Synthesis and Fabrication of Dye-Sensitized Solar Cell Using Delonix Regia Flower Dye

M.Tech. Thesis

By
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DEPARTMENT OF METALLURGY ENGINEERING AND MATERIALS SCIENCE
INDIAN INSTITUTE OF TECHNOLOGY INDORE
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A THESIS

Submitted in partial fulfillment of the
Requirements for the award of the degree
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Bhaskar Singh Chauhan

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **Synthesis and Fabrication of Dye-Sensitized Solar Cell Using Delonix Regia Flower Dye** in the partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY** and submitted in the **DEPARTMENT OF METALLURGY ENGINEERING AND MATERIALS SCIENCE, INDIAN INSTITUTE OF TECHNOLOGY INDORE**, is an authentic record of my own work carried out during the time period from 20 Aug of joining the M.Tech. Program to June 2022 of M.Tech. Thesis submission under the supervision of Dr. Parasharam M. Shirage, Professor, Department of MEMS and Dr. Rupesh S. Devan, Associate Professor, Discipline of MEMS, Indian Institute of Technology Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

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DEDICATION

Dedicated to my Parents, friends,

And teacher

ABSTRACT

The dye-sensitized solar cell is a hybrid solar cell it is a third-generation photo-electrochemical solar cell that shows good potential low-cost cost technology because of the large availability of ingredient material and its nontoxic nature its highly acceptable by human society, the flexibility of DSSC gives the edge to the commercialization of this product. In this work Dye-sensitized solar cell based on TiO_2 Nano rods is done by a coating of compact layer on fluorine-doped glass in spin coater latter TiO_2 Nano rods are grown up on the compact layer by the hydrothermal process at 150℃and let it cool to room temperature and then the same sample is annealed at 450℃ we called it photo anode. Natural dye is extracted from Delonix Regia flower by grinder and centrifuge to avoid solid impurity. To fabricate the device photo anode and Nickel-based counter electrode which was pressed and sonicated in ethanol for removing impurities. To oxidize the dye, we use electrolytes made up of Potassium Iodide, Iodine crystal. In this work of The energy conversion efficiency is evaluated as 0.17 % as a maximum value so far, the latest efficiency reported on dye-sensitized solar with Delonix Regia flower was 0.1% with carbon as counter electrode in the year of 2021. The improved solar cell characteristic open circuit voltage V_{oc} =0.3244 V, short circuit current J_{sc}=1.89 mA, and energy conversion efficiency η=0.17%, compact layer of TiO_2 on fluorine-doped glass subtract enhance the adherences of Nano rods by extracting natural dye it ensures the high absorbance level which result in higher efficiency, Potassium Iodide, Iodine crystal, and Ethylene Glycol mixture on propionate amount mixed which regenerate the oxidized dye to ground state to complete the cycle of regeneration.

Key words: Dye sensitized solar, TiO_2 Nano rods, hydrothermal process, Delonix Regia, Potassium Iodide, Iodine crystal

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ABBREVIATIONS

DI	De-ionized
DMF	Dimethyl formamaide
DMSO	Dimethyl sulfoxide
DSSCs	Dye-sensitized solar cells
ETL	Electron transport layer
ETM	Electron transport material
FTO	Fluorine-doped tin oxide
FESEM	Field emission scanning electron microscopy
ITO	Indium-doped tin oxide
HTL	Hole transport layer
HTM	Hole transport material
HOMO	Highest occupied molecular orbital
LUMO	Lowest unoccupied molecular orbital
NRs	Nano rods
MAI	Methyl ammonium iodide
MBI	Methyl ammonium bismuth iodide
PCE	Power conversion efficiency
PSCs	Perovskite solar cells
PV	Photovoltaic
TCOs	Transparent conducting oxides
XRD	X-ray diffraction
UV	Vis Ultra violet- visible

Chapter 1

1. Introduction

1.1. Solar cell

The demand of energy and environmental concerns increases globally because of rapid growth in population[1-2]. To ensure people's safety and security, clean energy is required to reduce air pollution and greenhouse gas (GHG) emissions. Renewable energy is required, which means that finite fossil resources must be gradually phased out. The necessary need of energy is fulfilled by the conventional source like coal, oil and natural gas which is being utilized all over the world however the unconventional source energy such as Biomass, tidal, geothermal energy, and Solar energy, along with wind, energy are evolving as substitute energy sources for our planet's energy deficiency [1–3]. Solar energy is one of the most promising alternative sources of renewable and clean energy, according to the mentioned above source of energy.

In the course of recent 10 years, Solar radiation emitted by the sun is over 3.8 million EJ/year, which is roughly 10,000 times more energy than the world's current energy needs, which we can harvest as needed [4]. The world is approaching toward the harvesting solar energy in greater amount According to Bloomberg New Energy Finance (NEF), photovoltaic systems with a combined capacity of 183 GW were deployed worldwide in 2021, over 40 GW higher than in 2020. Because of this high increase, the analyst has raised its forecast for 2022, estimating that new systems will reach between 204 and 252 GW [5]. Regardless of the circumstances, the mark of 200 GW should be broken for the first time this year. India targets 450 GW of renewables and 500 GW of non-fossil capacity by 2030. With 110 GW already installed, the nation needs to deploy 340 GW of new RE capacity on an average, 42.5 GW RE annually for the next eight years to meet the

2030 target. It would require the country's solar capacity to rise five-fold to 280 GW from 54 GW and wind to rise four-fold to 140 GW from 40 GW during this period. This translates to 29 GW of new solar and 12.5 GW of new wind capacity addition every year on average till the end of this decade – a far faster pace than the nation's record annual addition of 15 GW RE (14 GW of solar and 1 GW wind) in FY 2021-22 The report says it is more than possible for India to deliver on its 2030 targets of 450 GW RE or 500 GW non-fossil capacity if all the states are fully engaged and aligned with the national targets. We can see the demand in figure 1.1

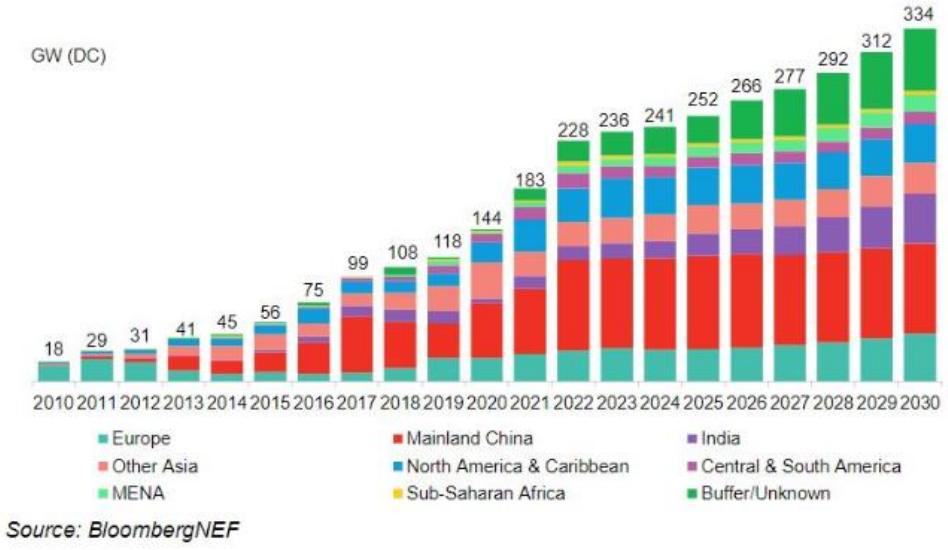

Figure 1.1 Global PV installation estimate and forecast as of January 2022

Photovoltaic systems with a combined capacity of Commercial and industrial systems will also witness an increase in their proportion in 2021, as they are becoming increasingly lucrative against the backdrop of growing electricity prices and electricity shortages in the country [5]. Solar cell is a device which works on the principal of photovoltaic effect, it converts light energy into electrical energy its electrical parameters such as voltage, current, or resistance – vary when exposed to light, it is also known as a

Photovoltaic cell or PV cell. Which is basically made up of p-n junction diode. When light falls on the device it generates voltage. Generation of voltage and current because of sun light falling on semiconductor is not new which result in conversion of sunlight into electricity this was introduced. Since 1839, when Edmond Becquerel discovered the effect of illuminating silver chloride inside an acidic solution, a great deal of work has been done to improve the efficiency of such a device, with Bell Labs achieving a more efficient version in 1954 [6].

The PV-effect is simple to comprehend because its basic principle has remained unchanged since the invention of the prototype mentioned above. The p-type dopant lowers the Fermi level in a solar cell made up of a junction of p and n-doped semiconductors, putting it closer to the valence band. Solar cell is device made by a junction of n-type and p-type semiconductor where p-type semiconductor valance band are closer to fermi level while conduction band are far away from fermi level. However, for n-type semiconductor valance band are away while conduction band are closer to the fermi level above which electron free from the hole bound. As we can see in figure 1.2 Solar light falls on junction of semiconductor material it gets absorb such that electron get excited and try to jump into conduction band. These electrons get sweeps toward the cathode side because of electric field generated in the depletion region on the other hand hole is swept away toward the p- type side anode because of same electric effect. Because of potential difference between the anode and the cathode force is generated called electromotive force, the same effect can be utilized to generate the current in closed circuit which can see in figure as V_{OC} by the displacement of the Fermi level upwards in the n-type and downwards in the p-type.

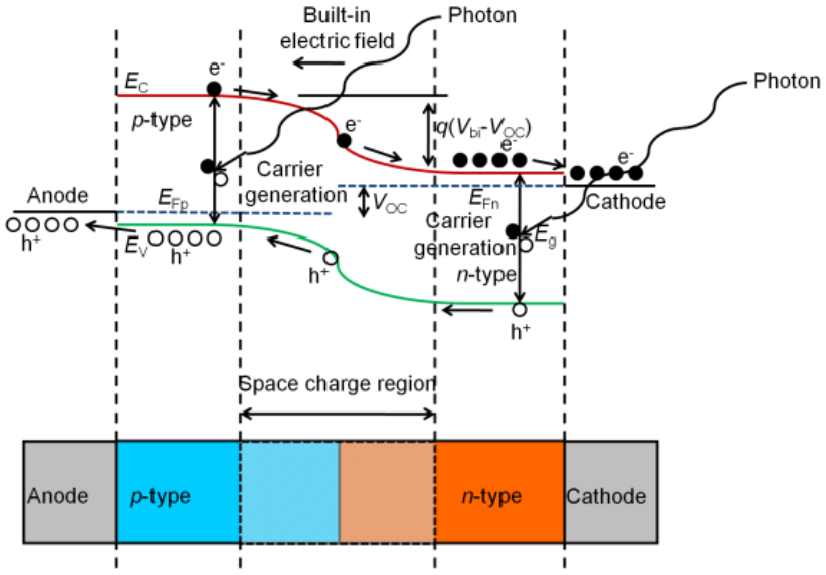

Figure 1.2 Energy-band diagram of silicon p-n junction solar cell

The photovoltaic effect can be understood when two different types of semiconductors, p-type (rich in holes) and n-type (rich in electrons), are brought together to produce a p-n junction. When these two types of semiconductors are linked, electrons flow to the positive p-side and holes flow to the negative n-side, forming an electric field. As a result of the electric field, negatively charged particles flow in one direction while positively charged particles flow in the opposite way.

Solar cells operate over a wide wavelength range, which is determined by the solar spectrum. Light is made up of photons, which are tiny bundles of electromagnetic radiation or energy. These photons can be absorbed by a photovoltaic cell, which is the type of cell utilised in solar panels. When light of a suitable wavelength is incident on these cells, the energy from a photon is transmitted to one atom of the semiconducting material in the p-n junction. The energy is sent to the electrons in the substance in a precise way. As a result, the electrons jump to a higher energy state known as the conduction band. As a result, the electron sprang up from

a "hole" in the valence band. As a result of the interaction, the electron moves.

