CHAPTER-1

INTRODUCTION

Introduction, background, and problem definition

This chapter discusses the energy demands of the world. The need to switch to unconventional sources of energy is presented and harnessing power from them in an effective way is discussed. Solar Energy being the most abundant source of energy needs to be utilized effectively. Many solar cell technologies are available today and the advantages of Dye Sensitized Solar Cells over other solar cells are discussed. The motivation and scope of this solar cell technology are also highlighted in this chapter.

1.1 Background

People have become increasingly reliant on energy extracted from the ground during the previous 200 years. Human survival depends on three basic elements: energy, water, and food. The world is now actively promoting cleaner energy technologies. This is due to widespread concern about the state of the environment. Because of the harmful toxic emissions during energy conversion, the ozone layer is quickly thinning. In today's life, the whole world is dependent on the non-conventional source of energy which is mainly fossil fuels. Fossil fuels, such as oil, natural gas, and coal, are the most widely used energy sources on the planet. These conventional sources are depleting due to their ease of use in transportation. Furthermore, the burning of fossil fuels emits tons of carbondioxide, which pollutes the ecosystem and alters climate circumstances. So, the world is moving to a better source of energy which is a renewable source. These sources are non-polluting and never end. These energy sources contain solar energy, tidal energy, geothermal energy, wind energy, and biomass energy [1]. Solar energy is one of the most importantand widely available sources of energy, with access to it in practically every corner of the globe. The sun deposits $12x10^7$GW of radiation on theearth, which is the largest single source of clean energy. At present, only about 5GW of power is utilized by solar cells [2]. Solar energy can be usedin a different number of ways. Solar cells are photovoltaic devices that convert solar energy directly into electrical energy. It works on the principle of the photovoltaic (PV) effect in which it ejects electrons in thepresence of sunlight which can be utilized to produce electricity [3]. This has inspired research into clean and efficient power generation options, with electrochemical solar cell technology. Solar cells have various advantages over traditional drive systems that make them desirable powersources. This chapter discusses the crucial role of energy in economic development, the different sources of energy (conventional and non-conventional), and the need for alternative energy sources due to energy crises. The article covers various types of solar cells and their technologies, including the advantages of Dye-sensitized solar cells (DSSCs) over other solar cells. Additionally, it highlights the motivation and application of this solar cell technology.

1.2 Importance of energy

The energy demand has been increasing day by day, driven by economic growth, technological advancements, and population growth. Increasing energy prices and growing attention on global warming driving more emphasis toward the development of economically and environmentally viable alternatives to fossil fuels. However, conventional energy sources such as fossil fuels have finite reserves, and their extraction, production, and consumption pose significant environmental challenges. These challenges include climate change, air and water pollution, and ecological damage. To address the increasing demand for energy while mitigating these environmental challenges, many countries are shifting towards non-conventional energy sources, such as solar energy. Renewable and sustainable, non-conventional energy sources offer a promising solution to address energy crises and ensure a secure energy future. Shifting towards non-conventional energy sources can mitigate energy crises, promote energy independence and security and create a more sustainable future for generations to come. Solar energy has gained popularity due to its abundance, reliability, and low environmental impact. A nation's economic development depends heavily on its access to energy. It is widelyused in agriculture and related industries, including those that produce andsupply pesticides, fertilizers, and farm equipment. Cooking, lighting, and warmth all require it in households. Throughout the last few centuries, the availability of energy has changed the path of human history. Not only have new energy sources been discovered—first fossil fuels, then nuclear, hydropower, and now various renewable technologies—but also the amount of energy we can generate and use. During the Industrial Revolution, the energy sector has undergone significant change. The challenge of shifting energy production away from fossil fuels and towards low-carbon sources of energy is harder to accomplish by growing energy consumption. More low-carbon energy must be developed to fulfill this increased demand while attempting to replace existing fossil fuels in the energy mix. The consumption of energy is necessary for rapid economic growth. There is a huge gap between consumer demand and electrical supply. Energy shortages can be significantly reduced by using non-conventional energy sources.

1.3 Sources of energy

Sources of energy can be classified into two:

- Conventional sources
- Non-conventional sources

Non-conventional sources:

Natural resources for non-conventional energy are plentiful and sustainable. These energy sources are environmentally friendly and can be renewed organically. Solar energy, geothermal energy, wind energy, biomass, hydropower, and tidal energy are a few examples of non-conventional sources of energy.

Conventional sources: Any buried natural resource is referred to as a conventional source. These energy supplies don't replenish as quickly as they are used up. Their replenishment takes millions of years. Coal, oil, and natural gas are the main examples of non-renewable resources. Natural gas, coal, petroleum, nuclear power, and liquid hydrocarbons are a few examples of conventional energy sources.

