, providing unmatched performance and flexibility. They make use of a substance known as polycrystalline with a crystal structure, which is usually created from organic-inorganic mixtures like the lead iodide ($\text{CH}_3\text{NH}_3\text{PbI}_3$) methylammonium. Perovskite solar panels can effectively convert a wide range of light into power because of their remarkable light absorption capabilities. They may be produced quickly and flexibly by employing low-cost solution-based fabrication techniques. Perovskite photovoltaic cells have surpassed conventional solar cells

made from silicon in the conversion of electricity thanks to ongoing advancement and research efforts. They are perfect for a variety of uses, from portable gadgets to rooftop structures, because to their small size and versatility. Research is still being done to address stability and environmental effect issues, despite these difficulties.(S.Liu et al.,2023)

When a piece of PSC is subjected to bright direct sunlight, its light-absorbing perovskite element produces excitons, which separate into holes and electrons to generate charged carriers. Excitement splitting occurs at the point of contact between the perovskite layer and the charge-transporting film. An electron is extracted from the hole in the semiconductor and deposited into a proton transporting layer (ETL) before it traverses the anode, which is usually made of zinc oxide (FTO) loaded with fluorine glass. Its HTL is instantly pierced, and the cathode which is often composed of metal is reached after that. Collecting electrons and holes separately, the opposing electrode and its functioning electrodes are updated and sent to the outer circuit.

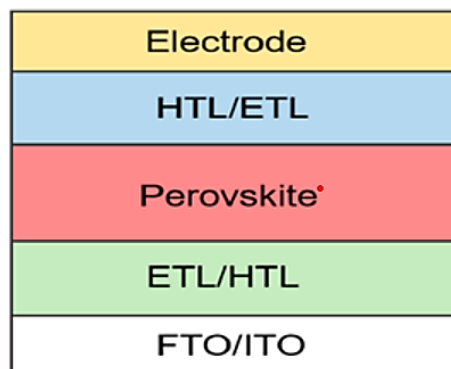


Fig.1.4.3.b: Structure of perovskite solar cell

(c) Organic solar cell:

Using a double-layer organically solar panel as an example, we may better understand the workings of an organic solar panel. Above both electrodes there are two functional organic compounds called Donor (D) or Acceptor (A). The donor material absorbs photons and releases electrons, while the acceptor material accepts these electrons, facilitating the flow of current. Typically, organic photovoltaic cells consist of a conjugated polymer (donor) and a fullerene derivative (acceptor). The key innovation in this design is the efficient charge the chemical structure and morphology of both

donor and acceptor materials to enhance device performance and stability, advancing the potential of organic solar cells for renewable energy applications transfer at the donor-acceptor interface, enabling high power conversion efficiencies the potential of organic solar cells for renewable energy applications transfer at the donor-acceptor interface, enabling high power conversion efficiencies.

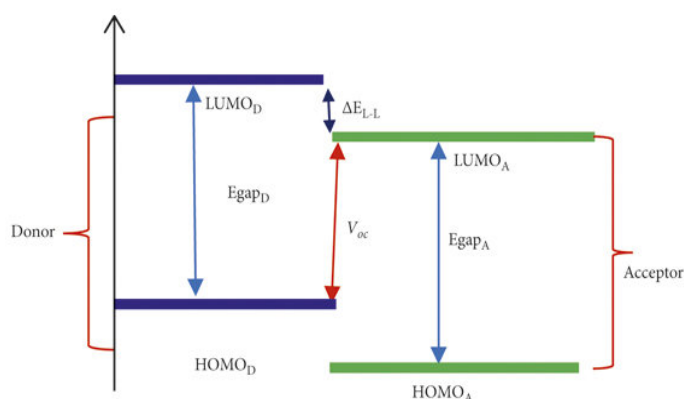


Fig.1.4.3.c: Diagram for a Donor-Acceptor in organic solar cells

For the substances that are active to be photoexcited, a minimum of one of both electrodes needs to be clear. Indium doped tin oxide is a widely used translucent conductive electrode (ITO). Glass, plastic, metal aluminium foil, and other support substrates were used to build the entire structure. There are at least five essential processes in the overall structure of the power transformation process. Single organic layers were the foundation of the very first generations of naturally occurring pv solar cells, which were constructed with two electrodes of metal with distinct roles in between. Most organic semiconductors have hole conductors with optical band gap of about 2 eV, which are far larger than silicon's and severely restricts the amount of solar spectrum that can be harvested. However, the potential for low-cost, large-scale production & chemical flexibility for alterations on the organic semiconductors through chemicals methods of synthesis are what motivate academic and industrial study in this area. The bulk a heterojunction idea was developed by combining two polymers with donor (D) and acceptor (A) characteristics in solution. This idea is comparable to that of the nonevaporated molecules.(Z.Hu et al.,2020).

1.5. DEPOSITION METHODS

The technique of producing and applying thin film coatings on a substrate material is known as thin film deposition. There are numerous materials that can be used to create these coatings. Additionally, thin film coatings offer a wide range of properties that can be used to modify or enhance certain aspects of the substrate's performance. Naturally, "thin" refers to a relative layer, but most thin film deposition processes are intended to create layers that are only a few tens of nanometers thick. In the modern world, thin films are frequently associated with semiconductors. Nevertheless, there are numerous more applications where coatings as thin as a few microns are required that make thin films significant.

➤ ***Physical methods:***

- a) Thermal evaporation
- b) DC magnetron sputtering
- c) RF magnetron sputtering

➤ ***Chemical methods:***

- a) Chemical/ electro photochemical bath
- b) Spin coating
- c) Spray pyrolysis

1.5.1. *Physical methods*

a) Thermal evaporation:

Thermal evaporation is a process that involves the conversion of a liquid or solid material into a vapor state through the application of heat. It is a widely used technique in various industries, including electronics, optics, and coatings, for the deposition of thin films onto a substrate. In thermal evaporation, the material to be evaporated is heated in a vacuum chamber, causing it to vaporize and condense onto the substrate, forming a thin film. The temperature at which the material is heated determines its evaporation rate and the properties of the resulting film. The process is typically carried out under controlled conditions to ensure uniformity and quality of the deposited film. Thermal evaporation offers advantages such as simplicity, versatility, and the ability to deposit a wide range of materials, including metals, semiconductors, and organic

compounds. However, it also has limitations, such as the potential for contamination and the inability to deposit films with complex structures. (Yunsong et al., 2020)

