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Fabrication of Solar Cells by using Nano-materials and Oxide Composites

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Abstract*—. Solar Energy is eco-friendly source of energy that can easily be harnessed. ZnO based solar cells were produced. There were number of methods available for synthesis of ZnO like co-precipitation method, sol gel method and gas phase reaction method. ZnO was synthesized using co-precipitation method. It is important to mention here that ZnO particles that were deposited on the ITO slides were produced using ZnCl2 and NaOH in the presence of De Ionized Water. XRD and SEM of ZnO particles were obtained and it is noted that the ZnO sample that was produced in the lab was in good condition. XRD and SEM of thin films was also obtained and analyzed. By the help of these results we were able to know about the structure of ZnO and the phase purity of the thin film. Similarly, crystalline size of nano particles of ZnO was also calculated by applying the Debye Scherrer Formula on the results of XRD of thin films. In the end, IV characteristics of the thin films were obtained by the help of simulator in the presence of light as well as in the dark region.

***Index Terms*— Bandgap, Insolation, Irradiation, Photovoltaic, PV Module, Pyranometer , Solar Cell .**

I. INTRODUCTION

Sunlight based vitality in some frame is the well spring of almost all types of energy on earth. All life existing on earth is dependent upon sun to fulfill their requirements like food, warmth in one form or another. Biomass, wind and even hydroelectricity is derived from sun.

Solar energy can be harnessed easily by the photovoltaics. Photovoltaics is a straight forward and rich strategy for trapping the sunlight.

Solar cells convert the rays of sun following directly on earth into electricity without polluting the environment. Solar power is renewable and therefore it can be called as a “green source” or “eco-friendly”. Photovoltaics were at first exclusively utilized as a major source of power from various applications ranging from small sized applications like battery of a calculator to medium sized applications like remote homes power by a roof top arrangement providing off-grid solution.

Currently, in world the largest photovoltaic power station is established at Longyangxia Dam Solar Park in China providing about 850 MW of power in the grid. Government of Pakistan is also promoting the solar based applications for off-grid as well as on grid arrangements. The largest solar power station Govt. of Pakistan is trying to establish is of 1000 MW located in Quaid-e-Azam Solar Park in the District of Bahawalpur. As per latest reports the said solar power plant is contributing approximately 100 MW in the national grid. The total contribution of solar power in the national grid of Pakistan during the FY 2017-18 is noted as 400 MW.

Sun is producing a constant amount of energy. The intensity of solar radiations at the surface of sun is considered to be about 6.33 X 10^7 W/m^2. It is a known fact that as soon as these radiations spread out from the surface of the sun, the intensity of these radiations become less intense and when these rays reach at the Earth edge, they become parallel.

Sun rays falling on the earth are mostly absorbed or scattered by the atmosphere. It is important to mention here that almost roughly half of the radiations were lost in the outer space due to the problem of scattering and the remaining half of these radiations are directed towards the earth from all the directions as diffuse radiations. It may be noted that the shortest wavelength of radiations that reaches earth is about 0.29 µm. Following figure represents the absorbed difference wavelengths by other gas molecules.

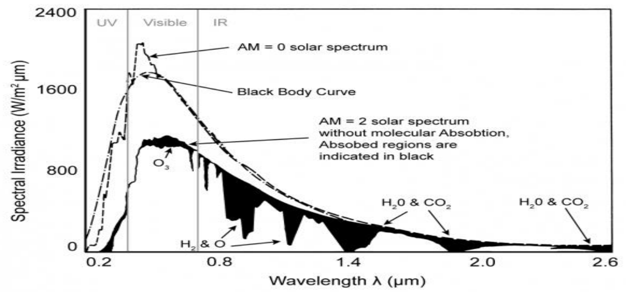

Figure 1: The extraterrestrial solar spectrum (AM = 0), the theoretical black body curve and the solar spectrum at the Earth's surface for AM = 2 and the absorbed regions shown in black. [1]

Temperature has an effect on the solar radiations reaching on the surface of earth and this is illustrated in figure 2.

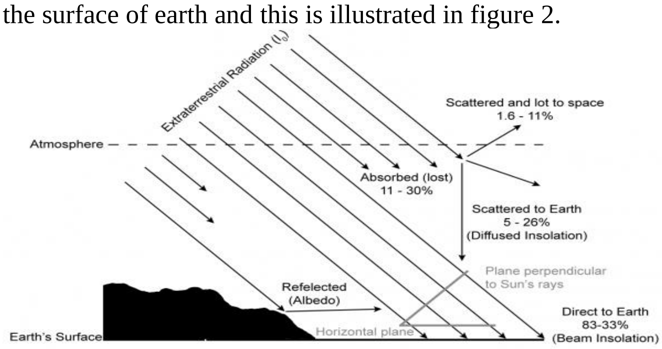

Figure 2: Effect of atmosphere on solar radiations [1]

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It is important to mention here that earth receives about 174,000 terawatts (TW) of solar rays coming from sun.There is a commonly used term "albedo of the earth atmosphere system" which defines the fraction of radiations that were reflected back to space due to clouds, scattering and reflection from earth's surface and is approximately 0.3 for the earth as a whole. It is a well proven fact that about half of the world is living in areas where insolation levels is 150-300 W/m^2. That translates into 3.5-7.0 kWh/m^2 per day.

