Multi-layer Coating of 6% Co Doped SiO_2 Nanoparticles to Enhance Light Absorption by Silicon Solar Cells

by:

Kamal Mustafa
(227-FBAS/MSPHY/F13)

Supervisor:

Dr. Imran Murtaza
Assistant Professor
Department of Physics, FBAS, IIUI

Co-Supervisor:

Mr. Qazi Ahkam
Lecturer Department of Physics, FBAS, IIUI

Department of Physics
Faculty of Basic and Applied Sciences
International Islamic University, Islamabad

(2017)

Multi-layer Coating of 6% Co Doped SiO_2 Nanoparticles to Enhance Light Absorption by Silicon Solar Cells

by:

Kamal Mustafa

(227-FBAS/MSPHY/F13)

This Thesis is submitted to Department of Physics International Islamic University, Islamabad for the award of MS Physics Degree

CHAIRMAN DEPT. OF PHYSICS International Islamic University Islamabad

Chairman, Department of Physics
International Islamic University, Islamabad

M. Arshad 31-1-18

Dean Faculty of Basic and Applied Science
International Islamic University, Islamabad

Department of Physics
Faculty of Basic and Applied Sciences
International Islamic University, Islamabad

Final Approval

It is certified that the work printed in this thesis entitled **"Multi-layer Coating of 6% Co Doped SiO_2 Nanoparticles to Enhance Light Absorption by Silicon Solar Cells"** by **Kamal Mustafa,** registration No.227-FBAS/ MSPHY/ F13 is of sufficient standard in scope and quality for award of degree of MS Physics from Department of Physics, International Islamic University, Islamabad, Pakistan

Viva Voce Committee

Chairman (Physics)________________________________

Supervisor_____________________________________

Co-Super visor__________________________________

External Examiner _______________________________

Internal Examiner________________________________

بسم الله الرحمن الرحيم

DEDICATED

to

My beloved

Mother

Father

&

My

Respected Teachers

Declaration

I **Kamal Mustafa** (Registration # 227-FBAS/MSPHY/F13), student of MS in Physics (session 2013-2017), hereby declare that the subject printed in the thesis titled " Multi-layer Coating of 6% Co Doped SiO_2 Nanoparticles to Enhance Light Absorption by Silicon Solar Cells'' is my own work and has not been published or submitted as research work or thesis in any form in any other university or institute in Pakistan or aboard.

Kamal Mustafa
(227-FBAS/MSPHY/F-13)

Dated;

FORWARDING SHEET BY RESEARCH SUPERVISOR

The thesis entitled **"Multi-layer Coating of 6% Co Doped SiO_2 Nanoparticles to Enhance Light Absorption by Silicon Solar Cells"** submitted by ***Kamal Mustafa*** in partial fulfillment of M.S. degree in Physics has been completed under my guidance and supervision. I am satisfied with the quality of student's research work and allow him to submit this thesis for further process to graduate with Master of Science degree from Department of Physics, as per IIU rules and regulations.

Dated: 01 Nov, 2017

Dr. Imran Murtaza,
Assistant Professor (IIUI)
Department of Physics,
International Islamic
University,Islamabad.

ACKNOWLEDGMENT

First, I owe my deepest gratitude to **Allah** Almighty for all his countless blessings. I offer my humblest words of thanks to HIS most noble messenger **Hazrat Muhammad (P.B.U.H),** who is forever, a torch of guidance and knowledge for all humanity. By virtue of his blessings today I am able to carry out our research work and present it.

I would like to acknowledge the worth mentioning supervision of **Dr. Imran Murtaza** who guided me and supported me during my whole research work. I am also thankful to **Mr. Qazi Ahkam** who helped and guided me to complete my research work in time. Moreover, under their supervision from the preliminary to the concluding level enabled me to develop an understanding of the field. Their wide and deep knowledge have been a great value for me. Frankly speaking without effort of **Dr. Imran Murtaza** and **Mr. Qazi Ahkam** it was impossible to complete this hard task of my life. **Dr. Imran Murtaza** is always an inspiring personality for me in all fields specially education. He always enlightened me and guided me at each and every step of my MS. Without his guidance, it was not possible for me to complete my MS. Almighty **Allah** blessed them in every part of life.

Moreover, I would like to express my sincere thanks to all the faculty members of Department of SCME NUST Islamabad especially to **Dr. Amir Habib**. I would also like to thank all other faculty members of my university for their sincere appreciation, comments and suggestions. I express my thanks to all staff of Physics Department, IIUI, for their various services. It will be un-justice if I do not mention co-operation of my senior Sibt-Ul-Hassan in this regard. I also pay special thanks to **Incharge Lab. IST** and **Dr.Yaqoob (NCP)** for SEM characterization and UV-VISISBLE characterization in time.

Kamal Mustafa

Table of Contents

List of Tables

List of Figures

Abstract

In this study, 6% Co doped SiO_2 nanoparticles are used for the coating of Si substrate and purpose of this study is to enhance the efficiency of silicon solar cell with the help of suppression of light reflection from the surface of Si solar cells. This study presents comparison of coated silicon substrate with 6% Co doped SiO_2 nanoparticles and uncoated silicon substrate of silicon solar cells to check the reflection percentage at the surface of silicon solar cells. To analyze the results and morphology of the substrate, scanning electron microscopy, x-ray diffraction and UV spectroscopy techniques are used. Light reflection is reduced or in other words light absorption increases because of the 6% Co doped SiO_2 nanoparticles coating on the substrate whereas uncoated substrates produce high reflection or low absorption of light radiation at the surface of silicon solar cells. The results obtained from SEM images show that the prepared sample consists of spherical particles. High intensity peaks in the x-ray diffraction pattern of the coated substrates indicate great improvement in the material's crystallinity. UV-Visible Spectroscopy results show that the reflectance of the samples prepared at a spin coating speed of 4000 rpm is much less than that of the uncoated substrates at 271 nm wavelength in NIR and UV regions. In short, the coating of 6% Co doped SiO_2 nanoparticles enhances the absorption of light radiation at the surface of Si solar cells.

Chapter: 1

Back Ground Physics

Introduction

1.1 Nanomaterials and Nanotechnology

In recent years, nanoscale materials have received great interest due to their wide technological applications. A nanomaterial is defined as the material having dimension below 100 nm. Current research activities in the area of nanoscience and nanotechnology have been driven by their vast application [1]. Nanomaterials and nanostructures often exhibit untypical physical and chemical properties that are far more superior from those at a larger or bulk scale. If these novel features can be suitably exploited, the usefulness of the materials and devices can be greatly enhanced. It is where nanotechnology comes into play.

Nanostructured materials have applications in different fields such as chemistry, medicine, biology, and material science [2]. Among all nanomaterials magnetic materials have found more attention because on nanometre scale these magnetic materials show unique properties. For example below a certain critical size magnetic nanoparticles acquire single-domain structure different from the multi-domain structure of their bulk counterparts. These magnetic particles are present in both naturally occurring and manufactured forms. These have a wide range of applications in different fields e.g., magnetic recording media, medicine, ferrofluids, magnetic imaging etc [3].

Our environment is undergoing huge smash-up due to urbanization and industrialization because of large amount of dangerous additives such as super numeracy chemicals, unwanted substances. Therefore, it indeed is our moral requirement to point out the mysteries that are existed in nature. Because of its unique properties, Nanotechnology uses are very much necessary for biological molecules. For the synthesis of metal nanoparticles the biological molecules experience greatly skillful assembly for creating them appropriate which was found to be safe and sound for ecological entities. Thus synthesis of metal and semiconductor nanoparticles is an attractive for the research in this direction. In the present field of material science, the arena of nanotechnology is one of the imminent regions of research. New functions of nanomaterials and nanoparticles are developing rapidly in numerous disciplines [3]. Transition metal oxide nanoparticles need a high fraction of surface atoms and a definite surface area. The scientists are taking interest in nanoparticles because of the new methods of synthesis and because of their unique physical and chemical characteristics of nanoparticles, as well as optical properties, electronic properties, antibacterial properties, magnetic properties and catalytic activity [4]. Nanomaterials of great scientific interest are efficiently a bridge between bulk materials and atomic or moleculer structures. Sometimes unexpected properties of nanoparticles are therefore in principle due to the large surface area, which dominates the assistance made by the small bulk of the materials. SiO_2 nanoparticles have been found remarkable applications in the fields of high sensitivity bimolecular detections, solar cell applications, diagnostic, catalysis, and microelectronics [5].

Introduction to Nanoparticles

1.1.1 Nanoparticles

Particles having one dimension that measures 100 nanometer or less are called nanoparticles. Many conventional materials change their properties when they are formed from nanoparticles. Nanoparticles have greater surface area per weight than large particles so that they become more reactive to some other molecules. They are produced by processes which can be physical, biological or chemical. Many Commercial products in daily use are produced by nanoscale materials. Variety of products using nanoparticles has been developed by researchers.

- MRI images can be improved when nanoparticles are magnetized and they are used for storage media to enhance its density.
- Heat transfer in storage tank through solar energy collector can be improved by nanoparticles and coolant system used by transformers can also be enhanced.
- Better wear and tear for any device can be provided by nanoparticles. These can also produce unseen anti-corrosion abilities in these devices and new composites and structural materials could be produced by these that are lighter and stronger.
- Electronic displays can be created which are cheap ,efficient and colored.

- Long lasting batteries having high energy density can be made. They can improve efficiency of solar panel and also engines.
- "Quantum dots" produced by Nanoparticles can detect disease and alter nutrient content.
- Water pollutants at industrial level can be cleaned by Nanoparticles. Clean drinking water can be provided through filtration by developing nanostructured filters by which virus cells in water can be removed.

1.2 Types of Nanoparticles

1.2.1 Metallic nanoparticles & Inter metallic nanoparticles

Metallic nanoparticles have very useful catalytic properties they are therefore used in many industrial applications [6]. They also have unusual optical properties as they show enhancement in the scattering of light. Nanoparticles of ferromagnetic metals are widely used in magnetic recording industry.

1.2.2 Metal oxide nanoparticles

Metal oxides nanoparticles have several applications in chemical, physical and materials sciences. A wide variety of oxide compounds are made by oxidizing metalic elements [7]. Oxide compounds can form large number of structural geometries with an electronic structure that results in different characters (metal, semiconductor, and insulator). Oxides are used in different technological applications. They can be synthesized by developing new techniques. Metal oxides play important role for fabrication of different devices such as fuel cells, electronic circuits, sensors and catalysts. Many delicate metal oxides structures can be synthesized on nanoscale. Many products, whose worth is billion dollars, are being produced through processes using metal oxide catalyst in chemical industries. Metal oxides nanoparticles have unique properties which lead to the fabrication of new devices. Nanomaterials of metal oxides are of great significance [8]. The range of different nanomaterials is shown in Fig. 1.1.

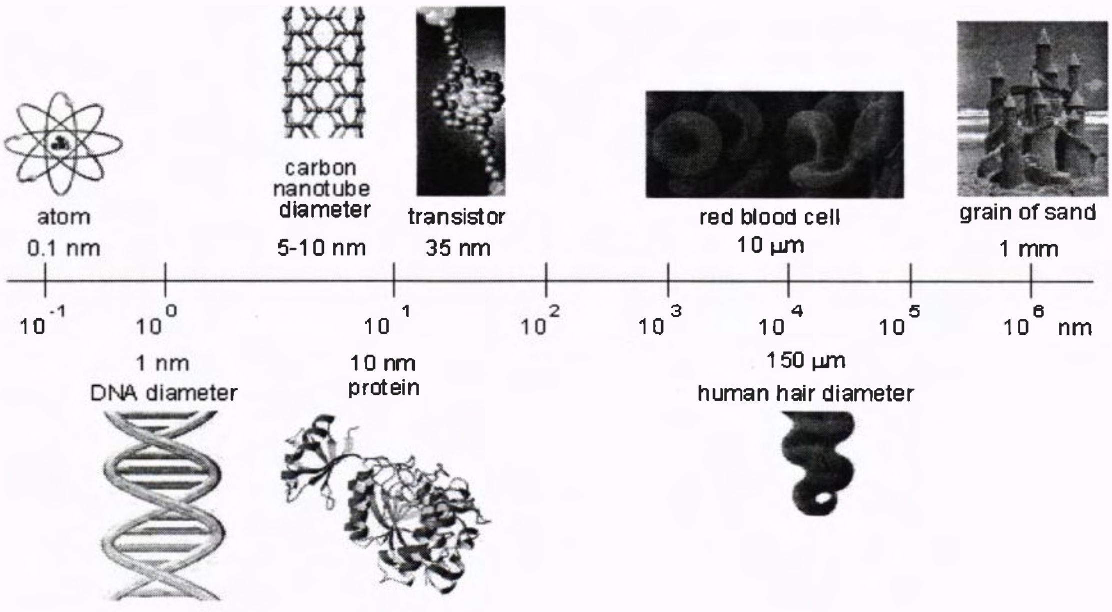

Figure 1.1: Range of different nanomaterials

Nanomaterials find a lot of applications in technology due to its novel properties. Examples of these applications are;

- Memory devices
- Lasers
- Sensors
- Cosmetics
- Solar cells
- Automobiles
- Medicines
- Electronics

1.3 Solar Cell:

As a civilization, we have achieved great successes in various engineering disciplines but the harsh reality is that all these achievements rely on energy like the industrial sector using petroleum and electricity for their implementation [9].

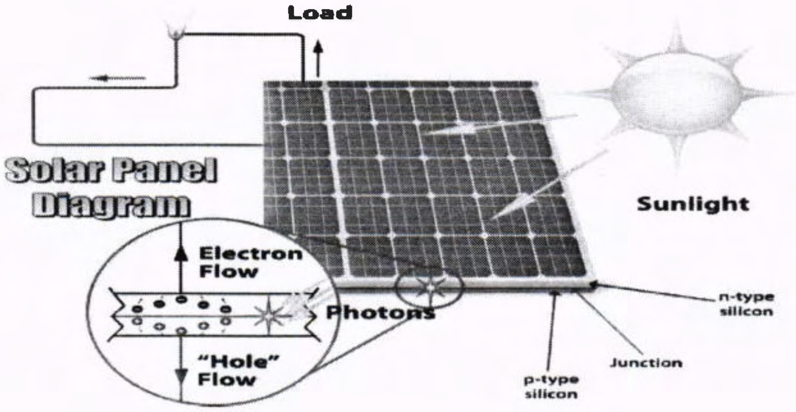

Figure 1.2: Solar penal diagrams

The energy utilization of the world, especially India and China, is on the rise which is predicted as 0.7 to 1.4% rise per annum [10]. We have been able to use various energy sources currently available particularly fossil fuels but, all these are not refillable [11]. By observing this high energy consumption, one can easily predict the energy disaster in the future. Appropriate alternates are required before this energy disaster which can be used reasonably as the source of energy [12]. Solar energy is the best alternative to remnant fuels which are obtainable easily by Sun which emits a great quantity of energy (3939.814W). The earth obtains ~174 petawatts (peta = 1015 units) of external solar energy out of which 30% is reflected into space. This also depends on various weather factors like clouds existence and the absorption by the atmospheric gases. The net solar radiations are the amount of radiations received by earth's surface in one hour and it is expressed in kWh/m^2. Solar energy is beneficial for the whole world because sunlight is available everywhere in the world, for example, the amount of energy received by a desert in south-western region of United States could meet the energy demand of the United States [14]. The solar energy is also causing the reduction in the cost of electricity because electricity can be produced by solar radiation by solar thermal route or the photovoltaic (PV) route. In these routes, the radiation is directly converted to DC by using modules. Photovoltaic (PV) devices use the photovoltaic effect that was discovered by Becquerel in 1839 to convert solar radiation to electricity [15].

Now there are second generation cells which are also known as thin-film solar cells. These cells include different devices which are made by chemical vapor deposition of materials of thin films, such as (Cu,In, CdTe and Si). Cadmium Telluride has a high absorption coefficient due to which it absorbs more and more sun energy and the band gap of cadmium telluride are 1.45 eV which is near to utilize incident radiation [13].