DSSCs work well under the sun, but because dye light absorption profiles are sometimes insufficient for the visible part of the solar spectrum, they work much better when lighted by non-natural light sources with emission spectrums similar to the Sun [3]. Figure 1.3 shows the power spectrum as a function of wave length; the area under the curve represents the total intensity of solar radiation; solar energy will scatter due to ozone, dust, water molecules, and the incidence angle of light [7].

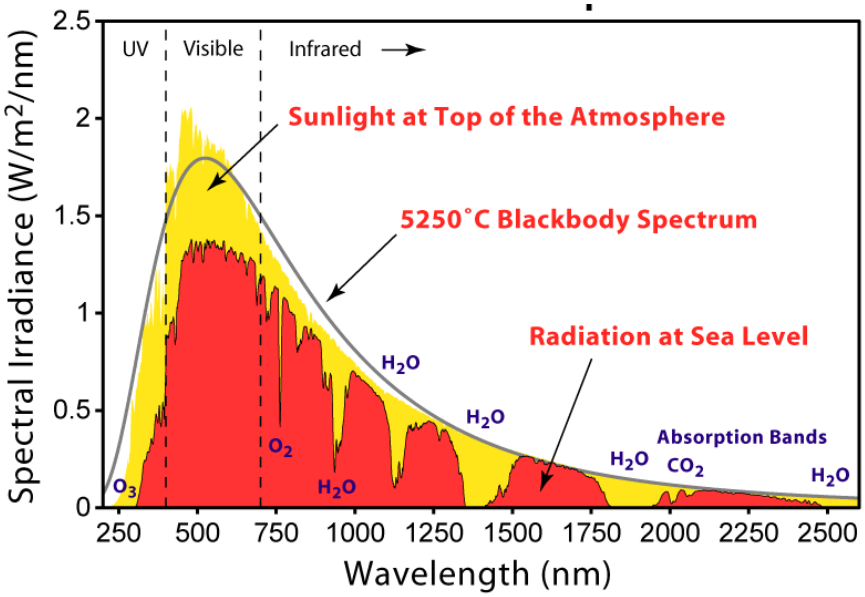

Figure 1.2 Solar irradiance spectrum.

1.2. Types of solar cell

Basically solar cell can classify in three categories on the basics of their performance and need. Their classification is represented in a hierarchy fission as following figure 1.4

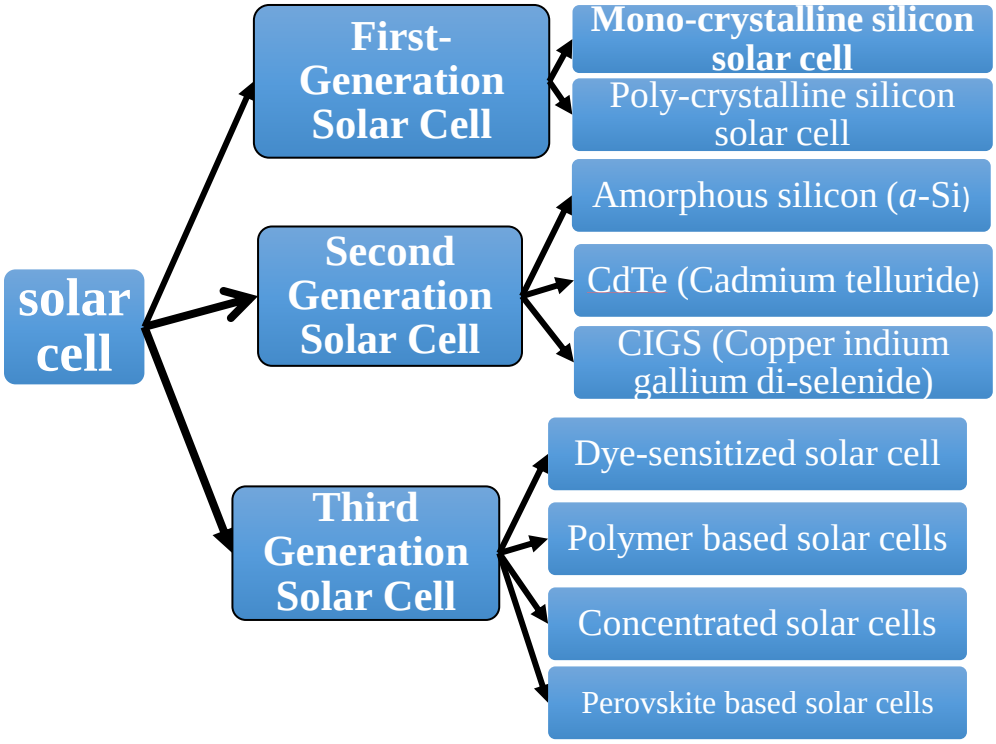

Figure 1.3 Various Types of Solar cell Technologies and Current Trends of Development.

1.2.1. First-Generation Solar Cell

The oldest and most popular is first generation solar cell, these solar cell are based on silicon wafers, its famous because of high power conversion efficiency. Silicon solar is the first generation solar cell which consist of single crystalline material, the fabrication is easy with silicon material, and the method adopted for the fabrication is Czochralski method it is basically divided into two group.

1. Mono-crystalline silicon solar cell
2. Poly-crystalline silicon solar cell

The efficiency of silicon solar cells, which are made up of silicon wafers, is higher. However, their manufacturing costs are significant, resulting in a high overall cost of commercially available crystalline solar. A crystalline solar cell's efficiency is influenced by its performance, which

is influenced by temperature. About 2-3 watt of power can be supplied by each wafer. Solar modules consisting of many cells are used to increase the power[8].If the whole wafer is only one crystal, then it is known to be mono-crystalline solar cell and if the wafer has many grain boundaries *i.e.* composed of crystal grains then it is said to be poly-crystalline solar cell. Efficiency of mono-crystalline solar cells records up to 25.8% which is higher than the poly-crystalline solar cells which has 22.3%[9]. But the production of polycrystalline wafer is easier and cheaper 49% of the worldwide production of solar cell are occupied by polycrystalline Si solar cell[10].

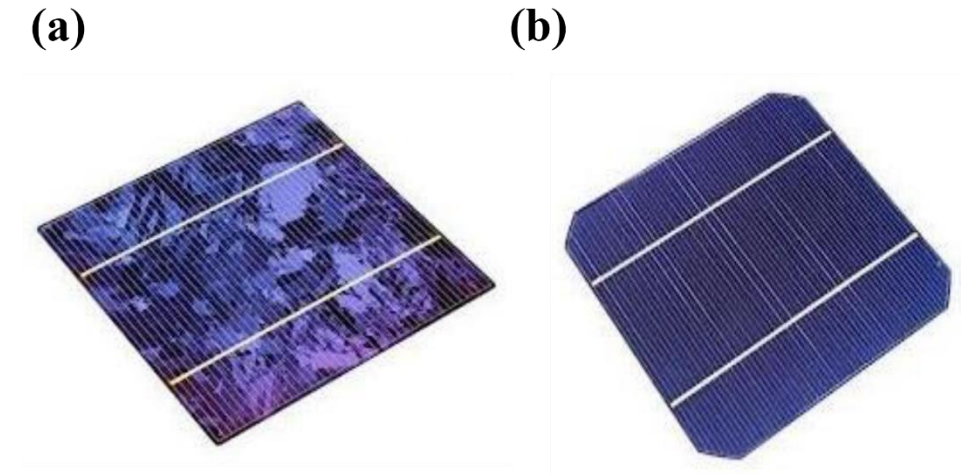

Figure 1.4 (a) Mono-crystalline Si solar cell (b) Poly-crystalline Si solar cell.

Though, first generation technology has high conversion efficiency, but the silicon availability is convoluted because of its high cost and complex fabrication process.

1.2.2. Second Generation Solar Cell.

Second generation is based on thin-film technology in which thin-film solar cells are having very thin light absorbing layers of thickness of order of 1 μm. It is classified as fallow;

(a) Amorphous silicon (*a*-Si)

(b) CdTe (cadmium telluride)

(c) CIGS (copper indium gallium di-selenide)

The second generation solar cell is a type of thin film solar cell which is usually called as amorphous silicon solar cell. It is due to the presence of powdered form which makes the cell more flexible and light-weight in the solar materials. However, the less efficiency of thin film solar cell is main hurdle Copper indium gallium selenide (CIGS), Cadmium telluride (CdTe) and amorphous silicon (a-Si) are the categories of thin film solar cell.

They are more economical in compared to first generation solar cell but has less efficiency normally in the range of 10-20%[11]. It has several advantages of having high absorption co-efficient thus reducing required area for photon absorption, can be processed in both vacuum and non-vacuum process, low cost substrate, can be grown on flexible substrates *etc*. and the disadvantages include environmental contamination of heavy metal like cadmium, low efficiency, difficult to find some materials, *etc*.

1.2.3. Third generation solar Cell

The third-generation solar cell promises for the novel technologies in developing highly efficient and low cost solar cells. Types which belong to this category are:

1. Nanocrystal based solar cells (7%-8%)
2. Polymer based solar cells (3%- 10%)
3. Dye-sensitized solar cell (organic solar cell) (11%)
4. Concentrated solar cells
5. Perovskite based solar cells (organic-inorganic solar cells) (23.3%)

This generation aims to improve electrical performance of second-generation thin film technology method while maintaining the cost of

fabrication by using variety of new materials beside silicon like nanotubes, organic dyes, conductive plastics, quantum dots, perovskites, *etc*. Still most of the research and development work on this generation technology are in the lab and thus most of these are commercially unavailable. Because of their low market captivity, sometimes they are referred as 'emerging technology'. Polymer solar cells are having advantage of flexibility because of polymer substrate, simple and large-scale production. Among these third generation solar cells, the perovskite based solar cell is the most emerging one as it achieved the record efficiency beyond 23% [12] on very small area in very less span of research time but not able to commercialized because of the stability and toxicity issues.

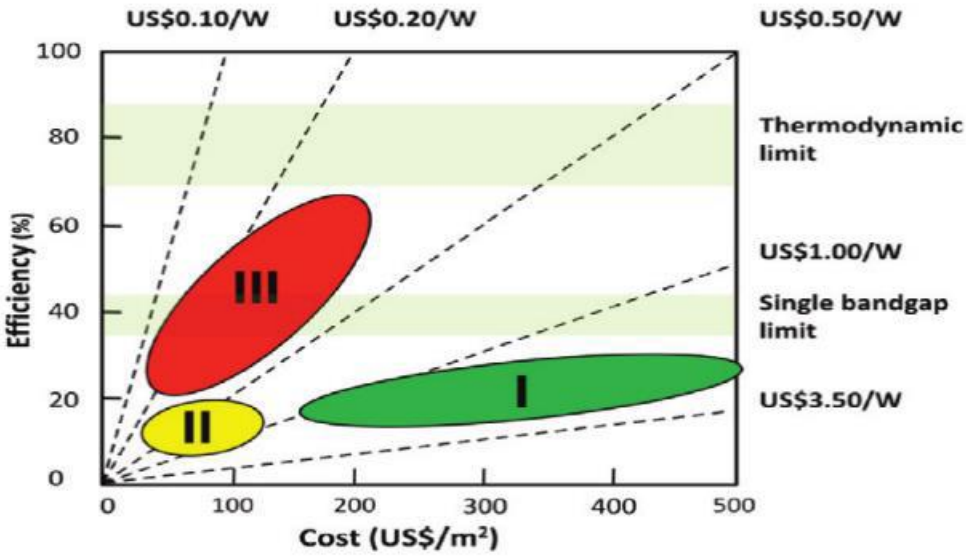

Figure 1.5 Efficiency vs cost among the different generations' solar cell [13]

1.3. Dye sensitized solar cell

Dye sensitized solar cell (DSSC) is the third generation solar cell, It is photo electro-chemical device as it involves photo-electrons and chemical reaction [2].