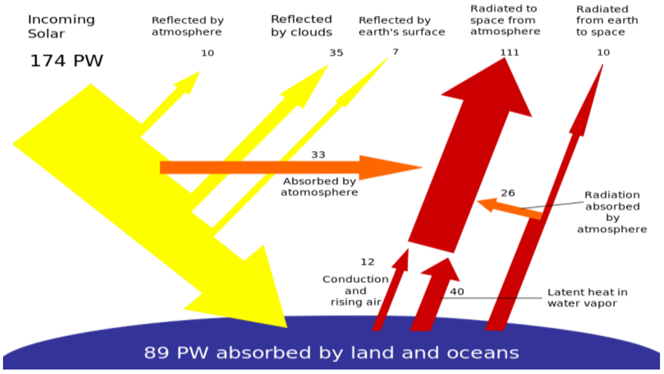

Figure 3: solar radiations reaching earth surface. [2]

Earth atmosphere, oceans and land masses absorbs approximately 3,850,000 exajoules (EJ) of solar energy per year. [3]

There are three types of radiations falling on earth i.e. Direct Radiation, Diffused Radiation and Reflected Radiation.

Direct radiations are defined as a type of radiations that are coming straight form the surface of sun and hit the plans of earth. These type of radiations are very directional.

Diffused radiations are scattered in the atmosphere and then luckily some of these scattered radiations managed to reach the plane of the earth.

Reflected radiations are beams and diffused radiations that hit the earth and then reflected back onto the plane.

In photovoltaics system design, the amount of radiations falling on solar cell plays a vital role and therefore it is essential to measure the amount of radiations available at a specific area at a particular time.

1.2 Different Methods for Solar Radiation Calculation

The two commonly adopted methods used for calculations of solar radiations falling on earth surface are Pyranometer and Reference Cell.

1.2.1 Pyranometer

A Pyranometer is a sort of actinometer utilized for measuring radiations on a planar surface and it is intended to gauge the radiations flux density. It may be noted that radiation flux density is measured on W/m^2.

Wavelength of spectrum of solar radiations falling on earth may vary in the range of 300 nm to 2800 nm.

Pyranometer can be classified into following three categories depending upon the type of technology.

I. Thermopile Pyranometer
II. Photodiode Pyranometer
III. Photovoltaic Pyranometer

➢ **Thermopile Pyranometer:**

It is basically a sensor that is based on thermopile, it is intended to quantify the broadband of sun based radiations flux density from an 180^0 field of view edge. It may measures a wide range of spectrum ranging from 300 nm to 2800 nm. They are usually mounted beside solar panels with a sensor surface on plane of panel. They are commonly used in climate change research, PV system etc.

➢ **Photodiode Pyranometer:**

It can detect the solar spectrum between 400 nm to 900 nm. It converts the said spectrum at high speed. It is composed of photodiode and a diffuser mounted in a housing dome. The current being generated by the device is directly related to irradiance. It has an output circuit that generates a voltage that is directly proportional to the generated current.

➢ **Photovoltaic Pyranometer:**

It is basically the modified form of photodiode based Pyranometer. It is in actual a photovoltaic cell working in short circuit conditions. It measures on the range of 350 nm to 1150 nm. They are commonly used in solar simulators.

1.2.2Reference Solar Cell

It is installed alongside the actual PV system for the calculations of PV measurements. It is composed of same type of material as of solar panel.

The basic unit of a solar array is a solar cell. Solar cells combine to form a solar module. Solar modules combines to form a solar panel and number of solar panels are collectively called as a solar array.

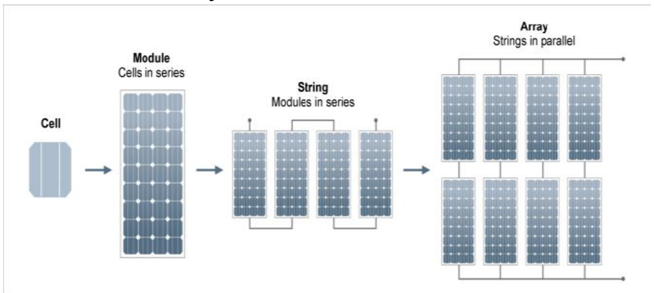

Figure 4: Solar Cell to Solar Array [4]

Solar cell basically works in response to potential difference that is created on exposure to visible radiations. Solar cells are made up of semiconductor materials based layers.

Semiconductors act as a conductor at high temperatures as at high temperature electrons break their covalent bonds and they are free to move. The minimum amount of energy required by an electron to break the bond and to participate in conduction is known as bandgap. When electron breaks this bond and moves to the conduction band, it leaves behind a space allowing a covalent bond to move from one electron to another. This left space is similar to electron but with a positive charge. Operation of solar cell is mainly dependent upon the following parameters:

i. Bandgap
ii. Number of free carriers available for conduction
iii. The "generation" and recombination of electrons and hole

When the n-type material is attached with a p-type material a PN junction is formed. It is evident that in n-type region electrons are majority carriers while hole are abundant in p-type region of a PN junction. A depletion region is formed by the movement of free carriers across the junction.

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When the junction is connected to an external load, the electrons flow through the circuit. Each solar cell generates about 1-2 watts of electricity. To increase power output cells are connected on a package to forma module and then arranged in parallel or series to from an array or string respectively.

1.3 Solar Cell Parameters:

Following solar cell parameters are kept in mind while analyzing the IV characteristics of a solar cell.

1.3.1Short Circuit Current (I_{sc}):

It is an important parameter of the solar cell. It is the amount of current generated when the applied voltage across the cell is zero.