Solar energy is absorbed by solar cells and then that energy is converted into electrical energy when required but some solar cells are not efficient because some of the absorbed sunlight can easily escape out into the air. There are different colours in sunlight but the efficiency of solar cell is greater at bluish light as compared to reddish light. The solar cell when absorbs the light then the sun light excites electrons to the conduction band which causes the flow of electrons but the energy will be lost in the form of heat if holes and electron are recombined. In conventional solar cells, the light is absorbed by the silicon and this light is then converted into potentially damaging heat. Electricity is produced by coupling of ultraviolet light with nanoparticles. The power performance of solar cell is improved by 60 % if high quality silicon nanoparticle thin film is used. Nanoparticles boost the energy absorption ability of the solar cell and so are beneficial to make efficient solar cells. However, there are some limitations of the solar cells due to different loss mechanisms involved which are described below;

- limited absorbtion at large wavelength.
- Thermalization of the energy of photons causes energy loss.
- Reflection causes the energy loss.
- Finite thickness may cause the incomplete absorption of sunlight which may cause loss of energy.
- Recombination of electrons and holes may cause the energy loss.
- Voltage factor may cause the energy loss.
- Fill factor, which is due to the presence of resistances, may cause energy loss.

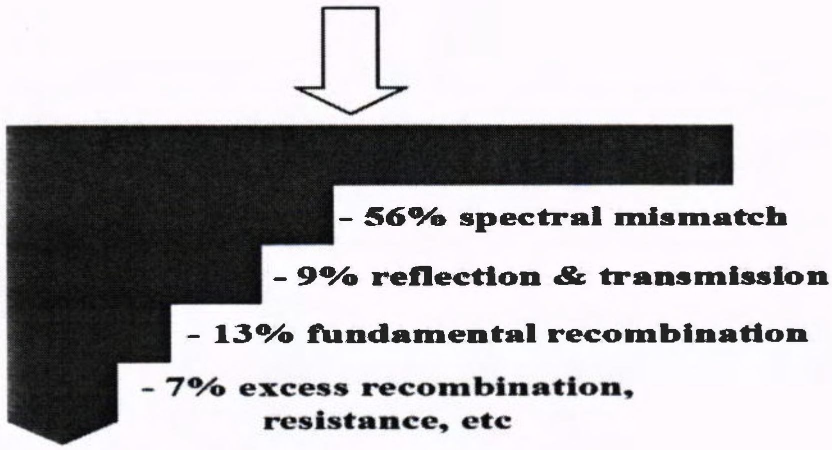

Figure 1.3: Losses in a commercial c-Si solar cell with 15% efficiency due to Spectral mismatch ; reflection & transmission; fundamental recombination; excess recombination, resistance [14].

1.3.1 Silicon Solar Cells:

The devices that are used to convert the solar energy to electrical energy are known as solar cells discussed above. Basically, in solar cells there is a semiconducting material. The photons in sunlight are responsible for the electricity because these photons can excite the negatively charged electrons from valence to conduction band. However, in the normal condition the excited electrons relax back into the ground state quickly. To prevent this relaxation of electrons to their original state, electrical asymmetry is provided. This electrical asymmetry is also provided to drive the excited electrons away from their vicinity. Once the electron gets energy then it excited which creates a potential difference. This potential difference is then used to produce current to any external circuit. In the most of the solar cells, p-n junction is used to produce current to external circuit and this p-n junction is made up of monocrystalline Si. When one part of Si p-type and other part n-type is doped then it is used for the fabrication of p-n junction. One part is n-type and other part is p-type just because one part is n-type to increase the electron relative to holes concentration and the other part is p-type to increase the hole relative to electron concentration. When these two types of silicon are put together then a p-n junction is formed. This p-n junction allows the holes and electron to diffuse in opposite region up to equilibrium state. After this, a region of fixed charge is formed and this region is called the depletion region. As the atoms are now ionized so the fixed charge of these atoms produces an electric field which resists the diffusion of majority carriers through the depletion region [16].

1.3.2 Single crystalline silicon solar cells:

The monocrystalline solar cell is also called single crystalline silicon solar cell, it consists of single Si crystal. The band gap energy of single crystalline Si solar cell is very good and beneficial because due to it the absorption ratio of solar irradiance spectrum and increases the efficiency of solar cell. When these single crystalline Si solar cells are constructed commercially then the efficiency of these solar cells exceeds 20%. Somehow, there is a drawback of these cells and that is its optical absorption coefficient which is low. This drawback is due to the indirect band gap material. It means the valance band energy is maximum but conduction band energy is minimum. The maximum electrons get excited in valance band but once they reach in conduction band then due to the momentum they lose the energy and then additional energy is required to increase the current flowing from the conduction band. Somehow, the thick single crystalline Si solar cells can be used to get good output power [17].

1.3.3 Thin-film Si solar cells:

The thin film Si solar cell is formed due to heavy cost in production of single Si crystalline wafer. Thin film solar cells can be classified into two more categories, one is amorphous Si solar cell and other is crystalline Si thin film solar cell. The key objective of the formation of these thin film silicon solar cells is to manufacture a more efficient and low cost solar cell and to reduce the thickness of solar cell. As the amorphous Si solar cell consists of rough crystalline structure that's why it increases the photon absorption at the entrance surface of solar cell. Due to its high absorption coefficient, thin film Si solar cell is better than the single crystalline silicon solar cell. When it comes to band gap then the band gap of amorphous Si is higher as compare to the band gap energy of crystalline Si. The amorphous Si shows high density of defects due to which it reduces the diffusion of charge carriers and decreases the efficiency of doping material. Due to the diffusion length of minority carrier's solar cell can be made with less thickness of thin film. This enhances the importance of the light trapping efficiency. Somehow, for thin film silicon solar cell, light trapping method is problematic. These surface textures consist of some features which typically have depth more than the thickness of the thin film of solar cell which is approximately one micron. Instead of this the substrate can also be used for the silicon film growth. Due to less thickness and rough crystalline structure it will absorb more solar energy which will increase its output power and efficiency [18].

1.4 Absorption and scattering of light:

When electromagnetic (EM) radiation fall on an object then the electric field of these incident radiations includes oscillation of electric charges. Sometimes these incident particles reflect back in all directions and this phenomenon of reflection is called scattering [19].Similarly, some radiations take part to make the particle of the substrate of solar cell excited but not reradiated and this phenomenon is known as absorption of light rays. This absorbed energy is then converted into other forms such as electrical or thermal energy. A detector can be used to measure the scattered radiation ratio. This detector is adjusted around the substrate of solar cell. Once the radiations fall on the entrance surface of solar cell then the scattered rays can be detected by the detector and can be measured. In this way, scattering ratio of the solar cell can be measured. Similarly, the absorption ratio of the solar can also be measured with the help of detectors. The detectors measure the scattered radiations, before this measurement the incident electromagnetic radiations ratio can be measured and absorption ratio can be measured by simply subtracting the scattered ratio from the incident ratio of EM radiation. The calculation is easy in this way but when we investigate or calculate the extinction of EM radiation at different distances which can be compared to the radiations wavelength then it is really very much difficult to differentiate between the absorbed, transmitted and scattered fields. Theoretically we can separate these fields as radiative and non-irradiative but experimentally we cannot observe these fields or it may be very much difficult to distinguish between the above mentioned fields [20].

1.5 Solar Cell Fabrication:

Solar cell fabrication consists of a major process which further consists of many steps. These steps include formation of n-type and p-type junction, antireflection coating and contact metallization. Other than these steps, some more steps are required to accommodate the other function for the fabrication process of solar cell. These other steps involve surface passivation, bulk passivation of impurities and defects and impurity guttering. However, these additional steps are expensive and additional cost is required for these steps. Due to cost problem, the photovoltaic industry has managed for other alternative steps to accomplish these all steps for the fabrication of solar cell. In the process of fabrication of a solar cell, photovoltaic industry manages the impurity guttering function during the contact and junction formation. Similarly, photovoltaic industry uses thin layer of SiO_2 for the surface passivation or uses the anti-reflection coating to enhance the absorption of solar light which can be further used to produce electricity or to increase the efficiency of fabricated solar cell [20].

Commercially, silicon solar cells are fabricated on the substrates which are of low cost and contain high concentrations of defects and impurities. In silicon solar cell fabrication, the most important issue is the mitigate deleterious effects of defects and impurities. It is very important that a typical solar cell processing must consist of impurity guttering for the removal of dissolved transition metals, also known as minority carrier lifetime killing impurities. Although this process is very useful but even then after guttering process there may be high concentration of residual defects and impurities. However, hydrogen (H) can be used as standard solution to passivate the defects and residual impurities. Although hydrogen is useful but hydrogen passivation also requires addition processing steps. These steps include plasma processing which is very much necessary to introduce the hydrogen deep into the solar cell. Before sometime it was difficult to combine metallization firing, surface passivation and hydrogen passivation but somehow now it is possible for the formation of anti-reflection coating. Detail knowledge is required for the integration of these all multiple functions of different mechanisms. These mechanisms influence interface charge, optical parameters and transport of hydrogen in silicon (Si) [21].

In the past decades, the photovoltaic industry had used different materials for anti-reflection coatings, such as TiO_2 and SiO_2. Here we will discuss an example of silver nitride which is used for the formation of solar cell. Silver nitride has determined a new exclusive niche. This exclusive niche was found in the above-mentioned application and is very much beneficial because it can accomplish different function and can also eliminate the extra fabrication steps that results in large output. There is another process known as nitridation process which will help in surface passivation. Moreover, nitridation process introduces hydrogen into silicon which resides in the damaged surface layer of plasma. When following the nitride deposition then this deposition produced a silver based contact metallization and then this nitride deposition is screen printed and fired by the nitride. In metallization the low ohmic resistance is achieved due to metal penetration by nitride and hydrogen to remove defects. This process is mainly used for passivation of surface as well as devices; by using this process the optical and electronic properties of solar cell are increased [22].

The optical properties of silicon nitride can be managed by controlling the film composition. The film consists of silicon, non-stoichiometric and high density has a high refractive index. Film has approximately 2.4 refractive index, due to which, it makes the solar cell absorption loss high and if the silicon film has low refractive index, approx. 1.9, then this low refractive index will cause low optical absorption loss [23].

Usually when a solar cell is constructed at commercial level then the texture of the solar cell is constructed by the deposition of silicon nitride 750 Å then a thick solid line is constructed which is known as reflectance spectrum of the solar cell which is approx. 300μm thick and contain an aluminium back contact. When constructing the solar cell then the refractive index should be well managed, the calculation of all the measurements uses a refractive index (n) of 1.95. The refractive index is adjusted at 1.95 just to maximize the performance of cell. These all performances are measured in air. However, for the construction of solar cell which should be operating in a module then the refractive index (n) should be adjusted at approx. 2.2. Many experimental calculations also show the excellent characteristics of anti-reflection coating for module operation and air. By these calculations photocurrent densities are achieved.

However, this above mentioned example is very much useful to understand the performance of solar cell depends on the selection of the deposition conditions. This deposition condition includes many factors such as low loss coating. Low loss coating means the coating should be of suitable refractive index. This suitable refractive index will make the anti-reflection coating which will enhance the performance of solar cell. When the refractive index is adjusted in a suitable way then it will help the subsequent nanoparticles to diffuse into the bulk of the solar cell's substrate [24].

The major part of this study is the fabrication of solar cell. For the fabrication many factors are very much important, such as thickness, its bulk resistivity and many other parameters. In this study we have fabricated solar cells on n-type FZ silicon wafers having thickness & resistivity of 160m & 10-13 Ωcm respectively. By using shallow phosphorus front surface is passivated, and textured by NaOH/isopropanol solution. The SiNx cover the back surface which is formed by

$POCl_3$ distribution. Laser aperture is used for emitter pattern formed by BBr_3 diffusion, and final black contacts are created by metal paste.

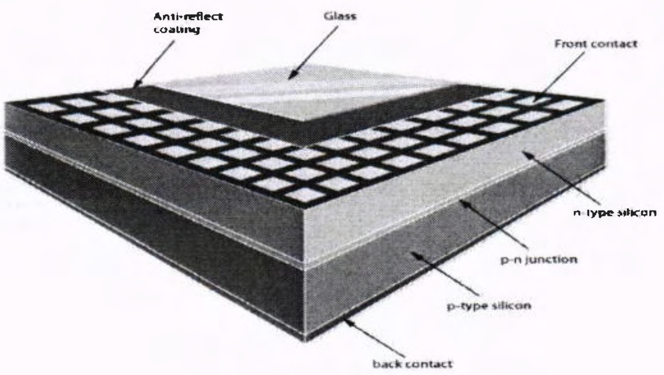

Figure 1.4: Solar cell process

The flow chart with the schematic cross-section and dispensation steps are presented in Fig. 1.5of the obtained cell. Starting from this structural design we urbanized highly developed frontage surface layer in order to increase the renovation energy efficiency. The reliability of the process and exact procedure sequence are still under exploration for a probable official document submission.

During the fabrication of solar cell, there is another way to enhance the performance of solar cell. This way is to use nanoparticles for the fabrication of solar cell. It will increase the output power of the cell and the fabrication process is easy. The solar cells which utilize nanotechnology are inexpensive and help to preserve the environment. These types of solar cells can be used with coating which contains roofing materials with plastic photovoltaic cells to cover the home's entire roof and to capture the enough energy to supply power to entire home. The solar cells, utilizing nanotechnology, are cheaper so they can be used to provide electricity to the rural areas of underdevelopment countries. It can also be used for the lighting, cooking and for medical devices.

1.6 Techniques for efficiency enhancement

Different techniques are used to increase the efficiencies of the solar cells. Carnot efficiency technique is one of them which increased the efficiency of solar cell up to 95%, which is huge improvement. However, now the use of tandem cells by decreasing the band gap between the source and back reflector has increased the efficiency of solar cell. These tandem cells basically prevent the thermalization losses. Fig 1.3 shows the different losses in the solar cell which contributes to 50% loss of incident energy of the solar cells. However, the high energy photons can be used to generate the low energy photons which can reduce the thermalization losses and this process is known as down conversion (DC). Similarly, low energy photons can combine to form a high energy photon which will cause the reduction in non-absorption losses and this process is known as up conversion (UC).

The reduction in thermalization and non-absorption losses leading to the enhanced usage of solar spectrum with down conversion (DC) and up conversion (UC) layers for c-Si are depicted in figure below,

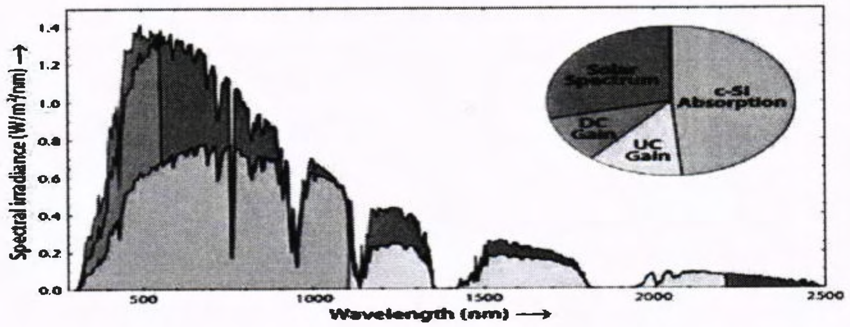

Figure 1.5: AM1.5 spectrum (blue) and the fraction of it utilized by c-Silicon solar cells (green), the potential gain by down converters (red) and by up converters (yellow) [25].

Interdigitated back contact (IBC) solar cells have potential to generate more power as compared to other solar cells and so are becoming more attractive for industrial use. N-type IBC Silicon solar cells have high efficiency (up to 24.2%), due to which these cells are highly recommended in industries. LIMA EU project has developed a screen printing method to make the IBC solar cells production simpler and to decrease the low absorption coefficient. Their project is to develop industrial development. They have now upgraded this process with Pioneering method to enhance the efficiency of the solar cell.

Also Silica nanoparticles are useful to enhance the efficiency of solar cell. In the Earth crust silicon and oxygen are present in the form of silicon dioxide also called silica. Silicon dioxide is one of the most importance factor for the applications of MOS transistors. It can easily stick to the materials and its particles can increase the growth by just increasing the temperature with the help of heating source. It also shows resistance to the chemicals during the etching process of materials and can be used to remove the unwanted impurities. It is very useful material for the integration because of its stability at high temperature. It is also used as an insulator because of its wide band gap.

