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END OF STUDY MEMORY, WITH A VIEW TO OBTAINING THE

DIPLOMA OF OPTION PHYSIQUE ENERGITIQUE

Topic

Materials studies apply on photovoltaic panel

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Abstract

In the last years all researchers and scientist in the world focus at the renewables energy and specially at the solar or photovoltaic one and with our sahraian nature in Adrar we try to focus at this method in this Worde we will study some physical properties and influence of time and solar seals and we will use characterization technique lick:

$XRD: X - ray\ diffraction$

$HE\ (Hall\ Effect)$

With these techniques we can study the structural, electrical magnetic properties

Résumé

Au cours des dernières années, tous les chercheurs et scientifiques du monde se concentrent sur les énergies renouvelables et spécialement sur l'énergie solaire ou photovoltaïque et avec notre nature saharienne en Adrar, nous essayons de nous concentrer sur cette méthode dans ce Word, nous étudierons certaines propriétés physiques et l'influence de temps et sceaux solaires et nous utiliserons la technique de caractérisation lécher :

XRD : diffraction des rayons X

HE (effet Hall)

Avec ces techniques, nous pouvons étudier les propriétés structurelles, électromagnétiques

Dedication

       All words cannot express gratitude, love, respect, gratitude, it is simply that: I dedicate this master thesis:

       To My Loving Mother: You represent for me the source of tenderness and the example of devotion which has not ceased to encourage me. You have done more than a mother can do to ensure that her children follow the right path in their lives and studies.

       To My Dearest Father: No dedication can express the love, esteem, dedication and respect I always have for you. Nothing in the world is worth the efforts made day and night for my education and my well-being. This work and the fruit of your sacrifices that you have made for my education and training over the years.

<div align="center">

"May God protect them"

To the smile of my heart;

To my grandmother;

To my dear brothers;

To my dear sisters;

To my dear nieces and nephews;

To my very dear friends;

To all my teachers since my early years of study.

To those who have helped me from far and near.

To all those who feel dear to me and whom I forgot to mention

</div>

Dedication

I dedicate this work:

To my parents, my brothers, my sisters, and my young daughter Maryam. I

thank my husband very much for the support and all my friends in the end I

dedicate the work to THE TOUDJI FAMILLY

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List of Abbreviations and Nomenclatures:

Pv: photovoltaic
EVA: Ethylene vinyl acetate
Bc: Conduction band
Bv: valence drain
Si: Silicon
Ge: Germanium
Cd: Cadmium
Te: Tellurium
In: Indium
Ga: Gallium
E_{Ph} : Photon energy (J)
H: Planck's constant (J.s)
V: Frequency (Hz)
λ: The wavelength (μm)
Q: The charge of the electron (C)
K: Boltzmann's constant (J / K)
T: The temperature in (K)
V: The voltage at the terminals of the photovoltaic cell (V)
I: The current delivered by the solar cell (A)
Iph: The current photo (A)
Is: The saturation current in (A)
N: The non-ideality factor of the junction
Rs: Series resistance of the module (Ω)
Rsh: Shunt resistor which models the leakage currents of the junction (Ω)
Eg The band gap energy
α : absorption coefficient
P: Phosphorus
B: Boron
hV : Photons energy
SiO_2: Silicon dioxide.
UV : ultraviolet
$C-Si$: Crystalline-Si
ND : donor atoms
NA : acceptor atoms
$XRD: X-ray\ diffraction$
SEM.: scanning electron microscopy.

General Introduction

In recent decades, our planet has experienced an increase in the rate of greenhouse gas emissions which has been the result of considerable advancement in technology and industry. This has had as a negative consequence, climatic upheaval and notable natural disasters. Resorting to the development of non-polluting energies then appeared as the ultimate solution to this problem.

Today, different forms of renewable energy under different technologies (solar, wind, hydropower, and biomass) offer great flexibility and reliability satisfactory to alleviate the energy deficit due to increased demand. It is in this context that the photovoltaic energy sector constitutes a relevant response to the energy issue

Among all the technologies allowing the production of renewable energy, our work will focus on the solar field, and more specifically on the photovoltaic line. The reason is that PV cells have a competitive advantage

In the first chapter, we detail, first of all, the motivations which pushed us towards the choice of this theme by briefly addressing the history of photovoltaic. Then we present the general operating principle of a PV solar cell and we give the main types of the latter before defining the photovoltaic parameters from which we evaluate the cell performance.

In the second chapter we will deal with the components of the photocell and discuss o the electrical characteristics of a photovoltaic cell in addition to its structural and physical characteristics. We will talk about each component inside the cell separately, and at the end of the chapter we will talk about the degradation of a photovoltaic module and its lifetime testing.

To study the effect of grinding conditions on the structural, fine and magnetic properties of the samples treated materials a, we have X-ray diffraction, this technique Introduced in Chapter 3. The experimental results obtained by X-ray will be discussed at the end of this chapter

CHAPTER I:

Generality about the photovoltaic cell

I   Introduction

In the last years, the rapid growth of development and the drive to expand the economy, society demands more energy. Coupled with the realization that unsustainable energy production can have a detrimental effect on our environment. Solar energy is the most prolific method of energy capture in nature. The economic drive to make solar cells more cost effective and efficient has driven developments in many different deposition technologies, Solar energy is at least utilized in 4 different ways in our daily lives, and this ranges from heating water to producing electricity.

Photovoltaic (PV) technologies are at the top of the list of applications that use solar power, and forecast reports for the world's solar photovoltaic electricity supplies state that in the next 12 years, PV technologies will deliver approximately 345GW and 1081 GW by 2020 and 2030, respectively [1].

photovoltaic cell is a device that converts sunlight into electricity using semiconductor materials. Semiconductor materials enable electron flow when photons from sunlight are absorbed and eject electrons, leaving a hole that is filled by surrounding electrons. This phenomenon of electron flow by photon absorption is called the photovoltaic effect. The PV's cell directs the electrons in one direction, which forms a current [2]; the amount of current is proportional to the number of absorbed photons, which means that PV solar cells are a variable current source.

I.1 History of photovoltaics solar energy

The first photovoltaic cell (or photocell) was developed in the United States in 1954 by researchers at Bell Laboratories, who discovered that the Silicon photosensitivity could be increased by adding "impurities". This is a technique called "doping" that is used for all semiconductors [3]. But despite the interest of scientists over the years, this is than during the run to space that the cells left the labs [4]. In Indeed, solar cells are the ideal solution to meet the needs of electricity on board satellites, as well as in any isolated site. But it has a great way in the history, and this followed give some important dates in the history of photovoltaics:

1839: Discovery of the photovoltaic effect by Alexander Edmond Becquerel

1883: 1st "real" PV cell by Charles Fritts with a yield of 1%

1905: Explanation of the photovoltaic effect by Einstein

1954: 1st Si cell with 5% yield, by Chaplin, Fuller and Pearson Bells Laboratories
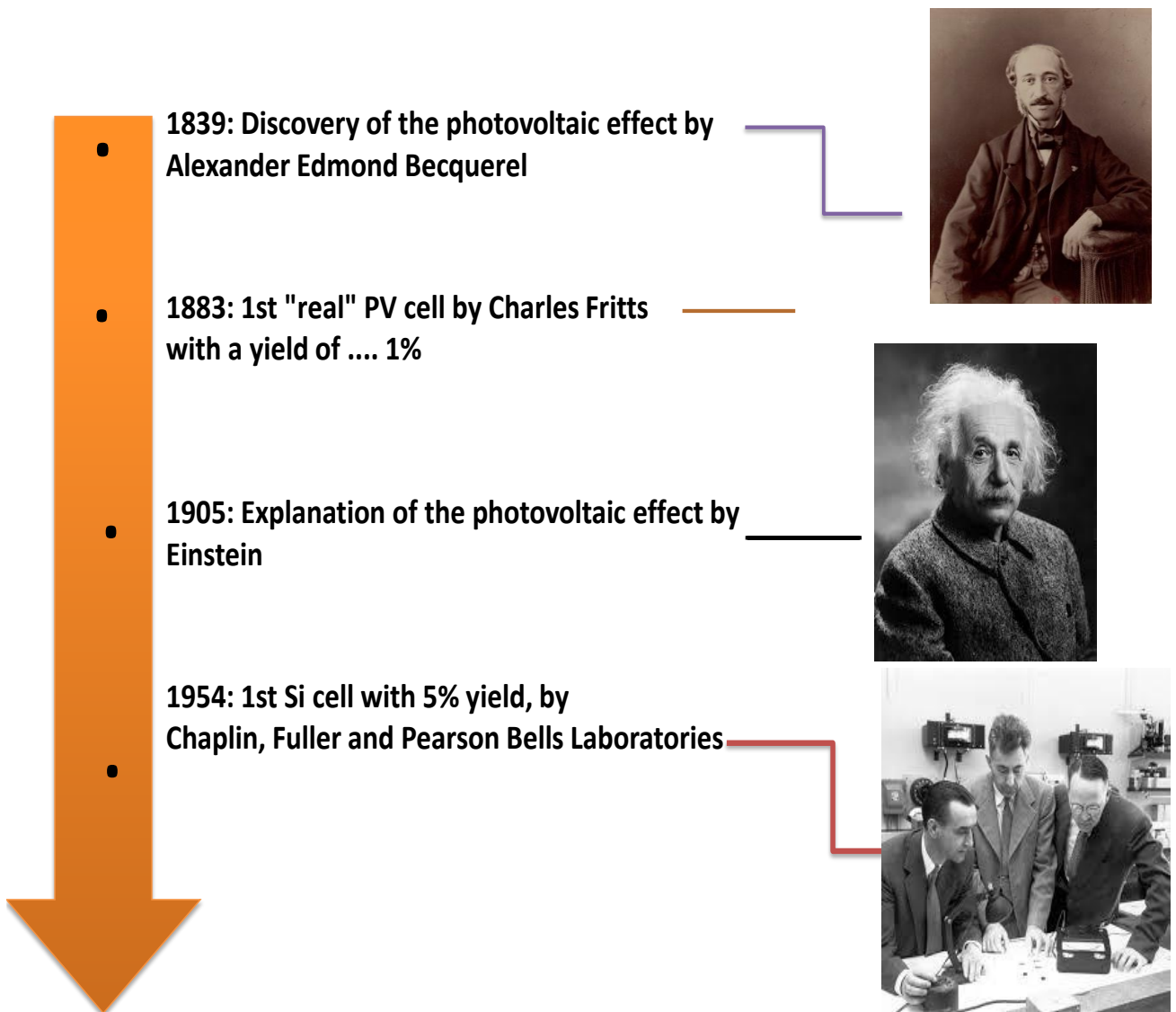
- **1959: First American scientific satellite fitted with PV modules - first applications spatial**
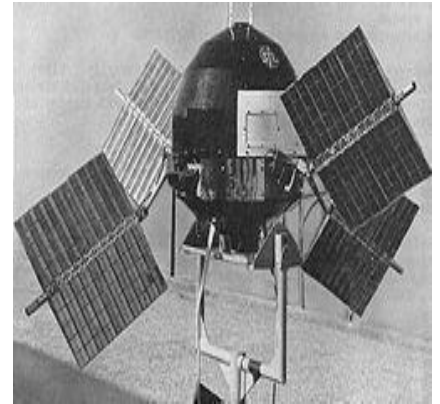
- **• 1990s:**
  • Appearance of the first hybrid cells and organic
  • Solar quality silicon development
  • Growth of the PV industrial sector (Germany, Japan, ...)

- **• 2000s :**
  • Rise of the industry in France
  • Diversification of the offer of modules / technologies
  • Optimization of production methods

I.2   Solar Radiation

The sun emits electromagnetic radiation included in a band of wavelength varying from 0.22 μm to 10 μm Figure (1) shows the variation in the spectral energy distribution. The energy associated with this solar radiation breaks down approximately as follows:

- 9% in the ultraviolet band (< 0.4 μm),

- 47% in the visible band (0.4 to 0.8 μm),

- 44% in the infrared band (> 0.8 μm) [5]

The Earth's atmosphere receives this radiation at an average power of 1.37 kilowatt per square meter (kW / m2), more or less 3%, depending on whether the earth moves away or approaches the sun in its rotation around that -this. However, the atmosphere absorbs part of it, so the amount of energy reaching the earth's surface rarely exceeds 1200 W / m2. The rotation and tilt of the earth also cause the energy available at a given point to vary with latitude, time and season. Finally, clouds, fog, atmospheric particles and various other meteorological phenomena cause hourly and daily variations which sometimes increase, or decrease the solar radiation and make it diffuse.
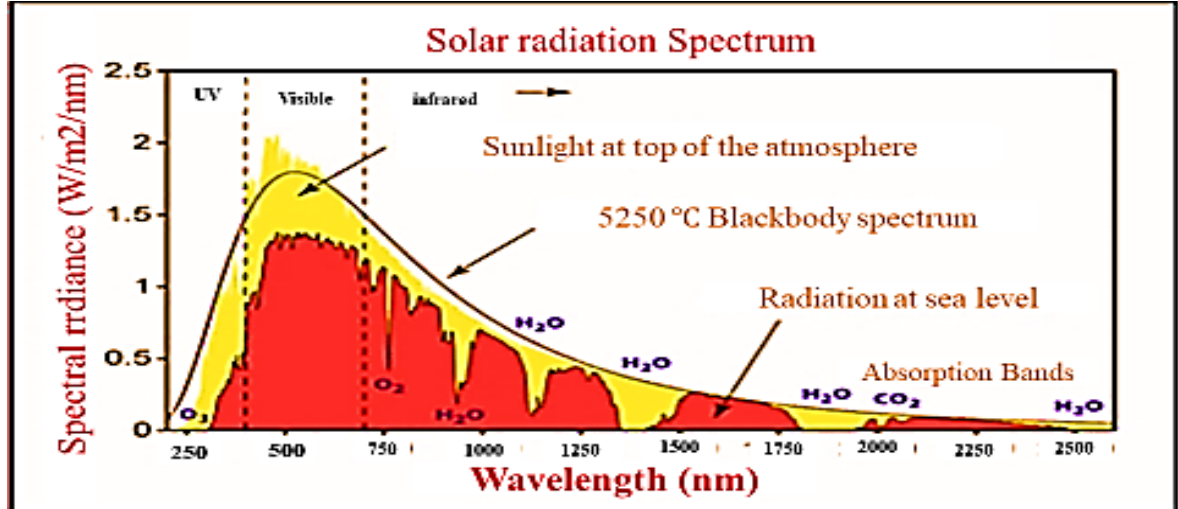
FigureI.1: Influence of wavelength at Irradiance

Photons are characterized by their frequency or by their wavelength, as well as by their energy. These parameters are related in the follow equation:

$$C = \lambda \, \nu \tag{1}$$

Where C is the speed of light (3×10^8 m/s), ν is the frequency in Hz and λ is the wavelength, in meters. On the other hand

$$E = h\nu = h\frac{C}{\lambda} \tag{2}$$

Where E is the energy of a photon (in Joule, J) h is Planck's constant (6.626×10^{-34}Js). The same equation can be expressed in a simplified form if the constants are replaced by their value:

$$E_{Photon}(eV) = 1240 / \lambda(nm) \tag{3}$$

I.3. Basic Semiconductor Physics

Semiconductors are the materials having electrical properties in between of conductor and a good insulator. Undoped or pure semiconductor is known as intrinsic semiconductor [6].
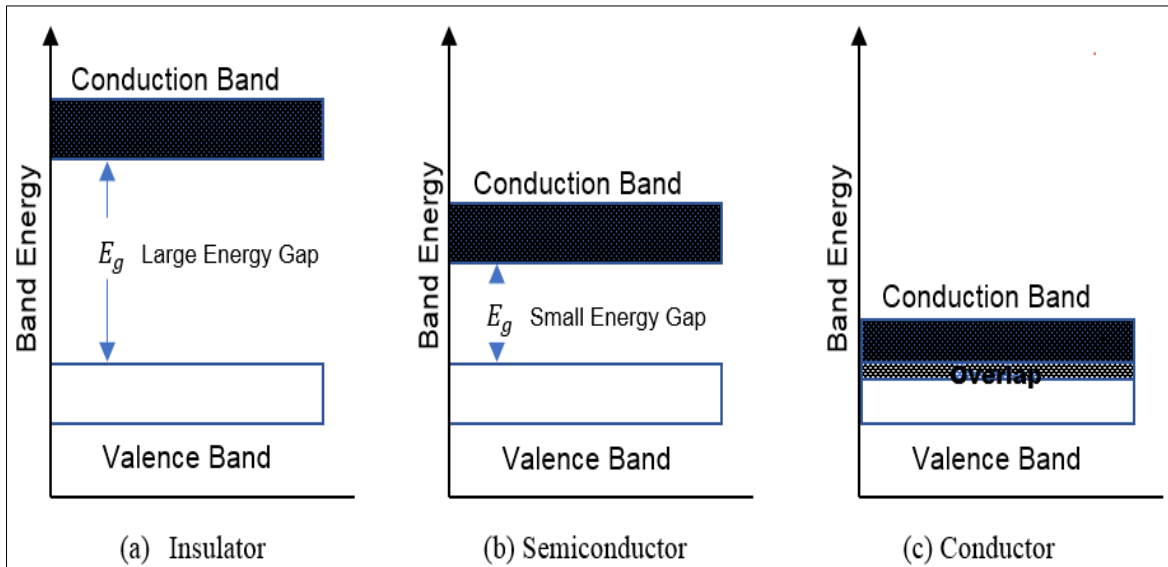
Figure I.2: Energy diagrams of different type of materials.

The semiconductor in its pure form is not a good insulator and nor a good conductor. In terms of energy bands, semiconductors have an empty conduction band and almost filled valence band having very small forbidden energy gap as shown in Figure.2(b). At 0K temperature conduction band have no electrons whereas valence band is completely filled. With the increase in temperature, the width of the forbidden gap is decreased. Therefore, some of the valence electrons jump into the conduction band. It means that the conductivity of a semiconductor is increased with

temperature [6]. Semiconductors are characterized by atoms with four valence electrons. More common semiconductor materials are given in Figure 3.