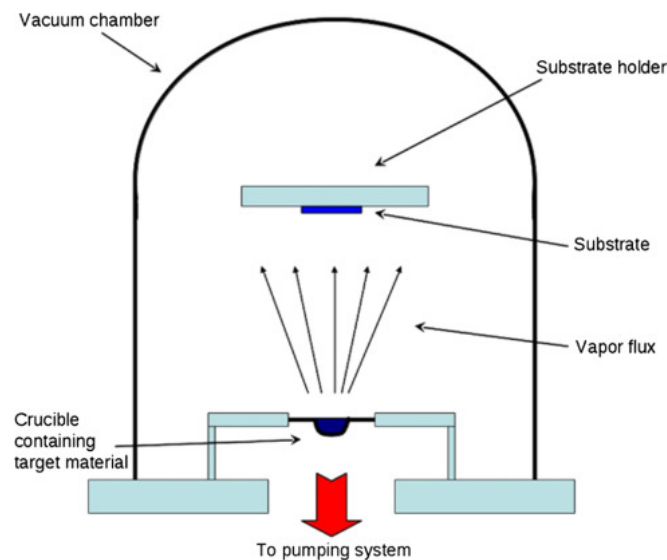


Fig.1.5.1.a: Process of Thermal evaporation

b) DC magnetron sputtering:

Magnetron sputtering is a widely used coating technology in industries such as semiconductor, chip preparation, and solar cell manufacturing. It is known for its ability to produce high-purity film layers and thin films of various materials. The quality of thin film deposition in magnetron sputtering is influenced by factors such as magnetic field distribution, plasma density distribution, working argon pressure, and temperature. In magnetron sputtering, a cylindrical sputtering device is used, and the magnetic field distribution is simulated using the equivalent magnetic charge model. The magnetic field intensity distribution is solved using the finite element method. The study of particle distribution within the plasma during magnetron sputtering is crucial. The distribution and order of magnitude of electrons, ions, and substable ions are considered under a uniformly distributed magnetic field distribution. As the working argon pressure increases, the distribution of sputtered atomic streams widens, and the target etching morphology tends to be more homogeneous. However, energy utilization decreases compared to lower argon pressures.

c) RF magnetron sputtering:

A flexible thin film depositing method, RF magnetron sputtering is widely used in many different industries, most notably in the semiconductors and solar energy industries. In this procedure, high-energy ions produced by a plasma explosion in a chamber with a vacuum are blasted into the target substance. A magnetron cathode is exposed to radio frequency (RF) power, which produces a field of magnets that increases the sputtering efficiency. A thin layer is formed on a substrate when atoms are displaced and deposited by the ions upon colliding with the target substance. Because RF magnetron sputtering provides exact management of layer its thickness, structure, and deposition rate, it can be used to produce highly reproducible and uniform complicated multilayer structures. It is essential because of its capacity to deposit a variety of materials, such as metals, oxides, and nitrides.(Fu.Y.Peng et al.,2023)

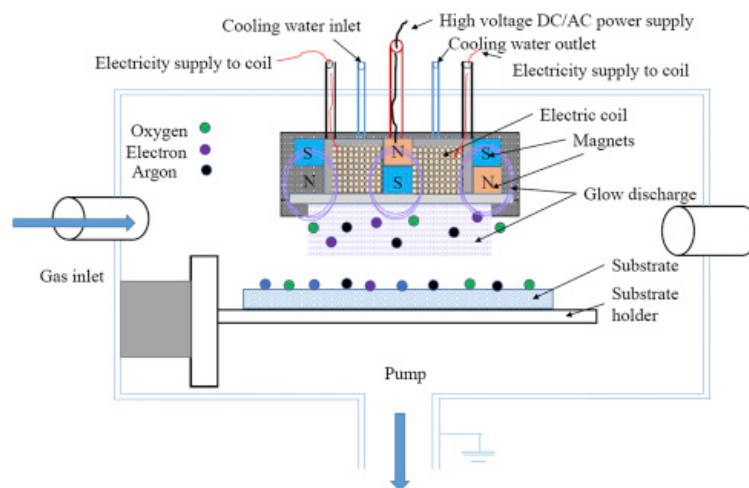


Fig.1.5.1.c: Diagram for the magnetron sputter coating machine's mechanism.

1.5.2. Chemical method:

a) Chemical/ electro photochemical bath:

Chemical methods for synthesizing metal chalcogenides, such as ZnS, are gaining attention due to their simplicity, cost-effectiveness, and suitability for large-scale deposition. These methods involve the deposition of thin films on various substrates, including insulators, semiconductors, or metals, at lower temperatures to reduce oxidation and corrosion. The deposition process can occur through ion-ion

mechanisms or the adsorption of hydroxide intermediates on the substrate. In the case of ZnS film deposition, a competitive process exists in the bath involving the presence of OH⁻ ions and the hydrolysis of thiourea as a source of S²⁻ ions. The formation of ZnS film occurs preferentially at the surface of hydroxide rather than nucleating separately in the solution.

(b) Spin coating:

Spin coating is a widely utilized thin-film deposition technique employed across various industries, particularly in microelectronics, optics, and nanotechnology. This process involves applying a solution or liquid precursor onto a substrate, which is then spun at high speeds to spread the material evenly over the surface. As the substrate rotates, centrifugal forces drive the liquid outward, forming a thin and uniform film. Spin coating offers precise control over film thickness and morphology, making it ideal for producing thin films with tailored properties. It is a versatile and cost-effective method suitable for depositing a wide range of materials, including polymers, semiconductors, and nanoparticles. This technique is commonly used in the fabrication of semiconductor devices, photovoltaic cells, and organic electronic devices. Despite its simplicity, spin coating requires careful optimization of parameters such as spin speed, solution viscosity, and drying conditions to achieve desired film characteristics. Ongoing research focuses on enhancing the uniformity, reproducibility, and scalability of spin coating processes to meet the evolving demands of advanced technological applications.