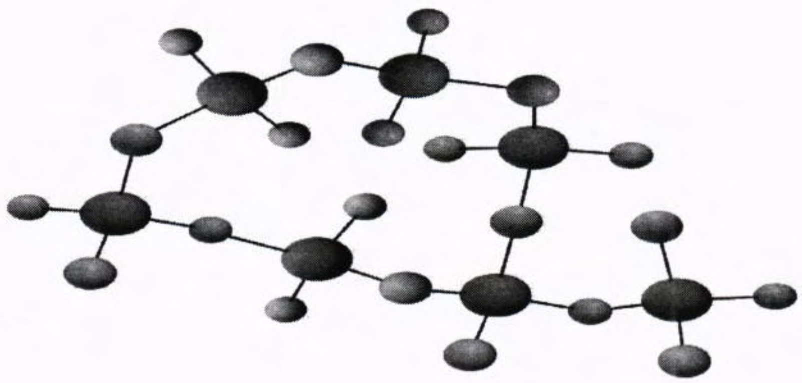

Figure1.6: Silicon dioxide

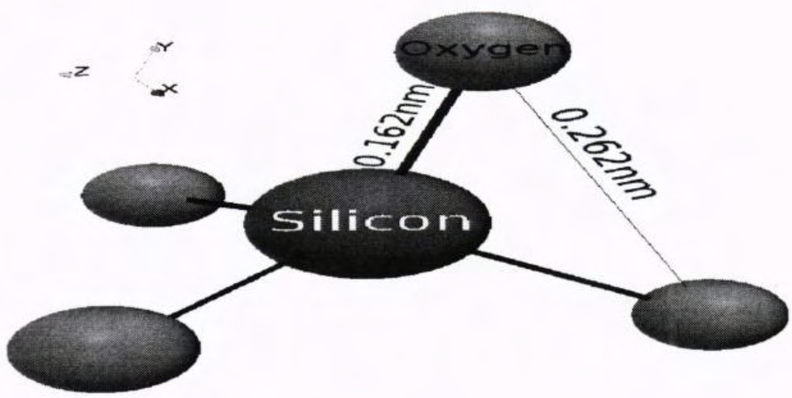

Figure 1.7: Silicon dioxide structure

However, silicon dioxide nanoparticles are also known as nanosilica or silica nanoparticles. According to their structure silica nanoparticles are divided in to two groups p-type and s-type. P-type particles are different from s-type because of numerous nanopores and s-type have smaller surface area. Silicon dioxide nanoparticles are in the form of powder having a white colour.Density and molar mass of silica nanoparticles are 2.4g/cm3 and 59.96g/mol respectively. Melting and boiling point of silica nanoparticles are 1600 C and 2230C respectively. Silica nanoparticles are used in rubber plastic, construction material and bio medical application.

1.7 Thesis Layout:

This thesis consists of five chapters. The first chapter is all about the introduction of nanotechnology, advantages of nanotechnology, uses of nanotechnology, the solar energy as a best alternative source replacing other energy sources such as electricity. This chapter also includes the fabrication of solar cell and will describe the advantage of using nanoparticles as an anti-reflection coating to silicon solar cells. The first chapter also provides information about the silica and silicon nanoparticles. The second chapter presents a review of the research work already done in the field and its results and conclusions. The third chapter describes the materials and methods used for the preparation of thin film coating with 6% Co doped SiO_2. It gives the full information on each and every step that has been followed for the construction of substrate coating and how the techniques have been used to analyse the sample. The fourth chapter consists of results and the discussion about the results obtained in this work. The results obtained are discussed in detail and the representation is provided with the help of graphs which will help to understand it in depth. The fifth chapter is the conclusion of this work which will help us to understand the importance of this work and at the end the bibliography consists of the references

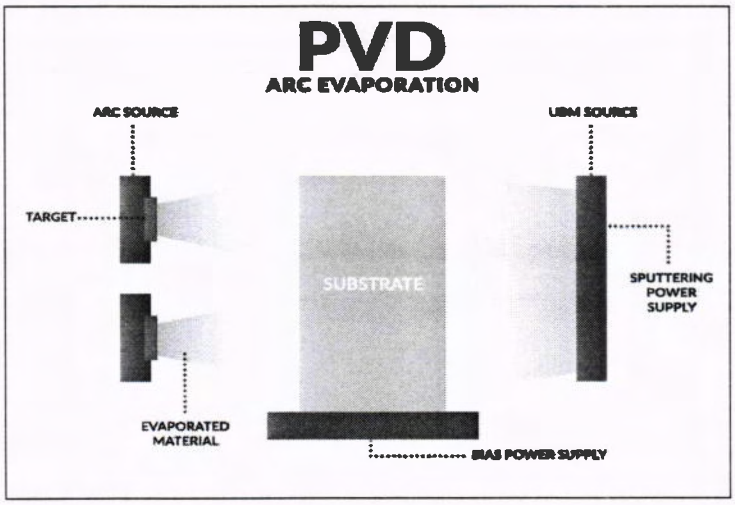

Figure 2.1: PVD ARC Evaporation

The thin layers are widely shaped by sublimation process also known as evaporation, the amount of impurities from later and temperature can be lowered by performing this process in vacuum. Some other technique for evaporation is also used as laser beam evaporation. In this type laser is used for evaporating in fine powder samples [27]. The laser is set to at outer side and its beam through a point on sample. There are different types of sputtering techniques that are given below,

- Magnetron-sputtering
- DC sputtering
- Radio Frequency sputtering.

For the deposition of thin film there are two novel sputtering methods which are given below:

- High Pressure Oxygen sputtering
- Facing Target sputtering.

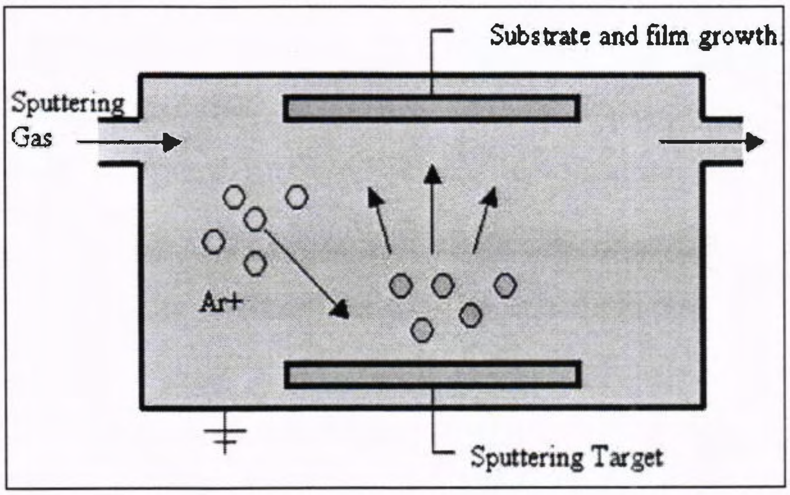

Figure 2.2 Sputtering block diagramme.

2.1.1 Anti-Reflective Coating of Amorphous thin film Si Solar Cell:

Amorphous thin film silicon solar cells are very attractive because they are cheaper and have mature processing technology but the effective absorption depth of Amorphous Si (α-Si) cell is only 1um and minority carrier diffusion length is only less than 30nm. However, in most cases the reflection of incident sunlight is a big issue. Amorphous thin film silicon solar cells have higher refractive index due to which most of the incident light rays reflect back to the atmosphere therefore any technique or method is required to enhance the light absorption capability of the solar cell [28]. For this purpose, some researchers used anti-reflection coating. In 1880, Lord Rayleigh observed two different media and graded interference between them to analyze the reflection of waves from the surface and realized that at a specific thickness of thin film anti-reflection coating, the reflection of incident light on surface becomes almost zero [29]. After that many types of research were carried out to observe the reflection of light by using metal assistant etching, plasma etching and nanorod arrays. Some researchers used oblique angle deposition, spin coated organic material and vapour deposition of materials to achieve the less reflection of incident light but these all techniques lead to thermal and mechanical reliability issues. Furthermore, many other factors affect the results such as humidity which affects the performance due to presence of voids. However, Ag nanoparticles were also useful to enhance the absorption of light or light trapping of the silicon solar cells [30].

Macdonald et al, used Chemical Vapour Etching method to perform Buried Metallic Contacts (BMCs) of multi-crystalline Silicon (mc-Si) solar cells to reduce the reflectivity to 8% in the 450–950nm wavelength range and induced the simple and low-cost technology with 12% conversion efficiency. Lee exposed a PCE of 6.75% by introducing a sponge like TiO_2 interfacial layer [31].

In 2006, Brain G Prevo et al, worked on colloid-based antireflective coatings on silicon solar cells. In their work, they focused on the anti-reflective coating of colloidal silica nanoparticles on a rough surface of polycrystalline Si solar cell. These colloidal silica nanoparticles reduced the reflectance of incident light on the surface of Si solar cell which caused 17% increment in output power of solar cell. The samples of these silica nanoparticles were then observed by SEM images and the results showed that the thickness was varying due to the rough surface of crystalline Si solar cell but the surface coverage by the coating sample was uniform for long ranges. They concluded that convective assembly completely deposited silica nanoparticles on multi crystalline Si surface and improved the photovoltaic cells.

In March 2012, JordieEscarre et al did their research on the thin film silicon solar cells. In their research they worked on the anti-reflective coating surface of the silicon solar cell to observe the minimum reflection losses and discussed the 13% efficiency of the tandem cell with absorber layer thickness of 1.5μm. In their research they used an alternative of the reflective coating. They used the textures of pyramidal based imprinting of random square with micrometric scale and applied this coating at the glass of thin film Si solar cell. This coating was used to minimize the reflection losses of the sunlight at the cell entrance. These processing steps were useful to enhance the light trapping in silicon tandem cells. By this experiment, there was remarkable increment in current gain; approx. 5%. They concluded that by using the anti-reflective surface with the solar cell we can obtain high efficiency of solar cells with less thickness. Anti-reflective surface will help the solar cell to absorb the maximum energy and will not allow the sunlight to reflect back from the outer surface of the cell [32].

In 2014, Yongxiang Zhao et al, worked on optimal structure of thin film solar cells and discussed which is better either multilayer antireflection coatings or dielectric nanoparticles? In their research they found how to enhance light trapping of solar cells and discussed for the improvement of the performance of light trapping of thin film used in solar cells dielectric nanoparticles are equivalent to the antireflection coatings. In their research, they used a cell surface of deposited dielectric nanoparticles as an alternative way to enhance the light trapping of thin film of Si solar cell. By their work on the enhancement of light trapping by the influence of dielectric nanoparticles, they proved that multilayer anti-reflection coating and dielectric nanoparticles are equivalent for the enhancement of light trapping of solar cells. Moreover, they concluded that the simple two layers SiO_2/SiC anti-reflection coating can enhance 34.15% efficiency of the dye-sensitized solar cells which was great improvement rather than plasmonic silver nanoparticles coating, which increased the efficiency approx. 32% [33].

In 2015, LotfiKhizami et al analyzed theoretically and experimentally the effect of porous silicon surface treatment in silicon solar cells. They discussed the decisive factors for the solar cells performances and examined the anti-reflection coating and surface recombination velocities. In Si solar cells, intrinsic parameters are the decisive factors solar cells performances and internal quantum efficiency (IQE). Particularly, when it comes to optoelectronic quality of silicon solar cell then, to quantify it, the most important parameter is front surface recombination velocity. So they examined the anti-reflection coating and front surface recombination velocity. They made theoretical and experimental analysis and the theoretical analysis results showed that decrease in front surface recombination velocity enhances the internal quantum efficiency for photons with 400-700nm wavelengths. For the experimental analysis, they studied the silicon solar cells with the treatment of front porous silicon under ambient condition and observed the performance of silicon solar cells. In their research, they calculated the internal quantum efficiency of the solar cell with Porous Silicon treatment and concluded that internal quantum efficiency of silicon solar cells with porous silicon treatment enhances in shorter wavelengths and the reflectivity of sunlight was reduced to 7% and there was an improvement in conversion efficiency of 5%. In short their research shows that the porous silicon treatment improves the quantum response of the Si solar cells[34].

2.1.2 Spin Coating Process Theory:

Some of the researchers also used Spin coating process for their research. Spin coating is basically used for the thin films application. This typical procedure involves depositing a tiny pond of a liquid resin at the centre of substrate and then to rotate the substrate at high velocity (typically around 3000 rpm). Due to this high speed rotational velocity of substrate, centripetal acceleration will be produced and will cause the resin to extend to the border of the substrate while leaving a thin film of resin on the facade. Final film size and other properties will depend on the nature of the parameters chosen for the spin process and the resin. These parameters involve drying rate, viscosity, surface tension, percent solids, etc. Factors such as acceleration, final rotating speed, and smoke exhaust add to how the properties of layered films are defined. In spin process slight variations in the parameters can result in extreme variations in the layered film. Spin coater basically follows the spin procedure. In the spin procedure a resin liquid is deposited on top of the substrate façade and moves with a very high speed. This high speed spin step causes a thin film creation of the liquid. Then there is a procedure to dry the liquid. This step is followed to remove overload solvents from the resulting film. Two ordinary methods are used for this purpose which is dispense are Static dispense and dynamic dispense. In Static dispense a small puddle of liquid is deposited on or close to the middle of the substrate. This is ranging from 1 to 10 cc depending on size of the substrate and the thickness of the fluid to be coated. During the high-speed spin process larger substrates and or higher thickness naturally need a larger puddle to make sure complete treatment of the substrate. Whereas, in dynamic dispense process even as the substrate is revolving at low speed. A pace of about 500 rpm is normally used and because of this liquid is spread over the substrate can effect in a lesser amount of waste of resin stuff since it is typically not compulsory to drop as much to wet the whole face of the substrate.

This is a mostly useful way when the substrate or liquid itself has reduced wetting abilities and can remove voids that might be formed. After the dispense pace it is ordinary to speed up to a comparatively high pace to form a thin layer of the fluid and will stop it when the thickness of layer becomes according to the preferred thickness. Typical spin speeds again depending on the properties of the fluid and varies according to the properties. The spin speed varies between the ranges of 1500-5000 rpm. This pace can take from 10 seconds to more than a few minutes. The time selected and arrangement of spin velocity for this pace will usually identify the closing film thickness. Upper spin speeds and longer spin period generate thinner films in broad-spectrum. After the high-speed spin step, a separate drying step is performed on the film for the evaporation of the solvents within the fluid.

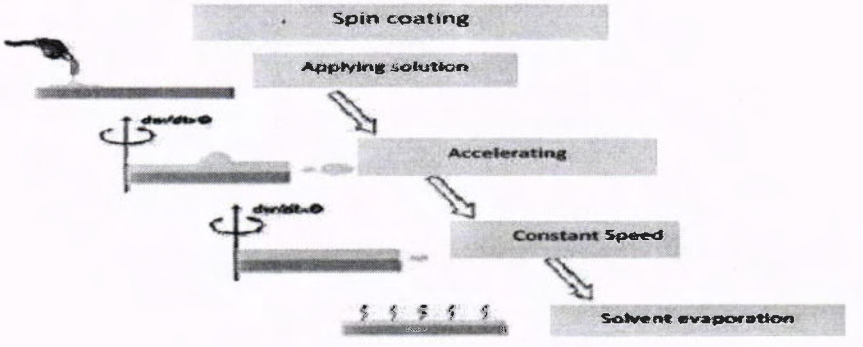

Figure 2.3: Spin coater process

In spin coating speed factor is one of the most important factors. The speed of the substrate (rpm) is affected by the level of radial (centrifugal) strength. The high-speed spin step in particular generally defines the concluding film width. The film thickness is largely a balance between the force applied to cut off the fluid resin towards the drying rate and the border of the substrate which affects the viscosity of the resin. The viscosity increases until the radial force of the spin process can no longer appreciably move the resin over the surface as therein dries. The film thickness will not decline considerably at this point with increased spin time. At all speeds all Cee spin coating systems are precise to be repeatable to within ±5 rpm. Typical performance is ±1rpm. Also, display of spin speed and all programming is given with a resolution of 1 rpm.

Towards the final spin speed, the speeding up of the substrate can also involve the layered film characteristics. During the first part of the spin cycle since the resin starts to dry, it is a key to precisely manage spin speed. In the first few seconds of the process, 50% of the solvents in the resin will be lost to evaporation in some processes. In the coat properties of patterned substrates spin speed plays an important role. The substrate will retain topographical features from previous processes in many cases; it is important to regularly coat the resin over and through these features. It is the acceleration that provides a twisting force to the resin while the spin process provides a radial (outward) power to the resin. This distortion aids in the dispersion of the resin in the region of geography that may otherwise dark portions of the substrate from the fluid. Speeding up of Cee spinners is programmable with a declaration of 1 rpm/second. In procedure the spin motor accelerates (or decelerates) in a linear slope to the ending spin pace.