Figure I.3: Common semiconductor material

Therefore, we shall use Crystalline-Si (C-Si) as an example to explain the concepts of semiconductor physics that are relevant to solar cell operation. The central semiconductor parameters that determine the design and performance of a solar cell are:

- Concentrations of doping atoms, which can be of two different types: donor atoms, which donate free electrons or acceptor atoms, which accept electrons. The concentrations of donor **(ND)** and acceptor atoms **(NA)** determine the width of the space-charge region of a junction [8].
- The mobility and the diffusion coefficient **D** of charge carriers is used to characterize the transport.
- The lifetime **t** and the diffusion length **L** of the excess carriers characterize the recombination generation processes.
- The band gap energy Eg, and the complex refractive index **n**, where **k** is linked to the absorption coefficient **α**, characterize the ability of a semiconductor to absorb electromagnetic radiation.

Table shows the gap width values for other materials. Another parameter of interest, especially to describe the operation of solar cells, and which we have already mentioned when discussing the radiative generation recombination mechanisms, is the absorption coefficient (**α**). This parameter

describes how easily the semiconductor absorbs a photon and creates an electron-hole pair, eh. It depends on the value of the semiconductor and nature, indirectly or directly from the bandgap.

Material	Bandgap (eV)
Si	1.11
Sic	2.60
CdAs2	1.00
CdTe	1.44
Cdse	1.74
Cds	2.42
GaAs	1.40

Table I.1: The materials indicated in bold are the most used in photovoltaic cells.

I.4 Silicon doping

Doping is a method for performing the P-N junction. It consists of introducing impurities into an intrinsic crystal to modify these electrical properties. The doped semiconductor is then called "extrinsic semiconductor". There are two types of doping: type N (Negative) and type P (Positive).

I.4.1 N-type doping

N-type doping consists in adding a phosphorus atom within the structure crystalline silicon. Phosphorus with 5 electrons on its electronic layer external will associate with 4 silicon atoms, thus leaving an electron free: This addition has the effect of giving the crystal structure a negative overall charge
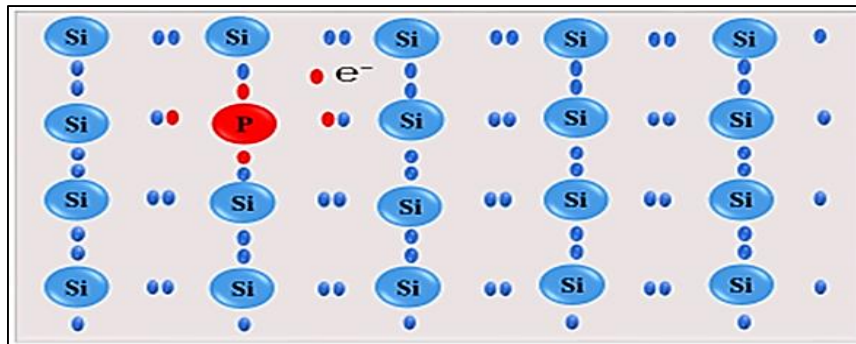
Figure I.4: N-type doping

I.4.2   P-type doping

P-type doping consists in adding a boron atom within the structure crystalline silicon. Boron with 3 electrons on its outer electronic layer will to associate with 4 silicon atoms, thus leaving a hole free: This addition has the effect of giving the crystal structure a positive global charge [9].
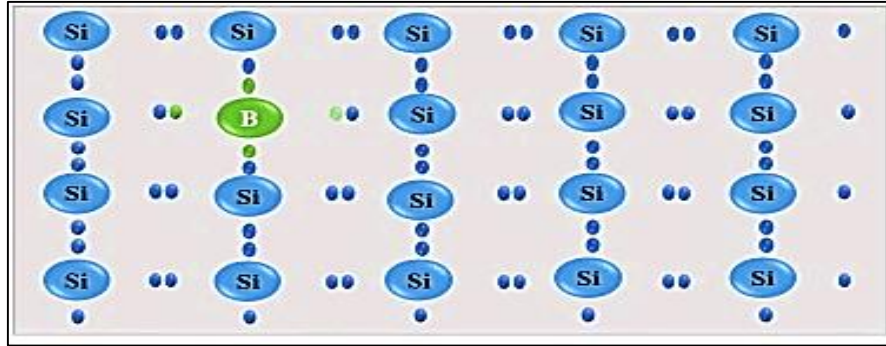
Figure I.5: P-type doping

I.4.3   P-N Junction

The P-N junction is the basis of most semiconductor applications. It is created by bringing a P-type semiconductor into contact with an N-type semi-conductor. In the contact zone, the free electrons of the N into the P and recombine with the holes. Likewise, the holes in segment P penetrate into segment N and recombine with the electrons. This phenomenon is called diffusion. As a result, at the segment transition, the appearance of an area free of mobile charges called the Transition Zone (also called Space Charge Zone or Depletion Zone), where only the atoms of fixed impurities (acceptor ions in the P segment, donor ions in the N segment) and atoms of neutral semiconductors. The charges formed by the fixed ions are at the origin of an electric field in the transition zone, and by the same one of a potential difference Vo (called potential barrier) at the terminals of this zone. This area has a high impedance. The electric field E tends to maintain the majority carriers in their respective regions and thus opposes the cause which gives rise to it, which leads to a state of equilibrium.
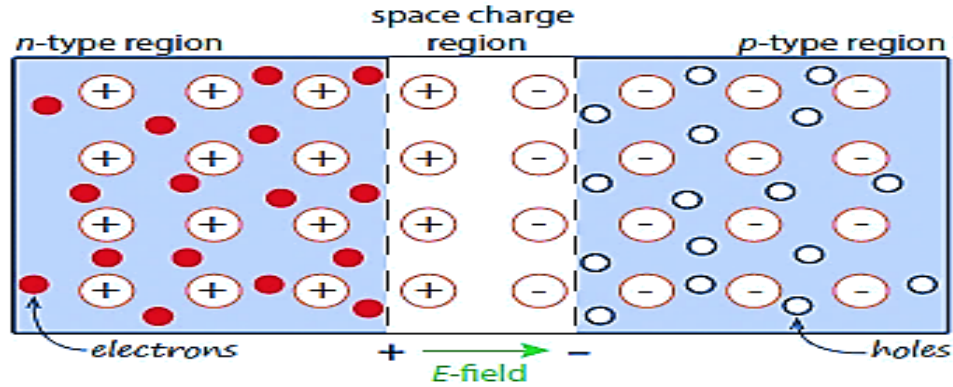
Figure I.6: P-N junction

However, the electric field E does not prevent the passage of minority carriers present in P and N type segments ("saturation" current Is). This movement is however balanced by the majority carriers who have the energy to cross the potential barrier. [10]

I.5   The Working Principle of a Solar Cell

The semiconductor material in a PV cell absorbs light (photons), and this displaces electrons to form pairs of electrons and holes, which are guided in one direction, creating a current. The semiconductor is doped to be a p-n junction with a potential difference, which will drive current flow vertically through the cell in one direction, so it can be harvested as electricity. The diffusion length is one of the important factors that affect the efficiency of the solar cell. Photons must have energy ($h\mathcal{V}$) equal to or more than the energy band gap (E gap) of the semiconducting material [11].

In summary, a photovoltaic cell is a device that converts sunlight into electricity using semiconductor materials; it has the same working principle as a semiconducting diode [12].
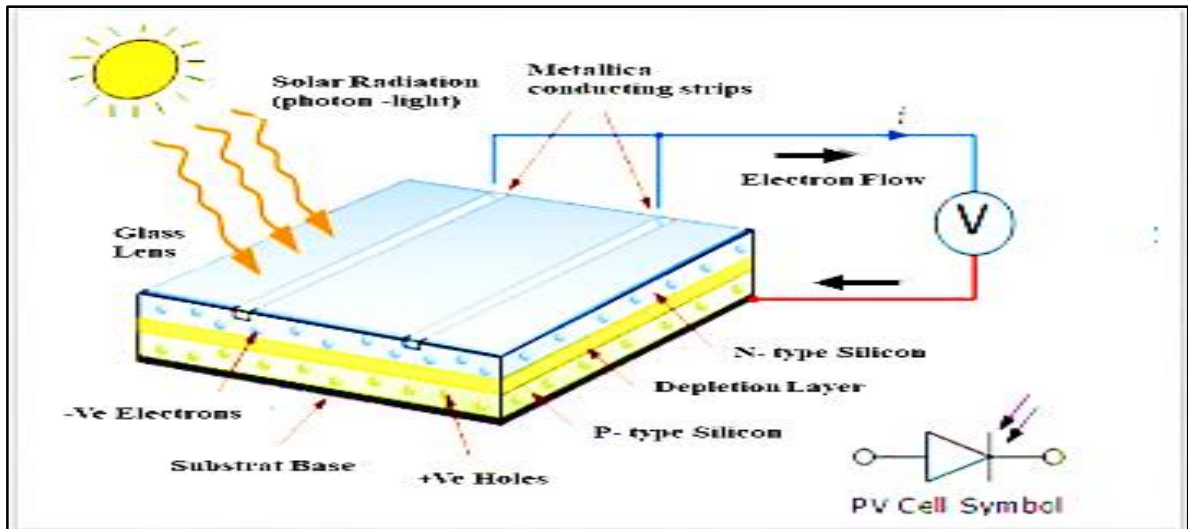
Figure I.7: Solar Cell