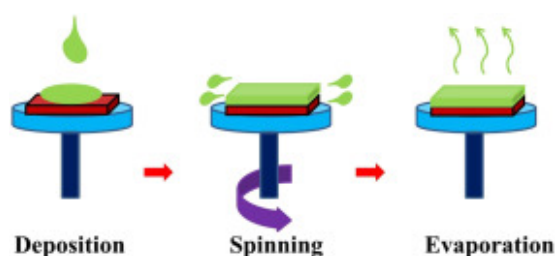


Fig.1.5.2.b: Spin coating process

c) Spray pyrolysis:

Spray pyrolysis (SP) is an efficient, simple, and cost-effective technique for synthesizing high-quality thin films. It involves spraying a solution onto a heated

substrate, which undergoes pyrolysis to form a thin film. Different types of Spray pyrolysis units exist based on the type of pyrolysis reaction and nozzle used for spraying the solutions. The nature of the thin film obtained from SP depends on various parameters, such as solution concentration, substrate temperature, and spray rate. Spray pyrolysis is commonly used for the synthesis of metal oxide films, which have applications in supercapacitors, gas sensors, optoelectronic devices, and solar cells. The advantages of Spray pyrolysis include its simplicity, cost-effectiveness, and efficiency compared to other deposition routes. However, Spray pyrolysis also has limitations, such as limited control over film thickness and uniformity.

It allows for the deposition of complex compositions and structures, facilitating the engineering of materials with tailored properties. Spray pyrolysis is extensively utilized in the production of functional coatings, transparent conductive oxides, and thin-film electronic devices. Ongoing research focuses on optimizing process parameters, precursor formulations, and substrate conditions to enhance film quality, efficiency, and performance for diverse technological applications.

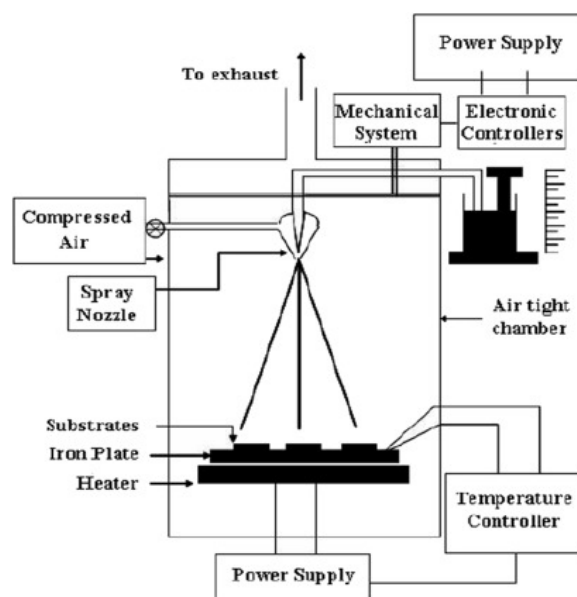


Fig.1.5.2.c: Schematic diagram of spray pyrolysis technique.

CHAPTER 2

LITERATURE SURVEY

Zhaoping Xia., Dan Li., et al., (2021) gives the conclusion, which highlights the creation of a thin-film microextraction device based on paper-based smart vapor production in the identification of volatile aldehydes as lung cancer biomarkers is covered. Use of stimuli-responsive core-shell gold nanorod (GNR) quantum dot (QD)-embedded metal-organic framework (MOF) structures, they studied about developed a smart vapor generation paper-based thin-film microextraction system that can be capable of both sensitive on-field fluorescence detection and accurate surface-enhanced Raman spectroscopy (SERS) quantification of volatile benzaldehyde (BA). In order to determine volatile aldehydes as lung cancer biomarkers, they studied and created a thin-film microextraction device based on smart vapor generating paper. Sensitive on-field fluorescence detection and precise surface-enhanced Raman spectroscopy quantification of volatile benzaldehyde are made possible by the method. Paper-based thin-film microextraction method using vapor generation Quantification of surface enhanced Raman spectroscopy (SERS) and directly fluorescence detection.

N. Zarabinia, Giulia Lucarelli, et al., (2022) gives the conclusion of this paper which highlights the method of creating flexible perovskite solar cells with a sheet of paper acting as an applicator is discussed in the study. In this work, perovskite films were deposited in air using a sheet of paper as an applicator dipped in a green anti-solvent. This increased the solar cell's efficiency by 82% over that of a dry sheet of paper. When utilizing the paper applicator soaked in anti-solvent, the solar cell's efficiency increased by 82%. A future-proof automated version of the process is suggested. Engineering with antisolvents and spin coating. paper sheet for deposition that had been soaked in anti-solvent.

Fahmid Kabir., et al., (2019) gives the conclusion of this paper which highlights the fabrication of a dye-sensitized solar cell (DSSC) with organic red and green dyes taken from Malabar and red spinach is covered in this research. The optimal cell efficiency determined by the combination of these colors is 0.847%. The authors of this paper employed red (*Amaranthus dubius*) and green (*Basella alba*) dyes that were derived

from Malabar spinach and red spinach, respectively, as the source of sensitizer for TiO₂ photoanode-based dye-sensitized solar cells (DSSC). When sensitized with separate green and red dyes, the DSSC's cell efficiency was 0.466% and 0.531%, respectively. The best cell efficiency of 0.847% was shown by the DSSC co-sensitized with the ideal dye mixture (20% green + 80% red). Using the extracted dyes, dye-sensitized solar cells (DSSC) are created.

Yehia Selim, Ahmed Mohamed., (2017) gives the conclusion of this paper which highlights the paper that is presented discusses how dyestuff might enhance the performance of dye-sensitized solar cells. An effective organic dye sensitizer for dye-sensitized solar cells is presented in this article. It is a material combination made up of an electrode that is transparent and coated in a dye-sensitized mesoporous film of nanocrystalline TiO₂ particles, an electrolyte that has an appropriate redox-couple, and an electrode. An overview of dyestuff, including its varieties and limits, is given in this work. It investigates the factors to consider while choosing a dye to improve DSSC efficiency.

Li Yiming., Deng Guoyun., (2016) gives the conclusion of this paper which highlights the sputtering target material and the CIGS-based thin film solar cell made with it be the topics of this paper. The paper is not particular about sputtering solar cells. This article presents a sputtering target material and a thin-film solar cell based on CIGS that can be made using the target material. However, the target materials can be deposited using either DC sputtering or AC sputtering, avoiding the need for an expensive RF sputtering apparatus to deposit a layer of zinc selenide. A sputtering target material of thin-film solar cells based on CIGS is provided in this paper. The target material for zinc selenide sputtering reduces production costs. Sputtering deposition techniques: DC and AC.