2.2 Enhancement of Light Absorption by Si Solar Cell:

In June 2012, K. Soderstrom et al studied experimentally the flat light scattering substrates in solar cells. In their work, they discussed the advantage of substrate of being physically flat and showed that the flat substrate allows the growth of cells in symmetry. In their work, for thin film Si solar cells, they studied the substrate which is physically flat and allows the excellent growth of cells with excellent quality [35]. The substrate is physically flat but optically rough to enhance the light absorption or light trapping which will lead to the high density of short circuit current. The substrate is made of zinc oxide (ZnO) which is then covered by silicon and, to expose the pyramidal ZnO surface, the stack was polished. The matrix with embedded ZnO provides the desirable scattering of light and to allow the good quality material growth. They presented the results of 4µm thick silicon solar cells with 520 mV open-circuit voltages and demonstrated the enhancement of light absorption by silicon solar cell and its efficiency gain of 10% [36-37].

In 2012, Yoon-Ho Nam et al worked on Multi-layer coating of Silicon dioxide nanoparticles for the enhancement of light absorption by Silicon solar cells. In their research, they found that the coated Si substrate with nanoparticles was very effective method to decrease the light reflection from the surface of silicon solar cells. For this purpose, two conditions are there, Firstly, the alleviation of the difference between air and Si refractive indexes and secondly the quarter wavelength of anti-reflection should be satisfied and there should be no intrinsic absorption. They concluded that the light reflection reduces by destructive interference at some wavelengths on the thick layer [38-39].

In June 2012, Y. Yang et al were working on the efficiency of crystalline solar cells to enhance light trapping by the application of Plasmon's. In their research they used silver (Ag) nanoparticles to create the surface Plasmon's. ThesePlasmon's were used to enhance the light trapping of silicon wafer cells. They also discussed and analyzed the dielectric layers and metal reflectors. Thickness of SiO_2 layer was optimized by using surface Plasmon's to achieve the optical enhancement. Moreover, they successfully analyzed and separated the optical and electrical properties of the designs of novel rear light trapping from the measured optical absorption data. They also calculated the relative errors for surface recombination velocity and lifetime bulk of effective minority charge carriers [40]. After him in October 2013, BhaskarParida et al worked to enhance the visible light absorption by silicon solar cells. For this work they used chemical vapour deposition and 3C-SiC nanoparticles. They investigated the Si solar cells which were embedded with 3C-SiC nanoparticles. This investigation was done with the help of chemical vapour deposition technique. In their research they used different size of SiC nanoparticles as the solar cell intermediate layer. As a result, there was the formation of nanocrystallites on SiC NP which heated the nano substrate and then was observed by Raman Spectra which revealed that the nano-particles were in mixed phases of nanocrystalline and amorphous silicon. As a result, the photo-reflectance was reduced due to the presence of 3C-SiC nanoparticles and silicon nanocrystals.

Also in some researches silver nitride has determined a new exclusive niche. This exclusive niche was found very much beneficial because it can accomplish different function and can also eliminate the additional process steps for the fabrication of solar cells which are of high efficiency and provides good output. In the processing sequence of a typical commercial solar cell fabrication, a thin layer of SiNx:H is deposited on an N/P junction. This silicon nitride is deposited by a plasma-enhanced CVD process. A nitridation process can also be used to produce an accumulation of +ive charge at the silicon nitride interface which will help in surface passivation. Moreover, nitridation process introduces hydrogen into silicon which resides in the damaged surface layer of plasma. When following the nitride deposition then this deposition produced a silver-based contact metallization and then this nitride deposition is screen printed and fired by the nitride. In the step of metallization, the metal penetrated by the nitride to form a contact of low ohmic resistance where the hydrogen diffuses into the bulk of solar cell to passivate the defects and impurities. Nitride is used for multipurpose and due to its multipurpose role, it demands that it should be a low absorption anti-reflection coating, promote favourable electronic processes and serve as a barrier layer for the metallization control that can be used to passivate the surface of the device as well as the bulk. It is imperative that silicon nitride processing and deposition be designed carefully to enhance electronic and optical properties of the solar cell.

2.3 Metal Nanoparticles Coated Plasmonic Solar Cells:

In 2009, Antti Pennanen worked for the enhancement of the efficiency of solar cell by using metal nanoparticles. In her work she observed that the photovoltaics industry is growing its business by the manufacturing of solar cells and the major focus of the physicist is to manufacture a solar cell which should be cheaper and efficient. For this purpose Antti worked on the industrial and academic level to enhance the efficiency of solar cells. Whenever there is developing application to be discussed or domestic enterprises in your research then academic level is very much helpful in it because it will help you for the competition with the international markets. For photovoltaic cells, Silicon (Si) is most widely used material. In 2004, it was used approx 94% commercially for the manufacturing of solar cells. This preference of silicon at commercial level is just because of its abundance in nature, non toxicity, and stability and well established refining. However, when it comes to commercial benefits then the single crystal Si solar cell is better because of less investment and less payback time but somehow when we come to quality then Si is better but it is costly. In short, its high manufacturing cost is the big hurdle in its commercial use. After the single crystal Si solar cell, there are thin film solar cell which are also cheaper but the drawback of thin film solar cells is that its quality is not good as compare to silicon solar cell. Also their efficiency is low as compare to single crystal Si solar cell. However, the focus of the researchers is the higher efficiency and low cost of the solar cell designs.

Antti, in her work, tried to get the best way to enhance the output of solar cell. She wanted to make a solar cell with high efficiency but in low cost so she used metal nanoparticles. Her goal was to enhance the optical properties of metal nanoparticles and then to use these nanoparticles in the manufacturing of silicon solar cell. By this way she wanted to enhance the efficiency of cell with low cost. In her research, she focused on Si as the photovoltaic material because at that time this was the major focus on its commercial use and the knowledge materials and processes about the manufacturing of silicon solar cells were already available in the marker. So it was a strong believes that silicon substrate is the best way to enhance the efficiency of solar cell. But Antti worked on metal nanoparticles to show something different and to provide a new thought to the market. By her work and her experiments, she concluded that by depositing the metal nanoparticles on the substrate of device of silicon solar cells we can obtain a good output. The devices we will used to be coated with metal nanoparticles should be planar wafer based, silicon on insulator and thin film silicon solar cells. The use of any of these three devices will cause the increment in the output power of solar cell. Somehow, the quality and quantity of this enhancement may be managed by several parameters such as shape, particle diameter, density, the thickness, material of the separating layer and the over-coating dielectric.

In all these three devices, the radioactive or the scattering properties take over the absorption properties of the particles when metal nanoparticles are deposited on the entrance surface of the solar cell. Somehow, then she tried to use particles embedded on semiconductor in her experiment and silicon on insulator solar cells was fabricated and the results were observed. After observation of results it was noticed that the SOI solar cells provide very good efficiency. The output efficiency was about 36% which was a great increment in the output of solar cells. She made some experiments for the manufacturing of silicon on insulator type solar cells with the help of amorphous silicon and poly crystalline to observe the enhancement in the efficiency by using metal nanoparticles. The efficiency, observed by these experiments, was really high enough to prove that she was successful in her experiments. She also made some experiments on the thick solar cells to observe its efficiency and found those solar cells 16% efficient when these cells were manufactured by metal nanoparticles. These all experiments proved that if we will use metal nanoparticles in the manufacturing of solar cell then it will provide enhancement in the photocurrent with the help of light trapping and light absorption at the wavelength region near infra red. And to enhance the absorption of visible region light radiations then antireflection coating on silicon solar cell is better to get the better output photocurrent. Antireflection coating will provide the approx 8% increment in the efficiency of the solar cell photocurrent [41].

In 2012, Y. Yang et al continued his research to plasmonic degradation and discussed the importance of metal nanoparticles coated plasmonic solar cells. In his research he discussed plasmonic for photovoltaic applications and investigated the optical effects of rear light trapping reflectors which were fabricated on silicon solar cells. They discussed, in their research, that Ag metal nanoparticles scattering reflectors perform current enhancement of 11% as compare to metal back reflectors. However, during their work they noticed that the Ag nanoparticles dampened the scattering properties. Most importantly, the over coating MgF_2 thickness improved and enhanced the photocurrent by 25.6%. They concluded that the thickness of coating layer depends on the wavelength, type of metal reflector and angular distribution of plasmonic nanoparticles [42].

In September 2013, Miriam Israelowitz et al, worked on nanoparticles interfaces for current enhancement in Si solar cells. For this they used nanoparticles arrays of metals because they array absorb visible to infrared wavelengths of light through interactions between free electron plasma of metal and incident EM field. Such interfaces enhance photocurrent and light absorption in Si solar cells. To fabricate the plasmonic interfaces which consist of Ag nanoparticles, they used a scalable and cost effective room pressure and temperature spin coating yields. This nanoparticles interface resulted in enhancement in photocurrent in a thin film of Si solar cell up to 200% than the previously reported enhancements. The coating consists of Ag nanoparticles of the diameter of 40nm. The morphology was observed by scanning electron microscopy (SEM). By their results, they compared the surface morphology and %age surface coverage of fabricated plasmonic interfaces to the feed solution particle concentration. Moreover, to understand the PE-morphology relationship they utilized theoretical models of clusters and particle strings and they found that the effectiveness of scattering mechanisms depends on nanoparticles size, material, shape, surface coverage and particle-substrate distance. The morphological features were determined by analyzing the SEM images of the interface. However, particles showed aggregation at higher particle concentrations which can be understood on the bases of the spin coating dynamics process by which they formed a particle embedded a thin layer of fluid. The particles come closer to each other after the fluid film evaporates. With the increase in particle concentration there is a decrement in the fluid film's initial inter-particle separation and as the fluid film is drying so the particles attain maximal proximity due to which the red-shifting and the hybridization effect of the Plasmon mode bulk resonance are more pronounced. When the particles are not linear and having multi poles then they also induce a separate plasmon resonance bulk peak which is different than the dipole peak. As Clusters are sensitive to geometric arrangements and light polarization so they become larger due to destructive interference. Their result showed that by using the spin coating and chemical fabrication techniques, we can get superior PE results as compare to the thermal evaporation method and chemically synthesizing the nanoparticles to the cylindrical shape may also produce greater PE response. In their results they also discussed the calculation of the scattering and absorption of embedded glucose with 69 nm Ag nanoparticles and showed that chemically spin coated synthesized AgNP also results in PE of up to 200%. Their study demonstrates that PE could be tripled by tailoring the interface morphologies and process parameters [43].

2.4 TAZO Films for Amorphous Si Solar Cell:

In February 2014, Shui Yang Lein et al presented their work about TAZO films for applications in amorphous silicon solar cells. In this study, their aim was to evaluate the feasibility to replace the tin oxide (SnO_2) by in-line sputtered doped zinc oxide (TAZO) in hydrogenated amorphous silicon thin film of solar cells. The results of their research showed that the TAZO can have lower resistance and higher haze as compare to commercial Asahi-U SnO_2 films. However, they improved the interface problem by inserting a microcrystalline silicon thin film (p-layer). They used wet-etching process to reduce the fluctuation in the haze of TAZO film and performed the light soaking test and concluded inline sputtered TAZO films for the silicon solar cells is cost effective and more efficient as compare to SiH thin film solar cells (S.Y. Lein, 2014). They further worked for the improvement in the performance of silicon based thin film solar cells. They prepared TiO_2 solution by microwave hydrothermal synthesis and mixed the solution with silicon dioxide solution to get a different ratio. The mixed solution is then coated on an anti-reflecting bi-functional layer. Their results showed that to minimize the reflectance by reflective index in not enough the improvement in the film interface is also necessary to optimize the efficiency of silicon based thin film solar cells [44-45].

2.5 Control of Refractive Index and surface treatment of Solar Cell:

In November 2014, Chao Hsuan Chang et al, worked on anode surface treatments to enhance the efficiency of dye sensitized solar cells. In their study they treated the titanium substrates with HF solution and potassium hydroxide (KOH) solution and used this solution to fabricate dye-sensitized solar cells. After the fabrication titanium substrate was exposed to O_2 plasma treatment to avoid current leakage of solar cell. They concluded that the surface treatment of titanium substrate and TiO_2 anode play very important role in the improvement of the efficiency of dye-sensitized solar cells [46-47].

2.6 Fabrication of Photonic Crystals:

Now-a-days solar energy is source of attraction and so there is need to control and use the sunlight. This need has helped the researchers for the development of optoelectronic devices and materials. The optical communication principles have been the driving area of these developments. The high speed light allows rapid transmission of technologies and information such as low-loss transmission fibres; multiplexers and solid state lasers have been developed. Somehow, technology areas such as information display, optical computing, biological and chemical sensing are all the benefit from components which increase the control of photo energy. The introductions and subsequent photonic crystals experimental demonstrations have created possibilities for many devices for the control, modification, or generation of light. Eli

Yablonovitch, Sajeev John and many other researchers have been working on such devices and experiments since the last 15 years. In last year's, it has been observed that there is a remarkable growth in the researchers' theoretical and experimental work on such structures [48].

In 1987, Yablonovitch presented the idea of "Inhibited Spontaneous Emission in Solid-State Physics and Electronics". In his work, he discussed the potential for the existence of 3D "electromagnetic band gap". Before his research work, there was existence of one-dimensional photonic crystals had already been demonstrated, such as a Fabry-Perot resonator use the periodic layers of dielectric thin films for the creation of forbidden gap. The light propagates perpendicular to the layers and the light rays are not allowed to propagate within the specific range of wavelengths. This forbidden gap of energy is tunable but it depends on the refractive index and interplanar spacing of each layer. Further, Yablonovitch also proposed two new ideas. The first idea was the expansion of spatial dielectric periodicity to three dimensions (3D) which results in an electromagnetic spectrum forbidden gap for all propagation directions of light and the second idea was about the overlapping of band gaps. According to this idea, the overlapping between electronic band gap and electromagnetic band gap edge of direct-gap semiconductor should result in electron-hole recombination. These ideas concluded that photonic crystals could be used as emission tailoring host materials. Within the month of Yablonovitch's publication, another physicist, S. John reported on the certain disordered dielectric super lattices and strong localization of photons. By his work, he also proposed the possibility of the creation of strong photon localization which can result in electromagnetic pseudo gaps. These gaps are formed by forming the micro structures of disordered Super lattice. These microstructures exhibit high dielectric contrast. He also claimed that the interplay between these ordered and disordered super lattice leads to the coherent back scattering to Bragg resonance channels. He focused that a properly designed material can localize and trap light [49].

Then Jeffery Stepleton worked on fabrication of OPAL based photonic crystals. In his study he discussed that the previous years have been in the rapid emergence of photonic crystals which structures exhibits dielectric constant of one, two and three dimensional periodicity. These dimensional periodicity of dielectric constant yield in a changes to the dispersion characteristics in isotropic materials from the normal angular "velocity= velocity * constant" relationship. In his work he discussed different electromagnetic phenomenon results which include the photonic band gap formation. These band gaps consist of specific energy ranges and within these ranges the EM wave propagation is not allowed and due to the presence of these energies the photon group velocity decreases from its normal value. Such modification in photonic band structure of material results in excellent control of light and also in the self-collimation phenomena. These results also allow the spontaneous emission modification through band edge effects and allow the lasing threshold reduction through either micro cavity defect incorporation or low group velocity.

For nano-scale fabrication technique, he tried to form photonic crystals and made some experiments at visible wavelengths and found that it was bit difficult to form photonic crystals at visible wavelengths and his research explained that the use of the subsequent and infiltration removal of OPAL templates can be beneficial for the fabrication of photonic crystal phosphors. By this experiment he formed inverted opal-based photonic crystals. In his work he also mentioned the advantages of atomic layer deposition which has an important method for the fabrication of photonic crystal (PCs). Atomic layer deposition is also used to highlight the exciting result whenever it is used in the optical inactive TiO_2 inverse OPAL and luminescent ZnS:Mn fabrication. Atomic layer deposition is also used for the composition of ZnS:Mn/TiO_2 luminescent inverse OPALs. After description of these advantages of atomic layer deposition, he further concluded that for the future of optoelectronics, photonic crystals are beneficial for exciting new results and prospects. In his work he also discussed that photonic crystals have many applications in different areas ranging from flat panel displays to the biological sensors. Yablonovitch's and John's work was ground breaking and their theoretical work led to many successes in all the laboratories. They had a great challenge to fabricate the three-dimensional photonic crystal at visible wavelength which was very difficult task for them but they met the challenge of fabrication of 3 dimensional photonic crystals (PCs) at visible wavelength and also demonstrated by their results that atomic layer deposition has great potential for structures construction. In their work they also discussed the fabrication methods for the formation of inverse OPAL, for that they used self-assembled silica thin film infiltration. They described that the OPAL based photonic crystals were infiltrated with TiO_2 and ZnS:Mn. Their results successfully described the filling fractions which could approach the theoretical maximum values.