There is question arise in our mind why an artificial leaf cannot be made?

We all know that plants make their own food by a process called as photo synthesis what they do. They take water molecule from ground, they absorb CO_2 and using H_2O and CO_2 by a process known as photosynthesis plants make food. Chlorophyll pigment helps to convert H_2O and CO_2 to convert glucose molecule and as by product O_2 is generated around the Chlorophyll pigment we will having magnesium atom these are used to absorb the visible light ranging from 400 to 700 nm[14].

O'Regan and Gratzel created the very first dye-sensitized solar cell in 1991[15]. One of the most effective substitute technologies for solar energy conservation is dye-sensitized solar cells. Dye-Sensitized Solar Cells (DSSCs) have been produced, and researchers are increasingly interested in them due to their low-cost material. A dye-sensitized solar cell (DSSC) converts light into electric energy through light sensitization on a wide energy-band semi-conductor.

Because of its immense popularity, dye-sensitized solar cells (DSSCs) have continued to surprise researchers with their recent advancements and distinctiveness during the last 30 years of research. The latest discoveries in this field have led to the invention of tunable transparency PV devices, which use photochromic dyes or near-infrared (NIR) absorption dyes to achieve this. As a result of these developments, DSSCs may now be installed in greenhouse windows, and the lovely colours of traditional DSSCs make them attractive as decorative building-integrated photovoltaics (BIPV).

There have been significantly to the increase in the broad field of dye-sensitized solar cells in past few decades. Under 1 sun light it is presented a co-sensitized carbazole/triarylamine-based system that yields effective and outstanding power conversion efficiency (PCE) of 14.3%

[10]. Following multiple key advancements over the previous few decades, new developments in dye and electrolyte engineering have published the NREL certified DSSC record of 13 %, and the efficiency of indoor DSSCs has reached 34 % under 1000 lux. Different types of dyes have been recorded to date, and they are still attracting a lot of interest in the dye world.

So this happens in leaf if we make Chlorophyll pigment in lab we can mimic the photosynthesis process, it was found that charge separation can be achieved by using large band gap semiconductor for example Cds, ZnO or TiO_2 in contact with an electrolyte that might be iodide

1.4. Structure and Working principle of DSSC;

As dye sensitized solar cell uses a thin film methodology, it comprises of several thin film layer as its component. The structure of the DSSC consists of;

(i) A transparent anode is comprised of a glass sheet that has been covered with a conductive oxide layer that is transparent.

(ii) To stimulate electronic conduction, a nano rod of TiO_2 is placed on the anode.

(iii) To improve light absorption, a monolayer charge transfer dye is covalently attached to the surface of the mesoporous oxide layer.

(iv) A dye-regenerating electrolyte including a redox mediator in an organic solvent.

(v) An electron-collecting cathode made of a glass sheet covered with a catalyst (Nickel sheet or gold-coated FTO).

The dye-sensitized solar cell (DSSC) is a photo electrochemical cell it consists of five components which seem like sandwich structure shown in figure 1.7 When sunlight falls on dye-sensitized solar cells, the dye molecule collects photons and generates electrons, which are then sent to the TiO_2 semiconductor films' conduction band. Following that, the dye molecules that have lost electrons are oxidized. These electrons travel

through the Nano rod and TiO_2 Thin film toward the transparent conductive electrode, which is the photo anode, and then to a load, where the operation is performed and delivered in the form of electrical energy to complete the circuit. The electrons then travel back through the external load and reach the counter electrode, completing the circuit.[16].

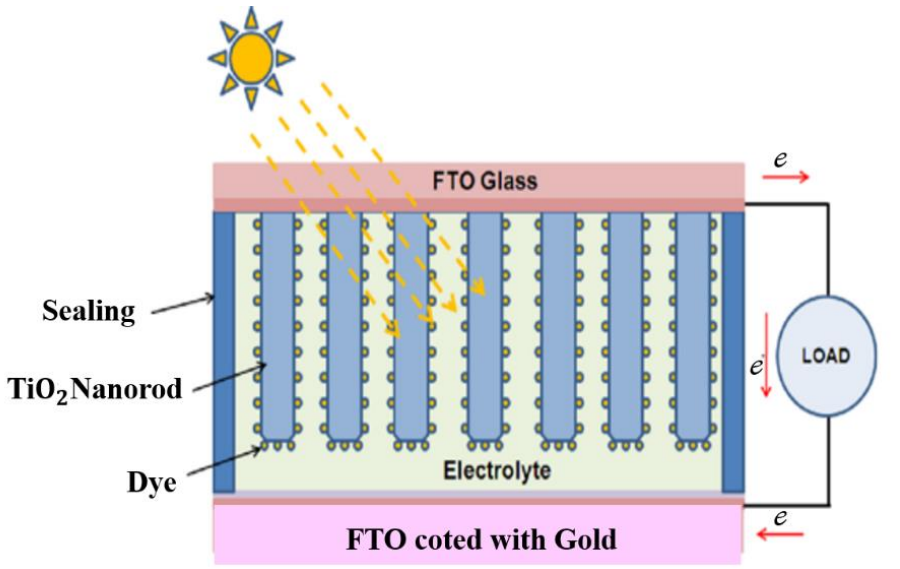

Figure 1.7 Working mechanism of the DSSC.

1.5. Performance parameter of DSSC

The open circuit voltage, short circuit current, fill factor, maximum voltage, and maximum current of a dye solar cell are the characteristics that determine its performance. As follows, each parameter is thoroughly investigated.

The photovoltaic efficiency is influenced by performance factors such as open circuit voltage, short circuit current, fill factor, maximum current, and maximum voltage of the device; the above parameters are explained in depth below.;

1.5.1. Short circuit current

The short circuit current (I_{SC}) can define as the value of current when voltage is zero this can be affected by band gap of material higher band gap material have low short circuit current and it is directly proportional to temperature. Here expression given below the I_{SC};

$$I_{SC} = I + I_0 \left[e^{\left(\frac{V}{V_t}\right)} - 1 \right] \ldots \ldots \ldots \quad \text{Eq. (1)}$$

1.5.2. Open circuit voltage

In solar cell open circuit voltage (V_{oc}) is defined at the as the value of voltage at which current is zero it depends upon the band gap of material, for higher band gap material open circuit voltage is higher the temperature of the cell increases, the V_{oc} decreases. The V_{oc} of the solar cell is expressed as below:

$$V_{OC} = V_t \left[ln \left(\frac{I_{SC}}{I_0} + 1 \right) \right] \ldots \ldots \ldots \quad \text{Eq. (2)}$$

1.5.3. Fill factor

The fill factor (*FF*) of a solar cell is the ratio of actual power to dummy power (product of maximum voltage *Vm* and maximum current; Im) (product of *Voc* and *Isc*).

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \ldots \ldots \ldots \quad \text{Eq. (3)}$$

1.5.4. Efficiency

The ratio of electrical power to the optical power which is incident on the solar cell is known as the efficiency. It can be mathematically expressed as follows:

$$\eta = \frac{FF.\ V_{oc} I_{sc}}{\text{Incident optical power}} \ldots \ldots \ldots \quad \text{Eq. (4)}$$

Where,

V_m – Maximum value of voltage,

I_{sc} – Short-circuit current,

I_m – Maximum value of current,

η – Efficiency of the cell,

V_t – Terminal voltage of the cel

V_{oc} – Open-circuit voltage.

1.6 Organization of the Thesis

This thesis is organized in the following way:

1. Chapter 1 discusses about the introduction to solar cell, types of solar cell, introduction to dye-sensitized solar cell (DSSC), components of to dye-sensitized solar and working principle of to dye-sensitized solar.

2. Chapter 2 gives the overview of past work, challenges in the development of dye-sensitized solar, motivation, and objectives of the work.

3. In Chapter 3, experimental technique has been discussed like synthesis technique of TiO_2 nanorods, preparation of natural dye and electrolyte.

4. Chapter 4 discussed about the results obtained from the various characterization technique of the different layer deposited on the substrates.

5. Chapter 5 conclude the work done during this research and tells about its future scope.

Chapter 2

2. Review of Past Work and Problem Formulation

Among the third-generation photovoltaic devices, researchers have been showing a great interest in dye-sensitized solar cells because of their remarkable flexibility, low cost, nontoxic, and high power conversion efficiency a decade of research work. In this section, we will look over the past work and progress made in the area of dye-sensitized solar.

2.1. Literature Survey:

2.1.1. Past research activity on dye-sensitized solar cell:

One of the alternative to silicon solar cells is the dye-sensitized solar cell [2]. Recent advances in the development of innovative materials for high-performance DSSC-based solar systems are discussed in this work. The pioneering work of Brian O'Regan and Michael Gratzel, who used natural dye sensitized Nano rods of TiO_2 film to get a power conversion efficiency of 6.92 percent [15]. It sparked interest in dye sensitized solar cells. Due to a combination of reasons, the titanium dioxide (TiO_2) nanoparticle-based electron transport layer proved to be the most efficient photo electrode in the DSSC system despite evaluating a range of semiconducting oxides in DSSCs. It is made up of five parts, each of which is described below:

- Glass subtract
- Photo anode
- Natural dye
- Electrolyte
- Counter electrode.

2.1.2. Glass subtract:

The most common substrate used for dye solar cell is Fluorine doped titanium oxide (FTO). As it highly efficient and because of its transparency make it important choice for the researcher to opt it.

2.1.3. Photo anode made by semiconductor:

Due to their wide utility in energy storage, semiconductors such as chalcogenides, TiO_2, ZnO and SnO_2 have been extensively researched. DSSCs have been tested using a range of semiconducting oxides, but the electron transport layer based on titanium dioxide (TiO_2) nanoparticles proved to be the most efficient photo electrode. The table below shows some of the possible combinations. They function as sensitizers to facilitate light-reduced redox processes because to their conductive electronic structure, known as valence band (V_B) and conduction band (C_B) [2]. Titanium dioxide (TiO_2) present in nature in three different form which are following;

1. Rutile.
2. Anatase.
3. Brookite.

Rutile is the most stable phase of Titanium dioxide (TiO_2), expected to sustain stable at any temperature. However, in terms of physical and chemical activity, Anatase is thought to be more active, which is why we employ it for dye-sensitized solar cells. TiO_2 acts as a sensitizer for light-reduced redox reactions known as conduction band (C_B) and valence band (V_B) because of their conductive electronic structure (V_B). When light strikes the surface of a semiconductor with an energy that exceeds or corresponds the bandgap (E_g), an electron is excited to the conduction band and left out with a hole with a positive charge at the valence bond, and we

can use these charges to produce an electric current for an external load

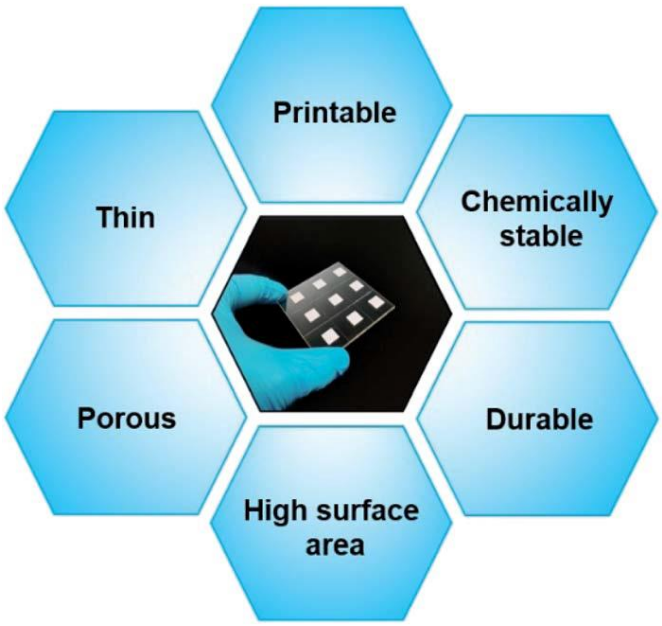

Figure 2.1. General characteristics of efficient semiconducting oxide layer in DSSCs