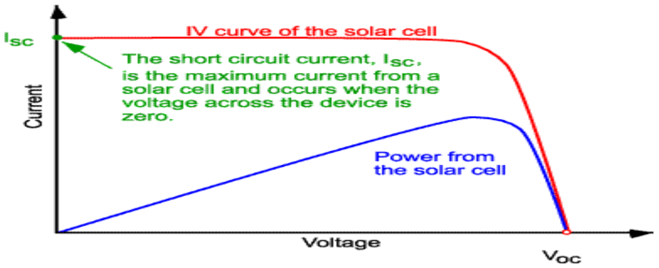

Figure 5: IV Curve of the solar cell [5]

It depends on number of factors that are listed below:

i. Area of a solar cell
ii. Incident light spectrum
iii. Absorption and reflection properties of solar cell
iv. Density
v. Number of Photons

The equation for short circuit current is

$$J_{sc} = qG\left(L_n + L_p\right)$$

Where
G = Generation Rate
L_n = Electron Diffusion Length
L_p = Hole Diffusion Length

1.3.2Open Circuit Voltage (Voc):

It is defined as the maximum voltage available at the output of a solar cell when the current is zero. The open circuit voltage can be derived by using the following equation. [6]

$$V_{oc} = \frac{nKT}{q} \ln\left(\frac{I_L}{I_O} + 1\right)$$

Where
V_{oc} = Open Circuit Voltage
I_o = Dark Saturation Current
I_L = Light Generated Current
T = Temperature

1.3.3Fill Factor:

In addition to open circuit voltage and short circuit current, the fill factor also determines the maximum amount of power from a solar cell.Mathematically it is a ratio of V_{oc} and I_{sc}.
In actual practices, the fill factor is lower due to losses that were called as parasitic resistive losses. The fill factor is determined by using the below mentioned equation. Ideally the fill factor is 1 [7].

$$FF = \frac{V_{MP} X I_{MP}}{V_{OC} X I_{SC}}$$

Where V_{MP} and I_{MP} are voltage and current at maximum power respectively. It is important to mention here that commercially available solar cells have high fill factor as > 0.70. High fill factor means that the solar cell has less series resistance and has high shunt resistance so there is less dissipation in internal losses.

1.3.4Efficiency:

It is commonly used parameter that is required in order to compare the performance of a solar cell. Efficiency of a solar cell depends upon the intensity of solar radiations and temperature of the solar cell. Terrestrial solar cells are measured in AM 1.5 conditions and at ISO temperature of 25 ^{0}C. It is basically defined as the “fraction of incident power that is being converted to electricity”. Efficiency is calculated by using following formula:

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

1.3.5Characteristic Resistance:

It may be defined as the resistance that is available at the output of the solar cell when the solar cell is at maximum power point. The solar cell is said to be operating at maximum power point when the load resistance is equal to the characteristics resistance of the solar cell. When the cell is operating at maximum power point, then maximum power is transferred to the load. [8]
It is given by the following equation.

$$R_{CH} = \frac{V_{OC}}{I_{SC}}$$

1.3.6Parasitic Resistances:

The output of the solar cell is reduced by the effect of parasitic resistances present in the circuit because of the fact that power is dissipated at these resistance. Shunt resistance and series resistance are the two common types of available parasitic resistance.

1.3.7Temperature Effect:

Temperaturehas surely an effect on solar cells like it has an impact on other semiconductor devices. The bandgap of the semiconductor material is reduced by increasing the temperature. Energy of the electron is increased by reducing the bandgap at higher temperatures. Therefore, lower energy is needed to break the bond. The impact of higher temperature on the nature of solar cell is shown in the below mentioned figure.

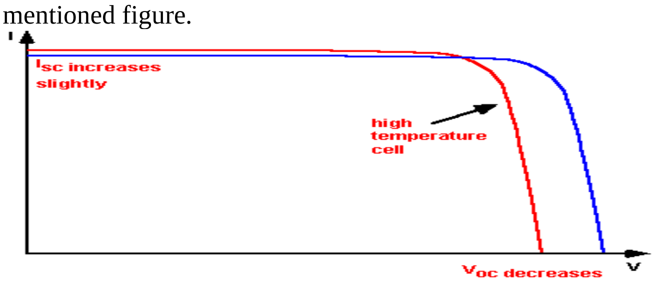

Figure 6: Effect of temperature on solar cell [9]

1.3.8 Effect of Light Intensity:

Different types of solar cell parameters like V_{OC}, I_{SC}, efficiency, fill factor, shunt and series resistance all are highly dependent on the intensity of light incident on the solar cell.

II. LITERATURE REVIEW

In the beginning of 19th century it has been observed that sunlight coming from the sun is capable of generating electrical energy. From then up till now, solar cells have been used historically when power form grid is unavailable.

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Solar cells can be characterized into following generations.

Silicon and germanium based solar cells doped with phosphorous and boron that consists of single layer PN junction are known as first generation solar cells. These cells are capable of generation of energy for different wavelengths. Diffusion method process is widely used for production of these cells. These types of cells are dominant at commercial level and used Si that has wide range of absorption and it has higher conversion efficiency. The only disadvantage of these cells is processing method that requires sophisticated techniques. Ingot that is growing of block of steel is very energetic process [10]. These cells can either be mono-crystalline or multi-crystalline.

Second generation cells are thin films solar cells. Examples of second generation solar cells is amorphous silicon cells that were formed from top metal contact to bottom as glass substrate, transparent contact, P-layer, intrinsic layer and finally N- layer.