J R Suresh., K Rajeshwar, Reddy., (2020) gives the conclusion of this paper which highlights the given document explains about how a solar photovoltaic system (SPVS) can produce electricity, but it makes no use of a paper that uses photovoltaic cells. The authors of this paper explained how the synchronized maximum power point solar tracking system (SMPPSTS) help the solar photo voltaic system (SPVS) produce electrical energy. The production of electrical energy using solar photovoltaic systems is presented in this paper. A solar tracking system can help to improve the efficiency

of the system. Synchronized maximum power point solar tracking system (SMPPSTS) with the purpose of increasing output in the solar photovoltaic system (SPVS) energy generation system.

Shital, Shinde., A., N., Cheeran., (2018) gives the conclusion of this paper which highlights the design for a completely isolated solar photovoltaic energy production system is the subject of the article that is supplied. It focuses on simulating and modeling a photovoltaic (PV) module plus a boost converter coupled to an AC load mathematically. Although the phrase "photo voltaic cell" is not used in the study precisely, it does address the photo voltaic (PV) module and its features. This work will examine current methods for MPPT algorithms and make extensive use of renewable solar energy by connecting PV modules and AC loads and obtaining a constant maximum power output from each module. PV module with a boost converter simulated and modeled mathematically. Application of the MPPT algorithm to maximize the PV module's power output module with a boost converter simulated and modeled mathematically. Application with the Perturb & Observer technique in the MPPT algorithm.

Elaheh Akbarnejad., Mahmood Ghoranneviss., (2017) gives the conclusion of this paper which highlights the given paper describes the fabrication of CdTe nanostructures by RF magnetron sputtering. The paper has no reference of DC magnetron sputtering. This article uses the methods of X-ray diffraction (XRD), UV-VIS-NIR spectrophotometry, scanning electron microscopy with field emission (FESEM), and atomic force microscopy (AF Microscopy) to investigate the impact of CdTe nanostructure thickness on crystalline, optical, and morphological properties, respectively. The process of RF magnetron sputtering was used to successfully produce CdTe nanostructures. The controlled mechanical properties and great purity in the nanostructures was proved. process of RF magnetron sputtering. Atomic force microscopy (AFM), scanning electron microscopy with field emission (FESEM), UV-VIS-NIR spectrophotometry, and X-ray diffraction (XRD)

Slawomir Gulkowski., Ewelina Krawczak., (2020) gives the conclusion of this paper which highlights the development and analysis of thin films deposited with sputtering are covered in the study, together with the application of RF/DC magnetron sputtering for the deposition of structures in CIGS-based solar cells. In they studied, energy-

dispersive X-ray spectroscopy (EDS), scanning electron microscopy (SEM), and four-point probe resistivity measurements were applied to examine the structural and electrical properties of the sputtered films. The Mo back contact sheet resistance decreased by $0.3 \text{ } \Omega/\square$ and $0.08 \text{ } \Omega/\square$ due to the aluminum layer. The chemical composition of the CIGS absorber was suitable, with CGI and GGI of 0.96 and 0.2, etc. Magnetron sputtering method for thin-film deposition. Analysis methods include four-point probe resistivity tests, SEM, EDS, and XRD.

Amit, Rastogi., Scott, Haymore., et al., (2017) gives the conclusion of this paper which highlights the RF magnetron sputtering is not discussed in the provided paperwork; instead of it analyzes DC magnetron sputtering. This article explains the use of a DC magnetron sputtering system to deposit a film on a substrate. The substrate support is made up of an edge area around a core region that is elevated in relation to the edge region. Device for DC magnetron sputtering. Technique for applying a coating to a surface.

Abdul Kuddus., Samia Tabassum.,(2019) gives the conclusion of this paper which highlights the given paper explains the spin coating method used to fabricate ZnO/CuO heterojunction solar cells. This paper presents a modeling and experimental study of sol-gel spin coating-fabricated a heterojunction solar cells (HJSC) based on zinc oxide (ZnO) and cupric oxide (CuO). The heterojunction solar cells' simulated efficiency was 5.5%. The manufactured solar cell outperformed 1.15% in terms of power conversion efficiency. Utilizing AMPS-1D software for simulation fabrication experimentation using the sol-gel spin coating method.

Tian Jianjun., Yuan Jifeng., (2018) gives the conclusion of this paper which highlights the given paper describes a spraying pyrolysis equipment and method for high flux thin film production. The term "spray pyrolysis based thin film paper" is not mentioned explicitly. This article uses the high-flux pyrolysis in-situ synthesis system as the system. Using a one-time spraying method, a few functional thin films with component proportions are created by various and controlling the components and the amount of precursor liquid, which is given into various spraying guns, along with the spraying pressure, distance, and amplitude in real time online. Preparation of multi-component thin-film materials with high flux increased effectiveness of thin-film material

preparation Pyrolysis in-situ synthesis in spraying Changing and controlling components and giving a sufficient volume of liquid precursor.

Wang Yujie., Zhang Yunhe., (2018) gives the conclusion of this paper which highlights the given research explains thin-film solar cells based on graphene; however, it makes no mention of thin-film solar panels. This article presents a thin-film solar cell based on graphene that has a transparent electrode and a thickness of no more than 20 nm. The device's stability and homogeneity are guaranteed by the employment of a suction filtering approach. The light conversion efficiency of thin-film solar cells based on graphene has increased. There is no heavy metal pollution and increased electron mobility in the graphene film. The thin film is prepared using the suction filtration process. The method used for managing the graphene film's thickness is water transfer.

Peng Shou., Wang Yun., et al., (2015) gives the conclusion of this paper which highlights the paper that is provided talks about thin-film solar cells, but it makes no mention of solar panels made using thin-film paper. According to this paper, a thin-film solar cell is composed of the glass substrate, a transparent conductive layer, a photovoltaic absorption layer, and a back electrode layer, in that order from bottom to top. Resistance decreases by using metal nanowires in place of transparent conductive coating in semiconductors. improved thin-film solar cell photoelectric conversion efficiency.

David Wagner., Chris Baber.,(2015) gives the conclusion of this paper which highlights the development and production process of high performance foldable solar cells is not covered in the paper which is provided. The main reason for the increasing appeal of alternative energies is the photovoltaic effect, which is defined in this article as the converting of optical energy into electricity. The aim of this research project is to better understand the photovoltaic (PV) effect by developing, constructing, and characterizing silicon solar cells. The purpose of the paper is to improve knowledge about the photovoltaic effect. The ideal photovoltaic performance is studied by a variety of arrangements in this research. The development, manufacturing, and evaluation of silicon solar cells of processing semiconductor wafers at various temperatures, diffusion times, and dopant materials.