They also discussed the photo luminescence data which showed that the quality of infiltrated OPAL is high and also demonstrated the emission modification of photo luminescence. In the end, they discussed the formation of multilayer of $ZnS:Mn/TiO_2$ photonic crystals and discussed the modification of photonic band structure and showed its exhibiting spontaneous emission. In the experimental results there were fabricated structures, they studied the characteristics of these structures and analyzed these characteristics of the structure with the help of scanning electron microscopy, FIB, x-ray diffraction (XRD), transmission, specular reflectivity and photo luminescence. In their experimental work they formed inverse opal and ZnS:Mn infiltrated with the help of atomic layer deposition infiltration of SiO_2 OPAL. For that they used H_2S, $ZnCl_2$ and provided the temperature about 500 °C by available commercial reactor. In their experiment they used the filling fractions approaching by which they achieved the maximum conformal growth amount about 86% and the same approach was used for the OPAL sizes which were ranging between 160nm to 460nm. In the results, the resulting OPALS exhibited the photonic layers that had intensity which could be compared to the ZnS:Mn thin films. They also studied the photonic band structure evolution as a function of infiltration amount and formation of Inver OPAL by etching process. The peak of the results was due to the existence of specular reflectivity which corresponds to the photonic band gaps in between 2^{nd} and 3^{rd} photonic bands. The results also showed the different shorter wavelengths peaks that correspond to either photonic band gaps for the inverse opal or flat bands for infiltrated OPAL. They compared the data with calculated photonic band diagrams and the results of this calculation revealed the good agreement between either silica opals, inverse opals or infiltrated opals. In experimental work they also used atomic layer deposition at low temperature for the fabrication of TiO_2 inverse shell opals and after the optimization of the purge and pulse lengths they achieved the opal film penetration of about 10μm and also achieved the self-seem bled 250-400nm seized silica opals these silica opals were then infiltrated by using the conventional precursors where the temperature was adjusted at 400°C.

By using the high frequency, they confirmed the width and position of photonic band gap, for this task they used specular reflectance and also transmission, which revealed the behavior of photonic band. Also by the consistent calculation, the peak position was revealed and this position indicated the filling termination of about 88% of the pore volume. If we consider the Bragg equation, then the estimation of this equation supported the theoretical prediction. This prediction showed that the maximum filling for shell OPAL will be approx. 89% and the experimental result showed the result in 88% which was approximately same to the theoretical prediction. The results were then analyzed by SEM and AFM which revealed the ultra-smooth and highly conformal film. The roughness of this film was less than 0.5nm. These results were obtained at low temperature or by short heat treatment. In addition, they also discussed the precise infiltration control which was less than 1 nm. This control was achieved with the same technique which made the fine-tuning of photonic crystal. The success of their work showed that the controlling of dielectric material and also the placement of dielectric material is possible by using the atomic layer deposition, enabling the fabrication and other optimized structures of having best optical properties.

Then they also observed the results by combining the atomic layer deposition with two independent materials control of photonic band gap properties and luminescent properties of multi-layer inverse opal photonic crystals and showed that tuning of photonic crystal and controllable optical properties can be used for the atomic layer deposition of ZnS:Mn and TiO_2. Their hard work on this and the successful results by using atomic layer deposition infiltration of silicon dioxide opals with TiO_2 and ZnS:Mn revealed the inverse, high quality infiltrated and multi-layered opals. The results also revealed the potential of this technique for the fabrication of photonic crystals in the future. Atomic layer deposition can be used for the photonic crystal fabrication but it depends on the opal architecture and it also has great potential for the other fabrication methods integration such as traditional lithographically produced multi-dimensional structures, holographic lithography and electronic beam derived photonic crystals. Its precision, conformal nature, low temperature capability and flexibility make it a useful tool for the future of photonic crystal fabrication [50].

2.7 Development for Single-Crystal Silicon Solar Cells:

In August 2014, Mihir H. Bohra worked for the development of Si solar cell. In his thesis he discussed that the most important renewable alternative of the other energy sources is the solar energy which is a viable source of energy and is rapidly growing in the advance technologies because of its low cost and abundant supply. Silicon is the major contributor in the manufacturing of the silicon solar cell. When it was tested at laboratory then the results demonstrated the efficiency of this cell up to 25%. However, the commercial cells have high concentration of impurities, due to which the efficiency of cell is 16 to 20%. When solar cell is constructed commercially then the focus of commercial manufacturer is the low cost due to which they do not focus on the quality and it also result in the reduction of the payback time of the manufactured solar cells. Here we can discuss an example of the use of metal pastes. During the firing process the metal pastes dissolve the dielectric. Now a days, commercially some solar cells are manufactured which are low cost and some single crystal Si photovoltaic module are available in price of $0.60/W. With such reduction there started a competition between all other photovoltaic technologies for the formation of low-cost Si solar cells. This competition also leads to the unique opportunity in the fabrication of photovoltaic cell process. If this competition also leads to the manufacturing of photovoltaic cell and expensive integrated circuits process just for the sake of high quality. When commercially high-quality solar cells were manufactured then the price of high quality solar cells increased up to $1/W. Somehow many people are working hard to perform some experiments for make a high quality solar cell at low cost. Somehow, we can say that his work provided a better platform for the evaluation of materials and processes. When it comes to the lithographic process then it consists of two steps which result in a baseline of 11 to 13% efficiency of solar cell. He basically discussed the inclusion of higher emitter doping, back surface field implant and an additional RCA which lead to the improvement in the output parameters of solar cell.

By his work he concluded that he worked for the optimization of the process flow of single crystal Si solar cell and his results showed his success. By his work he created a basic process flow and his results showed further improvements to this basic flow process. According to his results, he recorded 13% efficiency of solar cells. He got an opportunity to work on the sophisticated integrated circuits practices into photovoltaic practices and for that he tried to keep the process flow executing and simple and the fabrication was as quick as turnkey process.

During his work he fabricated the solar cell on the substrates and evaluated the difference between the device grade and test grade wafers. This work or conventional process flow was beneficial and provided the result as the 9.5% conversion efficiency. He worked on different substrates and by differentiating the substrates, actual performance parameters were masked and this he used non ideal ties in the device. Then to observe the result and further analyzation of junction depth and sheet resistance, he tried for simulation of highly doped emitter region by ATHENA. He also analyzed and simulated the integrated thermal anneal along with appropriate anti-reflection coating also he observed the fabricated device grade wafers. This fabrication improved the efficiency of the solar cell and the efficiency was recorded as 12%. He then tried with implementation of a back surface field. This implementation was done on low and high doped wafers and so this implementation was performed successfully. For this he used a p-type dopant or Boron which was implanted on the wafer's backside. This experiment helped in the redirection of the electrons towards the device front. This redirection was done because of the presence of barrier which was created with the p/p+ region. By this implementation the results showed that there was 8 to 9% increase in the output current and also it boosted the open circuit voltage. This increase was just in few mill volts. As open circuit voltage is in direct relation to the emitter doping that is why the increase in the open circuit voltage lead to the increase in the emitter doping, due to which higher doping was noticed. Then in his experimental work he used addition RCA clean step. This step was performed for the removal of the impurities because some photo resist was stuck in the solvent bath. Somehow by this removal, there was an increase in short circuit. This increase was about 25% and it was due to the extra cleaning step. It means in the photovoltaic production and for the integrated circuits practices, it is very much important to perform some cleaning steps which we neglect sometimes.

Somehow these experiments showed that the during the device fabrication, the ideality factors were still poor and this conclusion was because of the trapping of charges in the oxide. This trapping resulted in the inversion of surface which was connecting the two islands. These islands were used to provide a shunting path in the fabrication. Somehow in the fabrication process, the substrates were doped due to this doping, the substrate was affected by the ideality factor of the doped device. By his results he can also conclude that the back surface implant receiving wafers had to experience an extra furnace stet. Furnace step is used to try out the damage. By this process the lifetime of the charge carriers was affected. This all resulted in a maximum voltage point on voltage current graph curve. Hence we can conclude that the efficiency was degraded [51].

Chapter: - 3

Materials and Methods

The aim of this study is to investigate the optical properties of "Silicon Solar Cells". For this study the silicon substrate was coated by using 6% Co-doped silicon dioxide nanoparticles. The following materials and equipment were used:

- n-type (100) polished silicon substrate.
- 6% Co doped SiO_2 nanoparticles.
- Sodium hydro-oxide (NaOH).
- Ethanolamine (MEA, DEA & TEA) 99.99% pure.
- PANalyticalXpert Pro Philips Company.
- Heating source
- Furnace.
- Spin coater.
- Acetone.
- Scanning electron microscopy.
- UV-Vis-NIR spectrophotometer.
- Water.
- Powder X-ray diffraction.

6% Co doped SiO_2 nanoparticles were used for the coating of n-Type (100) polished silicon substrate and NaOH was used for the preparation of the solution for the thin films, whereas ethanolamine was used for the deposition of Co doped SiO_2 nanoparticles thin films. Water was used in the solutions as per requirement and a heating source was used to heat the coated substrate. The substrates were dried in a furnace before deposition. For the deposition of 6% Co doped silicon dioxide nanoparticles on the n-type silicon substrate, spin coater was used. The spin coater must be clean and free of dust so for that acetone was used. Once the sample is ready then the morphology of the sample was observed by using scanning electron microscopy (SEM). UV-Vis-NIR Spectrophotometer was used to study the optical property of the sample. For the analysis of X-ray diffraction patterns of samples, aPANalyticalXPert Pro was used and powder X-ray diffraction was used to identify crystal phase and to estimate the crystallite size.

3.1 Methods for Preparation of Thin Film:

For the preparation of thin film following methods were used;

3.2.1. Procedure for preparation of solution

For the preparation of solution for the thin film following steps were followed;

- Prepared a solution by adding 0.2 gram sodium hydroxide (NAOH) in 25 ml of water.
- Stirred the water for 10 minutes.
- 4 samples of n-type (100) polished silicon substrates were heated at 60°Cfor 30 minutes.
- Dried the substrates for 10 minutes at 60°Cin a furnace.

3.2.2. Deposition Process of Co Doped SiO_2 nanoparticles Thin Film

For the deposition of thin film following steps were followed;

- Prepared a solution by mixing 5ml ethanolamine and 0.02 gram 6% Co doped SiO_2 nanoparticles in 5 ml water.
- Sonicated the solution for 20 minutes at 60 °C for preventing agglomeration of particles.
- Spin coater method was used for the deposition of 6% Co doped silicon dioxide nanoparticles on the n-type silicon substrate.
- Dust particles are removed by cleaning spin coater with acetone.
- A suitable vacuum is used for fixing the substrate on spin coater.
- Speed of spin coater is set between two limits, First 10 Sec 100 rpm next 30 Second 3000 rpm.
- A 5 ml syringe is used to drop the solution on substrate to get specific thin film.
- Final substrate dried for 15 minutes in furnace at 80 °C.

- After drying 2nd layer was coated at the same speed and same process by spin coater and similarly multi- layer were deposited on the substrate having same speed and then dried in similar pattern.
- After making first sample another sample was made by using spin coater having speed 3500 rpm for 30 seconds.
- The solution was dropped on the top of the substrate by using syringe of 5 ml. Which was rotated at specific speed to get the required layer and was dried in a furnace for 15 minutes at 80°C.
- The 3rd sample was prepared by using spin coater having speed of 4000 rpm for 30 seconds.
- The solution was dropped in a similar pattern and then substrate was dried at 80 °C for 15 minutes in a furnace.
- After drying, sample was again coated and multi- layers were made on it by using spin coater.
- A sample of silicon substrate was just treated in the sodium hydroxide (NAOH) and water solution to remove its polished surface.
- This sample was uncoated and used for the comparison with coated samples.

3.3 Techniques to Analyse the Sample;

Our samples are characterized by using different techniques as given below,

- Structural studies by using X-ray diffraction (XRD).
- Shape morphology and surface morphology by Scanning electron microscopy (SEM).
- Physical and Chemical properties by UV spectroscopy.

3.3.1 X-ray Diffraction (XRD)

X-ray diffraction (XRD) is least ambiguous technique and frequently used for the determination of the atomic position with high precision in every type of material ranging from perfect crystals to multi crystalline powder. This technique is non-destructive which can be implemented for the naturally occurring and synthesized crystalline materials characterization. It offers information about the preferred crystal orientation, crystal structure, phases present and several other parameters like lattice constant, average grain size, lattice stresses and defects in structure [52].

In this work, Analytical X'pert Pro X-ray diffractometer (operated at 40 kV and 30 mA) which uses CuKα (1.5418Å) source was used to obtained diffraction patterns. The scanning range for the samples was from 20^0 to 80^0 with the step size of 0.025^0 for which the counting time was 1 sec/step. Small quantity of the sample is required to get powder diffraction pattern requires, as small as 10 mg, which yield good data. However, for common sample mounts, an amount of 50 mg of the sample is required. Sample preparation in diffraction work is extremely simple due to randomly situated crystal faces [53]

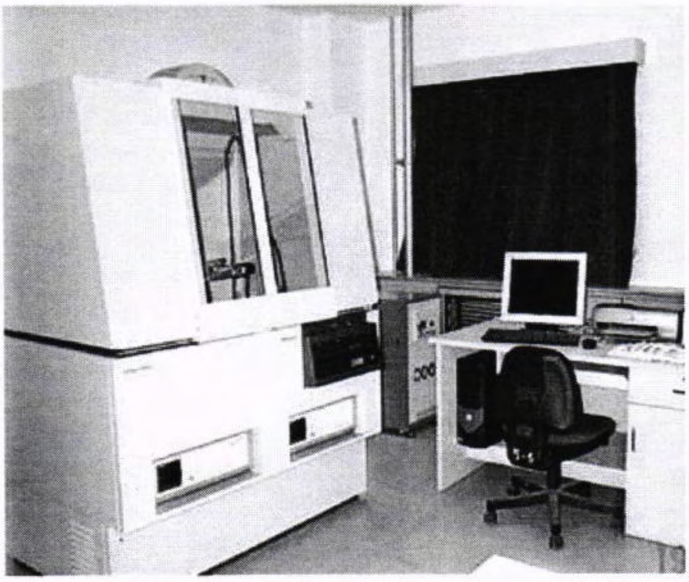

Figure 3.1: Photograph of the x-ray difractormeter using for the diffraction work.

3.3.2 Principles of X-ray Diffraction

X-rays are electromagnetic radiation in nature like light but the wavelength of the x-ray is very short which ranges from 0.5-2.5Å. X-rays when allow to pass through a material, itinteract with electrons of that material. There are two different ways by which matter absorb x-rays, by true absorption and by scattering. When X-ray's beam is bombarded on a material it interacts with its electron and scatter them in various direction. If the wavelength of the corresponding x-ray is in comparison with the interatomic distance of the crystal, the interference occurs. The monochromatic beam of x-ray scattered by every set of plan at certain specific angle constructively interfere with each other, hence produce x-ray diffraction peaks. The intensity of each peak can be determined from the arrangement of atoms in the lattice planes. The order arrangement of the scattering centre, like atoms and ions in crystalline materials, produce interference minima and maxima [54].

When a crystalline material is irradiated with x-ray, it scatters the radiation in different direction. After scattering x-rays interfere constructively or destructively. The diffraction effects are produced due to constructive interference. When x-rays enter into crystal each atom acts like diffraction centre and the crystal can be regarded as a diffraction grating. As the diffraction is due to the adjacent atoms of the crystal, therefore the diffraction pattern obtained provides information about atomic arrangement in the crystal.

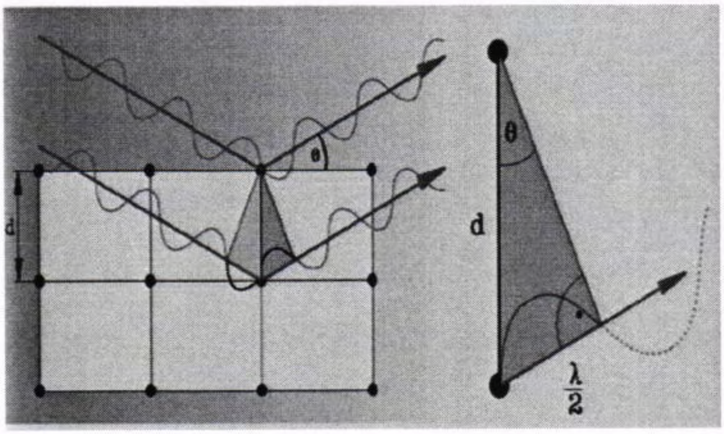

Figure 3.2: X-ray diffraction from atomic planes of crystalline materials.