A semiconductor with a large porous surface area and characteristics that match the sensitizer will boost the DSSC's efficiency. TiO_2 is most suitable candidate for the need of semiconductor, in table we can see the maximum efficiency achieved by the DSSC's is approaching to 7 % with dye name Z907 where counter electrode is used as platinum[1]. The property required for semiconductor layer is shown in figure 2.1

Table1: Comparison of TiO2 for DSSC and Characteristics

Photo anode	Electrode	Technique	Dye	*Voc* (*mV*)	J_{sc} (*mA* cm^{-2})	*FF*	η (%)	Ref.
TiO_2	-	Doctor Blade method	Xanthophyll	610	0.10	0.54	0.04	[17]
TiO_2	C	Doctor Blade method	Red amaranth leaves	362	0.24	0.54	0.05	[17]
TiO_2	-	Doctor Blade method	Chlorophyll	585	0.15	0.59	0.05	[18]
TiO_2	Pt	Sputtering	Anthocyanin	555	1.89	0.49	0.55	[19]
TiO_2	Pt	Sputtering	Chlorophyll	560	2.05	0.52	0.59	[20]
TiO_2	Pt	Spin coating and Doctor blade method	N749	745	3.89	0.72	2.09	[19]
TiO_2	Ti	Electron beam PVD	-	600	6.76	0.62	2.51	[21]
TiO_2	Pt	Sol-gel Method	N719 dye	731	9.72	0.36	2.59	[22]
TiO_2	pt	Chemical Crystal Template	N719	702	7.25	0.59	2.96	[23]
TiO_2	Pt	Template Method	N719	704	7.21	0.66	3.35	[24]
TiO_2	-	Sputtering	N3	709	6.4	0.67	3.8	[25]
TiO_2	Pt	Electrochemical deposition	N719	750	9.07	0.61	4.12	[26]
TiO_2	Pt	CVD	N3	658	8.9	0.71	4.2	[26]
TiO_2	$PtCl_4$	MOCVD	N719	8.22	752	0.66	4.13	[27]
TiO_2	Pt	Hydrothermal	N719	780	11.0	0.68	5.86	[28]
TiO_2	Pt	Template Method	N719	750	12.2	0.65	6.1	[29]
TiO_2	Pt	Spin coating	RuC9	673	15.0	0.67	6.80	[30]
TiO_2	Pt	Spin coating	Z907	691	14.1	0.71	6.92	[30]

2.1.4. Dye material

Fruits, flowers, leaves, microbes, and other naturally occurring materials, such as fruits, flowers, leaves, and other naturally occurring items, come in a range of colures and contain various pigments that are easily extracted and employed in DSSC.

The high absorption coefficients in the visible region, relative availability, ease of manufacture, and environmental friendliness of these natural dyes as photosensitizers in DSSC are all advantages. Most notably, because it does not need noble metals like Ru, the natural dye-based DSSC synthesis approach is cost effective.

The cost of the cell, environmental difficulties, maximum absorbance, stability problem, efficiency of the DSSC, availability of resources, and cell manufacturing process are some of the criteria that can be compared between synthetic and natural sensitizers, as discussed [26]. Metal complex sensitizers are made using a sophisticated fabrication procedure, whereas natural sensitizers are made from leaves, flowers, and roots, for example, using a simple ethyl alcohol, methyl alcohol, or water extraction process, and thus are less expensive than synthetic dyes. It has been noted that sufficient quantities of wild flowers, specifically Delonix Regia, are available during the summer season, indicating that the overall cost of DSSC is reduced.

2.1.5. Electrolyte

The DSSC's rely heavily on the electrolyte. Its job is to gather electrons from the cathode and transmit them back to the dye molecule. The Iodide/Tri-iodide (I^-/I_3^-), redox couple in an organic matrix, commonly known as Acetonitrile, is the most commonly employed electrolyte in terms of cell efficiency. Apart from these, there exists a lot of undesirable intrinsic

properties which are inherent of a liquid electrolyte prominently affecting a device's long-term durability and the Operational stability[5].

Electrolyte can classify in to three different section Liquid electrolyte, Solid state electrolyte and Quasi solid state electrolyte The most frequently used liquid electrolyte, namely Iodide/ Triiodide (I^-/I_3^-), works well because of its kinetics.

2.2. Motivation of the Work:

Motivation of this work comes from the historical and remarkable achievements of dye-sensitized solar cells in a decade years of experiment only and its current drawbacks and challenges. Dye-sensitized solar cells are leading candidates as an alternative to silicon solar cells as they bear high efficiency, are easy to fabricate, flexible and more economical. However, there is a lot of hindrance in its commercialization due to its stability challenges and lifetime working issues like liquid electrolyte materials. Although some researchers have tried to fabricate dye-sensitized solar cells by solid electrolyte but failed to maintain the efficiency.

By analyzing the various literature, we found that the remarkable efficiency of DSSCs comes with the use of mesoporous TiO_2 as a photo anode material with the dye and also there is nickel as counter electrode to fabricate. So here in this research work, we tried to get the remarkable performance of DSSCs by optimizing the length and diameter of TiO_2 Nano rods in conventional natural dye PSCs.

- When compared to other solar cell technologies, dye sensitised solar cells (DSSC) have a greater energy conversion efficiency in diffuse light or cloudy circumstances, as well as at higher temperatures.
- It is both environmentally friendly and biodegradable. The synthesis procedure in DSSC is simple and inexpensive.

- It is critical to lower material and production costs in addition to enhancing device performance.
- The synthetic dye, which employs poisonous raw chemicals and requires intricate processing, is one of the most extensive components in DSSC.
- Natural sensitizers can be extracted readily from natural plants such as fruits, flowers, and leaves and used as a DSSC sensitizer.
- Precursors of DSSC are widely available.

2.3. Objectives:

Taking account of all the above-mentioned facts following objectives are aimed:

- To synthesize the TiO_2 Nanorods by the simple and economical hydrothermal method.
- To extract natural dye using Delonix Regia flower.
- Fabrication of an efficient Dye Sensitized Solar Cell (DSSC) with natural using Delonix Regia flower dye, testing and optimizing the parameters.

In summary this chapter we discuss about problem formulation and literature survey is done and shortlisting the TiO2 as photo anode, nickel as counter electrode, Delonix Regia as natural dye.

Chapter 3

Experimental Technique

This chapter deals with the techniques used for the materials synthesis and characterization.

3.1 Experimental Techniques:

3.1.1. Spin coating

Spin coating is one of the widely used technique for applying the uniform thin films to substrates by the action of centrifugal force. It is a solution based process in which a solution of material and a solvent is spun at high speeds, the surface tension and the centripetal force of the liquid together produce a uniform covering ranging from a few nanometers to a few microns in thickness. Deposition, spin up, spin off, and evaporation are the four steps represented in Figure 3.1. The FTO substrate is first placed on the vacuum turntable of the spin coater, and a small amount of the solution material is coated on the substrate, followed by sequential spin up and spin off while the evaporation stage occurs.The solution is distributed on the substrate by centrifugal force, and high spinning speeds cause the layer to thin [33]. The applied layer is then dried after this procedure. Because of the volatile nature of the solvent, uniform evaporation and removal of volatile components from the substrate is achievable. In this research work, a rotation speed of 3000 rpm for 30 secs is used to obtain a uniform film of TiO_2 compact layer of about 80 nm thickness. The deposition of absorber layer and hole transport layer is also done by this spin coating technique with respective rotation speed.

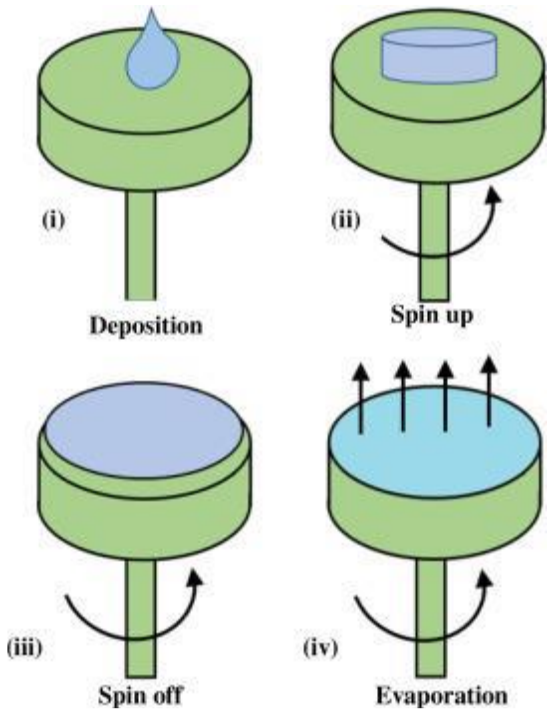

Figure 3.1 Stages of spin coating technique on substrate [34]

3.1.2. Hydrothermal Synthesis Technique

Hydrothermal synthesis technique is one of the important methods for processing of nanostructured materials which has applications in the vast field of electronics, optoelectronics, energy storage device, *etc*. The word 'hydrothermal' is a Greek word where 'hydro's' means water and 'thermos' means heat. Thus, any chemical reaction in the presence of water (DI water) under the conditions of pressure and temperature are defined as hydrothermal reaction process [35]. The reaction takes place in a sealed vessel/container known as 'Autoclave' which can withstand highly corrosive solvent at high temperature and pressure and it is generally made up of stainless steel as shown in the figure 3.2. Teflon lining beaker is used to protect the autoclave main part from highly corrosive substances and extreme pH conditions. The precursor solution made of DI water is poured into the Teflon beaker and then the Teflon beaker was kept inside the stainless-steel autoclave and further the well-sealed autoclave kept into the

oven at desired temperature. The main advantage of this method over others is its ability to produce crystalline phases that are not stable at the melting point and this is well suited for growing large, good quality crystals by maintaining the important parameters like reaction time and temperature and the concentration of precursors and solvent. In this research work, hydrothermal technique has been used to synthesize well oriented one-dimensional TiO_2 Nano rods whose length and diameter were controlled by varying the time of the reaction.

Figure 3.2 1) Teflon lining, and 2) Autoclave

3.2. Fabrication of solar cell

Steps involved in the fabrication of solar cell are:

Cleaning of FTO glass, synthesis of TiO_2 compact layer, synthesis of TiO_2 Nano rods, extraction of dye from Delonix Regia, and synthesis of electrolyte and cleaning of Nickel as counter electrode.[18]

Materials: FTO (Fluorine-doped tin oxide) coated glass, Titanium Diisopropoxidebis (acetylacetonate), 1-Butanol, Titanium(IV) Butoxide (97% Sigma Aldrich), concentrated HCl (35% by weight), DI water, Ethanol(C_2H_5OH), Acetone, Methyl ammonium iodide (TCI chemicals), natural dye extraction and nickel sheet as counter electrode.