CHAPTER 3

AIM AND SCOPE

3.1 AIM:

The goal of creating high-performance photovoltaic cells includes a few important goals. First and foremost, it aims to create novel solar cell materials that provide increased versatility and adaptability, facilitating integration into a range of settings and applications. Second objective is to maximize solar cells' efficiency and power production capacity so they can efficiently capture solar energy for a variety of uses. The objective also involves addressing technical challenges related to durability, longevity, and mechanical strength to develop foldable solar cells capable of withstanding harsh environments and repeated folding cycles. Researching cost-effective production methods and materials to balance performance and affordability for widespread accessibility. And the aims to explore innovative design principles and mechanical aspects of foldable solar cells, encompassing factors such as resource origins, manufacturing methodologies, and end-of-life disposal considerations

3.2 SCOPE:

The deposition of individual layers of aluminum (Al) and copper oxide (CuO) thin films using a DC magnetron sputtering system. The scope of this research extends from the preparation of micro-glass slides through thorough cleaning processes, including soaking, rinsing, ultrasonic bath treatment, and vapor cleaning, to ensure pristine substrates for thin film deposition. The deposition conditions, such as achieving a base vacuum and maintaining specific sputter gas and power parameters, were meticulously controlled to ensure uniform and high-quality film growth. The primary objective of this study is to transform non-conductive glass substrates into conductive substrates through the deposition of aluminum, followed by the growth of a copper oxide film via magnetron sputtering and subsequent oxidation. This research holds promise in various applications, including optoelectronics, sensors, and thin film electronics, where precise control over film properties and substrate conductivity is essential for device performance and functionality.

CHAPTER 4

MATERIAL AND METHODOLOGY

4.1 MATERIALS:

The selection of appropriate cleaning materials, along with the careful choice of deposition parameters and materials, is essential for achieving the desired characteristics and performance of the thin film layers deposited on the glass substrates. This systematic approach ensures the success of the experimental work and the reliability of the results obtained.

- **Coating**

- a) Aluminum Target
- b) Copper Target
- c) Argon Gas
- d) Glass slide (76.2 mm X 25.4 mm X 1 mm)

- **Cleaning**

- a) Acetone
- b) Distilled Water
- c) Isopropyl Alcohol

4.1.1. Aluminium target

The utilization of aluminium targets in DC/RF sputtering processes holds paramount significance. The size of the target is 25mm These targets serve as the elemental source for the deposition of thin layers of aluminium onto substrates, facilitating the creation of crucial layers within solar cell structures. Aluminium, renowned for its conductivity, affordability, and compatibility with photovoltaic materials, emerges as a preferred choice for such applications. Through DC/RF sputtering, aluminium atoms are dislodged from the target surface by bombarding it with ions generated from a plasma discharge. This process allows for precise control over the thickness and uniformity of the aluminium layer, ensuring optimal performance and efficiency in solar cell designs. Moreover, the versatility of sputtering techniques enables the deposition of aluminium onto various substrates, including glass, flexible plastics, and even unconventional materials, expanding the scope for innovative solar cell architectures.

The integration of aluminium targets in DC/RF sputtering processes underscores their indispensable role in advancing thin-film solar cell technology towards enhanced sustainability and renewable energy solutions.

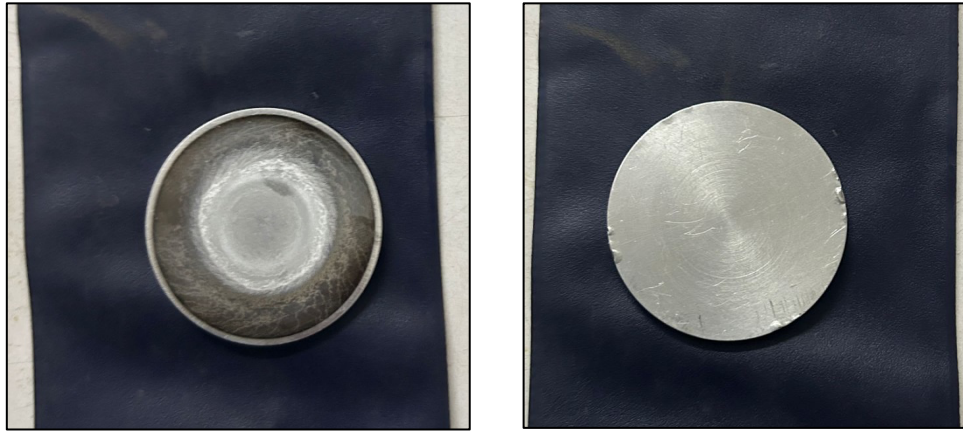


Fig.4.1.1: Aluminum Target

4.1.2. Copper target

DC/RF sputtering methods, copper (Cu) targets are essential to the creation of thin-film solar cells. The size of the target is 25mm. These targets provide a vital supply of atoms of copper that are needed to deposit thin layers on substrates and constitute essential structural elements of solar cells. With such uses, copper is a desirable option due to its great electrical conductivity, affordability, and suitability for photovoltaic materials. By subjecting the target surface to an ion bombardment produced by a plasma discharge, copper atoms are freed from it in DC/RF sputtering. Improving the functioning and effectiveness of solar cells requires precise regulation of both the thickness and homogeneity of the copper's layer, which can only be achieved through this regulated method. Additionally, the flexibility of sputtering processes makes it possible to layer copper onto a variety of substrates, such as glass, flexible polymers expanding the possibilities for innovative solar cell designs.



Fig.4.1.2: Copper Target

4.1.3. Argon gas

In the fabrication of thin-film solar cells using DC/RF sputtering techniques, quantity 40 [Sccm] argon gas plays a pivotal role in creating the necessary plasma environment for efficient deposition. Argon, chosen for its inert properties and high ionization potential, serves as the sputtering gas within the vacuum chamber. During the sputtering process, argon ions are generated from the plasma discharge and accelerated towards the target material, which may consist of elements like silicon, cadmium telluride, or other photovoltaic materials. These accelerated argon ions collide with the target surface, dislodging atoms and causing them to be ejected onto the substrate, where they form thin layers of semiconductor material. The use of argon gas ensures a stable plasma discharge, enabling precise control over the deposition process, including layer thickness, uniformity, and composition. Additionally, argon's inert nature prevents unwanted chemical reactions that could compromise the quality and performance of the deposited thin films. Thus, argon gas is indispensable in DC/RF sputtering for thin-film solar cell coating, facilitating the production of high-efficiency photovoltaic devices vital for renewable energy generation.