The above figure explains the working principle of diffraction in which the monochromatic incident beam of x-ray of wavelength λ strike the atomic planes of a crystalline material. The x-ray diffracted from the planes interferes with each other constructively or destructively, depending upon the path difference of these diffracted rays. If the path difference is integral multiple of wavelength i.e. λ, 2λ, 3λ . . ., then the diffracted rays constructively interfere with and hence satisfy the Bragg's law of diffraction [55].

(3.1)

Where λ is wavelength of the monochromatic beam of x-rays, n is any integer, θ is the angle of incidence and d_{hkl} is interplaner distance between atomic planes.

3.3.3 Structure Determination

Mostly the crystal structure of the materials is determined using x-ray data of single crystal but in certain circumstances it is advantageous to use powder data. Powder data have generally been used to solve the structure of metals and alloys, which are mostly cubic, tetragonal or hexagonal. Now days, the powder data are widely used for structure determination of ceramic and composite materials. The cell dimensions of these structures simply can be calculated by indexing them using reference data card called JCPDS (joint committee on powder diffraction standards) cards. In unit cell all or some of the atoms are situated at some special positions like origin, body centre, base centre, face centre etc. and hence the quantity of positional parameters which varies from structure to structure when determined is either zero or small. The lattice constant of the cubic system can be calculated by using relation [56].

$$a = d_{(hkl)} (h^2+k^2+l^2)^{1/2} \qquad (3.2)$$

In which h, k and l are Millar indices and $d_{(hkl)}$ is the interplaner distance which is the characteristic of the material under investigation.

3.3.4 Measurement of Crystallite Size

The particle size affect the physical properties of the materials therefore it is necessary toestimate this parameter. Different techniques are used for estimating crystallite size from data contained in x-ray diffraction patterns. Single peak Scherrer technique is less accurate but widely used for the crystallite size determination of ceramics and polymer materials.

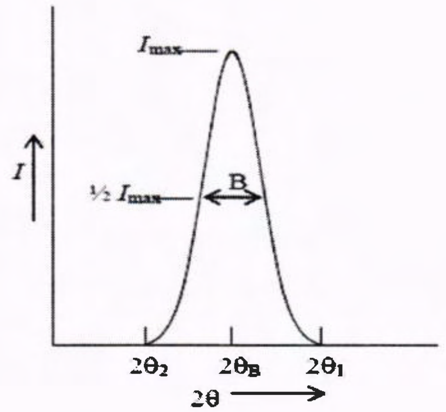

Fig 3.3: Peak in the figure represents the FWHM and Bragg's angle.

It provides explanation of the peak broadening by means of incident beam divergence, that helps to satisfy the necessary (Bragg's) condition for non-adjacent inter atomic diffraction planes. Scherrer formula establishes a relationship between the width, thickness and Bragg's angle of diffraction. The well-known Scherrer relation is given by

$$t = \frac{0.9\lambda}{\beta Cos\theta} \qquad (3.3)$$

Where k (0.9) is shape factor, λ is the wavelength of x-ray, θ is Bragg angle, β is FWHM of the peak in radians and t is used for thickness of crystallite [57].

3.3.5 Density Measurements

The density has no link with the external factors therefore it is not a mechanical property. Due to this reason, it must be considered first before studding any other property of the materials. The density is important parameters which have pronounce influence on certain physical properties of the materials. Generally, two types of densities are widely calculated.

- Measured density
- X-ray density

3.3.6 Measured Density

Measured density represents a relationship between volume and mass and is an important intrinsic property of the materials. For the prediction of various properties of the specimen, the measured density is used as independent variable. The characterization of the measured density is difficult because it can be influenced by type and amount of substituent's, temperature and pressure. It can be measured from the dimensions of the pellet using standard formula.

$$\rho_m = \frac{m}{\pi r^2 h} \qquad (3.4)$$

where m is the mass, h is the height and r is its radius and of the cylindrical disc like pellet.

3.3.7 X-ray Density

The x-ray density can be calculated from the information contained in x-ray pattern by using formula [64].

$$\rho_x = \frac{8M}{Na^3} \qquad (3.5)$$

Where 8 is the number of formula units, M denotes molecular weight, N is Avogadro's number and a^3 is the volume of the cubic unit cell.

3.3.8 Porosity

The storage capacity of a material is called porosity. The physical properties such as electrical, magnetic etc. of a material depend on porosity which itself depend on the size of the grain, its size and degree of their packing.The porosity of the material were calculated with the help of following relation.

$$P = \frac{\rho_x - \rho_m}{\rho_x} \qquad (3.6)$$

Where ρ_x and ρ_m are x-ray and measured densities respectively.

3.3.9 Specific Surface Area

The calculation for specific surface area (m^2/g) was carried out using formula.

$$s = \frac{6000}{t\rho_m} \qquad (3.7)$$

Where t is the thickness of crystallite in nm and ρ_m is measured density in g/cm^3 of the sample

3.4 Scanning Electron Microscope (SEM)

Scanning electron microscopy (SEM) is the most important, versatile and widely used technique which is enable to provide information about the surface morphology of powder as well as of thin films. The x-ray machine though capable to provide information about the structure of the materials but do not tell us about distribution, morphology and growth of the synthesized particles, therefore SEM is utilized. It used high energy beam of electron, instead of light (limited magnification), in raster scan pattern to obtain a highly magnified three dimensional micrographs. It provides micrographs of high resolution which helps to examine the closely space features of the particles. The sample must first make conductive for SEM analysis which is easy process. Better magnification, high resolution, ease of sample observation and larger focus depth makes it one of the most widely used apparatus in modern research [57].

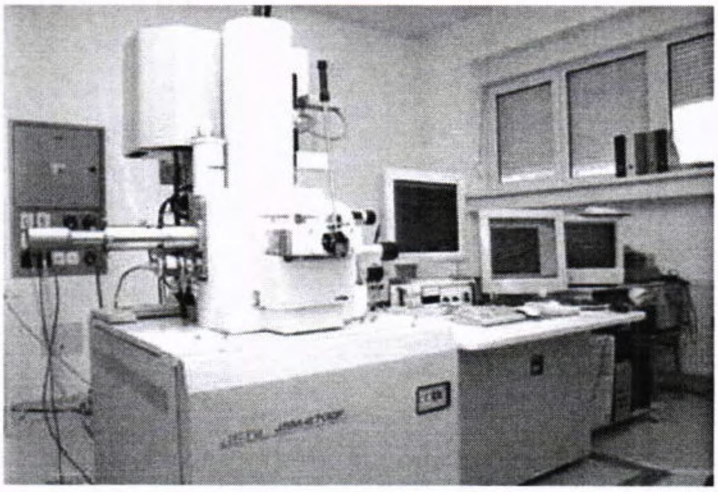

Figure 3.4: Photograph of the JEOL JSM-6700F Scanning Electron Microscope.

3.4.1 Working Principle of SEM

The working of SEM can better be understood from the fig. 3.5 given below. The beam of electrons ejected from afield-emission, Schottky or thermionic cathode are accelerated by applying high negative voltage at cathode which ranges from 0.1 keV to 50 keV. The anode is at positive potential therefore attracting this beam. The beam of electron at gun have large diameter at gun which can be demagnetised using two or three electromagnetic condenser lens system. The collimated beam is finally focused by objective lens on the surface of the sample. Increasing the potential of the cathode increase the kinetic energy of the electrons.

When beam of the fast moving electron strike the surface of a solid material, it penetrates into that solid and lost most of its kinetic energy by ionizing atoms of the material. The incoming electrons interact with the sample and produce numerous effects including a reflected electron current, secondary electron emission, beam-induced, cathode luminescence and conduction. The cascade of the secondary or ejected electrons is formed within the time frame of 10^{-9} s which lost its kinetic energy gradually by diffusing outward from the lattice, generate heating effect in the lattice.

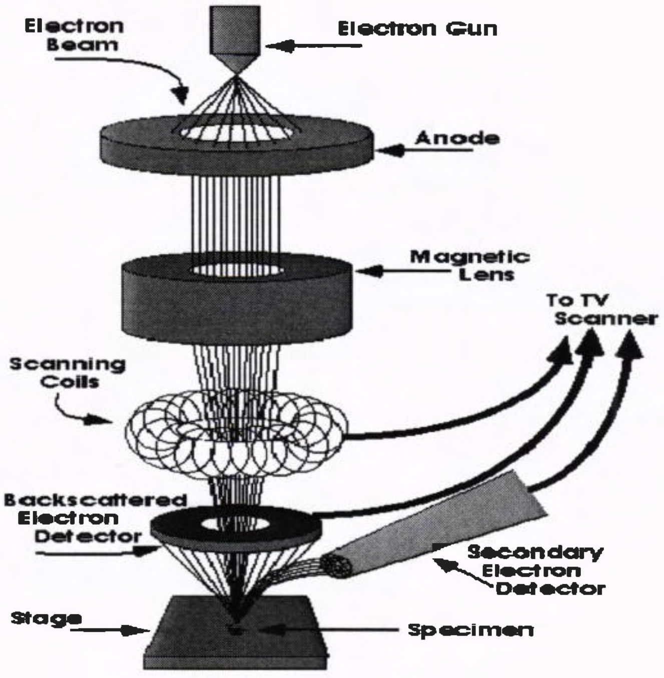

Fig: 3.5 Ray diagram of SEM

The secondary and backscatter/reflected electrons are collected by secondary electron detector and backscatter electron detector respectively which convert them into voltage and amplified. This voltage is then transfer to CRT which change the intensity of spot of light. The image on the surface of the sample is formed by thousands of spots which have different intensity that correspond to the topography of the sample [58].

3.5 UV-Visible Spectroscopy

In this study, we used UV-2600 Spectrometer (Shimadzue) accessible at the department of chemistry, Federal Urdu University, Karachi. Figure shows a photograph of this apparatus. In this section, we also present a concise description of the elementary physics and measurement system of the UV visible spectroscopy.

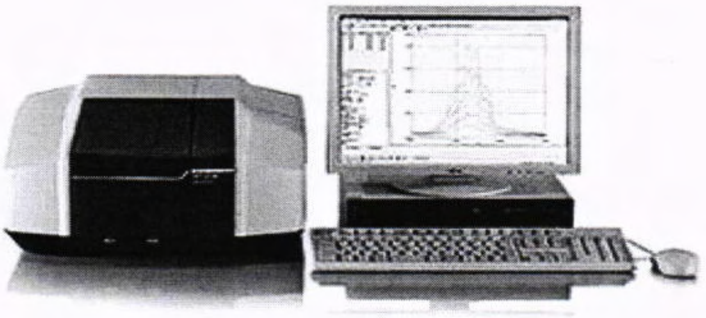

Figure: 3.6 UV-2600 Spectrometer (Shimadzue).

The ultraviolet light has wavelengths between 190 and 400 nm, on the other hand the visible light scales from 400 to 800 nm. In ultraviolet/visible spectroscopy the electron skipped from a base electronic state to the excited electronic state by the captivation of ultraviolet light. As the absorption of ultraviolet and visible radiations is due to the transition of electronic energy levels, thus it is sometimes called electronic spectroscopy [59-60].

3.5.1 Principle and working of UV Spectroscopy;

In UV spectroscopy, the specimen transmits or reflects the incident ray of light falling on specimen. Photo detector is used to detect the transmitted and reflected light whose pattern used to calculate the reflectance and transmittance. There are two types of spectrometer, single and double, single spectrometer used for intensity measurement and double spectrometer for wavelength of light.

3.5.2 Uses of UV Spectroscopy;

UV spectroscopy is used to find

- Semiconductors energy band gap.
- Molecular Electronic transitions.
- Kinetics of reaction.
- Structure elucidation

Chapter 4

RESULTS AND DISCUSSION

4.1 SEM Images of Powder Form of 6% Co doped SiO_2 Nanoparticles;

The scanning electron microscope (SEM) was used to study the morphology of the prepared sample of 6% Co doped SiO_2 nanoparticles. While preparing the samples, we could control the thickness of the thin films by adjusting spin coating speed and concentration of SiO_2 solution. The layer thickness was decreased by increasing the rpm speed and decreasing the concentration of the SiO_2 solution. The image results obtained from SEM are discussed below,

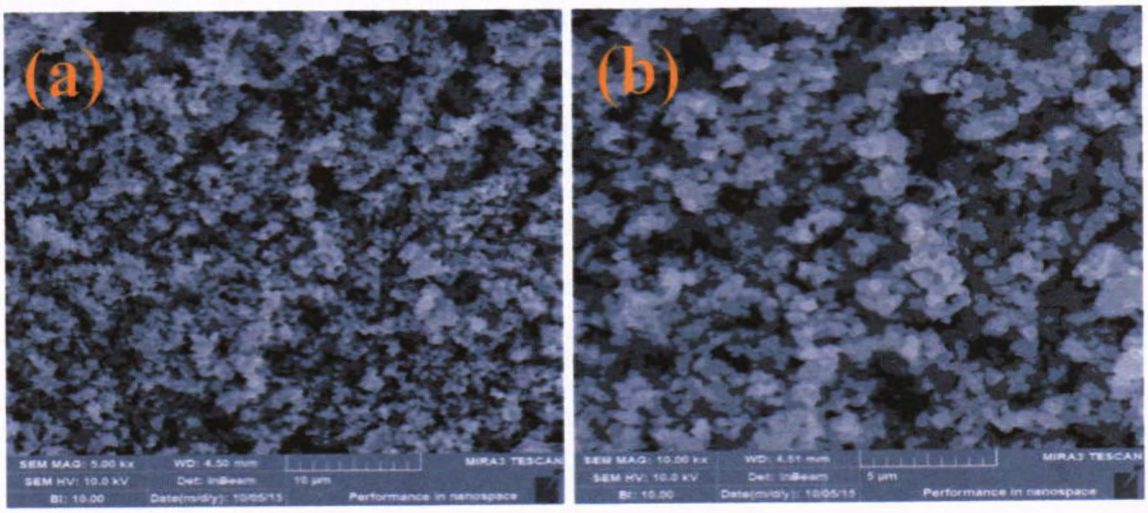

Figure 4.1: (a) SEM image of powder form of 6% Co doped SiO_2 nanoparticles. **(b)** SEM image of the powder form of 6% Co doped SiO_2 nanoparticles.

Voltage (10 kV) was supplied to SEM to analyse the samples. The magnification was adjusted at 5 kx to obtain the image of the sample of width 4.50 mm. Fig.4.1 (a) shows the SEM image of the powder form of 6% Co doped SiO_2 nanoparticles. This result shows that the prepared sample consists of spherical particles. During the growth of nanoparticles particles caused the aggregation due to which the boundaries of the particles are diffused and formed a discrete structure.

Then SEM magnification was set at 10 kx to observe the sample deeply at the width of 4.51 mm and obtained the image. Fig 4.1 (b) shows the SEM image of the powder form of 6% Co doped SiO_2 nanoparticles. This result shows the discrete structure of the diffused spherical particles.

The particles were dispersed uniformly on the whole surface; samples show porous structure which is introduced due to the doping of the samples. We have doped 6% Co that increases the performance and form branched structure of samples. The pores formed in the structure increases the absorption properties of SiO_2 nanoparticles, we have observed different ratios of doping and 6% found most effective. The Co doping produce good results as compare to other materials because it produces considerable porosity that enhances the absorption of light.