1.4 History of photovoltaic solar cells

Edmond Becquerel's discovery of the photovoltaic effect in 1839 [4] marks the beginning of the development of solar photovoltaic cells. Becquerel discovered that certain materials produced an electric current when exposed to light. Before Albert Einstein released his Nobel Prize–winning theory of the photoelectric effect in 1905[5], no one could explain the photovoltaic effect. According to this idea, specific photon intensities, also known as incident light, can interact and eject electrons from conductive metal. Charles Fritts created the first solar cells using selenium wafers and transparent gold covers fifty years after Becquerel's idea [6]. By the turn of the 20th century, silicon had replaced selenium in photovoltaics [7]. Due to its low cost, wide availability (found in quartz in sand), and numerous advantageous chemical characteristics, silicon was a preferred material. The process of thermally reducing silica with carbon was used to create these silicon photovoltaic cells [8]. However, the materials used in their production were expensive, full of unwanted contaminants, and wasteful. Less than 1% of incident solar energy was also transformed in these early models, making the device incredibly ineffective and expensive. It wasn't until the 1950s that silicon PV cells were considered a practical commercial power source because of the quantity of wasted materials, low solar conversion rates, and expensive costs [9].

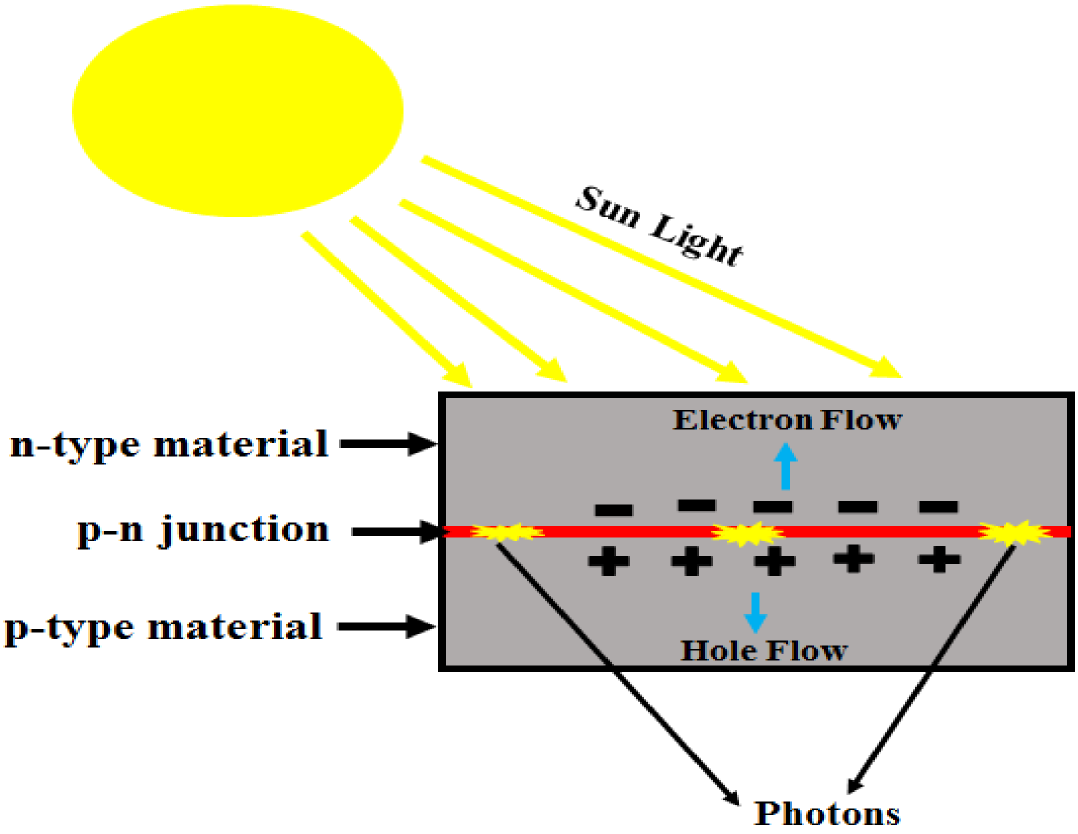

Fig.1: Basic working principle of a PV cell

1.5 Classification of PV solar cell

With access in almost every region of the world, solar energy is one of the most significant and accessible sources of energy. There are several ways to utilize solar energy. Sunlight is directly converted into electrical energy by solar cells, which are photovoltaic technology. Their primary operation is based on the photovoltaic effect [3], in which the presence of sunlight causes them to emit electrons that can be used to generate energy. When sunlight's photons hit a material's surface, the photovoltaic effect occurs, and free electrons are released. A solar cell can be constructed from a wide range of materials, and they all work to convert solar energy into direct current (DC) electricity [10]. Solar cells can be classified into first, second, and third-generation cells [11]. The first-generation cells—also called conventional, traditional, or wafer-based cells—are made of crystalline silicon, the commercially predominant PV technology, that includes materials such as polysilicon and monocrystalline silicon. Silicon is generally an element used to make crystalline solar cells [12]. It is a plentiful resource that is also environmentally friendly. These solar cells are fabricated by using the Czochralski process [13]. These solar cells have better efficiency than other solar cells. However, their cost of fabrication is extremely high, which makes them unsatisfactory for commercial use. Second generation cells are thin film solar cells that include amorphous silicon [14], CdTe [15] and CIGS [15] cells are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaics, or in small stand-alone power systems. Second-generation solar cells consist of thin-film solar cells. The material used in thin-film solar cells is in powder form, which makes it lightweight and more flexible. The fundamental challenge that thin film solar cells face is their low efficiency [16]. The third generation of solar cells includes several thin-film technologies often described as emerging photovoltaics—most of them have not yet been commercially applied and are still in the research or development phase. The third-generation solar cell consists of dye-sensitized solar cells [17], [18], perovskite solar cells [19], and quantum dot solar cells [20]. These solar cells have more efficiency than thin-film solar cells but less than silicon solar cells [21], [22]. As the first-generation solar cells, silicon-based photovoltaic cells have already proven their dominance in the solar market due to their high efficiency. However, their indirect optical band gap requires a thick active layer for solar conversion, which results in the expensive fabrication of large-area materials as well and the waste produced is hazardous. To counter these issues second and third generation of photovoltaic (PV) materials was introduced to reduce the fabrication cost through thin film sand highly photoactive materials respectively. However, the same performance limitations occur in both the first and second-generation devices, such as "red losses"(photo swit energies below the device's band gap cannot be absorbed) and "blue losses" (photons with energies above the band gap waste their excess energy as heat). Presently, third generation PVs are designed to exceed the limits of single-junction devices for a high efficiency and a low production cost [21]. Since dye-sensitized solar cell (DSSC) was first reported in 1991 by O’Regan and Grätzel [22], Due to its low production cost, simple fabrication techniques, relatively high-power conversion efficiency (PCE), and wide spectrum response in the visible light range for indoor applications, it has been hailed as of the most promising third-generation solar cells.