Polycrystalline silicon solar cells have anti reflection layers to capture the light waves having wavelength several times greater than thickness of cell wand these cells are mainly composed of grain that are of 1 mm and are separated by boundaries.

Copper indium Di selenide (CIS) cells absorb almost 99% of the light before it reaches 1 micrometer of the cell. They can be homojunction as well as hetrojunction but it is noted that hetero junction cell made up of CIS along with cadmium sulphide (CdS) are found to be more stable.

It is also noted that thin film solar cells have efficiency in the range of 12-20% while for prototype this efficiency is decreased to the 7-13%.

Now-a-days, the inorganic cells are very popular and it is importantt to mention here that these cells have high cost and the main key factor for this high cost is because of high demand of energy for purification of silicon di oxide and silicon from sand.

Third generation solar cells have the advantage to overcome the Shockey – Queisser limit of 31-41% efficiency for solar cells based in single bandgap while Graetzel Cells or Dye sensitized solar cells have efficiency of about 11%.

Nano crystal substrate are used for formation of nano crystal solar cells. The commonly used method for coating of thin films on anon substrate is spin coating. Other techniques that were being used for the same purpose are dip coating and doctor blading etc.

Fourth generation solar cells are flexible solar cells composed of polymers and larger molecules whose structure is repeating. Their bandgap is less than or equal to 2eV and having conversion efficiency of about 5%. Plastic solar cells are also a type of polymer solar cells.They comprises of a layer that is either electron or hole blocking and that layer is placed over the layer of ITO conductive glass and that is followed by the electron donor or electron acceptor.

It is important to mention here that fourth generation solar cells are basically organic – inorganic cells.

In 1839 Edmond Becquerel, a French scientist observed a strange behavior of electrolytic cell that was made up of two metal electrodes placed in electrolytic solution. He observed photovoltaic effect and this effect increases in the presence of sunlight. In 1883, an American scientist first described the solar cell made up of selenium wafers[11].

In 1954, Daryl Chapin, Calvin Fuller and Gerald Pearson working in Bell Labs succeeded in developing the first ever silicon based solar cell that is capable of converting solar radiations into electricity and that electricity can be used for different applications. The solar cells developed at Bells Labs achieved the efficiency of 4% initially. Solar cells developed at Bell Labs have achieved efficiency of 11%. [12].

In 1959, after lot of efforts Hoffman Electronics succeeded in achieving 10% efficiency in PV at commercial level. In addition to this Hoffman also learnt the way to use a grid contact and how to reduce the series resistance effectively. Later on in 1960, they achieved the efficiency of 14%.

In the year of 1964, NASA launched its NIMBUS Spacecraft, the first satellite powered by 740 watt photovoltaic array [13].

In 1982, the world-wide production of PV exceeds 9.3 MW and in 1983 it reaches at 21.3 MW.

The first cell to attain the conversion efficiency of 30% was developed by National Renewable Research Laboratory in 199 [14].

During the recent years, due to rising concerns about the environment and shortage of petroleum, photovoltaic technology has become one of the most chased renewable technology. In current era, silicon based crystalline solar cells rule the PV market because of their non-toxic and abundant nature. It is important to mention here that silicon based PV cells have already achieved their peak in efficiency in conversion and it is difficult to improve much more [15].

Cu_2O can be used as a material for terrestrial applications based solar cells. B.P Rai [16] has made solar cell using Cu_2O as the top cell in cascade cell structure. He noted that starting materials have high resistances. Although the solution has been developed to some extent by preparing Cu_2O by thermal oxidation. The poor performance of electrodeposited Cu_2O cells still remains.

Copper oxide is also another widely studied and used semiconductor material in photovoltaic applications due to their abundance in nature and because of their explicit optical properties. It may be noted that optical and insulating properties from insulating nature to conduction nature cane be tuned by use of these materials.

Different types of oxides can be used for fabricating n-type layer of suitable bandgap on nano materials. The major advantage of depositing oxides over nano materials is that oxides do not react with nano materials. Cadmium oxide (CdO), Zinc Oxide (ZnO), Indium Oxide (In_2O_3) and many others can be used for this purpose.

One way to improve the efficiency of the solar cell is the use of hetrojunction solar cell instead of homojunction solar cells. Olsen et al [17] mentioned that the lower efficiencies of Cu_2O and Cu solar cell is mainly due to potential barriers and the same can be improved by the use of hetero junction cell structure.

ZnO can also be used as a semiconductor material for solar cells as it exhibit both semiconducting and piezoelectric properties. A number of researchers have done research on being using ZnO as a semiconductor material in solar cells and tries to improve the conversion efficiency. In this regard, S.Tanemura, L.Mao, F.Y Ran S.P Lau [18] have used ZnO and suggested that the ZnO is attracting material for applications to UV.