4.2 SEM Images of Coated Silicon Substrate;

Silicon substrate coated with multi-layer 6% Co doped SiO_2 nanoparticles was observed with the help of SEM to study the morphology. The image results obtained from SEM are discussed below,

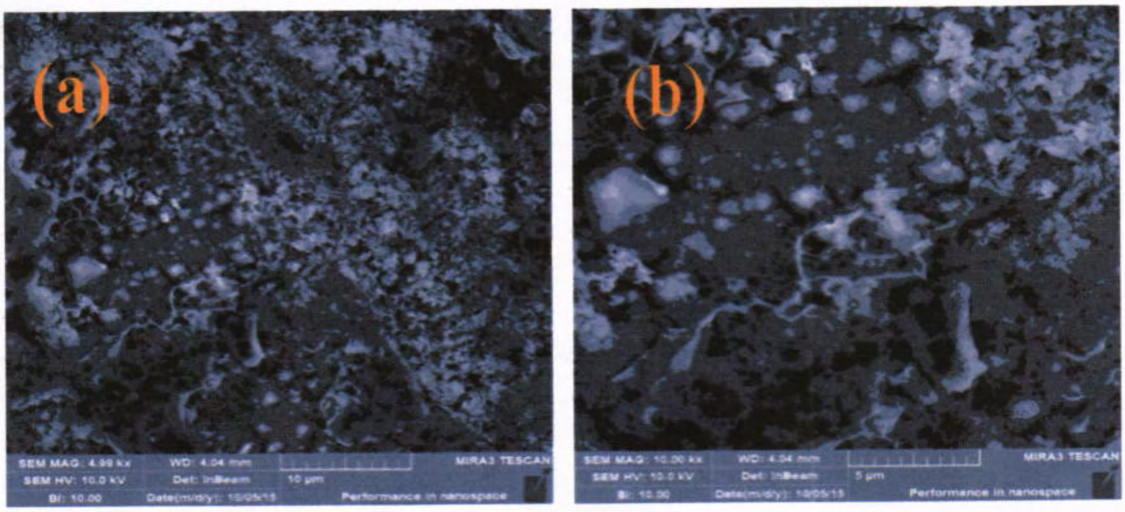

Figure 4.2: (a) **SEM image of coated silicon substrate, (b) SEM image of coated silicon substrate.**

When silicon substrate coated with 6% Co doped SiO_2 nanoparticles was annealed at 80 °C, the coated material diffused in the silicon substrate to form a layer with spherical structure which can be useful to enhance the absorption of sunlight. This coated silicon substrate was analysed by SEM. SEM magnification was adjusted at 5 kx and width at 4.04 mm to observe the image. Fig 4.2 (a) shows the SEM image of silicon substrate multi-layer coated with 6% Co doped SiO_2 nanoparticles. This image shows the diffusion of 6% Co doped SiO_2 nanoparticles into the silicon substrate.

The SEM magnification was adjusted at 10 kx to observe the image of silicon substrate coated with 6% Co doped SiO_2 nanoparticles. Fig 4.2 (b) shows the SEM image of silicon substrate multi-layered coated with 6% Co doped SiO_2 nanoparticles. This image provides the deep vision of the diffused coating material in the silicon substrate and showed a formation of layer on the substrate of spherical structure which can be useful to enhance the absorption of sunlight.

4.3 X-RAY Diffraction Analysis;

The powder sample of 6% Co doped SiO_2 nanoparticles and coated silicon substrate with 6% Co doped SiO_2 nanoparticles were analysed by X-Ray Diffraction analysis. The results are discussed below,

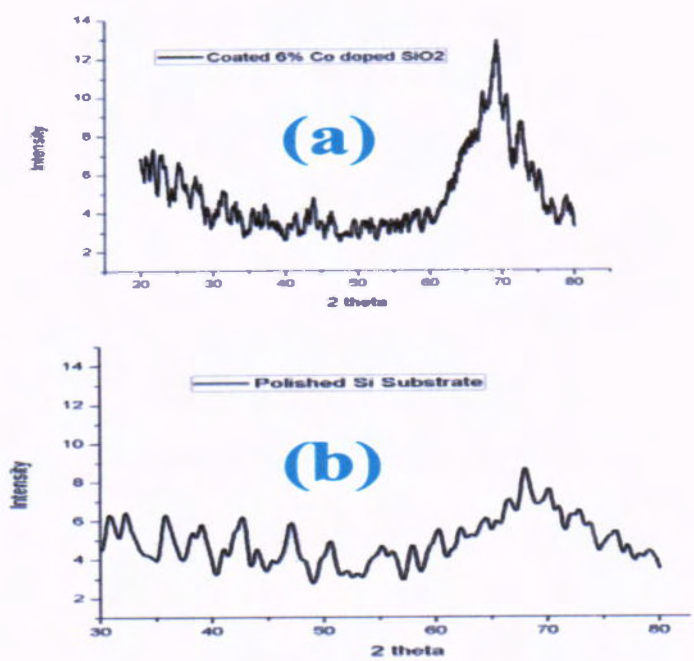

Figure 4.3: (a) XRD image of 6% Co doped SiO_2 Nanoparticles coated Si substrate, (b) XRD image of polished Si substrate.

The X-ray diffraction pattern of the substrate coated with 6% Co doped SiO_2 nanoparticles was observed. Fig 4.3 (a) shows the XRD results of substrate coated with 6% Co doped SiO_2 nanoparticles. With the help of this graphs one can easily calculate the size or the thickness of crystallites by using Debye-Scherer equation ($D = K \lambda / \beta \cos\theta$). Thickness and speed are inversely proportional to each other as on increasing the speed the thickness of the film decreases and there is broad peak in the graph as shown in figure 4.3 (a). In this graph the sharp peak at the intensity of $13Wm^{-2}$ shows the high rate of crystallinity. It is concluded that thinness shows the smoothness and increase in the crystallinity.

The X-ray diffraction pattern of the polished silicon substrate was observed. Fig 4.3 (b) shows the results of substrate without coating. With the help of this graphs size and thickness of crystallites can be calculated easily. In this graph the sharp peak with the intensity of $9Wm^{-2}$ shows the high rate of crystallinity. However, the increase in diffraction intensity peaks indicates the improvement in the material's crystallinity so this confirms that the material is having discrete structure which can be used for the adsorption processes or for catalytic purposes. On comparing our obtained XRD spectrum for 6% Co doped SiO_2, one can assure that the peaks reveal the dimensions of the particles in nm range and reveals the reflection from (110), (102), (200) and (201) planes, at 2θ values of 36.550°, 39.470°, 42.457°, and 45.800°. From the XRD pattern, it is observed that the material has hexagonal crystal structure and has a primitive lattice of lattice parameters a = b = 4.903 Å and c = 5.403 Å.

4.4 UV Visible Spectroscopy Analysis;

To analyze the absorption or the reflectance spectra of 6% Co doped SiO_2 nanoparticles the UV visible spectroscopy technique was used. The results obtained from the UV visible spectroscopy analysis are discussed below,

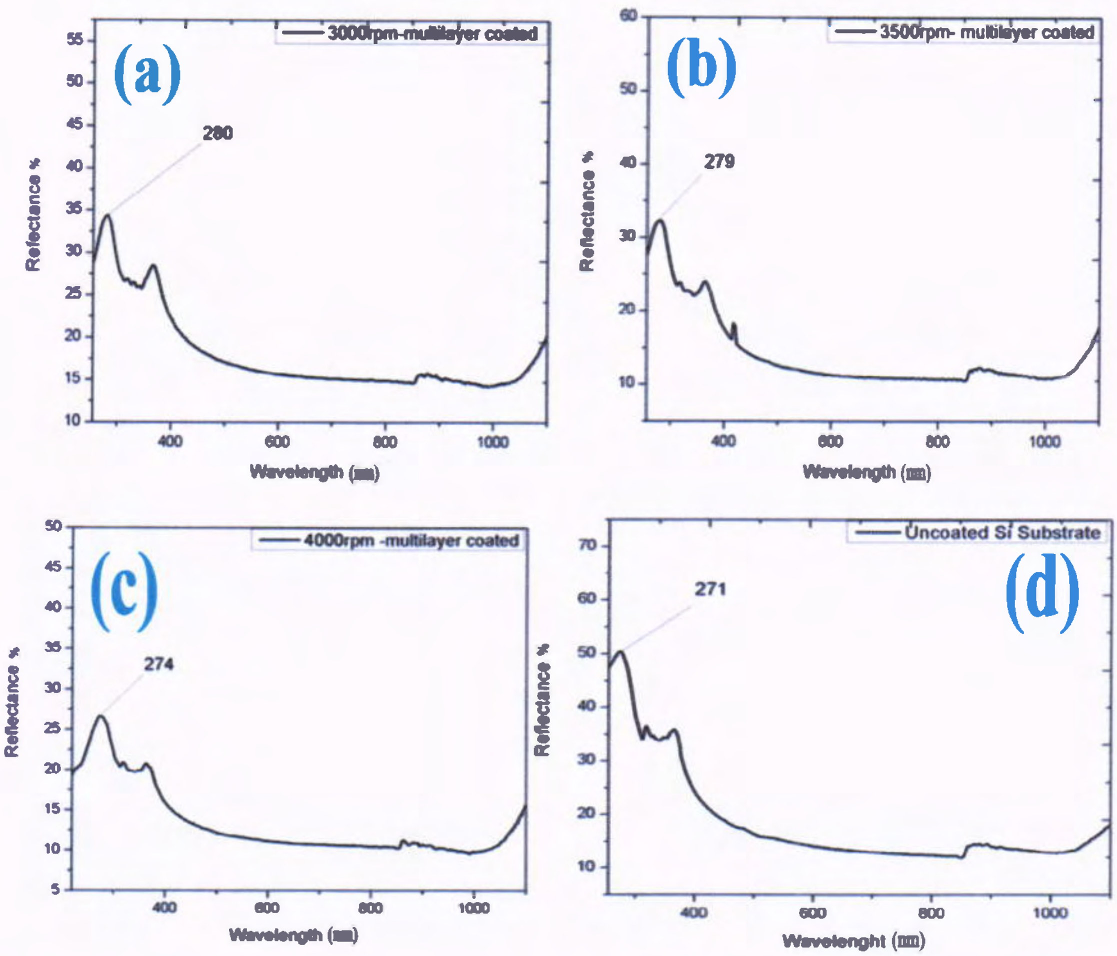

Figure 4.4: (a) **UV image of coated Si substrate at speed 3000 rpm.** **(b)** **UV image of coated Si substrate at speed 3500 rpm.** **(c)** **UV image of coated Si substrate at speed 4000 rpm.** **(d)** **UV image of uncoated Si substrate.**

Fig 4.4 (a) illustrate the reflectance spectra of 6% Co doped SiO_2 nanoparticles coated substrates at speed of 3000 rpm. The results show that at the speed of 3000 rpm the 6% Co doped SiO_2 nanoparticles coated substrate exhibits low reflectance (20%) at the wavelength of 995 nm and exhibits high reflectance at 280 nm wavelength in NIR region and UV region. Fig 4.4 (b) illustrate the reflectance spectra of 6% Co doped SiO_2 nanoparticles coated substrates at speed of 3500 rpm. The results show that at the speed of 3500 rpm the 6% Co doped SiO_2 nanoparticles coated substrate exhibits low reflectance (15%) at 850 nm and exhibits higher reflectance at 279 nm wavelength in NIR region and UV region. As the reflectance decreases due to the coating of 6% Co doped SiO_2 nanoparticles so the absorption increases which makes it suitable for electronic applications like solar cells. Fig 4.4 (c) illustrate the reflectance spectra of 6% Co doped SiO_2 nanoparticles coated substrates at speed of 4000 rpm. The results show that at the speed of 4000 rpm the 6% Co doped SiO_2 nanoparticles coated substrate exhibits low reflectance (10%) at 995 nm wavelength and exhibits higher reflectance at 274 nm wavelength in NIR region and UV region. As the reflectance decreases due to the coating of 6% Co doped SiO_2 nanoparticles so the absorption increases which makes it suitable for electronic industries and solar cells. At speed of 4000 rpm the reflectance is lesser as compare to other results.

Fig 4.4(d) illustrates the reflectance spectra of an uncoated Si substrate. The results show that the 6% Co doped SiO_2 nanoparticles coated substrate exhibits low reflectance at 800 nm and 995 nm wavelength and exhibits higher reflectance at 271 nm wavelength in NIR region and UV region at speed 4000 rpm.

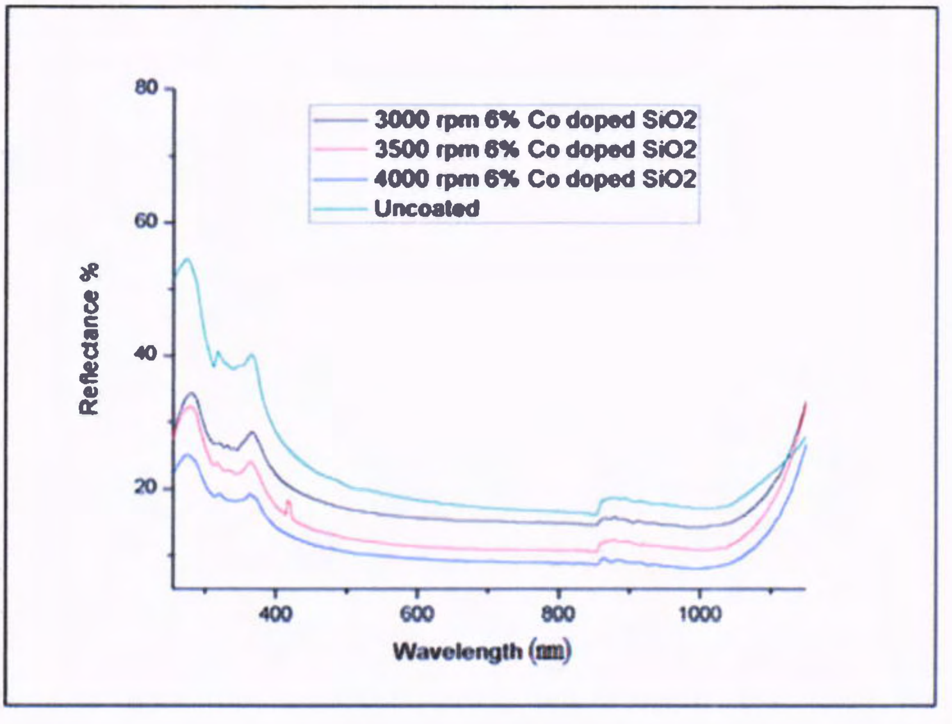

Figure 4.5: UV combine image of coated Si substrates and uncoated Si substrate.

Fig 4.5 shows the total reflection spectra of the multilayered SiO_2 nanoparticles coated silicon substrates with an uncoated silicon substrate. The multi-layered SiO_2 nanoparticles reduce light reflection over the wavelength from 400 to 1200 nm. The wavelength of maximum suppression λ_{min} of the light reflection was caused by the destructive interference. For the substrate with a multi-layer coating of 6% Co doped SiO_2 nanoparticles at speed 3000 rpm, the destructive interference occurred rather in a high energy region. This thickness is not suitable for antireflection coating in silicon solar cell because silicon solar cells are sensitive to light in the visible and near infrared region rather than to light in high energy region. Thus, the destructive interference should be in the visible and near-infrared region. At speed 3000 rpm multilayered coating of 6% Co doped SiO_2 nanoparticles the reflectance spectra show 20% reflectance; at speed 3500 rpm the reflectance spectra show the 15 % reflectance and at speed 4000 rpm it shows 10% reflectance. The uncoated sample for comparison shows the greater reflectance which is 25%. The results show that by increasing the speed of spin coater the layer thickness decreases and the reflectance decreases. A multi-layer coated sample at speed 4000 rpm is considered for an optimized anti reflection layer.

4.5 Comparison;

When comparing the above graphs, Fig 4.4 (a), (b), (c), (d) and Fig 4.5, it can be observed easily that the coated substrate has shown good absorption than the uncoated substrate. Also in the coated substrate, the higher speed, 4000 rpm, is showing great decrease in reflectance and so great increase in absorption of light of about 351 nm wavelength. The band gap energies can also be determined with the help of equation $E_g = hc/\lambda$.

Where, Eg is for band gap (eV), c is velocity, h is the Planck's constant (4.135 x 10^{-6} eV), and λ (nm) is the wavelength. In addition, the absorption spectra of the coated silicon substrate shows a stronger absorption than uncoated silicon substrate under UV irradiation, indicating that 6% Co doped SiO_2 coated silicon substrate could be a best approach for increment in the catalytic activity.

Table 4.1: Average Absorption and Relative Enhancement β_{abs}

Speed RPM	Average absorbance. A=1-R	Relative enhancement. β_{abs}
3000 RPM	0.8	1.067
3500 RPM	0.85	1.133
4000 RPM	0.9	1.2
Uncoated	0.75	1

Based on reflectance the average absorbance was calculated by the formula A=1- R. The relative absorption enhancement, β_{abs} was calculated by formula,

$$\beta_{abs} = \frac{\int_{400nm}^{1200nm} A_{ARC}(\lambda)dy}{\int_{400nm}^{1200nm} A_{bare}(\lambda)dy}$$

Where $A_{UC}(\lambda)$ and $A_{ARC}(\lambda)$ are the average absorption of uncoated sample and coated samples of multilayered SiO_2 nanoparticles over wavelength 400-1200 nm. The β_{abs} listed in table 4.1 were calculated $A_{ARC}(\lambda)$ over $A_{UC}(\lambda)$. As expected the sample with lower reflectance had greater light absorption.