I.6   The Different Types of Photovoltaic Cells

Photovoltaic cells consist of semiconductors based on silicon (Si), germanium (Ge), selenium (Se), cadmium sulfide (Cds), cadmium telluride ($CdTe$) or gallium arsenide ($GaAs$). Silicon is currently the most used material to make photovoltaic cells, because it is very abundant in nature. It is found in nature in the form of silica stone. Silica is a chemical compound (silicon dioxide) and a mineral with the formula SiO_2. It is the main constituent of detrital sedimentary rocks [13]
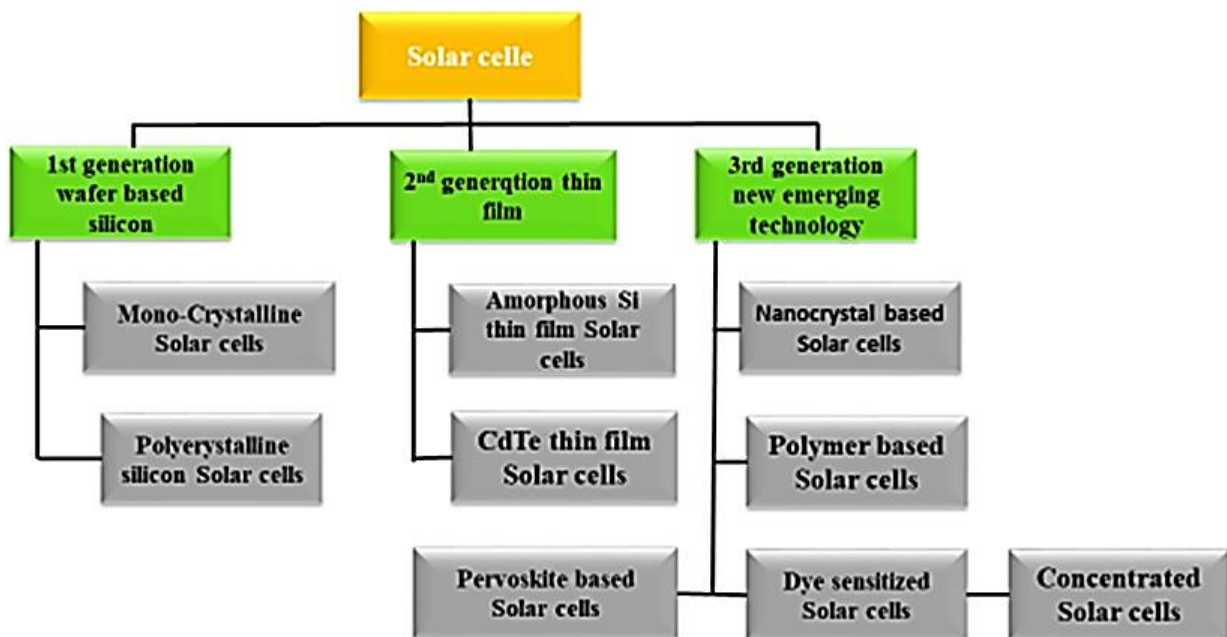
Figure I.8: Various types of solar cell technologies and current trends of development

I.6.1 Monocrystalline silicon solar cells

These types of solar cells belong from first-generation solar cell technologies. The width of the wafer used in these types of solar cells is up to $200\mu m$. The cell slice is cut from a pure silicon bar, which allows them to more efficiently converting the sunlight radiation energy into electrical energy. Silicon used in monocrystalline is single-crystal silicon. The complete cell is aligned in the same direction, so when the light falls on the cells at the accurate direction, they are very efficient.

In a sunny day, photovoltaic cells work best with the sunlight directly falls on accurate direction. They are absorbing most of the solar radiation, so they have a uniform blacker color. Cost of the production of these types of solar cells is more than in the comparison of a polycrystalline cell. In a comparison of polycrystalline, monocrystalline is the most efficient type of photovoltaic solar cells [14].
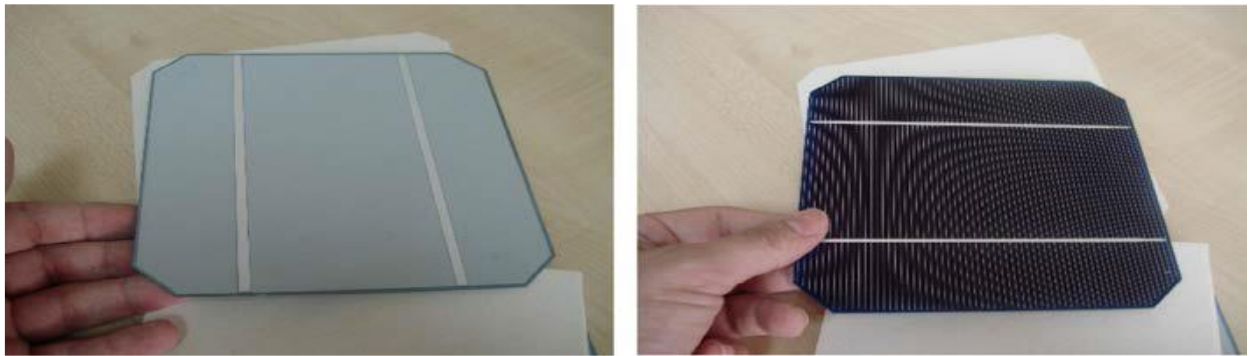
Figure I.9: Back and front of a monocrystalline silicon cell .

I.6.2 Polycrystalline silicon solar cells

Polycrystalline PV modules are generally composed of a number of different crystals, coupled to one another in a single cell. The processing of polycrystalline Si solar cells is more economical, which are produced by cooling a graphite mold filled containing molten silicon. Polycrystalline Si solar cells are currently the most popular solar cells. They are believed to occupy most up to 48% of the solar cell production worldwide during 2008 [15]. During solidification of the molten silicon, various crystal structures are formed. Though they are slightly cheaper to fabricate compared to monocrystalline silicon solar panels, yet are less efficient ~12% - 14% [16].

Figure I.10: Polycrystalline silicon cell

I.6.3   Amorphous silicon cells

Amorphous silicon   solar cells belong from a thin-film solar cell. In these types of solar cells, one or more layers of photovoltaic materials are deposit on a substrate. In comparison with other technologies, they have low manufacturing cost. To make thin-film photovoltaic solar cells, manufacturers spray a layer of silicon on a substrate. They are produced by placing one or more thin layers of photovoltaic composite on a substrate. Thin film photovoltaic solar cells are different from other types; they are also more flexible than other types. It can be put onto different surfaces curved and straight [17]
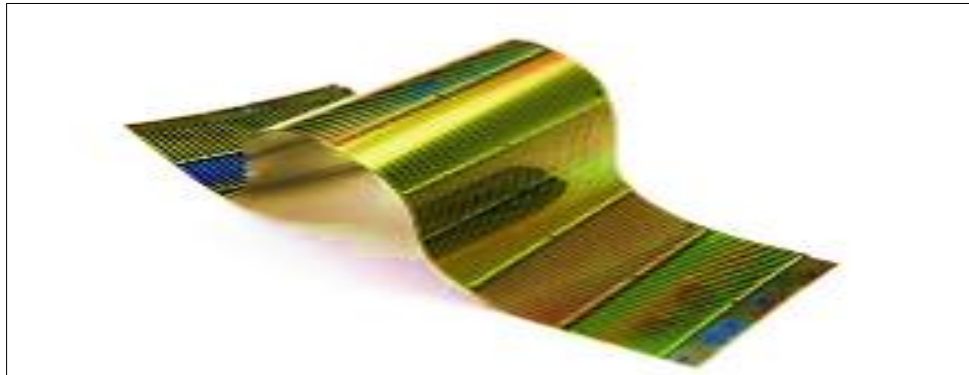
Figure I.11: Amorphous silicon.