Emitters and for gas sensing applications also.
While L Loh, J. Briscoe and S Dunn [19] described the disadvantage of using the ZnO as it has poor stability and can be prone to corrosion effects.
J. Katayama, K. ITO, M. Matsuoka and J. Tamaki [used electrodeposition method (i.e. a two-step approach for fabrication of solar cells) for fabrication of Cu2O/ZnO with improved performance. The fabricated solar cell has fill factor of about 0.295, an open circuit voltage of 0.19 V while the short circuit photocurrent density of 2.08 mA and efficiency of 0.117%. Here it is evident that for practical/terrestrial applications this efficiency is inadequate. These researchers have also mentioned the reasons for this poor conversion efficiency as defects that were being induced by the mismatch at heterojunction and the efficiency can be improved be eliminating this effect [20]. A number of copper oxide based devices have been prepared and were reported in literature and these devices were often prepared by using low cost and solution based methods [21]. Ohashi derived a way to synthesize a β -CuGaO2 semiconductor material. It may be noted that β -CuGaO2has a narrow band gap of 1.47 eV. This bandgap requires energy to attain maximum efficiency. He prepared a device using β -CuGaO2 as a p-type material and ZnO as a n-type material. This new material because of its properties is a good light absorber and can be easily used in thin film solar cells [22].
A well-established PV technology is thin film silicon based solar cells. It is relatively simple and cost effective process [23]. The main advantage is that it has low temperature coefficient [24-25].Most recently achieved efficiency of thin film silicon based solar cells is 12% and for commercial scale it is 10.3%. Olinda Isabella [26] in his paper presented a scenario in which he uses thin film silicon based quadruple junction solar cell and he succeeded in achieving 8.7 m/cm^2current density and 19.8% efficiency.It may be noted that nano materials are being used in order to reduce the cost and size and thereby improving the efficiency of PV cell [27]. A number of options have been worked out in order to enhance the efficiency for increasing PV devices optical absorption. Sunlight plays a vital role in excitation of surface plasmon resonance that leads to scattering. In this phenomenon, light is tapped and due to strong electromagnetic field, the dye absorption process strengthen [28].

III. MATERIALS AND METHODOLOGY

In this chapter, we will discuss the materials and methods that have been used for fabrication of solar cell and also the calculations that have been used for calculating the amount of materials.

3.1 Materials:

3.1.1Zinc Oxide (ZnO)

Zinc oxide has been used by me as a semiconductor material for the fabrication of the solar cell along with other materials. It is an inorganic material and it can be found in the form of white powder that can be extracted by the reaction of different chemical materials. It is basically a semiconductor that lies in the II-VI semiconductor group. It is known because of its several properties like good transparency, wider bandgap etc. These kind of properties made it as a good option to be used for fabrication of PV devices.

3.1.2Structure:

Naturally it occurs rarely in the form of Zincite. In addition to powder form it occurs also in crystalline form in the form of nano particles. In crystalline shape it occurs either as Hexagonal Wurtzite or as cubic zinc blend. While comparing these two available crystalline shapes of ZnO, the former one is more stable form at ordinary conditions i.e. room temperature [29]. It is important to note that ZnO will be converted to rock salt motif at relatively higher pressures in the range of 10 GPa [30]. Both of the crystalline forms have no reflection symmetry. It is important to note that piezoelectricity of both crystalline polymorphs and pyro electricity of hexagonal structure is mainly due to this and other symmetry [31]. It is worth mentioning here that the hexagonal structure of ZnO has a 6 mm point group.
These structures are shown in figure 7 and 8 below:

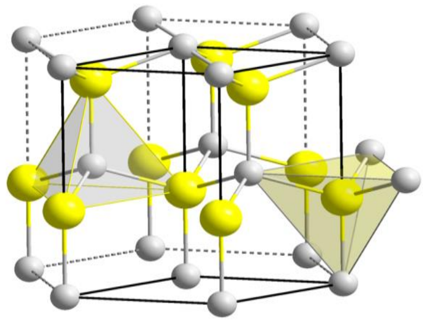

Figure 7: Hexagonal Structure (Hexagonal Wurtzite ZnO) [32]

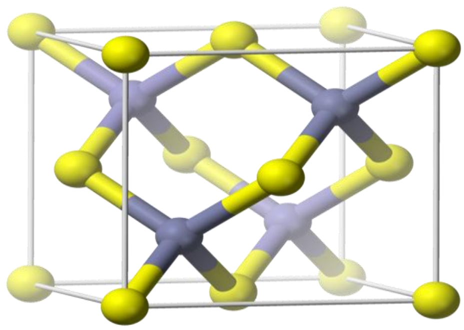

Figure 8: Zinc Blend Structure ZnO [32]

3.1.3Band gap Structure:

Bandgap of a semiconductor is the important parameter for selection of the material. It is basically defined as the difference between the valence band and the conduction band of the material. It may be noted that it is dependent on the temperature as the temperature of the material increases, it decreases. Therefore, it is suggested that for higher temperature operations, materials with higher band gap energy may be used. Zinc Oxide (ZnO) is an example of materials having wider bandgap having a direct band gap of approximately 3.3 eV at normal temperature. Wider band gap of ZnO makes it suitable for tolerating larger electric field and allow higher breakdowns [33].

3.1.4Mechanical Properties:

The hardness of ZnO is about 4.5 mohs that makes it relatively softer material [34]. Among the semiconductor materials that have been tetrahedrally bonded, it is noted that either ZnO has highest piezoelectric effect or at least comparable with other semiconductor materials of same nature like GaN, AIN [35]. ZnO has the lifetime as high as 133 ps at 10 K [36].

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3.1.5 Optical Properties:

Nano-particles of zinc oxide are transparent to the visible spectrum of solar radiations. When ultra violet spectrum of light falls on the ZnO material it absorbs almost all part of the UV light and it act as a transparent medium allowing the visible light to pass through it [37].

3.1.6 Electrical properties:

ZnO can be used as n type material for PV devices. It may be noted that it can be doped with group III elements of the periodic table or replacing oxygen with group VII elements fir controllable n-type doping.