4.1.4. Acetone

Acetone, a common solvent, is not typically used in thin film solar cell coating via DC/RF sputtering. Instead, sputtering processes predominantly rely on vacuum environments and noble gases like argon for the deposition of thin film layers onto substrates. Acetone is primarily utilized in cleaning and preparation steps prior to sputtering, ensuring the substrates are free from contaminants that could affect film quality. However, it's crucial to handle acetone carefully due to its flammable nature

and potential health hazards. In the context of thin film solar cell coating, precise control over the deposition environment and materials is essential for achieving optimal device performance and efficiency. Therefore, while acetone plays a role in the preparation process, its direct involvement in sputtering is limited.



Fig.4.1.4: Acetone

4.1.5. Isopropyl alcohol

Using DC/RF sputtering methods, isopropyl alcohol (IPA) has a small usage for thin film solar cells coating. Before substrates are deposited, IPA is usually used to clean the impurities that could lower the quality of the film. Maintaining a controlled pressure environment and using noble gases, such as argon, during the deposition process are the main goals of sputtering. Although IPA works well as a cleaning solvent, it has very little direct effect on the sputtering process. Rather, it is an essential part of the preparatory stages that enhance the overall dependability and quality of the manufacture of thin-film solar cells.



Fig.4.1.5: Isopropyl alcohol

4.2 METHODOLOGY:

Aluminium and Copper sputtering targets were used to deposit individual layers. A DC magnetron sputtering system was employed for depositing thin films. Micro-glass slides were cleaned by soaking them in soap-less solution, followed by rinsing with tap water, distilled water, and acetone-distilled water. For further cleaning, the glass slides were placed in an ultrasonic bath of acetone for 30 mins. To remove the grease from the substrate the cleaned substrate was cleaned using isopropyl alcohol vapor. The substrates were then dried in a hot air oven for approximately 2 hours to remove residual solvents. The dried substrates were immediately loaded into the DC magnetron sputtering chamber for the deposition of individual layers of Al and Cu.

The deposition conditions for the growth of individual layers of Al and CuO thin film are outlined below. A base vacuum was achieved using a diffusion pump backed by a rotary pump, and the sputter chamber was maintained at 5×10^{-6} mbar for all depositions. Argon was used as the sputter gas, with a sputter power of 80 W and a working pressure of 0.02 mbar maintained for all depositions. To convert the non-conducting substrate into a conducting substrate, Al was coated on the substrates for 30 mins. Subsequently, a copper oxide (CuO) film was grown via magnetron sputtering of the conductive Cu film deposited, followed by oxidation at 450°C in air for 2 hours.

Table 4.1 Growth parameter of Aluminium and copper layers

Sample No:	1	2	3	4	5	6
Time [min]	15	20	25	30	35	45
Sputtering gas	Argon					
Argon flow rate [Sccm]	40					
Power supply type	DC					
Sputtering power[w]	200					
Temperature	Room Temperature					
Substrate	Borosilicate Glass					
Base Pressure[torr]	1×10^{-5}					
Target	Aluminium & Copper form a CuO film.					

4.2.1 Application:

- **Building-Integrated Photovoltaics (BIPV):** Thin film solar cells, with their lightweight and flexible characteristics, can be seamlessly integrated into building materials such as windows, facades, and roofing tiles. BIPV systems enable the generation of clean energy while serving as functional architectural elements, contributing to sustainable building practices and reducing reliance on conventional energy sources.
- **Portable Electronics:** Thin film solar cells are well-suited for powering portable electronic devices such as smartphones, tablets, and wearables due to their lightweight and compact form factor. Integrating thin film solar cells into the design of consumer electronics enables convenient recharging of batteries using ambient light, extending device runtime and promoting energy autonomy.

CHAPTER 5

RESULT AND DISCUSSION

5.1. SAMPLES

The bare sample exhibited a conductivity of 0.1 shown in Fig 5.1. While the aluminium-coated sample showed a conductivity of 0.7 which is seen in Fig.5.2.a. Sample 2 displayed a higher conductivity of 1.3, and sample 3 showed a conductivity of 0.6. These results indicate a clear enhancement in conductivity with the aluminium coating, suggesting improved electrical properties due to the coating's conductivity. Sample 2 notably higher conductivity may imply a more effective coating or a difference in material composition. However, sample 3 lower conductivity compared to the coated sample suggests potential inconsistencies in the coating process or variations in material quality. Further analysis and optimization of the coating method may be necessary for achieving consistent and desired conductivity levels.



Fig:5.1: Bare glass without coating

5.2. ALUMINIUM COATED SAMPLES



Fig:5.2. a: Sample 1- Al coated - 000.7



Fig:5.2. b: Sample 2- Al coated - 001.3



Fig:5.2. c: Sample 3 – Al coated - 000.6

5.3. Al – Cu COATED SAMPLE



Fig:5.3.a: Sample 1- Al-Cu - 009.4

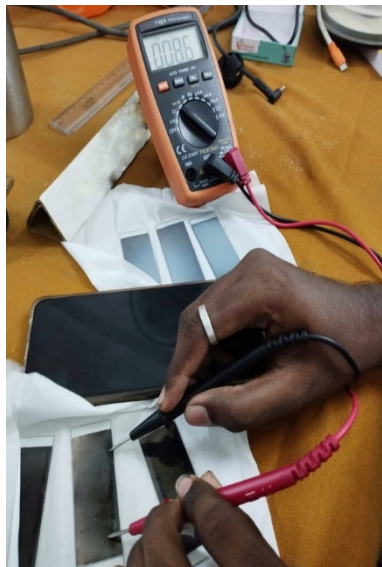


Fig:5.3.b: Sample 2- Al-Cu - 008.6

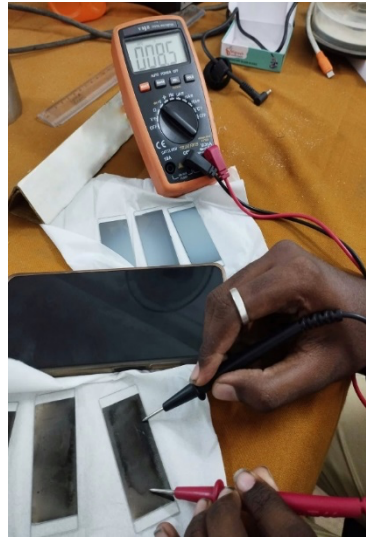


Fig:5.3.c: Sample 3 - Al-Cu - 008.5

Our goal is to investigate the impact of copper oxide formation on conductivity and explore potential optimization strategies. Sample 1 exhibited a conductivity of 9.4, indicating a significant improvement compared to the bare sample, while sample 2 displayed a conductivity of 8.6. However, sample 3 showed a slightly lower conductivity of 8.5. These results suggest that copper oxide formation and coating contribute positively to conductivity, albeit with some variability. Further research could focus on refining the copper oxide coating process to enhance and stabilize conductivity levels, ensuring consistent performance in practical applications requiring reliable electrical conductivity.