I.7   The manufacture of photovoltaic cells

I.7.1   Production of silicon wafers

Monocrystalline and multi-crystalline silicon wafers can be produced.   we illustrate the production process of monocrystalline silicon wafers. The lowest quality of silicon is the so-called metallurgical silicon, which is made from quartzite. Quartzite is a rock consisting of almost pure silicon dioxide (SiO2). For producing silicon, the quartzite is molten in a submerged-electrode arc furnace by heating it up to around 1900°C, as illustrated in FigureI.12. Then, the molten quartzite is mixed with carbon. As a carbon source, a mixture of coal, coke and wood chips is used. The carbon then starts reacting with the SiO2. Since the reactions are rather complex, we will not discuss them in detail here [18] The overall reaction however can be written as:

$$Si + 2C \rightarrow Si + 2CO \qquad (1)$$

As a result, carbon monoxide (CO) is formed, which will leave the furnace in the gas phase. In this way, the quartzite is purified from the silicon. After the reactions are finished, the molten silicon that was created during the process is drawn off the furnace and solidified. The purity of metallurgic silicon, shown as a powder in Fig.is around 98% to 99% [19]
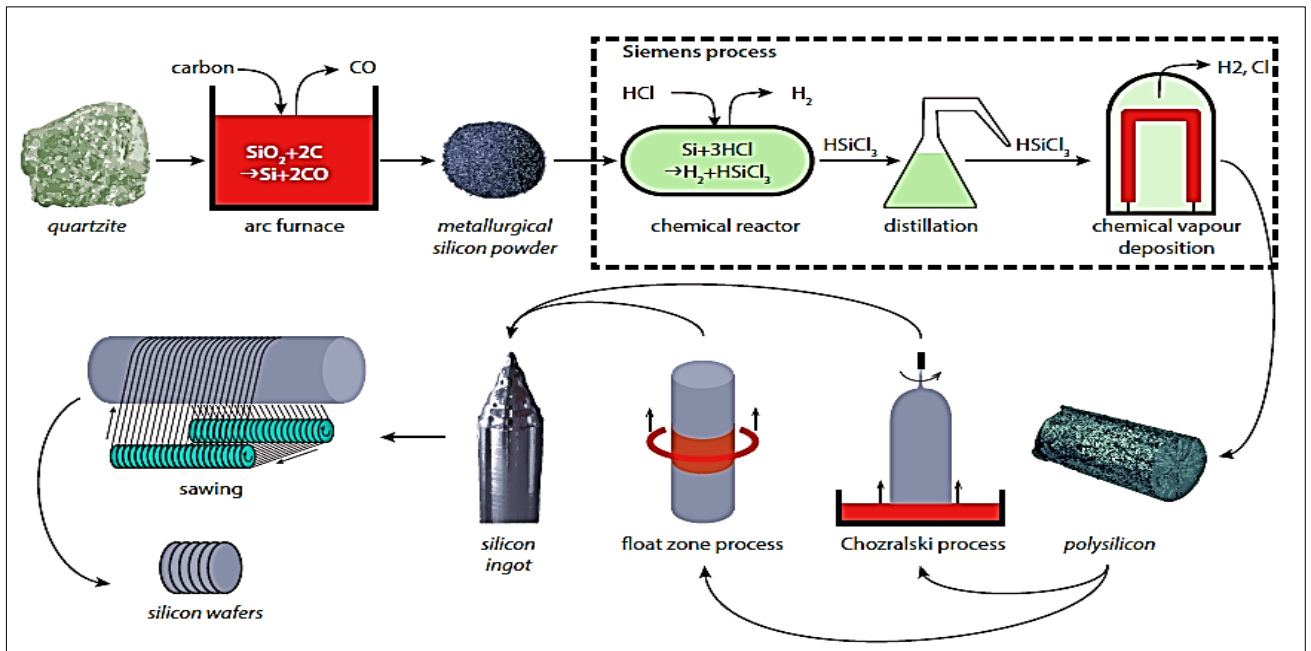
Figure I.12: Illustrating the production process of monocrystalline silicon wafers.

The silicon material with the next higher level of purity is called polysilicon. It is made from a powder of metallurgical silicon in the Siemens process. In the process, the metallurgical silicon is brought into a reactor and exposed hydrogen chloride (HCl) at elevated temperatures in presence of a catalyst. The silicon reacts with the hydrogen chloride [20]

$$Si + 3HCl \rightarrow H_2 + HSiCl_3 \hspace{2cm} (2)$$

Leading to the creation of trichlorosilane ($HSiCl$3). This is a molecule that contains one silicon atom, three chlorine atoms and one hydrogen atoms. Then, the trichlorosilane gas is cooled and liquefied. Using distillation, impurities with boiling points higher or lower than $HSiCl$3 are removed. The purified trichlorosilane is evaporated again in another reactor and mixed with hydrogen gas. There, the trichlorosilane is decomposed at hot rods of highly purified Si, which are at a high temperature in between around 850°C and 1050°

The Si atoms are deposited on the rod whereas the chlorine and hydrogen atoms are desorbed from the rod surface back in to the gas phase. As a result, a pure silicon material is grown. This method of depositing silicon on the rod is one example of chemical vapor deposition. As the exhaust gas still contains chlorosilanes and hydrogen, these gasses are recycled and used again: Chlorosilane is liquefied, distilled and reused. The hydrogen is cleaned and thereafter recycled back in to the reactor. The Siemens process consumes a lot of energy.

Not only monocrystalline silicon ingots, but also multicrystalline silicon ingots, which consist of many small crystalline grains, can be fabricated This can be made by melting highly purified silicon in a dedicated crucible and pouring the molten silicon in a cubic shaped growth crucible. There, the molten silicon solidifies in to multi-crystalline ingot in a process called silicon casting. If both melting and solidification is done in the same crucible [21]

It is referred to as directional solidification. Such multicrystalline ingots can have a front surface area of up to 70 cm2 and a height of up 25 cm. Now, as we know how to produce monocrystalline and multicrystalline ingots we will discuss how to make wafers out of them.

The process that is used to make the wafers is sawing, as illustrated in Fig. Logically, sawing will damage the surface of the wafers. Therefore, this processing step is followed by an polishing step. The biggest disadvantage of sawing is that a significant fraction of the silicon is lost as kerf loss, which usually is determined by the thickness of the wire or saw used for sawing. Usually, it is in

the order of 100 μm. As typical wafers used in modern solar cells have thicknesses in the order of 150 μm up to 200 μm, the kerf loss is very significant [22].

I.7.2   Fabricating solar cells

In the illustrations used there, both the p-doped and n-doped regions have the same thickness. This is not the case in real c-Si devices. For example, the most conventional type of c-Si solar cells is built from a p-type silicon wafer, as sketched in Fig. However, the n-type layer on the top of the p-wafer is much thinner than the wafer; it typically has a thickness of around 1 μm. Often, this layer is called the emitter layer. the whole wafer has typically thicknesses in between 100 and 300 μm. Because of the Lambert-Beer law, the intensity if light inside the silicon bulk decays exponentially with the depth.
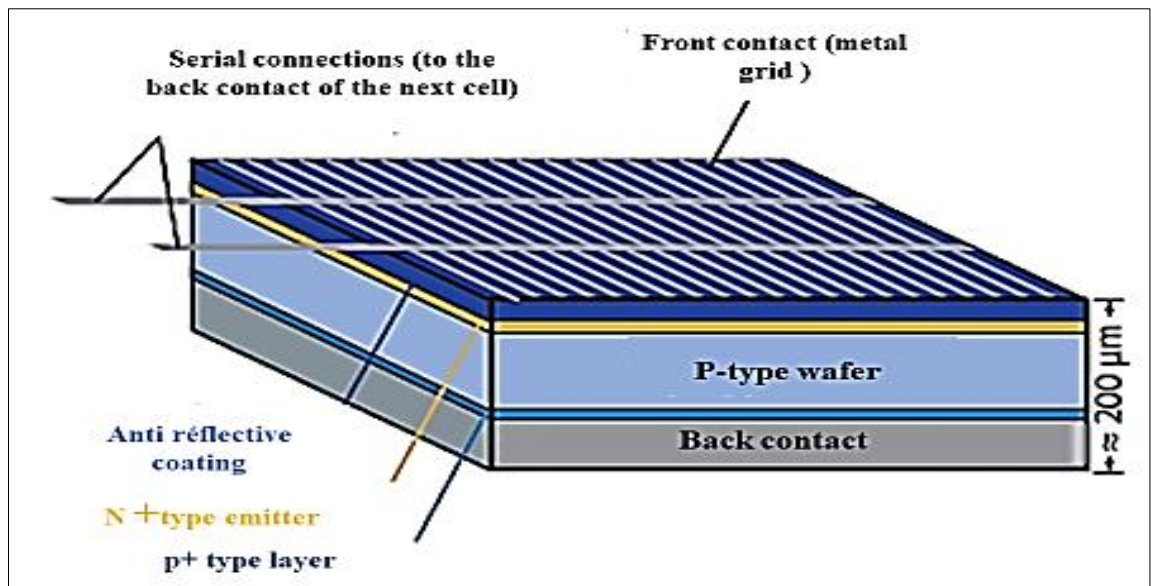
Figure I.13: Scheme of a modern crystalline silicon cell.