3.2.2. Cleaning of FTO substrate

FTO coated glass comes in 100 mm x 100 mm sheet which was cut into pieces of 15 mm x 15 mm. cleaning was performed in the following steps:

1. First, FTO glass substrates were ultra-sonicated with DI water and soap for 30 minutes.

2. In the next step, substrates were ultra-sonicated in acetone for 30 minutes to degrease and remove the dust and chemicals present in earlier step.

3. After that substrates were again ultra-sonicated in ethanol for 30 minutes. In this step the carbon-related impurities will be removed, which were attached during acetone cleaning.

4. Finally, they were dried with hot blower and then kept on hot plate at 120 °C for 20 minutes to remove any organic solvents left on the substrates[31].

3.2.3. Synthesis of compact (c) TiO_2 layer

According to layout of device fabrication, firstly, a compacted TiO_2 layer was coated over FTO glass substrate by spin coating method.

Chemicals required: Titanium di Isopropoxidebis (acetylacetonate), 1-Butanol.

In order to prepare a dense *c*-TiO_2 layer, solutions of 0.15 molar (M) and 0.3 M titanium diisopropoxidebis (acetylacetonate) solution in 1-Butanol, have been prepared and were kept at stirring for overnight. First, a layer of 0.15 M diisopropoxidebis (acetylacetonate) in 1-Butanol solution was spin coated on FTO glass substrates and then it was dried at 120° for 30 min on hot plate. Followed by this a layer of 0.3 M diisopropoxidebis (acetylacetonate) solution in 1-Butanol was spin coated and dried at 120 °C for 30 min [36]. In this process a *c*-TiO2 was deposited with thickness around 80 nm. All the deposited substrates were then placed in furnace for

annealing at 500 °C for 30 min. Nanorods were grown over this dense TiO_2 compact layer in the next step.

3.2.4. Synthesis of TiO_2 Nanorods

Chemicals required*:* Titanium (IV) Butoxide (97%, Sigma Aldrich), Conc. HCl acid (35% by weight) and DI water.

In a typical synthesis, 30 mL of DI water was mixed with 30 mL of concentrated HCl acid *i.e.* in 1:1 by volume so that a total volume of 60 mL in a Teflon lined stainless steel autoclave (100 mL) and the mixture was stirred for 30 minutes at ambient conditions. After proper stirring of the mixture, 0.7 mL of titanium butoxide was added to it and the new solution formed was once again magnetically stirred for another 30 minutes. The ultrasonically cleaned FTO substrates were wrapped by Teflon tape on one end, 0.3 mm from side, and were placed on the bottom of a Teflon-liner with the conducting side facing upwards. The solution was transferred to the Teflon-liner for the reaction to take place. For the hydrothermal synthesis, autoclave was placed in furnace at a temperature of 150 °C. The process was repeated for different reaction times of 3-20 hrs to study the behavior of growth of nanorods with time. After reaction, autoclave was removed from furnace and cooled to the room temperature. TiO_2 coated FTO substrates were taken out of the autoclave, mixed with DI water, and then dried in ambient air conditions. Finally, TiO_2 coated FTO substrates were annealed at 500°C for 30 minutes in an electric furnace[32].

Figure 3.3. TiO_2 coated FTO substrate after hydrothermal synthesis

3.2.5. Dye Extraction

Dye plays crucial role in DSSCs fabrication, because of their performance, ease of synthesis, stability, tenability, low cost and eco-friendly characteristics [5]. In this work natural dye is selected for the device fabrications, to extract the dye from the flower we follow following process;

1. Washing flower with normal water to remove the dust and washable impurities.
2. Sonicating the flower with DI water for 7 minute for impurities removal.
3. After wasting and sonicating we grind the flower to extract the dye by using DI water as solvent in appropriate amount.
4. Take the dye to the centrifuging process to remove solid sediment and filter it with coffee paper.
5. Take the same dye for evaporator to evaporate solvent and get pure dye extract

3.2.5. Electrolyte Preparation

Iodine crystal which is inform of solid ball and Potassium Iodide were mixed together when it became black color it is mixed with Ethylene Glycol to prepare the electrolyte solution the quantity used is 0.42 ml Potassium Iodide and 0.64 ml Iodine were mixed with concentration of 5 ml ethylene glycol and put it to for stirring for sufficient time and it should be done in darkness.

3.2.6. Preparation of Counter Electrode

Nickel foam sheet taken of same size of FTO and pressurized it to compress it latter it is washed with ethanol and sonicated for 5 min to avoid impurities presence

3.3 Characterization Techniques

3.3.1. Fill Factor and Efficiency measurements using Current density – Voltage (J-V) measurements

Scientific Instrument Solar simulator was used to measure J-V characteristics offering a 1.5 G solar irradiation spectrum in both forward directions. The 100 MW power was applied to measure 1cmx1cm sample. Using the power output at constant voltage close to the maximum power point, the stable PCE of perovskite solar cells was determined. The temperature of the device was kept at a constant value of 27°C. Solar simulation technology's major goal is to provide illumination that closely resembles natural sunshine in order to create a controllable indoor test facility under laboratory settings. A solar simulator is an apparatus that is used to replicate sunlight in a laboratory setting (sometimes called a sun simulator). A light source in a solar simulator is meant to have a similar intensity and spectral composition to that of the sun light

Figure 3.4. Schematics of solar simulator

3.3.2) X-ray diffraction (XRD)

XRD is a most common and powerful nondestructive technique for characterizing crystalline materials. It provides information on various structural parameters such as structures, grain size, crystal defects, unit cell dimensions and phases.

Working Principle: For X-ray wavelengths crystal structure acts as a 3D diffraction grating so when they are strike on the sample, they are scattered at specific angles from the set of lattice planes. Provided that scattered beams interfere constructively X-ray diffraction peaks will be formed. The distribution of the atoms within the lattice determines the peak intensities and since this distribution is specific to the structure, XRD acts as a fingerprint of periodic atomic arrangements. The condition for constructive interference is given by Bragg's law:

$$n\lambda = 2\, d_{hkl} \sin\theta$$

where '*n*' is the diffraction order (an integer > 0), 'λ' is the wavelength of the incident X-ray, '*d*' is the interplanar distances of the lattice planes (*h,k,l*) & '*θ*' is the angle of incident beam to the same set of lattice planes. Fig.3.5 shows the X-ray diffraction in atomic planes

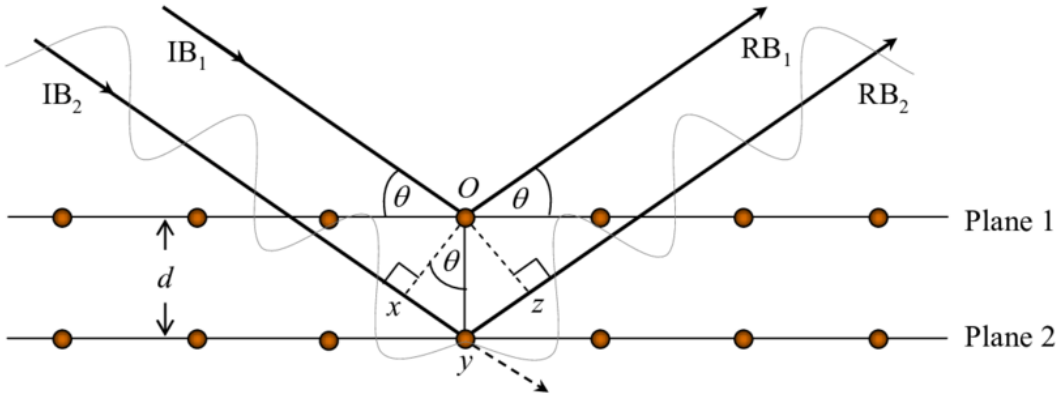

Figure 3.5 Schematic of X-ray diffraction [37]

3.3.2.1 Instrumental Arrangement:

An X-ray tube, a sample holder, and a detector are the three components of an X-ray diffractometer. A cathode ray tube's filament was heated to produce electrons, which were then propelled towards the target by adding a voltage. Characteristic X-ray spectra were created when accelerated electrons bombarded the target and had enough energy to knock off inner shell electrons of the target material. The most popular material for single-crystal diffraction is copper, which has a radiation Kα radiation, λ = 1.5418 Å .Those X-rays were then collimated and directed towards the sample which was rotated along with the detector and intensities of reflected X- rays were recorded. Reflected rays interfere constructively then, a peak in intensity appears. The detector detects and processes this X-ray signal which was converted to a count rate and then output provided to the user. Collimated X-ray beam hits the rotating sample at an angle θ and the detector collects the diffracted beams while rotating at an angle of 2θ as shown in the figure 3.6.

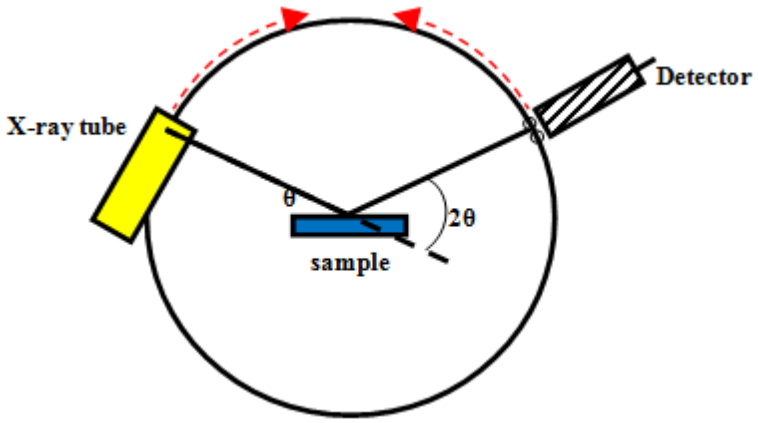

Figure 3.6 Basic components of a X-ray diffractometer [37]

3.3.3 Scanning Electron Microscope (SEM)

SEM is basically a high-resolution version of optical microscope which takes highly magnified images of solid samples using focused

scanned electron beam and also determine the composition of the samples. We have used the most common mode of SEM i.e. secondary electron image which is a map of secondary electron emissions as a function of spatial position which is shown in figure 3.7 Since these emissions are dependent on angle between the surface and the beam, it displays the topography of the sample.

Working Principle: Primary electrons are bombarded on the sample generating low energy secondary electrons which gives the topographic nature of the specimen.

3.3.3.1 SEM Instrumentation

At first, an electron optical system was used to produce probe electrons which consist of an electron gun, a condenser lens, an objective lens and a scanning coil. The electron gun produces the electron beam and the lenses are used to focus & control the diameter of the beam. After that there is specimen stage to place the specimen and then a secondary electron detector to collect secondary electrons. This data is shown as an image on The display unit which is connected to an operating system for perform various operations.