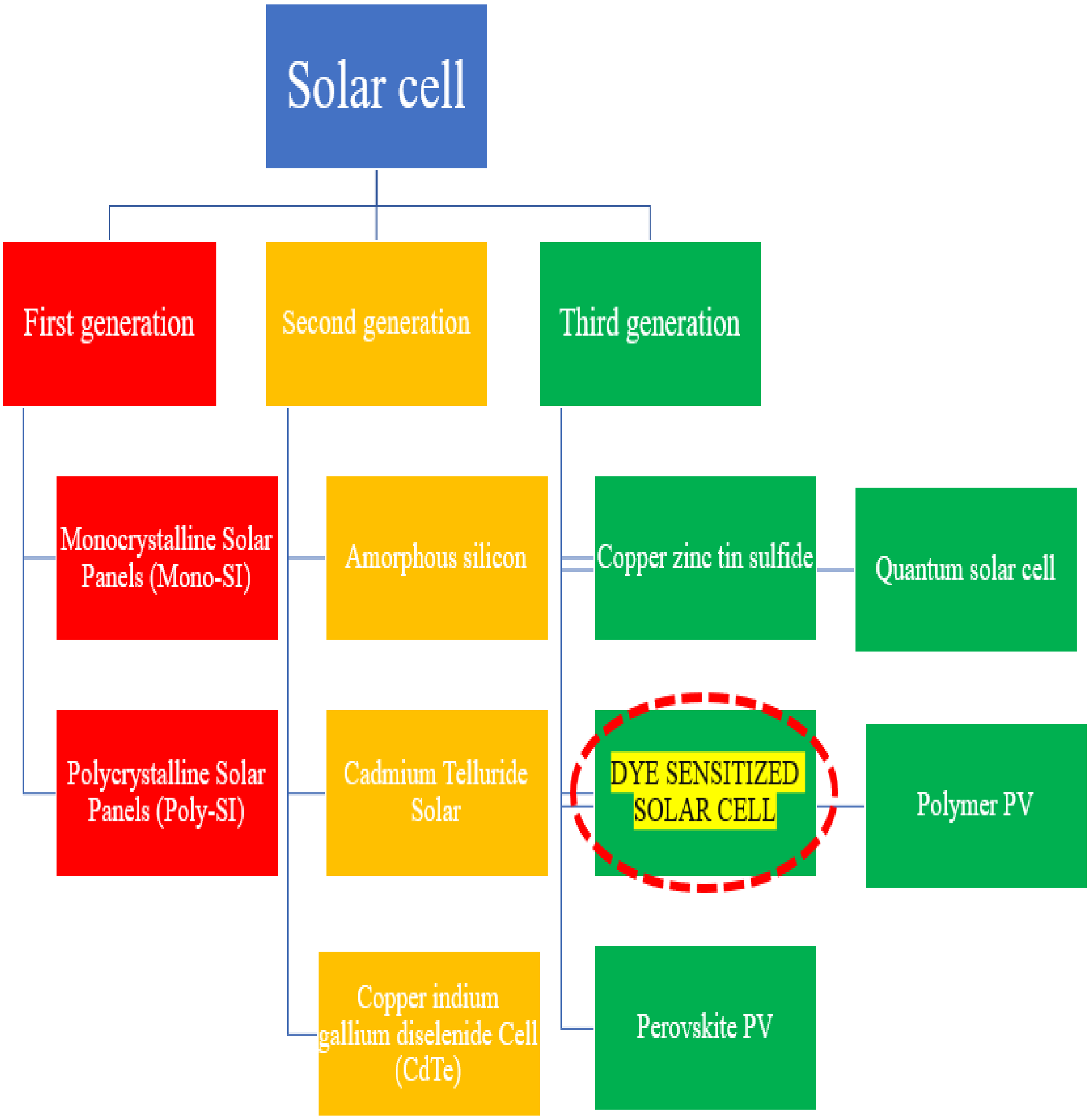

Fig. 2: Classification of PV Solar Cells

1.6 Dye-Sensitized Solar Cells (DSSCs):

Dye-sensitized solar cells (DSSCs) are a viable alternative to silicon-based solar cells that have been explored intensively in recent years due to their predicted cost-effectiveness, customizable transparency, high efficiency, compatibility with flexible substrates, as well as the capacity to work in low-light environments. The structure of DSSC consists of a transparent conductive oxide film, semiconductor photoanode, dye absorbed on it, redox electrolyte, and platinum-coated cathode as shown in fig 3. As a technically and economically viable alternative to top-n junction photovoltaic devices, dye-sensitized solar cells (DSSCs) have emerged. Electricity may be produced by organic dyes in electrochemical cells, it was found in the late 1960s [23]. At the University of California, Berkeley, spinach was used to extract chlorophyll (photosynthesis). In 1972, the first zinc oxide (ZnO)electrode that was chlorophyll-sensitized was created. Photons turned into electricity through the introduction of excited dye molecule electrons into a semiconductor with a large bandgap. Numerous studies on ZnO-single crystals have been conducted, but the efficiency of these dye-sensitized solar cells was relatively low because themonolayer of dye molecules could only absorb 1% of incident light. To increase the absorption of dye across the electrode and, consequently, the light-harvesting efficiency (LHE), the efficiency was improved by improving the porosity of the electrode is made up of fine oxide powder. As a result, nanoporous titanium dioxide (TiO_2) electrodes with aroughness factor of ca.1000 were rediscovered and in 1991, DSSCs with 7% efficiency were invented. These cells, often referred to as Grätzel cells, were first developed in 1988 at UC Berkeley by Brian O'Regan and

Michael Grätzel and continued to be improved upon until 1991 at Ecole Polytechnique Fédérale de Lausanne (EPFL) [23]. Brian O'Regan and Michael Grätzel fabricated a device based on a 10-μm-thick, high surface and optically transparent film of TiO_2 nanoparticles, coated with a monolayer of a charge transfer dye with ideal spectral characteristics to sensitize the film for light harvesting. The Device harvested a high proportion of the incident solar energy flux of 46% and showed exceptionally high efficiencies, even more than 80% efficiencies for the conversion of incident photons to electrical current. The overall incident photon to current conversion efficiency (IPCE) yield was 7.1–7.9% in simulated solar light and 12% in diffuse daylight. A large short-circuit current density exceptional stability (sustaining at least five million turnovers without decomposition) and low cost made the practical application feasible. In 1993, Grätzelet al. reported a 9.6% efficiency of cells, and then in 1997, they achieved 10% at the National Renewable Energy Laboratory (NREL). The sensitizers are usually designed to have functional groups such as $–COOH$, $–PO_3H_2$, and $–B(OH)_2$ stable adsorption onto the semiconductor substrate. Till now, an efficiency of ~10% was reported in many research groups [24], [25]. In a Traditional Solar Cell, Si provides acts as the source of photoelectrons and provides an electric field to separate the charges and create a current. But, in DSSCs,the bulk of the semiconductor is only used as a charge transporter and the photo-electrons are provided by photosensitive dyes. The Theoretically Predicted Power Conversion Efficiency (PCE) of DSSCs was approximately 20%. Thus, extensive research has been made over the years on DSSCs to improve their efficiency and augment their commercialization. However, in the last few decades, a lot of experiments have been carried out to improve the performance of DSSCs. For instance, if one goes through the review articles or papers published between 1920 and 1921, a remarkable difference may be observed in the performance as well as fabrication of these cells. A few review papers are discussed below with the objective and main results shown in a respective article to get an idea of how the performance of these cells has been improved and, thus, how the DSSC became an important topic for researchers. In comparison with high-cost conventional silicon solar cells, dye-sensitized solar cell faucets are known as cost-effective photovoltaic devices because of their inexpensive materials and simple fabrication process. Dye-sensitized solar cells are composed of titanium oxide (TiO_2) semiconductor which is commonly used as a paint base in the pigment industry, and the Dye sensitizer that can be extracted from a variety of natural resources with minimum costs. In addition, carbonaceous materials could be used to replace platinum catalysts which can further reduce the material cost. As such, DSSCs are easy to fabricate since they are insensitive to environmental contaminants and processable at ambient temperature.

These unique features are favored in the roll-to-roll process, which is a continuous, low-cost manufacturing method to print dye-sensitized solar cells on flexible substrates. Furthermore, DSSCs work better even during darker conditions, such as in dawn and dusk or cloudy weather. Such capability of effectively utilizing diffused light makes DSSCs an excellent choice for indoor applications like windows and sunroofs.