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CHAPTER II:

Composition and Characteristics of a photovoltaic module

II   Introduction

Silicon was discovered in 1824 by J.J. Berzelius in Stockholm, Sweden. It is, after carbon, the most abundant element on earth. It is generally found as silicate in many rocks, clays and soils. Silicon is obtained by reducing silica (sand, SiO2) with carbon. A subsequent zone fusion gives a purer element for applications requiring high purity silicon (for example semiconductors)

Silicon has 4 electrons on their peripheral layer because they belong to the 4th column of the periodic table of the elements. It is possible to produce them with a high degree of purity. [1]

Figure II.1: metallurgical silicon

Silicon is a chemical element in the family of crystallogens, symbol Si and atomic number 14. It is the most abundant element in the earth's crust after oxygen, 25.7% of its mass [2]. It does not exist in the free state, but in the form of compounds: in the form of silicon dioxide ($SiO2$), silica (in sand, quartz…)

II.1   Characteristics Electronic properties of silicon

The structure of a crystal is completely described by the lattice parameters, its elementary lattice, its space group and the position of the atoms in its crystal lattice. Thus, the crystallographic structure of silicon is a diamond cubic structure in which two face-centered cubic networks interpenetrate where each atom is surrounded by 4 close neighbors equidistant from the other network forming a tetrahedron. The bonds between the atoms are of covalent type with an inter atomic distance of 2.35 A° and a lattice parameter a = 5.43 A°. The forbidden band (gap), separating the valence band from the conduction band is equal to $Eg = 1.12\,eV$ at room temperature.
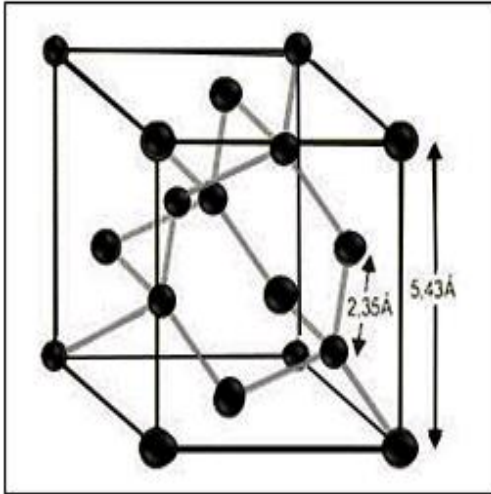
Figure II.2: crystallographic structure of monocrystalline
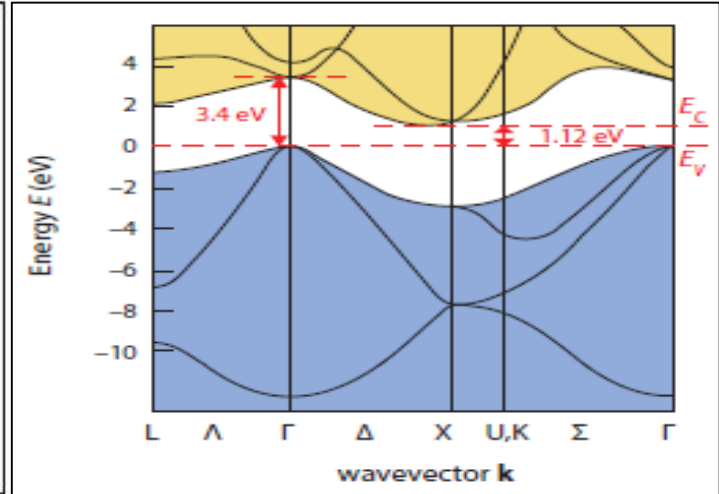
Figure II.3: The band diagram of crystalline silicon.

Silicon remains the main material for photovoltaics and despite the expected innovations in the technologies of other materials for photovoltaic uses such as thin layers, it is considered that even in the next two decades, crystalline silicon will still represent 80% in the manufacture of photovoltaic cells. This is due to several reasons, first of all, the optical absorption of silicon allows satisfactory exploitation. Then, silicon is also an abundant element on earth in the form of silica ($SiO2$). Finally, it is the best known semiconductor material not only in the technology of manufacturing photovoltaic components and cells, but also in the electronics industry. Note That the silicon exists in different structures, crystalline silicon and amorphous silicon   [3]

II.2   Crystalline silicon:

For crystalline silicon, it consists of the monocrystalline which offers a better conversion rate with a higher cost and the polycrystalline silicon, cheaper in its production produce with a limited yield. Indeed, polycrystalline silicon is a material formed of grains separated by joints of grains which are areas containing a large number of structural defects. These grains vary in size from a millimeter to a few centimeters (Fig I.3) [4]
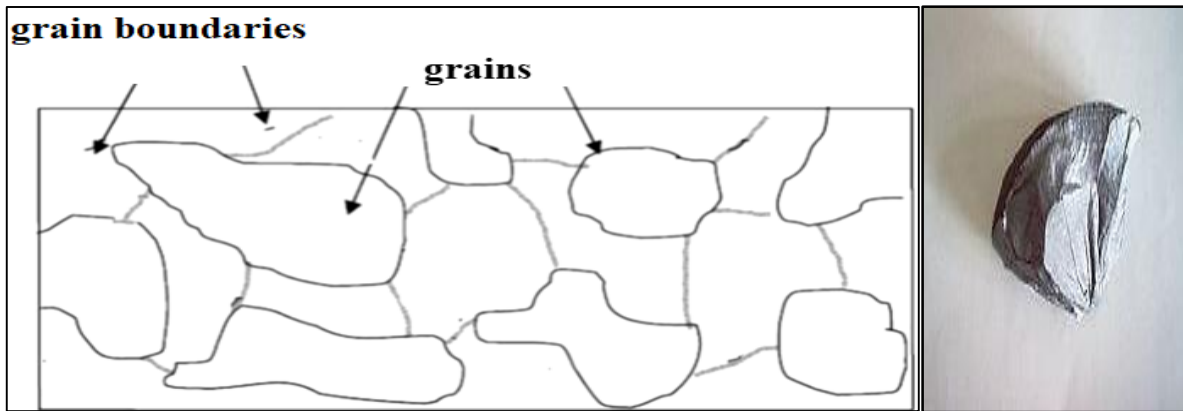
Figure II.4: polycrystalline silicon

II.3 The diamond structure:

In the diamond structure each atom is surrounded by 4 closest neighbors, which makes it possible to form covalent bonds. It can be described as being formed of 2 structures. Moved relative to each other along the main diagonal. The position of the origin of the second structure compared to the origin of the first one is (1/4, 1/4, 1/4). Diamond crystallizes in this structure, but also Silicon and Germanium.

This structure is typical of the elements of column IV of the periodic table, but also of the compounds III - V in which the sites (0, 0, 0) and (1/4, 1/4, 1/4) are occupied by different types of atoms. One speaks in this case of Zinc blende structure [4].

The band structure is the relationship between the energy of the particle and its vector k:

E (k). We represent the evolution of the energy of the electron by the curve E (k) by forcing the wave vector k to remain in a remarkable direction of the space of k, that is to say a direction crystallographic of the reciprocal network. [5]
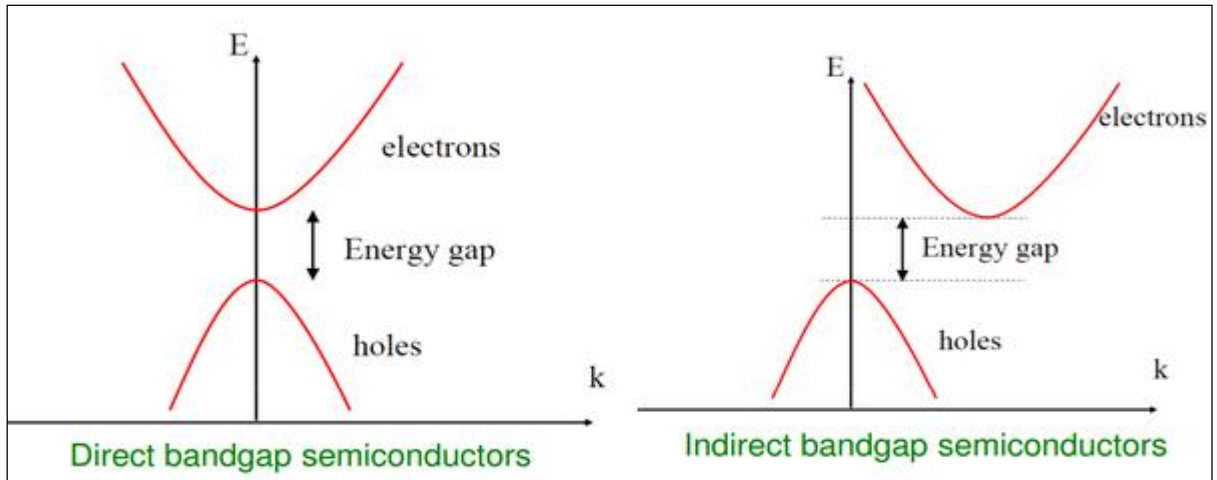
Figure II.5: band gap semiconductors

The band structure of Silicon has been the subject of several studies which have made it possible to know it with great precision. The minimum of the silicon conduction band is in the direction [010] and therefore, by symmetry, also in the directions [0 10], [001], [00 1], [100], [100] or in total six minimums. On the contrary, for germanium, the minimum of the conduction band takes place in the directions corresponding to the diagonals of the cube, so we are in the presence of 8 minima [6].