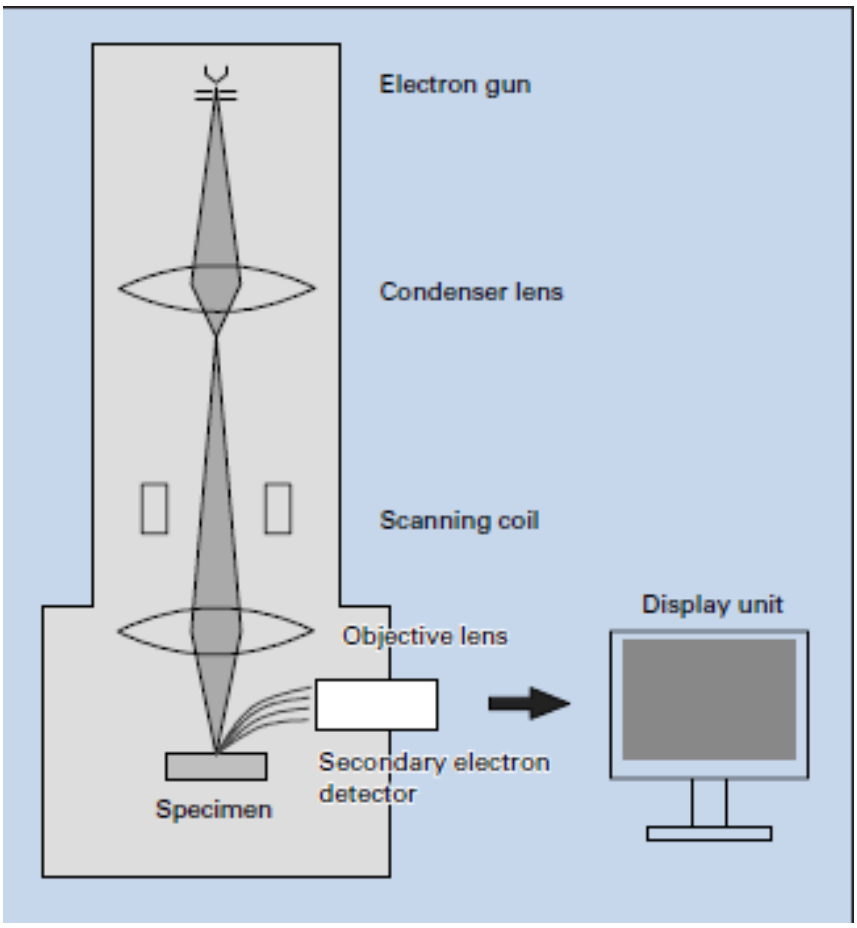

Figure 3.7 Basic construction of a SEM (Image source: *www.jeol.co.jp*)

3.3.4 UV-Visible spectroscopy

Light absorption in the visible/ultraviolet range (210–900 nm). Transitions between electronic energy levels are responsible for the absorption of electromagnetic radiation in this area of the spectrum. In most cases, the transition from highest occupied molecular orbital (HOMO) (VB) to lowest occupied molecular orbital (LUMO) is the most likely (CB).This technique is useful for determining the band-gap of the semiconducting materials. Figure shows the experimental set-up of UV-Vis spectrometer:

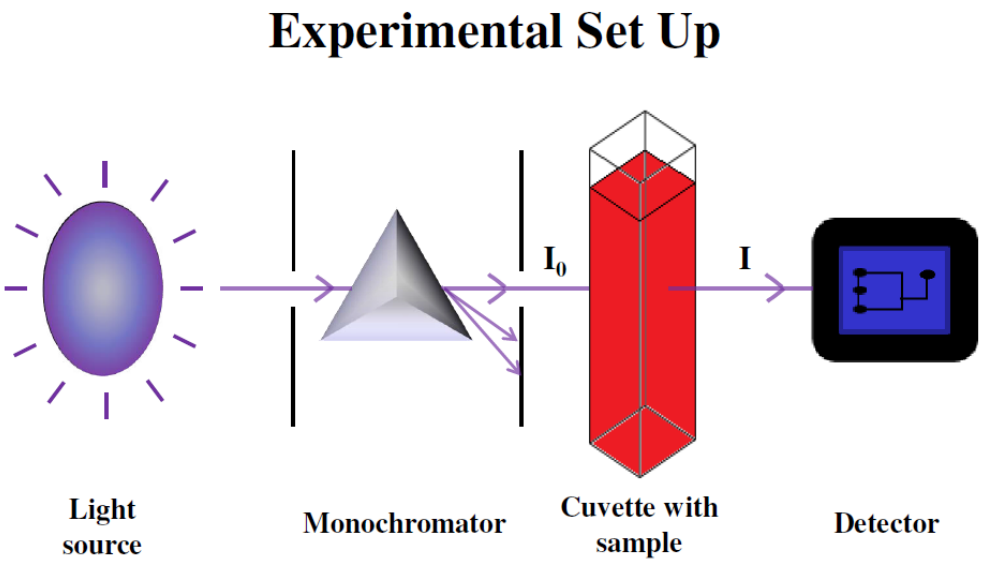

Figure 3.8. The experimental set-up of UV-Vis spectrometer [38].

In Summary the materials synthesis process is successfully established. The photo anode, counter electrode, dye material and electrolyte synthesis process were discussed in detail. The basic characterization tools introduced.

Chapter 4

Results and Discussion

In this chapter we will discuss the results obtained by various characterization techniques like XRD, FE-SEM, UV-Vis spectroscopy and Raman spectroscopy for the synthesized TiO_2 Nano rod arrays on FTO substrates at different reaction time and evaluation of efficiency by solar cell simulator.

4.1 Analysis of TiO_2 layer

4.1.1 XRD analysis of TiO_2

The crystal structure and phase crystallinity of the TiO_2 NRs film by hydrothermal technique at different reaction time of 3 h- 20 h on FTO substrates were analyzed by X-Ray diffraction (XRD). All the XRD patterns as shown in figure 4.1 has been screened with CuKα radiation (where, λ= 1.5406 Å) at scan speed of 2.5 min^{-1} from 20° to 80°. The diffraction peaks, as shown in figure 4.1, of the TiO_2 Nano rods agree well with the tetragonal structure and rutile phase which are confirmed with JCPDS No. 00-021-1276(SG: *P42/mnm*; $a = b$ = 4.593±0.003 nm and c = 2.959±2 nm). The strong intensity peaks at 27.51° is related (110) peak, indicating the formation of rutile phase of TiO_2 Nano rods. The intensity of two peaks (101) and (002) obtained at 37.05° and 63.78°, respectively, are majorly affected with the variation in reaction time and it is indicating that the growth of Nano rods is highly favored in either (101) or (002), direction. There is no change in the phase of TiO_2 NRs with the variation of reaction time and keeping the precursor concentration constant as all the patterns at 4 h, 6 h, 8 h, 15 h, 17 h and 20 h shows same rutile phase. The XRD pattern for growth at 3 h is well matching with FTO substrates at all peaks that is there is no symbol of growth of TiO_2 nano rods at this 3 h reaction time.

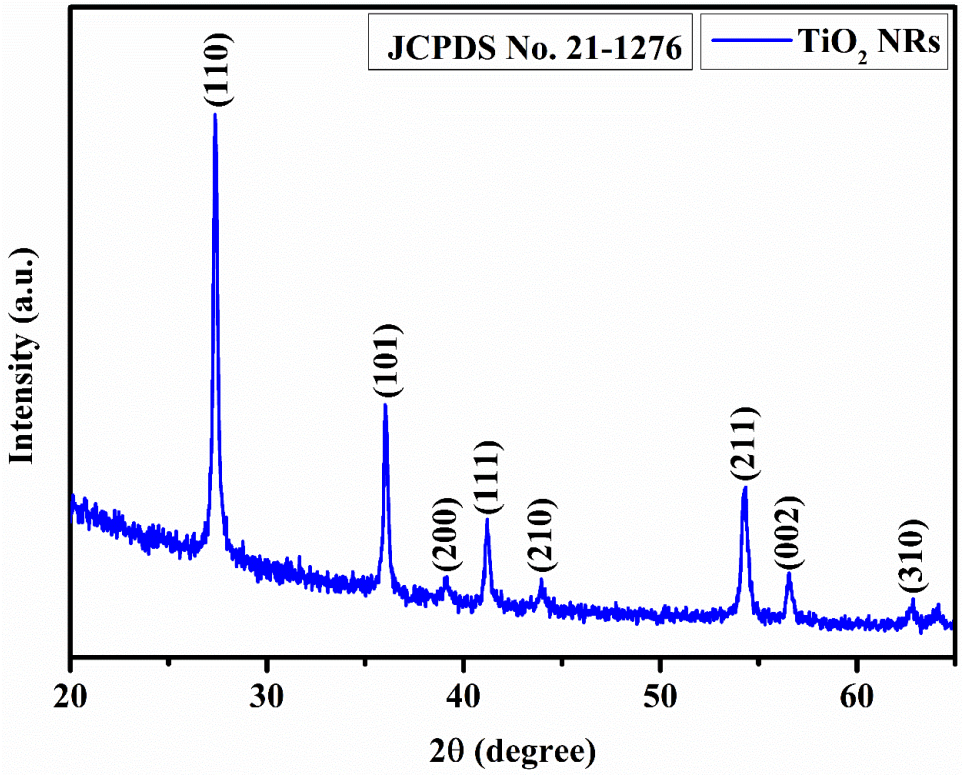

Figure 4.1 XRD of Powder sample of TiO_2 synthesis at 8h of reaction time.

No considerable amount of peak shift was observed. No impurity peaks were observed, indicating the phase pure material. This is very important as small amount of impurity may kill solar cell efficiency. The variation in the intensity with different time is due to change in the orientation of the films *i.e.* being the polycrystalline material the grain growth changes the planes orientation.

4.1.2 FE-SEM Analysis of TiO_2 Nanorods

The FESEM images, shown in figure 4.2 and 4.3, were used to investigate the surface morphology. The size and shape of the TiO_2 Nano rods grown on FTO substrate over compact film at 150 °C for 8 h reaction time. Figure 4.2 shows the FESEM top view image of nano rods on FTO substrate and with compact layer deposition on that.

As we can see the morphology obtained in figure 4.2 is not good enough asTiO_2 NRs are not dense and rods are scattered at some part would not result in efficient dye sensitized solar cell.

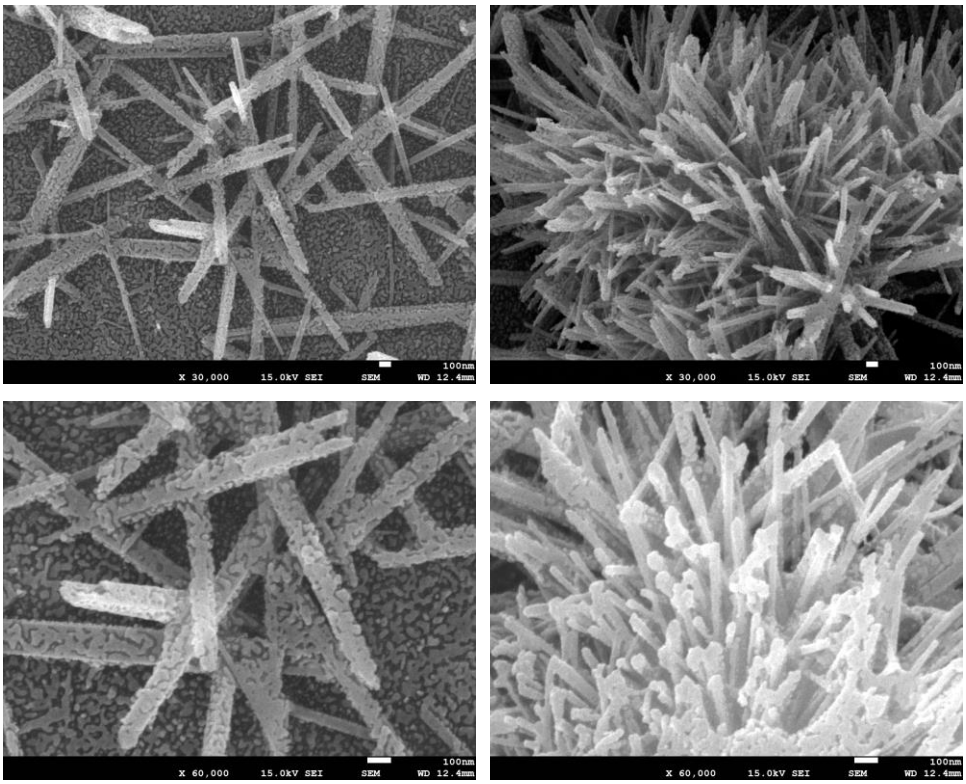

Figure 4.2 Non-uniform surface coverage of TiO_2 NRs grown hydrothermally over the FTO substrate

This compact film act as a seed layer to favor the growth of Nano rods. Figure 4.3 shows the growth of TiO_2 Nano rods at different time periods. By analyzing the FESEM images of Figure 4.4 with the help of Image software, it was found that length and diameter of TiO_2 Nano Rods vary with the reaction time. With the increase in reaction time, length, and diameter both increases thereby making it more densely packed. Average diameter of Nano rods calculated were 82.71 nm for 8 h.