5.4 FABRICATED SAMPLES

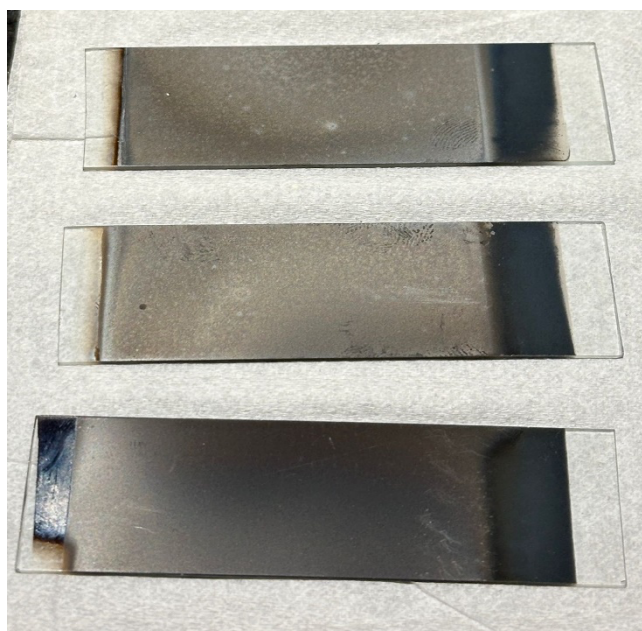


Fig:5.4: Thin film coated sample

The fabricated samples consist of micro-glass slides meticulously cleaned to ensure surface purity, initially coated with aluminium (Al) using a DC magnetron sputtering system to create a conductive substrate. Following this, a thin film of copper oxide (CuO) was deposited through magnetron sputtering of a conductive copper (Cu) layer, subsequently oxidized at 450°C for 2 hours in ambient air. The deposition process was conducted under a base vacuum of 5×10^{-6} mbar, employing argon as the sputter gas with a power of 80W and a working pressure of 0.02mbar. These meticulously fabricated samples are poised for further characterization and analysis in various applications, leveraging their tailored material properties.

5.5. CHARACTERIZATION TECHNIQUES

5.5.1. X-ray diffraction:

The phase purity and structural characteristics of the synthesized CuO thin films were carried out using XRD analysis. The XRD Diffraction patterns appeared at 2θ (31.75°, 34.38°, 36.18°, 38.81°, 43.09°, 56.59°, 62.85°, 66.36°, 67.90° and 68.99°) values and they were assigned to the corresponding 110, 002, 101, -112, -202, 020, 202, -113, 022 and -311 planes, respectively. The obtained XRD patterns indicated that the synthesized thin films are highly crystalline with monoclinic structure of CuO, which

was confirmed by the Joint Committee on Powder Diffraction Standards (JCPDS) (card no: 80-1268). The other impurity products like $\text{Cu}(\text{OH})_2$ and Cu_2O characteristic peaks were not observed, revealing the phase pure formation of CuO Thin film. The average crystallite size of the CuO was estimated to be 14.85nm m by using the Debye–Scherrer formula,

$$D = \frac{k\lambda}{\beta \cos\theta}$$

where, D is crystallites size in nm, k is Scherrer constant (0.9) , λ .is the wavelength of X-ray sources (0.15406 nm), β is the FWHM in radians and θ is the peak position in radians. The XRD results confirmed the existence of CuO and the absence of an Al peak in this XRD pattern suggests that the CuO was uniformly coated onto the Al-coated substrate.

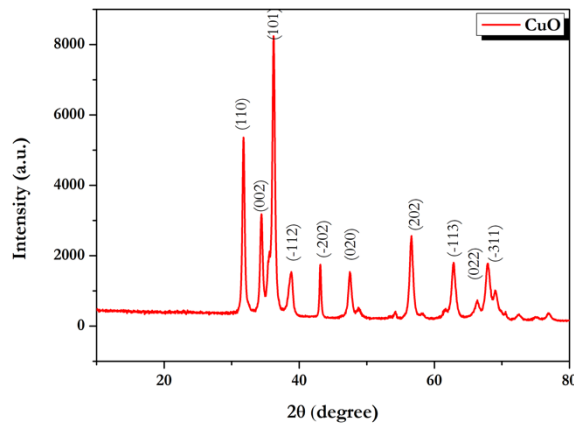


Fig: 5.5.1. X-RAY DIFFRACTION

5.5.2. FIELD EMISSION SCANNING ELECTRON MICROSCOPE:

At higher magnification, the FE-SEM images (Fig.5.5.2) indicate that the deposition parameters chosen for RF magnetron sputtering were adequate for preserving the typical cylindrical form and high aspect ratio of the nanowires throughout each preparation step. The RF magnetron sputtering method was employed to deposit a granular, nanostructured, and uniform CuO layer onto the surface of the Al conducting substrate. In the higher resolution SEM images, a clearly observable rod-shaped structure is evident, with the rods randomly oriented due to the presence of different crystal planes as observed in XRD. These rods have an average length of about 1.5 mm and an average diameter of about 0.2 mm. The formation mechanism of CuO

nanowires includes: (i) the creation of a thin liquid Cu layer on the Al substrate surface; (ii) oxygen molecule adsorption onto the liquid Cu surface, leading to the formation of solid CuO nanoclusters that serve as growth seeds for CuO nanowires; (iii) Cu ion surface diffusion along the nanowire's side wall, reacting with oxygen and causing simultaneous growth in both axial and radial directions of the nanowires.