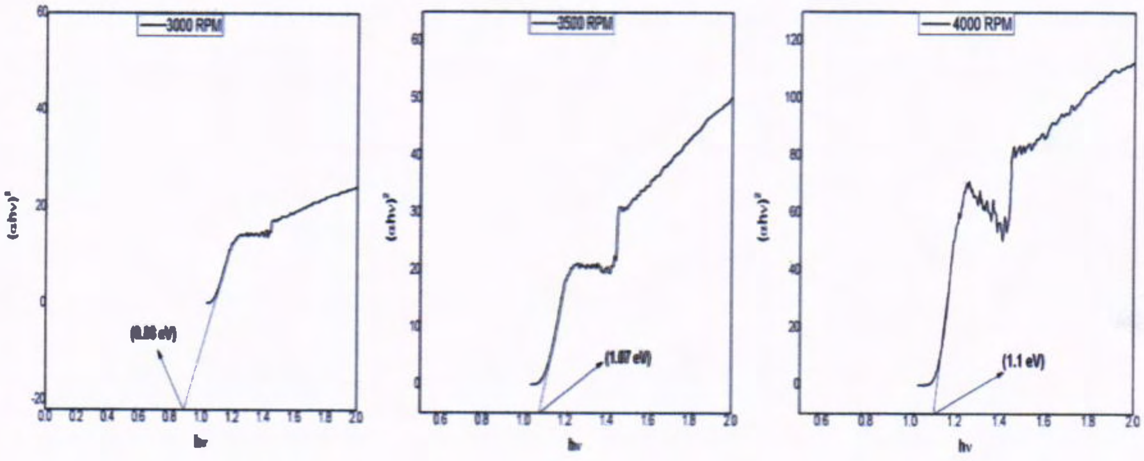

Figure 4.6: **Relation between speed (rpm) and energy band gap (eV)**

Table 4.2: **The Energy Band gap of Coated Samples at Speeds 3000, 3500 and 4000 rpm**

Speed	Bandgap
3000	0.88
3500	1.07
4000	1.1

Fig 4.6 and Table 4.2 shows that by increasing the speed of spin coater the energy band gap was increased. At a speed of 3000 rpm energy band gap was observed to be 0.88 eV, which was increased at the speed of 3500 rpm to a value of 1.07 eV and the energy bandgap was increased to 1.1 eV at speed 4000 rpm.

CONCLUSION

In our experimental work thin films of 6% Co doped SiO_2 nanoparticles were deposited and then analysed the sample with SEM, XRD and UV spectroscopy. Coated and uncoated samples were observed to understand the difference and to conclude the advantages of coated silicon solar cell. This coating on silicon solar cell acted as anti-reflection coating and enhanced the absorption ratio of solar energy. Firstly, the powdered form of 6% Co doped SiO_2 nanoparticles was observed. The results obtained from SEM images showed that the prepared sample consists of spherical particles. Due to the temperature provided to the sample during formation the particles growth increased which caused the aggregation due to which the boundaries of the particles diffused and formed a discrete structure. Then the substrate coated with 6% Co doped SiO_2 nanoparticles was prepared and characterized.

The coated and uncoated samples were examined by x-ray diffraction. For uncoated substrate, sharp peak at the intensity of 13 Wm^{-2}shows the high rate of crystallinity. It is concluded that thinness shows the smoothness and increase in the crystallinity. When the coated substrate was observed then, in the results, the increase in diffraction intensity peaks indicates the improvement in the material's crystallinity so this confirms that the material is having discrete structure which can be used for the adsorption processes or for catalytic purposes.

In the end the coated and uncoated samples were studied by UV-Visible Spectroscopy. The results show that at the speed of 3000 rpm the 6% Co doped SiO_2 nanoparticles coated substrate exhibit low reflectance at the wavelength of 995 nm and exhibits high reflectance at 280 nm wavelength in NIR region and UV region, at the speed of 3500 rpm the 6% Co doped SiO_2 nanoparticles coated substrate exhibits low reflectance at 850 nm and exhibits higher reflectance at 279 nm wavelength in NIR region and UV region, at the speed of 4000 rpm the 6% Co doped SiO_2 nanoparticles coated substrate exhibits low reflectance at 995 nm wavelength and exhibits higher reflectance at 274 nm wavelength in NIR region and UV region. As the reflectance decreases due to the coating of 6% Co doped SiO_2 nanoparticles so the absorption increases which makes it suitable for electronic applications such as solar cells. At speed of 4000 rpm the reflectance is lesser as compare to other samples. Then the uncoated Si substrate was observed and the results show that uncoated substrate exhibits higher reflectance (56%) at 271 nm wavelength in NIR region and UV region. At speed 3000 rpm multilayered coating of 6% Co doped SiO_2 nanoparticles the reflectance spectra show 20% reflectance at speed 3500 rpm the reflectance spectra show the 15 % reflectance and at speed 4000 rpm reflectance spectra shows 10% reflectance. The uncoated sample for comparison shows the greater reflectance which is 25%. The results show that by increasing the speed of spin coater the layer thickness decreases and the reflectance decreases. A multi layered coated sample at speed 4000 rpm was considered for an optimized anti reflection layer. At a speed of 3000 rpm energy band gap was observed to be 0.88 eV, which was increased at the speed of 3500 rpm to a value of 1.07 eV and the energy band gap was increased to 1.1 eV at speed 4000 rpm.

In the end, this work concludes that 6% Co doped SiO_2 coating is beneficial for the Si solar cell because it enhances the absorption of solar light and enhances the efficiency of the solar cell or in other words it decreases the reflection of solar light which increases the output power of Si solar cell.

However, further work on the silicon solar cell can optimize its efficiency. In future, the researchers may use other nanoparticles for the purpose of antireflection coating to observe the enhancement in the efficiency of the silicon solar cell. However, if there will be any advancement in silicon solar cell by using the cheap material which will show higher efficiency then that will be the appreciable work. As we have discussed in our work that the major problem in commercial manufacturing of the solar cell is that most of the time quality is compromised with the cost which is not a good practice and in future, there should be some research to make silicon solar cells with maximum efficiency, good quality and low cost.

References

1. Banyopadhyay, A.K., *Nanotechnology.* New Age International Publishers Edition, **81** 224-2820 (2008).

2. Cao, G., *Nanostructures and Nanomaterials, Synthesis, Properties & Applications.* Imperial college press, **2** 126-137 (2004).

3. D., J., *Winefordner Chemical Analysis* Journal of analytical Chemistry, **71** 12 (1996).

4. (POPIN), U.N.P.I.N., *World Population Prospects: The 2004.* Revision Population Database, (2004).

5. Nemetµµ, G.F., *Beyond the learning curve: factors influencing cost reductions in photovoltaics.* Energy Policy, **34** 3218-3232 (2006).

6. Ramsden, J., *Nanotechnology and its Applications.*Ventus Publishers, 1st Edition, 288 (2009).

7. Queisser, W.S.a.H.J., *Detailed Balance Limit of Efficiency of p-n Junction Solar Cells.* Journal of applied physics, **32** 3 (1961).

8. L. Senesac, T.G.T., *Nanotechnology and its Applications.* Materials Today, 28-36 (2008).

9. (POPIN), U.N.P.I.N., *WorldPopulation Prospects.* The 2004 Revision Population Database, (2004).

10. Agency, I.E., *Energy Utilization.* World Energy Outlook, (2010).

11. Anonymous, *BP Statistical Review of World Energy*, (2010).

12. Interior, U.S.D.o.t., *Technology White Paper on Solar Energy Potential on the U.S. Outer Continental Shelf*, (2006).

13. Green, M.A., *Third generation photovoltaics: solar cells for 2020 and beyond.* Journal of Physics, **14** 65-70 (2002).

14. *Losses and Optimization*, in *PV basics lectures,* (2011).

15. Nelson., J., *The Physics of Solar Cells.* Imperial College Press, first edition, 384 (2007).

16. Kazmerski., L.L., *Solar photovoltaics R&D at the tipping point: A 2005 technology overview.* Journal of Electron Spectroscopy and Related Phenomena, **150** 105-135 (2006).

17. M. Jiang, X.L., *electrical and optical properties of Al–Ti co doped ZnO (ZATO) thin films prepared by RF magnetron sputtering* Journal of Applied physics, **255** 3175-3178 (2008).

18. Huffman, C.F.B.a.D.R., *Absorption and Scattering of Light by Small Particles,* (1998).

19. H. Li, R.F., R.L. Stolk , J. K. Rath,R.E.I.Schropp, *Mechanism of shunting of nano crystalline silicon solar cells deposited on rough Ag/Zn O substrates,.* Journal of Solid State Phenomena, **131-133** 27–32 (2008).

20. M. Boccard, P.C., M.Despeiss, D. Domine, *A.Feltrin,N.Wyrsch,C.Ballif, Substrate dependent stability and interplay between optical and electrical properties in mc-Si: H single junction solar cells.* Solar Energy Materials and Solar Cells, **95** 195–197 (2011).

21. Brendel, R., *Thin-film crystalline silicon mini-modules using porous Si for layer transfer.* Journal of Solar Energy, **77** 969-982 (2004).

22. S. Yae, T.K., T. Kawagishi, N. Fukumuro, H. Matsuda,, *Antireflective porous layer formation on multi crystalline silicon by metal particle enhanced HF etching.*Jornal of Solar Energy, **14** 701 (2006).

23. M. Ben Rabha, B.B., *Enhancement of photovoltaic properties of multi crystalline silicon solar cells by combination of buried metallic contacts and thin porous silicon.* Solar Energy, **84** 486 (2010).

24. J. Bravo, L.Z., Z. Z .Wu ,R .E .Cohen ,M .F .Rubner, *Transparent super hydro phobic films based on silicon nanoparticles.* Journal of physics, **4** 7293-7299 (2007).

25. Van Sark, A.M.a.R.E.I.S., *Solar Spectrum Conversion for Photovoltaics Using Nanoparticles*, 13-31 (2008).

26. Park, K.M., Jung, J.H., Bae, S.I., *Solar Cells; Operating Principles Technology and System Applications.* Mater. Sci., **133** 8416-8419 (2011).

27. Y. Gao, H.N., C. Q. Chen, *Sublimation method of solar cell.* Chem. Phys., **3** 1-141 (2003).

28. Zeng Acosta, R.E., Romankiw, L.T., VonGutfeld, R. J., Thin Sol.Zeng Acosta, R.E., Romankiw, L.T., VonGutfeld, R. J., *Thin Sol. Films.* Journal of Material Sciences, 95-131 (1982).

29. Behrisch, R., *Sputtering by Particle Bombardment.* Journal of Material Science, **47** 1-8 (1981).

30. X.Wang, J.S., *Sol-gel derived durable antireflective coating for solar glass* J. Sol–Gel Sci. Technology, **53** 322–327 (2010).

31. M. Ben Rabha, B.B., *improvement of photovoltaic properties of multi crystalline silicon solar cells by combination of thin porous silicon and buried metallic contacts.* Solar Energy, **84** 486 (2010).

32. S. Yae, T.K., T. Kawagishi, H. Matsuda, N. Fukumuro,, *Antireflective porous layer formation on multi crystalline silicon by metal particle enhanced HF etching* Solar Energy, **14** 80-701 (2006).

33. Brendel, R., *Thin-film crystalline silicon mini-modules using porous Si for layer transfer.* Journal of Solar Energy, **106** 20149-20154 (2007).

34. C.H. Lee, W.H.C., K.M.Lee , W.F. Hsieh, J.M. Wu, J. Mater., *Introduction of TiO2 interfacial layer.* Journal of Material Sciences, **19** 5114-5119 (2014).

35. Escarre, J., *Geometrical Light Trapping of High Effiecient Thin Film Silicon Solar Cell.* Journal of Solar Energy Materials and Solar Science, **98** 1-502 (2011).

36. Yongxiang Zhao, F.C., Qiang Shen, and Lianmeng Zhang, *Optimal structure of light trapping in thin-film solar cells: dielectric nanoparticles or multilayer antireflection coatings.* Journal of Material Sciences, **20** 11121-11136 (2014).

37. Khezami, L., *Theoretical and Experimental Analysis of porous Silicon Surface Treatement in Multilayer coating.* Journal of Applied Surface Science, **119** 19272-19278 (2015).

38. al., K.S.e., *Experimental Study of Flat Light Scattering Substrate of Silicon Solar Cell.* Journal of Solar Energy Materials and Solar Science, **101** 193-199 (2012).

39. Yoon-Ho Nam, H.-D.U., Kwang-TaePark, Sun-MiShin, Jong-WookBaek and Min-Joon Park, *Multi-layer Coating of SiO2 Nanoparticles To Enhance Light Absorption by Si Solar Cells.* Journal of Applied Surface Science, **60** 1944-1948 (2012).

40. Y. Yang n, S.P., H. Mehrvarz, M.A. Green, *Plasmonic degradation and the importance of over-coating metal nanoparticles for a plasmonic solar cell.* Journal of Solar Energy Materials and Solar Science, **8** 41-43 (2013).

41. Pennanen, A., *Enhancing Silicon Solar Cell Efficiency With Metal Nanoparticles.* Journal of Physics, **48** 064501 (2009).

42. Y. Yang n, S.P., *Enhancement of Light trapping of Silicon Solar Cell.* Journal of Applied Surface Science, **261** 1-916 (2012).

43. Miriam Israelowitz, J.A., Tao Cong, *Spin Coated Plasmonic Nanoparticle Interfaces for Photocurrent Enhancement in Thin Film Si Solar Cells.* Journal of Physical Society, **135** 1845-1852 (2013).

44. Y. Nasuno, M.K., A .Matsuda „ *Effects of substrate surface morphology onmicrocrystalline silicon solar cells* Japanese Journal of Applied Physics, **81** 303-305 (2001).

45. H. Sakai, T.Y., T.Hama, Y.Ichikawa „ *Effects of surface morphology of transparent electrode on the open-circuit voltage in a-Si :H solar cells* Japanese Journal of Applied Physics, **29** 630-635 (1990).

46. Y. Zhang, N.S., B. Jia, S. Fan, M. Gu, *Towards ultra-thin plasmonic silicon wafer solar cells with minimized efficiency loss.* Journal of Sciences, **10** 4939 (2014).

47. Chang, C.H., *Enhancing dye-sensitized solar cell efficiency by anode surface treatment.* Journal of Thin Solid Films, **2014** (2014).

48. D.R. Uhlmann, T.S., K. Davidson, J.M. Boulton,G.Teowee,, *Sol–gel derived coating son glass* J. Non-Cryst. Solids, **218** 113-122 (1997).

49. Schulz, U., *Wide band antireflection coatings by combining interference multi- layers with structured to players* Opt. Express, **17** 8704-8708 (2009).

50. M. Faustini, L.N., C .Boissière ,P. Innocenzi ,C. Sanchez, D. Grosso, *Hydrophobic ,antireflective, self-cleaning ,and anti fogging sol–gel coatings: an example of multifunctional nanostructured materials for photovoltaic cells.* Journal of Material sciences, **22** 4406-4413 (2010).

51. H. Föll, M.C., J. Carstensen, G. Hasse,, *Morphology of porous Silicon.* Materials Science and Engineering, **39** 93-141 (2002).

52. Stuart, H., *Island size effects in nanoparticle-enhanced photodetectors.* Journal of Physics., **73** 3815-3817 (1998).

53. Schaadt, *Enhanced semiconductor optical absorption via surface plasmon excitation in metal nanoparticles.* Appl. Phys., **86** 063106 (2005).

54. Pillai, C., , Green. M.A., *Surface plasmon enhanced silicon solar cells.* J. Appl. Phys., **101** 093105 (2007).

55. A., C.K.R.P., *Plasmonic solar cells.* Optics Express, **16** 21793-21800 (2008).

56. HarshaRohira, A.G.B., AnuragPassi,, *X-Ray diffraction.* Journal of Appleid physics, **5** 166-173 (2012).

57. Adaskaveg, M.D.D.J.E., *Introduction to Scanning Electron Microscope.* Journal of Applied Physics, **97** 3-28 (1997).

58. L.F, B.H.G.p., *SEM analysis.* Levine Science, **134** 178-192 (1991).

59. A. Lussier, J.D., Y. U. Idzerda, S. B. Oagle, S. R. Shinde, R. J. Choudary, T. Venkatesam,, *UV Spectroscopy.* Journal of Applied Physics, **61** 7190 (2004).

60. Sharma, Y.R., *Elementary Spectroscopy.* S. Chand Publisher, (2010).