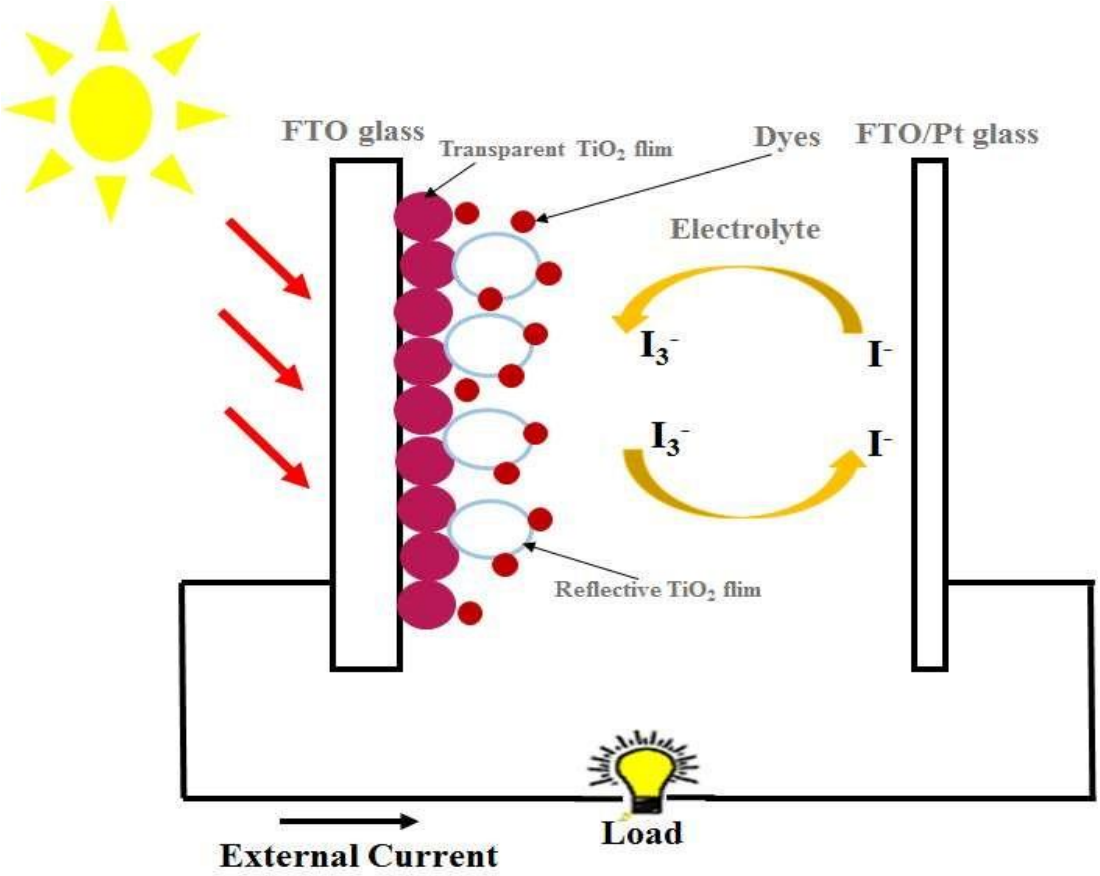

Fig. 3: Schematic diagram of DSSC

1.7 Working principle

The working principle of DSSC involves four basic steps: light absorption, electron injection, transportation of carriers, and collection of current [26], [27]. The following steps are involved in the conversion of photons into current.

a. Firstly, the incident light (photon) is absorbed by a photosensitizer, and thus, due to the photon absorption, electrons get promoted from the ground state (S^+/S) to the excited state (S^+/S^*) of the dye, where the absorption for most of the dye is in the range of 700 nm which corresponds to the photon energy almost about 1.72 eV.

$$S^+/S + h\nu \rightarrow S^+/S*$$

b. Now, the excited electrons with a lifetime of nanosecond range are injected into the conduction band of nanoporous TiO_2electrode which lies below the excited state of the dye, where the TiO_2absorbs a small fraction of the solar photons from the UV region. As a result, the dye gets oxidized.

$$S^+/S* \rightarrow S^+/S + e^-(TiO_2)$$

c. These injected electrons are transported between TiO_2 nanoparticles and diffuse towards the back contact (transparent conducting oxide [TCO]).

Through the external circuit, electrons reach the counter electrode. The electrons atthe CE reduce I_3^- to I^-, thus, dye regeneration or the regeneration of the ground state of the dye takes place due to the acceptance of electrons fromthe I^- ion redox mediator, and I^- gets oxidized to I_3^-.

$$S^+/S* + e^- \rightarrow S^+/S$$

d. Again, the oxidized mediator (I_3^-) diffuses towards the counter electrode and reduces to I^-ion.

$$I_3^- + 2\ e^- \rightarrow 3I^-$$

1.8 Components of DSSC

Components of DSSC are transparent conducting substrate, wide band gap semiconductor, sensitizer, electrolyte, and counter electrode material. These components are described below in detail [27].