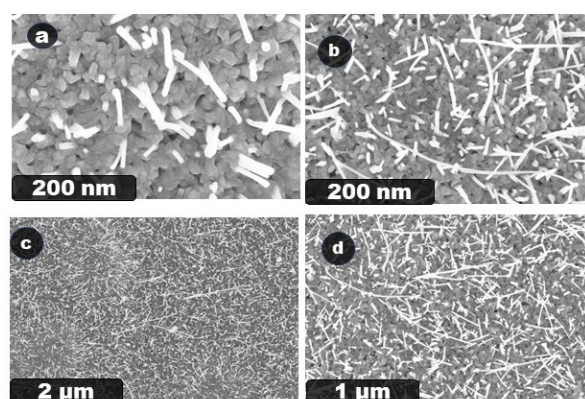


Fig: 5.5.2. FIELD EMISSION SCANNING ELECTRON MICROSCOPE

The EDX mapping images demonstrate a uniform distribution of chemical elements across the examined surfaces. The EDX spectrum of CuO nanowires indicates the presence of Al, Cu, and O elements, while the EDX spectrum of CuO nanowire-decorated Al substrate arrays simultaneously reveals signals associated with Al, Cu, and O elements. Based on the EDX analysis, the atomic percentages of the elements in the analysed samples were estimated at approximately 69.12% for Cu, 0.33% for Al, and 30.54% for O.

Table.5.5.2. Result of Field Emission Scanning Electron Microscope

Sample No:	EHT (kV)	Mag (K X)	WD (mm)	Signal A
Sample A	10.00	100.00	5.5	InLens
Sample B	10.00	50.00	5.5	InLens
Sample C	10.00	10.00	5.5	InLens
Sample D	10.00	25.00	5.5	InLens

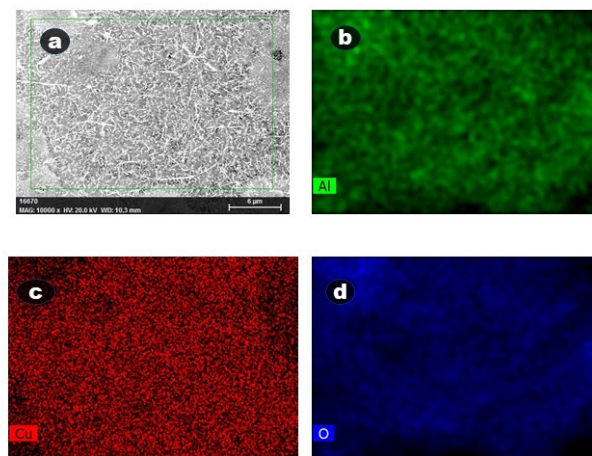


Fig: 5.5.3. EDX ANALYSIS

The fabricated heterojunction device demonstrated rectifying behavior with a turn-on voltage of approximately 1.3 V and an ideality factor of 1.96, indicative of a built-in potential barrier essential for diode functionality. Moreover, under solar light irradiation, the device exhibited photovoltaic activity, evidenced by an open circuit voltage of 0.59 V and a short circuit current of 0.3 mA, highlighting its promising potential for solar energy conversion applications. The deposition process involved the use of aluminium and copper sputtering targets with a DC magnetron sputtering system. Comprehensive cleaning protocols ensured substrate purity, crucial for uniform film deposition. The subsequent deposition of individual layers of Al and CuO followed precise conditions, with a base vacuum of 5×10^{-6} mbar maintained using argon as the sputter gas. The sputter power of 80 W and working pressure of 0.02 mbar were consistent for all depositions. At higher magnification, FESEM images revealed well-preserved cylindrical nanowires deposited via RF magnetron sputtering, ensuring uniformity and high aspect ratio. The formation mechanism involved liquid Cu layer creation, oxygen adsorption, and Cu ion diffusion, leading to the growth of CuO nanowires. EDX mapping and spectra confirmed uniform elemental distribution and the presence of Al, Cu, and O elements, supporting successful CuO deposition onto Al-coated substrates. XRD analysis further elucidated the structural characteristics of the synthesized CuO thin films, showing distinct diffraction peaks corresponding to monoclinic CuO structure. The absence of characteristic peaks for impurities like $\text{Cu}(\text{OH})_2$ and Cu_2O confirmed the phase purity of CuO. The calculated average crystallite size of 14.85 nm indicated nanoscale dimensions, contributing to the material's unique properties. Notably, the absence of an Al peak in the XRD pattern

suggested uniform coating of CuO onto the Al-coated substrate, validating the efficacy of the deposition process. Overall, these findings underscore the successful fabrication of the heterojunction device with tailored structural and electrical properties, essential for its potential applications in photovoltaic devices and beyond.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 SUMMARY

The study presents the successful fabrication of a heterojunction device using a combination of oxidation of a thin film and magnetron sputtering techniques. Monoclinic CuO film formation was confirmed via X-ray diffraction, and scanning electron microscopy revealed grain morphology. Meticulous control over deposition conditions ensured uniform film growth. Electrical characterization demonstrated rectifying behavior and promising photovoltaic characteristics under solar light. The Al-CuO heterojunction exhibited a turn-on voltage of approximately 1.3 V and an ideality factor of around 1.96. Under solar light, it displayed an open circuit voltage of 0.59 V and a short circuit current of 0.3 mA. This work showcases the potential of Al-CuO heterojunctions for electronics and photovoltaic applications, suggesting avenues for further optimization and investigation into their properties.

6.2 CONCLUSION

The study represents a significant achievement in the fabrication of heterojunction devices through precise deposition techniques. By employing magnetron sputtering and oxidation methods, the research establishes a reliable approach for depositing aluminum and copper oxide thin films on glass substrates, ensuring consistent and uniform growth while maintaining meticulous control over deposition conditions. Structural analysis utilizing X-ray diffraction and scanning electron microscopy confirms the formation of monoclinic CuO film and elucidates the structural characteristics of the deposited layers, providing crucial insights into their composition and morphology. Electrical characterization reveals promising rectifying behavior in the Al-CuO heterojunction, with a turn-on voltage and ideality factor indicating good diode-like behavior, thus affirming its potential for electronic applications. Moreover, under solar light irradiation, the heterojunction exhibits open circuit voltage and short circuit current values suggestive of its viability for photovoltaic applications, thereby offering a pathway for renewable energy harnessing. With its unique properties and fabrication process, the fabricated heterojunction holds promise for various

applications in electronics, optoelectronics, and surface engineering. Furthermore, there exist optimization opportunities whereby further refining fabrication processes and device structures could enhance performance and broaden potential applications, ultimately advancing the field of heterojunction devices.

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