For ZnO, P-type doping is challenging. The main problem is because of p-type dopants low solubility and it is important to mention here that they have n-type impurities.

The maximum achievable electron mobility of ZnO is 2000 $cm^2/$ (V.S) at temperature of about 80K and it varies as the temperature of the environment varies [38].

3.2 Synthesis of Zinc Oxide (ZnO):

As mentioned earlier ZnO is not available naturally as white powder rather it can be prepared by chemical reaction of different materials. There are number of method available for synthesis of ZnO like co precipitation method, sol gel method and gas phase reaction method. It may be noted that I have used the co-precipitation method for synthesis of ZnO by keeping in view the controllable factors that affect the synthesis. These factors are PH value, reaction duration, temperature and pre cursors.

Following formulas have been used for calculation in order to achieve the 1M solution of $ZnCl_2$ and 1M NaOH solution.

$$No.of Moles = \frac{Molarity X Volume in cm^3}{1000}$$

ZnO is prepared by the reaction of 1M $ZnCl_2$and 1M NaOH in the presence of di-ionized water. A number of samples have been prepared by varying the amounts of $ZnCl_2$ and NaOH. It may be noted that for preparation of 1M $ZnCl_2$ about 0.136 g/ml of the is used and for 1M NaOH solution the amount of NaOH used is calculated to be as 0.04 g/mol. 10 ml of 1M $ZnCl_2$is added in 10 ml of DI water and the solution is heated till 70ºC and kept at the same temperature for at least 5 minutes. After that the solution was examined to check whether the precipitates were formed or not. If precipitates were formed then we stop the reaction but in case there were no precipitates, then 5 ml of 1M NaOH have to be added in the same solution and then solution was checked for precipitates. If yes then we stop the reaction otherwise add another 5 ml of 1M NaOH in the same solution. It is important to mention here that solution is being heated all the time. The process of adding is repeated till the formation of precipitates. In our case precipitates have been achieved after 2 iterations i.e. by addition of 10 ml of 1M NaOH. The process of heating the solution can either be performed on hot plate or on hot tub equipment.

Figure 9: Synthesis of ZnO

The colloidal solution that we were trying to obtain is now ready and is shown in below mentioned figure.

Figure 10: Colloidal Solution of ZnO

After the formation of precipitates, the colloidal solution of ZnO is placed in a centrifuge machine (PLC Series) to separate the particles from the excessive species that were left un reacted in the solution. The solution from beaker is shifted in the tubes and then these tubes were placed in the centrifuge machine and the tubes containing these solution were centrifuged at a speed of approximately 1500 rpm for the time of 10 minutes. This process is repeated for three times and the solution was washed for three times at least.

Figure 11: Centrifuge Equipment

Now after the centrifuge, the particles of ZnO were achieved but they were wet. These wet particles were dried in the furnace. The temperature of the furnace was set at 450-500 ºC and the particles were let there in the furnace to dry overnight.

3.3 Dye:

During fabrication of dye based solar cells, immersion of thin film slide in dye is one of the important step as it results in increase of conversion efficiency.

3.4 Electrolyte:

Another step is incorporation of electrolyte in thin film solar cells to fill up the gaps between the nano particles deposited on active electrode and on counter electrode.

3.5 ITO:

Indium tin oxide or Fluorine tin oxide may be used as conductive glass slide to complete the circuit as well as to collect the charges. It is basically a low resistive glass slide that can be used for charge collection. It may also be called as a Transparent Conducting Oxide (TCO).

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3.6 Methodology:

3.6.1Thin Film Formation:
Following steps have been performed while preparing thin film formation. The detailed description of each step is mentioned below.

3.6.2Cleaning of ITO:
ITO is basically the glass slides on which we have to deposit the active material. As it is very sensitive process therefore it is required to clean the ITO slides so that there may be no impurity that later on affects the efficiency of the device. Following steps have been performed for cleaning of slides.

3.6.3Cleaning with Detergent:
Glass slides of desired dimensions were cut and were cleaned with detergent. The detergent is used to remove the stains from the slides along with the finger prints and dust particles that were left while handling the slides. After cleaning with detergent the slides were sonicated for approximately 10 minutes.

3.6.4Cleaning with Tap Water:
After the cleaning of ITO pieces with detergent, these pieces were cleaned under tap water and afterwards these pieces were again sonicated for another 10 minutes.

3.6.5Cleaning with Acetone:
Organic compounds that were present on the slides were removed by the Acetone that is a volatile chemical.

3.6.6Cleaning with IPA:
After performing these series of cleaning processes of ITO slides, finally these slides were immersed in IPA (Isopropyl Alcohol) for almost 12 hours. This removes all the remaining impurities. Now these slides were dried at room temperature.

3.6.7Dense Layer and porous Film Formation:
The dense layer or otherwise called compact layer was formed by using MeOH. For ZnO, the nano particles that were obtained after drying the solution obtained from centrifuge was suspended in vinegar at a concentration of 0.1mg/ 2ml.

Now that material was pasted onto the low resistive ITO slide via doctor balding method and the same ITO slide was kept in the furnace to a high temperature of about 450 OC. The slides were masked from the sides for attaching it with back electrode at later on stages. Afterwards, these slides were cooled at the room temperature and this whole process may took 16-24 hours.

3.6.8Dye Incorporation:
These ITO slides were incubated in the dye for almost 24-48 hours because of the fact that by immersing in dye the porous gaps between the active materials that were being deposited on the slides were filled. The dye being used for incubation of thin film slides was Methylene Blue.