(i) Transparent and conductive substrate

DSSCs are typically constructed with two sheets of conductive transparent materials, which are a substrate for the deposition of the semiconductor and catalyst, acting also as current collectors [18, 19]. There are two main characteristics of a substrate being used in a DSSC: Firstly, more than 80% transparency is required by the substrate to permit the passage of optimum sunlight to the effective area of the cell. Secondly, for efficient charge transfer and reduced energy loss in DSSCs, it should have a high electrical conductivity. The fluorine-doped tin oxide (FTO, SnO_2: F) and indium-doped tin oxide (ITO, In_2O_3: Sn) are usually applied as conductive substrates in DSSCs. These substrates consist of a soda lime glass coat with layers of indium-doped tin oxide (ITO) and fluorine-doped tin oxide(FTO).

(ii) Working electrode (WE) or anode

The working electrodes (WE) are prepared by depositing a thin layer of oxide semiconducting materials such asTiO_2, Nb_2O_5, ZnO, SnO_2 (n-type), and NiO (p-type) on a transparent conducting glass plate made of FTO or ITO. Due to being non-toxic and less expensive and its easy availability, TiO_2 is mostly used as a semiconducting layer. However, these semiconducting layers absorb only a small fraction of light in the UV region; hence, these working electrodes are then immersed in a mixture of a photosensitive molecular sensitizer and a solvent.

(ii) Photosensitizer Dye

Dye is the component of DSSC responsible for the maximum absorption of the incident light. Any material being dye should have the following photophysical and electrochemical properties:

- The dye should be luminescent.
- The absorption spectra of the dye should cover ultraviolet-visible (UV-vis) and near-infrared region (NIR).
- The highest occupied molecular orbital (HOMO) should be located far from the surface of the conduction band of TiO_2 and the lowest unoccupied molecular orbital (LUMO) should be placed as close to the surface of the TiO_2, and subsequently should be higher to the TiO_2 conduction band potential.
- HOMO should lie lower than that of redox electrolytes.
- The periphery of the dye should be hydrophobic to enhance the long-term stability of cells, as it results in minimized direct contact between electrolyte and anode; otherwise, water-induced distortion of the dye from the TiO_2 surface can appear which may reduce the stability of cells.

(iv) Electrolyte

An electrolyte (such as I^-/I_3^-, $Br^-/Br_2^-$and Co(II)/Co(III)) has five main components, i.e., redox couple, solvent, additives, ionic liquids, and cations. The Following properties should be present in an electrolyte:

- Redox couples would be able to regenerate the oxidized efficiently.

- Should have long-term chemical, thermal, and electrochemical stability.
- Should be non-corrosive with DSSC components.
- Should be able to permit fast diffusion of charge carriers, enhance conductivity, and create effective contact between the working and counter electrodes.
- The absorption spectra of an electrolyte should not overlap with the absorption spectra of a dye.

(v) Counter electrode (CE)

CE in DSSCs is mostly prepared by using platinum (Pt) or carbon (C). Both working and counter electrodes are sealed together, and subsequently, an electrolyte is filled with a syringe. Pt is used mostly as a counter electrode as it demonstrates higher efficiencies, but the replacement of Pt was much needed due to its higher cost and less abundance.