II.4 Physical property of silicon
II.4.1 The height of the band prohibited
The size E_g of the band gap gives important electrical characteristics to each semiconductor (Table 1). These variations can be roughly described by the universal function (I.1).

Semi-conductor	E_g (0) ($e\mathcal{V}$)	a($e\mathcal{V}/k$)	b(k)
Si	1.170	4.73 .10^{-4}	636

Table II.1: Parameters of the variation of the forbidden band as a function of the temperature

E_g (0) is the height of the BI at 0 ° K, T temperature in ° K, a and b are constants The evolution of the variation of the width of the forbidden band of silicon and germanium as a function of the temperature is illustrated in Figure I.5. We can notice that E_g strongly depends on the temperature. Indeed, for higher temperatures, there is a significant decrease in the width of the forbidden band.

Property a 300 ° K		Si
Prohibited bandwidth E_g (ev)		1.12
Concentration of atoms (cm³)		$5.\ 10^{22}$
Intrinsic concentration (cm³)		$1.45.\ 10^{10}$
Intrinsic mobility (cm² / V.s)	μ_n	1350
	μ_p	480
Dielectric constants relative		11.7
Breakdown field V / m		$-30.\ 10^6$

Table II.2: Electrical properties of the main semi-conductors [7]

II.4.2 Conductivity

Good thermal conductivity is necessary in the semiconductor substrate, firstly to reduce the temperature of the substrate by dissipation, and secondly to ensure a uniform temperature throughout the substrate, in order to improve the similarity of the behavior of the devices of identical nature but placed in different positions in the semiconductor substrate.

Solid state electronics successfully took over, thanks to its higher integration density and lower energy consumption, which no longer required any thermal considerations. Likewise, new semiconductor materials with a larger forbidden band and greater thermal conductivity, such as Sic and Diamond, are being studied for applications above 300 ° C.

The semiconductors occupy a large interval there because their conductivity depends significantly on the temperature, but it varies especially very strongly according to the presence of small quantities of well-chosen impurities. In an intrinsic silicon single crystal, at room temperature some electrons (1.5. 1010 electrons for 5.1022 atoms in a cm3) are thermally excited from the valence band to the conduction band, and the free electrons and the positive holes as well created together contribute to the conductivity of the material, but this remains fairly low.

The current in a semiconductor being in general the sum of that due to the displacement of the free electrons, and that due to the displacement of the holes, the conductivity σ is related to the density of the carriers n and p, and to their mobility μ by the relationship [7]:

Name	Silicon
State	solid
Melting point	$1414 \degree c$
Boiling point	$2223 \degree c$
Melting energy	50.5 5Kj / mol
Evaporation energy	$384.22 \ Kj \ / \ mol$
Molar volume	$12.06 * 10^{-6}$ m^3 mol^{-1}
Vapor pressure	$4.77 \ Pa$
Sound speed	$8.433 \ m \ s - 1$ at $20 \degree c$
Specific heat	$700 \ j \ Kg - 1. K - 1$
Electrical conductivity	$2.52 \ 10^{-4} S. m - 1$
Thermal conductivity	$148 w \ m - 1. k - 1$
Density	$2.328 g \ cm - 3$
Dielectric constant	11.9
Nc	$2.8 \ 10^{19}$
Nv	$1.04 \ 10^{19}$
Electron affinity	4.05
Gap energy	$1.12 \ eV$
Intrinsic concentration of carriers	$1.45 \ 10^{10}$
Minority life	$2.5 \ 10^{-3}$
Mobility of electrons	$1500 cm2 \ v - 1 \ s - 1$
Refractive index	3.44

TableII.3: of physical properties of Si

II.5 Different types of silicon

The silicon used for photovoltaic cells must be of high purity, whatever its form. Like many other elements, silicon can exist at room temperature in different structures, the two extremes of

which are the amorphous state and the crystalline state (monocrystalline or multicrystalline), respectively.

II.5.1 Monocrystalline silicon

The realization of many devices begins with the production of a monocrystalline material of high purity. In particular, the manufacture of microelectronic chips requires monocrystalline semiconductor substrates, for example silicon, germanium or gallium arsenide. In the case of silicon, zone fusion and crucible pulling (method of Czochralski) are the two methods commonly used to obtain high purity monocrystalline ingots several meters long and up to 300mm in diameter We have high photovoltaic yields, over 15%. [8]

II.5.2 Polycrystalline silicon

A large ingot can be produced at once by directional cooling of a mass of molten silicon. The ingot obtained is composed of several large crystals, separated by grain boundaries. This less homogeneous material than monocrystalline silicon, therefore has a slightly poorer energy efficiency (13%) in commerce, but its manufacture is easier. These multicrystalline silicon ingots must also be cut into slices of 200 to 400 mm, this time using a wire saw. [8]

II.5.3 Amorphous silicon

Amorphous silicon has a disordered, non-crystallized, glassy atomic structure, but it has a light absorption coefficient about 1000 times greater than crystalline silicon. A thin layer of 0.3 mm is therefore sufficient to absorb most of the visible spectrum. [9]

II.5.4 Impurities in silicon

The impurities can occupy different sites in the silicon network, interstitial sites (generally for metallic impurities), substitutional sites (for dopants B, P, Al, etc.). The impurities can combine with each other to form either complexes or precipitates if locally their concentration is greater than the solubility limit. Studies on the electrical activity of impurities in crystalline silicon divide impurities into four classes:

- Doping agents (B, P, Al,)
- Rapid diffusers (Fe, Cr, Cu,)
- Slow diffusers (Al, Ti, Au,)
- Light elements (O, C, N,) [10]

II.6   The components of solar panel

To get a solar panel, we assemble 48.60 or 72 solar cells and carefully arrange them between two transparent layers of encapsulate. We then place a film on the back side and heat this stack (imagine a sort of solar sandwich passed over the grid) to create a waterproof protective envelope around the solar cells. After that, to protect the structure and guarantee its stability, we place glass on the front side and an aluminum frame on the periphery, gluing everything with a water-resistant adhesive. Finally, we add a junction box to the back of the solar panel: it is the output terminal of our solar electricity. [11]

PV module must withstand various influences in order to survive a lifetime of 25 years or even longer. In order to ensure long lifetime, the components of that a PV module is built must be well chosen. Figure1. shows the typical components of a usual crystalline silicon PV module. Of course, the layer stack may consist of different materials dependent on the manufacturer. The major components are:
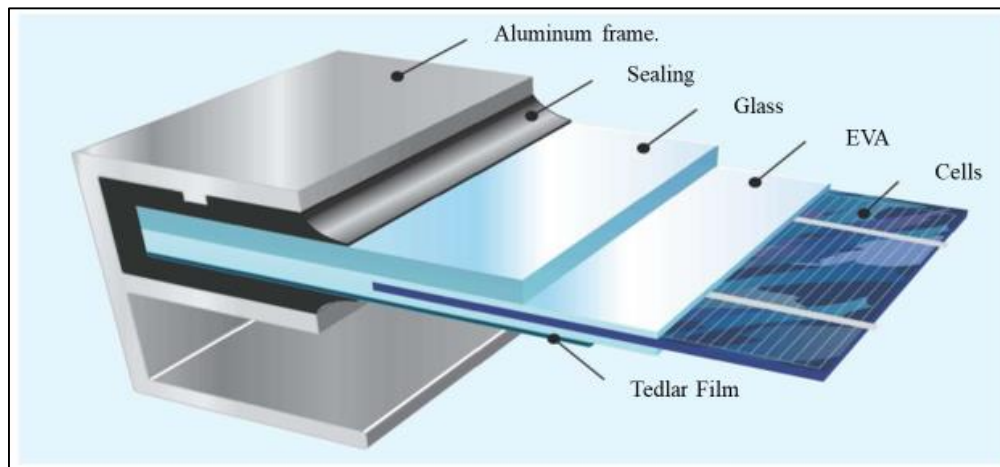
Figure II.6: Assembly of a solar panel

II.6.1 The glass

Glass have a thickness of several millimeters, which provides mechanical stability while being transparent for the incident light. It is important the glass has a low iron content because iron leads to absorption of light in the glass which can lead to losses. Further, the glass must be tempered in order to increase its resistance to impacts.

- ▪ Defined: solar glass.
- ▪ Thickness: 4 mm.
- ▪ Optical transmission:95% in the useful.

- Range of the solar spectrum: (380 nm to 1,200 nm). [12]

Figure II.7: Glass

II.6.2 EVA (ethylene vinyl acetate) Film

The solar cells are sandwiched in between two layers of encapsulates. The most common material is ethylene-vinyl-acetate (EVA), which is a thermoplastic polymer (plastic). This means that it goes into shape when it is heated but that these changes are reversible.

In the solar industry, the most common encapsulation is with cross-linkable ethylene vinyl acetate (EVA). With the help of a lamination machine, the cells are laminated between films of EVA in a vacuum, which is under compression.