3.6.9Formation of Back Electrode:
Now, it is the time for preparation of back electrode, the cathode. It is important to mention here that cathode may be carbon coated so it may collect electrons emitted from dye incorporated ZnO non porous film.

The back electrode may be coated carbon by using graphite, lead pencil or by the flame of candle. I coated the back electrode by using the flame of the candle. It is pertinent to mention here that carbon coating was done on the conductive side of the ITO slide and that side was checked by using multimeter.

3.6.10 Electrolyte Injection and Joining of Electrodes:
Both the electrodes, one with active ZnO material with dye and the other with carbon coated were joined tightly by the help of paper clips. Before testing IV characteristics, one or two drops of the electrolyte were also injected between the two electrodes.

3.7 Characterization Methods:

Different characterization techniques were used including X-ray diffraction, Scanning Electron Microscopy and IV Characteristics for the characterization of ZnO based dye sensitized solar cell.

3.7.1X-Ray Diffraction (XRD):
X-ray diffraction is the characterization technique. It is in actual an analytical technique being used for phase identification. It also helps in guessing cell dimensions.

Cathode ray tube is the major source of creation of these X-ray radiations and then these are filtered to produce monochromatic rays.

X-rays hits the sample and constructive interference is produced which has to satisfy the below mentioned condition of "Braggs Law".

$$\eta\tau = 2d \sin\theta$$

By using this technique, we are able to find size, structure and thickness of atoms present in test compound.

3.7.2Scanning Electron Microscopy (SEM):

It is a type of electron microscope that uses beam of electrons to produce image sample. Sample's surface and composition can easily be found by using this technique. A resolution better than 1 nm can be obtained by SEM.

An electron beam falls on the sample under study and produces 3D magnified image. It tells about the surface morphology. There are two types of signals originating from SEM i.e. secondary electrons and back scattered electrons. It uses a narrow electron beam therefore micrographs obtained have large field depth.

In typical equipment, a beam of electron is emitted from gun fitted in cathode. Cathode is made up of tungsten filament because of its properties like higher melting point.

The energy range of beam may vary from 0.2 keV to 40 keV. The optic used for focusing can be large and coarse. While SE detectors is of quite small size i.e. size of the fist and simple detects current. The obtained resolution depends upon instrument and it can be in the range between less than 1 nm and 20 nm.

3.7.3IV Characterization:

The testing of solar cell in order to find out its conversion efficiency is basically known as IV characterization of the solar cell. The IV characterization can be done either in outdoor conditions in which solar cell is exposed to sun light and solar radiations directly fall on the subject solar cell and we measure the reading by the use of multimeter or in indoor conditions in which sample solar cell is exposed to the sun simulator and accordingly readings of the current and voltage are measured. Outdoor measurement method tells us the actual efficiency of the solar cell.

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IV. RESULTS AND DISCUSSIONS

In this section, results obtained by applying different characterization techniques on our sample will be discussed. X-Ray Diffraction, Scan Electron Microscopy and IV characteristics of our sample has been done and in this chapter their results will be shared.

4.1. XRD of ZnO Particles:

Following figure shows the XRD of ZnO particles.

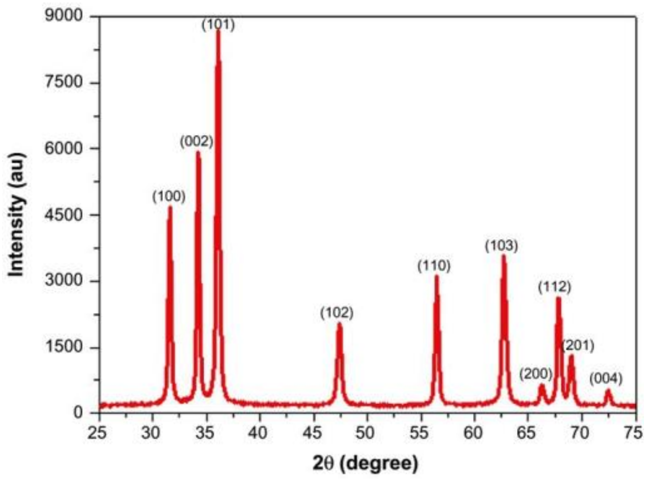

Figure 12: XRD of ZnO Nano-Particles

ZnO particles were obtained earlier using co-precipitation method. The phase purity of the obtained particles were checked by using the below mentioned formula:

$$PhasePurity = \frac{MatchedpeakIntensity}{TotalIntensity} X\ 100$$

The result obtained shows that our ZnO particles were 100% phase pure.
All the indexed peaks obtained in the XRD of the sample were exactly the same as of reference card peaks and were matched accordingly this also shows that our sample is phase pure.
The crystalline size of nano particles of ZnO can be calculated by Debye Scherrer Formulae.

$$D = \frac{0.9\ \tau}{\beta \cos\theta}$$

It may be noted that figure of 0.9 mentioned in the above mentioned equation is Machine Constant and τ is defined as the wavelength and its value is taken as 1.54 Å while β is the Full Width Half Maxima (FWHM) and its value comes out to be as 0.3561by using origin software. By using all these values, the size of particles comes out to be 13 nm.

4.2 SEM of ZnO Particles:

Following figure represents the SEM of the sample i.e. ZnO particles. It shows star like behavior.