Appropriate dimension, initially non-uniform surface coverage was observed as shown in the figure 4.4 of surface morphology of the thin films.

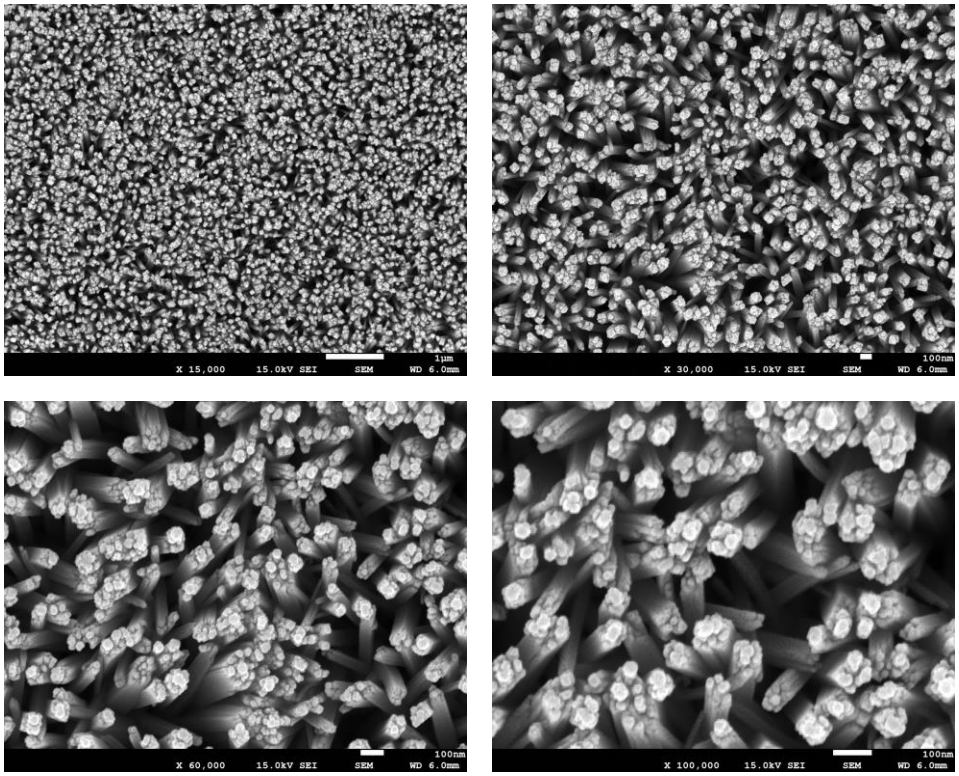

Figure 4.3 Uniformly vertically aligned TiO_2 NRs grown over the FTO substrate by hydrothermal method.

4.1.3 UV-Vis spectroscopy of TiO_2 Nano Rods

UV-Vis spectroscopy has been done to investigate the optical properties of the TiO_2 Nano rods for the various reaction time at constant temperature of 150°C and constant precursor concentration in hydrothermal technique. Figure 4.4 demonstrate Absorbance plot of TiO_2 Nano rods grown hydrothermally at 150 °C for different reaction time of 7h and 8h.The bandgaps were calculated with the help of Tauc plot as shown in figure 4.5. It was found that the bandgap of TiO_2 Nano rods for different reaction time lies in the range of 3.20 eV – 3.65 eV. These bandgap values are corresponding to onset value of absorption spectra near 380-400 nm which confirms the absorption of only desired ultraviolet light thereby confirming the presence of TiO_2 material in the device. Figure 4.6 demonstrate Absorbance plot of Delonix Regia Dye To ensure band gap in decreasing order of dye UV-Vis is performed which is shown in figure 4.7 band gap in range of 1.72 eV- 1.8 eV which is suitable for the for the device.

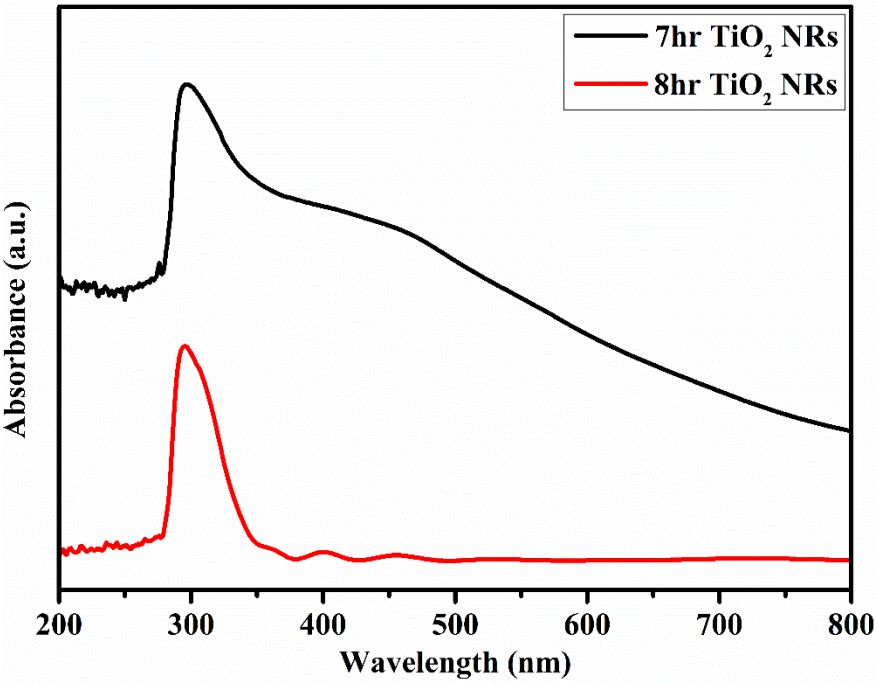

Figure 4.4 Absorbance plot of TiO_2 Nano rods grown hydrothermally at 150 °C for different reaction time of 7h and 8h.

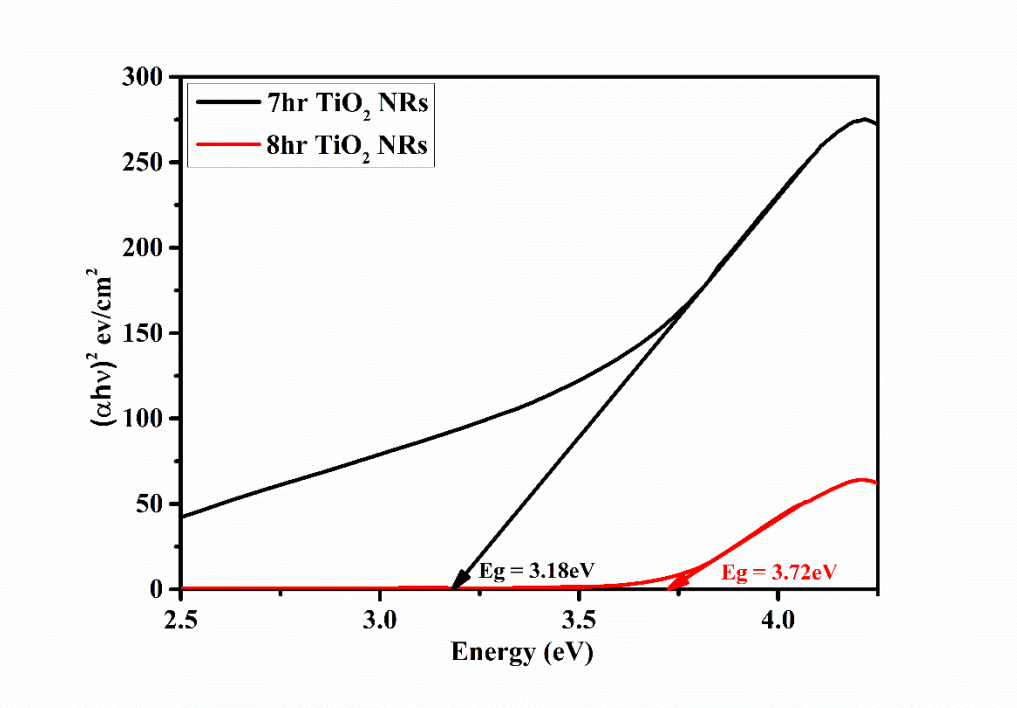

Figure 4.5 Tauc plot of TiO_2 Nano rods grown hydrothermally at 150 °C for different reaction time of 7h and 8h.

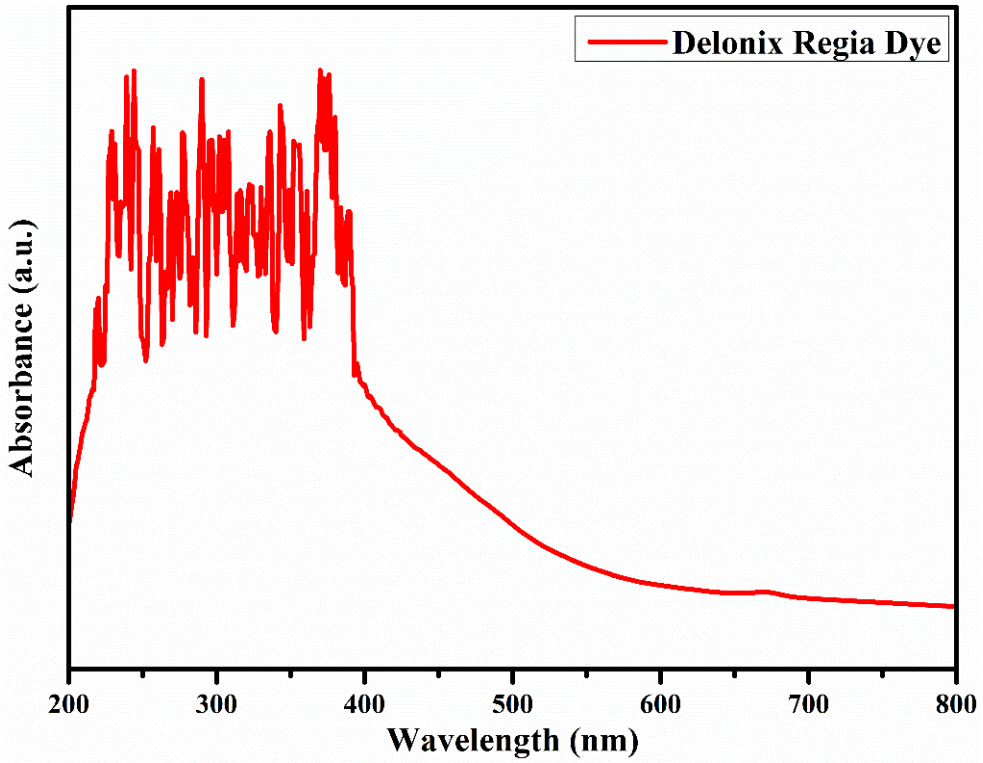

Figure 4.6 Absorbance plot of Delonix Regia Dye.