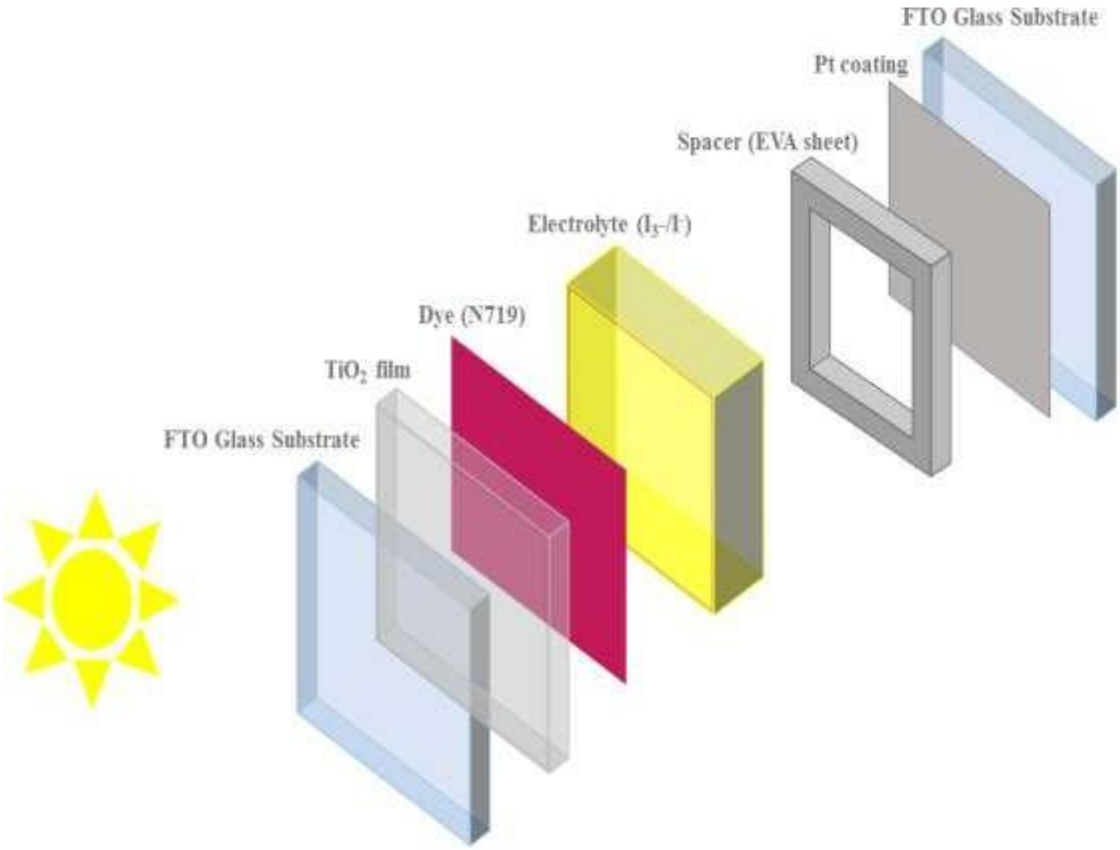

Fig.4: Schematic of DSSC components

1.9Advantages of DSSCs

The advantages of dye-sensitized solar cells can be called upon to expand the range of applications where conventional solar cells are unsuitable. These solar cells have numerous advantages over their counterparts and are there commonly used in low-density applications and portable gadgets. Here are some of the advantages of DSSCs [28].

- **Low-light performance:** It works in a wide array of lighting conditions making it suitable for a diverse range of shaded and diffuse light locations, without suffering from angular dependence of sunlight or light.

- **Optimized performance:** DSSC materials and dyes can be tuned for optimization in a variety of lighting conditions making it suitable for indoor applications and outdoor applications.
- **Higher temperature performance:** The efficiency of DSSC does not degrade with increased temperature, meaning you can continue to efficiently harvest energy in direct sunlight.
- **Low-energy manufacturing process:** DSSC is manufactured using a low-energy consumption, high-efficiency, roll-to-roll manufacturing technique.
- **Variety of substrates:** DSSC is produced on a thin film, flexible, robust, plastic substrate. DSSC can also be applied to metal and glass substrates.
- **Versatile product integration:** DSSC indoor modules are highly flexible, durable, and lightweight. As a result, they are very versatile and can be incorporated into a wide variety of products. DSSCs can be produced on flexible substrates, which makes them suitable for use in a variety of applications, including wearable electronics.

- **Cost-effective:** DSSCs are cost-effective due to the use of low-cost materials in their construction, such as titanium dioxide and organic dyes.

- **High efficiency:** DSSCs have high energy conversion efficiency, which is the percentage of sunlight that is converted into electrical energy. The efficiency of DSSCs can be as high as 15%.

- **Ecologically friendly solar**: DSSC uses inexpensive and eco-friendly nanomaterials without concern about shortage of resources. It uses non-toxic materials and does not produce any harmful emissions making it environmentally friendly.

1.10 Disadvantages of DSSCs

Despite the potential of DSSCs, there are several significant drawbacks associated with them [29]. These include:

- **Poor photo thermal stability and low efficiency:** DSSCs have poor photo thermal stability and low efficiency, which is often less than 1%. This makes them unsuitable for commercial use.

- **Leakage and sealing problems:** DSSCs with liquid electrolytes exhibit leakage and sealing problems that affect long-term device stability. This limits their practical uses for continuous use and device lifetimes.

- **Volatility of organic solvents:** The volatility of the organic solvents used in the liquid electrolytes results in unavoidable leakages from the DSSC cell assembly and performance degradation over time.

1.11 Application of DSSC

DSSCs have several applications in various fields. Some of these applications include [30]:

- **Building-integrated photovoltaics (BIPV):** DSSCs can be integrated into building facades and windows to generate electricity and reduce the building's energy consumption.
- **Portable electronic devices:** DSSCs can be used to power portable electronic devices such as smartphones and laptops.
- **Wearable electronics:** DSSCs can be integrated into clothing and accessories to power wearable electronics.
- **Transportation:** DSSCs can be used to power electric vehicles and reduce their cost.

This thesis discusses the fabrication steps of DSSC in detail. Also, the optimization of the fabrication steps of DSSC to maximize its efficiency is discussed. The dye desorption (less reported) challenge of DSSC, which is the main cause of low efficiency, is addressed in the present work. Graphene synthesis and its application in DSSC fabrication to optimize its performance and reduce its cost, is presented in this work. Further, leakage issue of DSSC is discussed and addressed by development of biodegradable gel electrolyte and its incorporation in DSSC.

Chapter 3 gives details on chemicals and apparatus required in section 3.1 and section 3.2, respectively. The experimental procedure is discussed in section 3.3. Details on characterizations performed on samples are given in section 3.4.

Chapter 4 discusses optimizations done on various steps of fabrication to optimize DSSC performance. Experimental section 3.1.1 gives details on chemicals required to fabricate DSSC. Section 3.2 has information on the apparatus required for the experiments. Section 3.3.1.1 presents all types of solutions for the fabrication of DSSC. Detailed fabrication steps of DSSC are discussed in section 3.3.1.2. Section 4.1 discusses effect of coating method i.e. conventional doctor blade vs. spin coating Method.