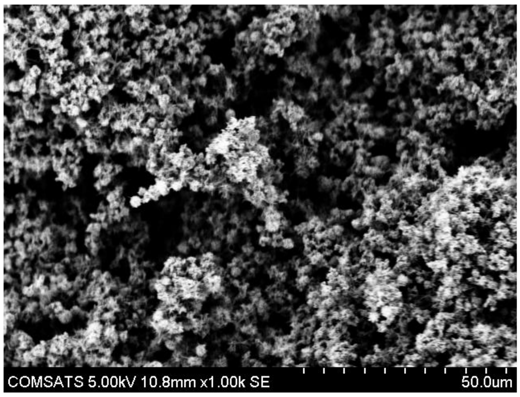

Figure 13: SEM of ZnO Nano-Particles

4.3 XRD of ZnO Thin Film:

Following figure represents the results of peaks obtained after the XRD of thin film of Zn.

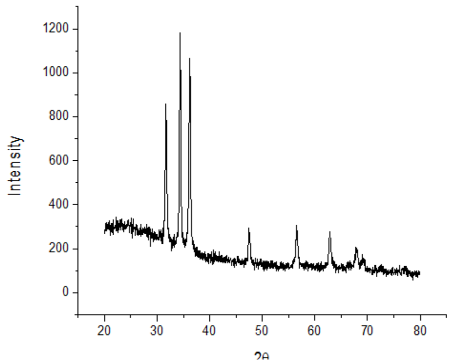

Figure 14: XRD of ZnO Thin Film

4.4 SEM of ZnO Thin Film:

The figure shown below is the SEM result of ZnO thin film:

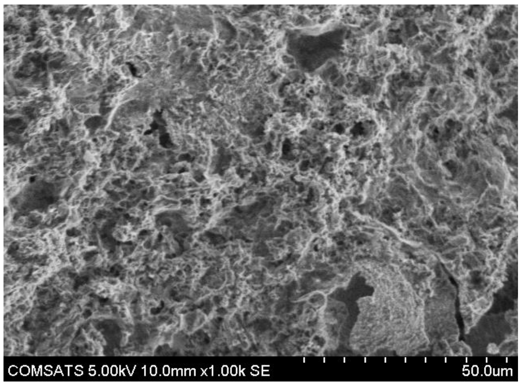

Figure 15: SEM of ZnO Thin Film

4.5 IV Characteristics:

IV characterization is one of the important test to check the conversion efficiency of the device. It is evident from the graphs obtained through simulator that the tested device is short. It seems that current followed a least resistive path through the ZnO layer to the substrate instead of electrons hopping through the electrolyte and holes passing on via ZnO to the respective electrodes.

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The IV curve obtained after performing the results shows a type of linear graph in both dark and in light region.

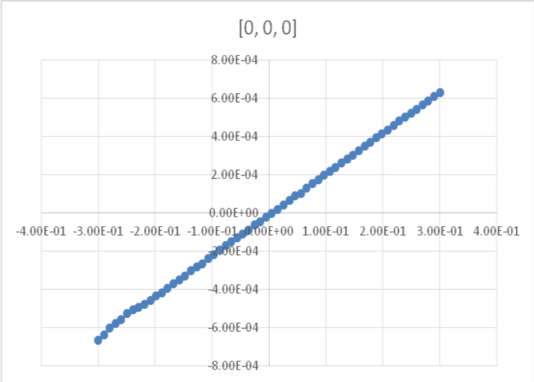

Figure 16: IV Characteristics in Dark region

The results for lighter region are shown below:

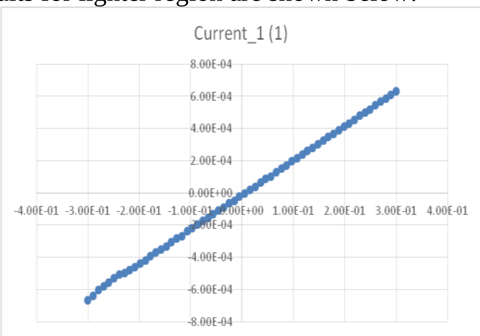

Figure 17: IV Characteristic Curve in Light Region

There seems to be a number of reasons that caused the device to be short circuit. The compact layer form via spin coating might have some leakage point that gave way to electrolyte to reach the ITO slide. ZnO adhesion to the surface of ITO film may be inadequate. The incubation/sensitization time of substrate in the dye solution was prolonged due to unavailability of the sun simulator.

It is noted that the electrolyte helps in transportation of electrons while ZnO helps in the transportation of holes in the substrate. In our device, the electrolyte is already intact with substrate that's why we did not achieve the profile as of ideal case as shown in the following figure.

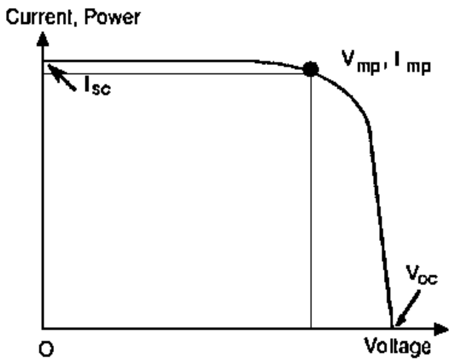

Figure 18: IV Characteristics curve of an ideal solar cell

4.6 Future Work:

For the future outlook it is suggested that fabrication of ZnO matrix using doctor's blading method to form porous matrix may be done.

Protocols should be established that can overcome energy losses as well as help in system optimization.

Device stability should be checked over a period of time to observe energy losses that may occur because of oxidation of dyes or due to any other factors.

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