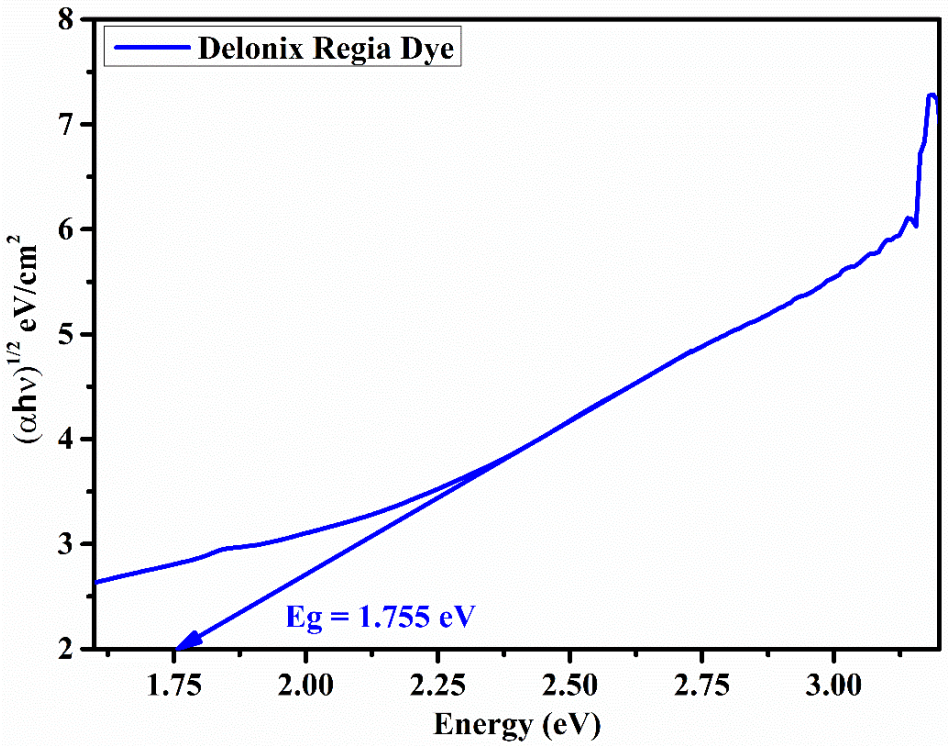

Figure 4.7 Tauc's plot of Dolenix Regia Dye.

4.1.4. Raman spectroscopy

The structural properties of produced TiO_2 Nanorods is studied by Raman spectroscopy which is shown in Figure 4.8 that is Raman spectra for Rutile phase TiO_2 Nanorods grown on Florine doped Tin Oxide (FTO) substrate by hydrothermal method. The three active Raman nodes A_{1g} + B_{1g} + E_g. provide evidence of this. It was determined that the rutile phase in produced TiO_2 Nanorods includes Raman peaks at B_{1g} (121.4 cm^{-1}), multi-photon process (245.5 cm-1), Eg (447.3 cm-1), and A_{1g} (606.0 cm-1). Raman spectroscopy is a technique for examining the structural qualities of objects**.** The symmetric bending vibration of O–Ti–O makes a severe weak peak at 120 cm^{-1} which concerns B_{1g} mode. O–Ti–O symmetric stretching vibration has caused another intense characteristic peak for the rutile TiO_2 phase, which appeared at 447 cm^{-1}**.** A broad peak at 245 cm^{-1} confirmed that the nm scale of rutile TiO_2 due to the scattering of multiple photon and the small bump peak at 695 cm^{-1} confirmed the nano flower-like structure made up of TiO_2 Nanorods. These results indicate the presence of rutile TiO_2 Nanorods and dismiss any claim for the presence of mixed-phase in line with XRD analysis

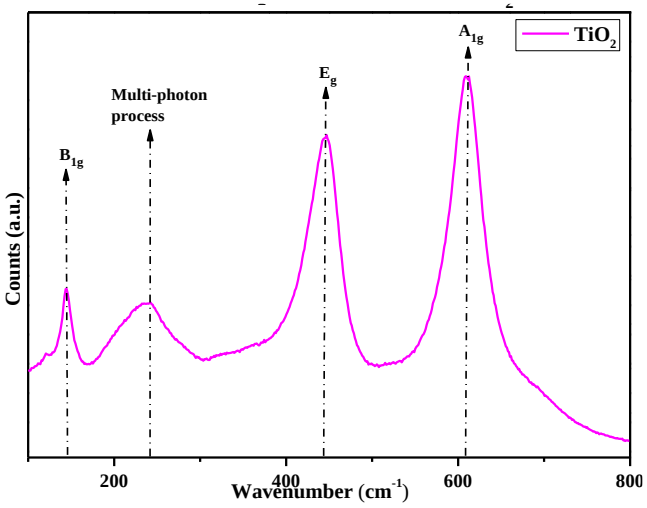

Figure 4.8 Raman spectra for Rutile phase TiO_2 Nanorods grown on Florine doped Tin Oxide (FTO) substrate by hydrothermal method.

4.1.5. Analysis of solar cell characteristic

(i) Analysis of DSSC solar cell through the *J-V* curves which are shown in figure 4.9 are fabricated by using 1D-TiO_2 Nanorods on TiO_2 compact layer coated using FTO substrate, Natural dye is prepared by using the Delonix Regia. In this work we aims to find the maximum efficiency of the Delonix Regia dye by using Nickel as counter electrode. The solar cell parameters such as Current density (J_{SC},)open-circuit voltage (*V*oc), efficiency η % and fill factor (*F.F.*), of DSSCs using Ni as the counter electrodes are given in table 2**.** The increase in DSSCs Efficiency under the illumination of 1000 W/m^2 Light can be described by two factors.

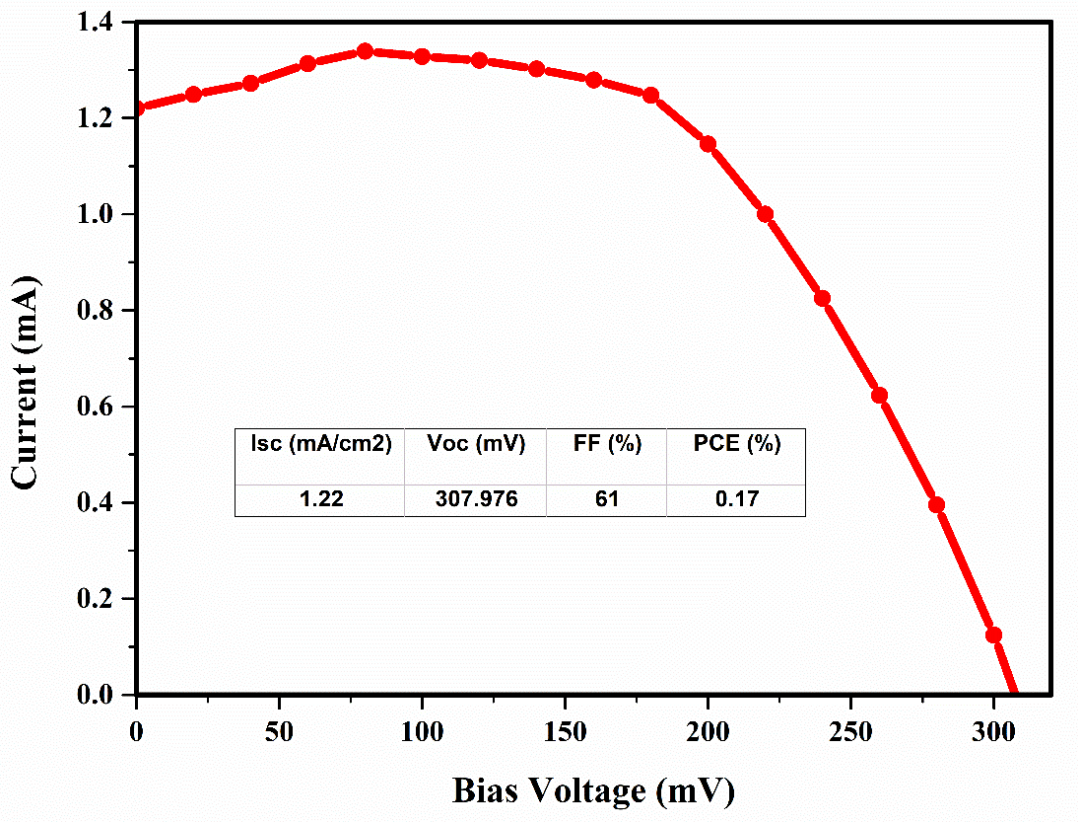

Figure 4.9 I-V curve of DSSC based on Delonix Regia dye.

Contact area increases between the FTO and compact layer of TiO_2 as a result in reduce in resistance of electron transfer which increases the collection efficiency of electron. The blocking effect of the TiO_2 compact layer also considerably decreases the FTO reaction sites.

Natural dye	**Anode**	**Cathode**	J_{sc} (mA / cm^2)	V_{oc} (V)	*FF (%)*	*η (%)*	**Ref.**
Delonix Regia	Tio_2	-	0.114	0.47	57.9	0.031	[40]
Delonix Regia	Movable TiO_2	Platinum	0.10	0.45	38	0.02	[41]
Delonix Regia	Monolithic	PANI electrode	0.11	0.56	60	0.04	[41]
Delonix Regia	TiO_2	Carbon	0.81	0.42	29	0.10	[42]
Delonix Regia + Pawpaw leaf	Nano crystalline TiO_2	platinum-coated	0.01849	0.525	52	0.0051	[43]
Delonix Regia	TiO_2 NRs	Nickel	1.35	0.2860	42.5	0.17	Present work

In summary that the highest efficiency of 0.17% achieved is in the present work, as we have used TiO_2 Nano rods as a photo anode and Nickel as counter electrode which is based on natural dye extracted from Delonix Regia.

Chapter 5

Conclusions and Scope for Future Work

In this project work, our main aim was to fabricate Dye sensitized solar cell and to get higher efficiency for that natural dye extracted from Delonix Regia. In this work dye-sensitized solar cells have successfully fabricated using dye from Delonix Regia and TiO_2 photo electrode annealed at different temperatures. Dye-sensitized solar cells (DSSCs) is suitable device to replace the traditional solar cells by using TiO_2 material, natural dye, electrolyte & counter electrode Materials these material used in DSSC are generally inexpensive, innocuous and abundant the environment. TiO_2 Nanorods were grown over fluorine-doped tin oxide substrates coated with compact layer. It is found that as the reaction time changes, length of Nanorods changes while the diameter of Nanorods is greatly influenced by concentration of precursor. X-ray diffraction (XRD), UV-Visible spectroscopy, and Field Emission Scanning Electron microscopy were performed to determine the structural, optical and morphological properties, respectively, of the one-dimensional Nanorods. XRD analysis confirmed the presence of rutile TiO_2 nanostructures and the bandgap of around 3.2-3.6 eV was obtained by UV-Vis spectroscopy. Apart from growing TiO_2 Nanorods on fluorine-doped tin oxide substrates, electrolyte is prepared by iodide in the absence of sun light to oxidized dye made from Delonix Regia and UV-Visible spectroscopy of dye is done to understand the absorbance of dye, finally, attempts have, by performing above characterization we understood the properties are fit to make device. In this work improvement of device efficiency is focused for natural dye extracted from Delonix Regia flower, by using nickel as counter electrode and Potassium Iodide, Iodine crystal, and Ethylene Glycol mixture as an electrolyte it results in the energy conversion efficiency of 0.17% maximum which is measured from solar simulator.

Future Scope

There are lots of work to be done on DSSC;

1. Improvement of efficiency
2. Only I^-/I_3^- redox couple has slow recombination kinetics
3. Liquid electrolyte is undesirable because of handling
4. During the course of the life time of fuel cell their oxidation migration affect stability.

In future the work will be carried out to address these issues

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