Conventional $TiCl_4$vs. TTIP compact layer coating solutions are discussed in section 4.2.1. The need for pre and post-compact layer on % of functioning cells are discussed in section 4.2.2. The Dye Desorption challenge of DSSC is presented in section 4.3.1 and addressed in section 4.3.2. AFM images showing thickness of layers are presented in section 4.4. Effects of thickness of the transparent layer is presented in section 4.5. Section 4.6.1and 4.6.2 discusses the effect of the temperature of the anode before dye soaking and cell assembly before electrolyte filling on the performance of DSSC. Finally, JV and PV curve are explained in 4.7 section.

Chapter 5 discusses the results of the synthesis of graphene and its application in DSSC. Section 5.1 discusses the results of the synthesis of graphene. Section 3.1.2 gives details of the chemicals required for the synthesis of graphene and for its application in DSSC. The experimental procedure of Synthesis of graphene via physical exfoliation, chemical exfoliation, and combined method is presented in section 3.3.2.1. Section 3.3.2.2 presents experimental procedures to prepare graphene counter electrodes. The experimental procedure for the preparation of graphene liquid electrolyte is discussed in section 3.3.2.3. Results of synthesis of graphene SEM-EDAX, XRD, RAMAN SPECTRAL analysis, HRTEM, EIS Study, PSD, and UV-vis absorbance study are discussed in sections 5.1.1, 5.1.2, 5.1.3, 5.1.4, 5.1.5, 5.1.6 and 5.1.7 respectively. The application of graphene as a counter electrode material to reduce the cost of DSSC is discussed in section 5.2. The application of graphene liquid electrolytes to optimize the photovoltaic efficiency of DSSC is presented in section 5.2.

Chapter 6 presents performance of different Gel DSSC. Section 3.3.3 discusses preparation of gel electrolyte and its modification. Section 3.3.3.1, 3.3.3.2, 3.3.3.3 and 3.3.3.4 give details on synthesis of aqueous, non- aqueous, non-aqueous with N719 dye and non-aqueous with N719+RGO (S4) gel electrolyte. Chapter 6 mainly presents comparison of liquid and gel DSSC.

Chapters 7 and 8 present conclusions and the future of current work.

1.12 Motivation and scope of the present work

The energy by the sun is more than sufficient to fulfil the requirements of the entire planet, and in contrast to fossil fuels, it is not going to run out any time soon. The only constraint that solar power has as a source of renewable energy is our inability to convert it into electricity in an effective and economical way. When solar panels are used to generate power, there is no emission of gases that contribute to climate change. In addition, because the sun gives off more energy than humans could ever utilize, the generation of electricity through solar power is a vital component to the creation of clean energy. Maintenance and operation costs are low compared to other types of electricity generation ways. Solar power may generate enormous amounts of electricity without the risk and expense of ensuring a fuel supply. This makes solar power an attractive alternative to traditional power sources. This motivated me to study solar energy utilization.

There are many solar cell technologies, but DSSC extracts energy from both artificial and natural light. Since it has a strategic structure, it can extract more protons from the sun’s rays. This solar cell is capable of absorbing fluorescent light and diffused sunlight. It can work effectively in cloudy climatic conditions and can work at wider angles. It does not require any apparatus and is more economical than semiconductor cells. These many features of DSSC motivated me address some of its drawbacks.

In a DSSC cell, optimization of each step is needed to get maximum efficiency from the cell. Therefore, the role of each step and its optimization is discussed in this work. As a coating method, compact layer coating, and the thickness of transparent and reflective layers affect the performance of DSSC. These steps need optimization. Dye desorption is evident in DSSC, which lowers its performance significantly. Therefore, the Dye desorption challenge is addressed in this work. The temperature of the anode before dye soaking and the temperature of cell assembly are crucial steps to get high efficiency of DSSC. Therefore, temperature effects are explored in this work.

In DSSC cell applications, counter electrode material such as Platinum is commonly used. Despite their advantages, Platinum has a disadvantage that restricts its effectiveness in DSSC cells, which is higher costs. Given these circumstances, it was important to create an alternative, such as graphene nanosheets, that would alleviate the disadvantages. Graphene is an environmentally and economically friendlynanomaterial. Also, graphene is added to liquid electrolytes to increase electrolyte conductivity to increase DSSC efficiency. Leakage and volatility of liquid electrolyte issue is addressed in this work by developingbiodegradable agar-agar-based gel electrolyte. Many modifications were performed in gel electrolyte to overcome Gel DSSC low performance issue.

1.13 Objective

1. Optimization of fabrication steps of DSSC to enhance performance of DSSC.
2. Overcoming dye desorption challenges in fabrication of DSSC to increase its stability.
3. Synthesis of graphene nanosheets by different routes of synthesis i.e. physical exfoliation method, chemical exfoliation, and combined method.
4. Fabrication Of Graphene-based counter electrodes for Pt-free DSSCs for the Cost reduction in DSSCs application.
5. Incorporation of gel electrolyte in DSSC Assembly to improve long-term stability of DSSC.
6. The addition of graphene in liquid and gel electrolytes of DSSC to improve the efficiency of DSSC.