The material of the transparent EVA directly affects the life of the components. EVA exposed to the air is susceptible to aging and yellowing, which affects the light transmittance and the power generation quality of the module. In addition to the quality of EVA itself, the laminating process of component manufacturers is also an important factor. For example, EVA adhesiveness is not up to standard, EVA and tempered glass, back sheet adhesive strength is not enough, it will all cause premature aging of EVA and affect the life of the components. [13]

Figure II.8: EVA

It is a transparent, heat-sensitive resin formed from chains of copolymers of ethylene and vinyl acetate, E.V.A. Heat treated between 150 and 160 ° C, it exhibits great adhesive, dielectric, thermal and sealing properties.

The four characteristics that have made EVA a material of choice for encapsulation are:

- its high electrical resistivity which makes it as a good electric insulator,
- its low fusion and polymerization temperature,
- its very low water absorption ratio,
- its good optical transmission.

Table II.4: EVA properties.

Properties	Value
Density	$0.957\ g/cc$
Thickness	$\approx\ 0.45\ mm$
Breakdown elongation	$900 - 1100\ \%$
Elasticity modules	$4.8\ MPa$
Electrical resistivity	$10^{14}\ \Omega/cm$
Melt index ($\mathbf{190°C}$ /$\mathbf{2.16\ kg}$)	$43\ g/10min$
Melting point	$63\ °C$
Water absorption	$0.05\ \% - 0.13\ \%$
Refractive index	1.482

pores trap the incident light reducing the surface reflection to a value lower than 8% in the range of 380 nm–1200nm as shown in Figure II.18
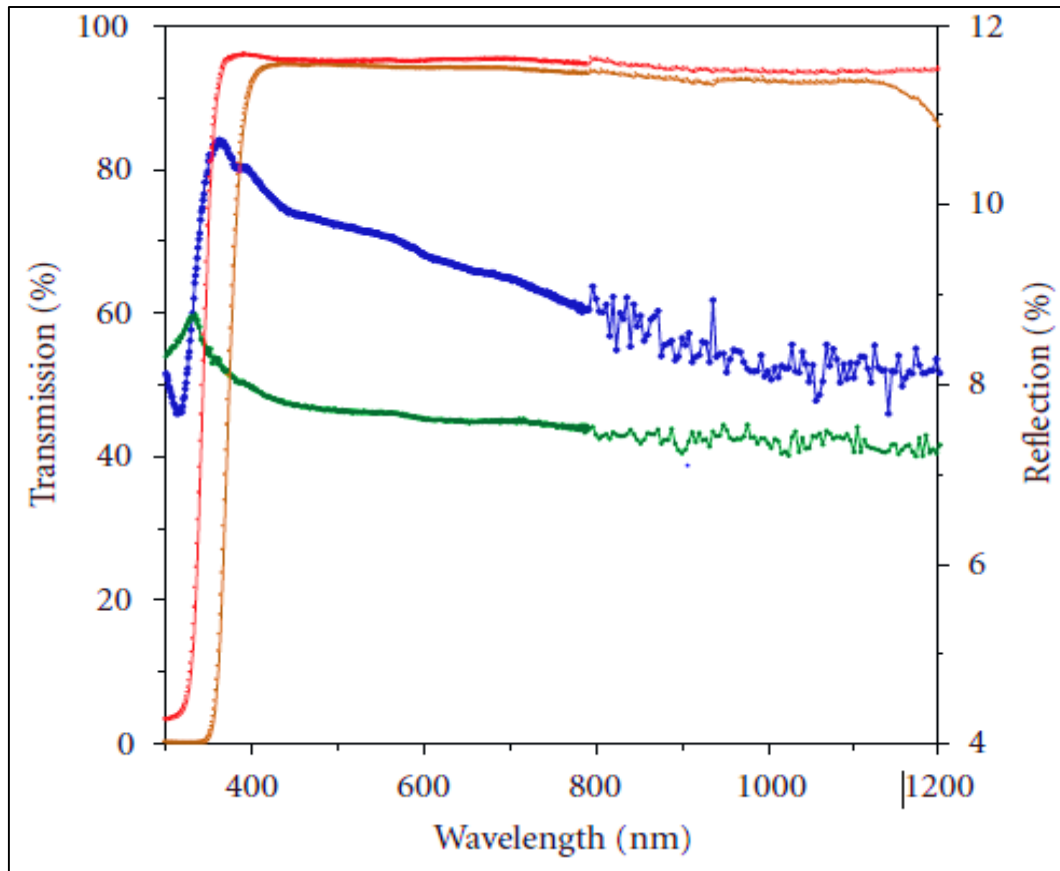
Figure II.9: XRD spectra of darkest and a lighter shade sample of both type of EVA degradations.

II.6.3 Solar Cells

The mainstream solar cells in the market are crystalline silicon solar cells and thin-film solar cells. Both have their advantages and disadvantages. The production equipment of crystalline silicon solar cells costs is relatively low, the material consumption is so large that the cost of the solar cell is high, but its photoelectric conversion efficiency is also high. The production cost of thin-film solar cells is low, but its photoelectric conversion efficiency is not high. Its advantage is that it has a good power generation effect in weak
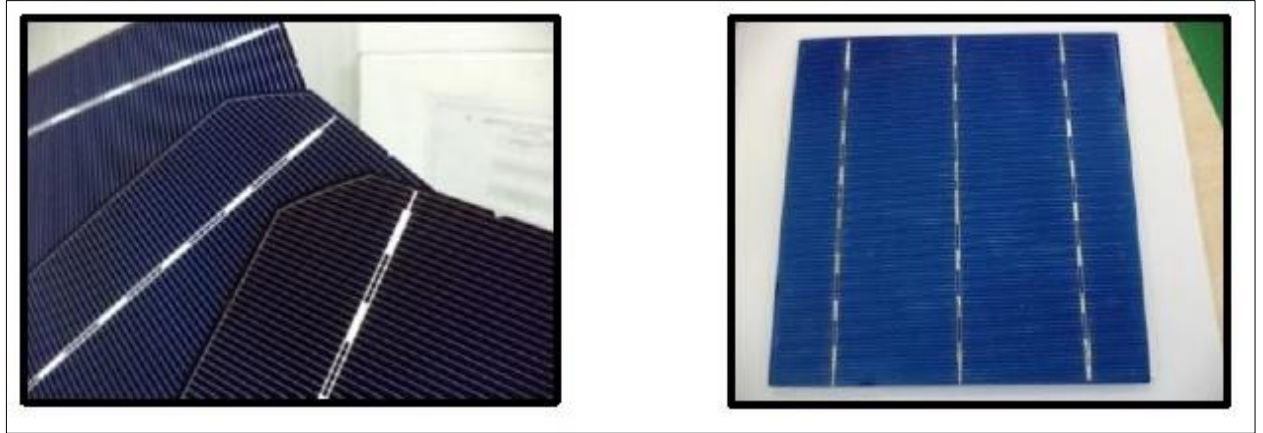
Figure II.10: Cellules de type mono et poly cristallin

light, and it can also generate electricity under ordinary lighting, such as solar cells on calculators. [14]

II.6.4   Tedlar:

is a fluoropolymer used in a photovoltaic module to provide surface protection. Indeed, TEDLAR is particularly resistant to external aggressions (UV, temperature variations, corrosive atmospheres, ...), abrasion as well as chemicals. [15]

Figure II.11: Back sheet

II.6.5   Aluminum Frame

This product can be used to encapsulate all crystalline PV modules and many thin modules, it is non-sticky at room temperature so that it is easy to cut, so it is not oxidizable in the open air. And it is used to:

- Protect the edges of the glass,
- Improve the overall mechanical resistance of the module,
- Improve the degree of tightness with the injection of silicone gel.
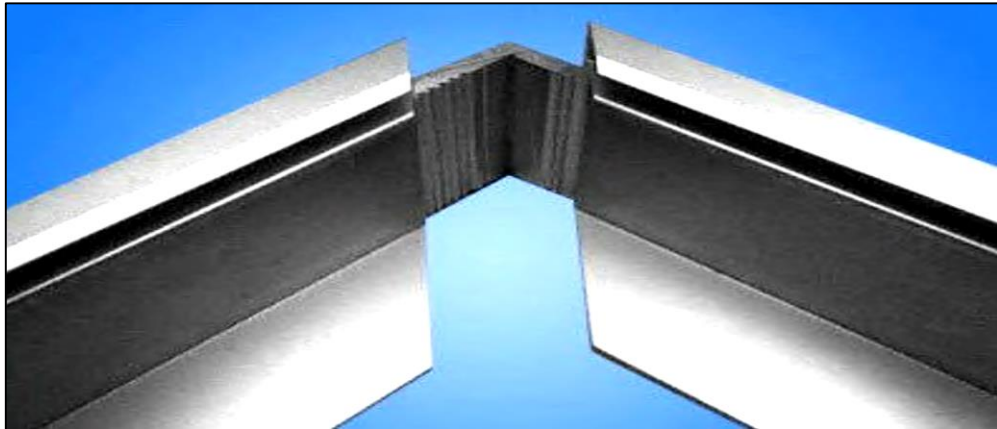
Figure II.12: Aluminum Frame

II.6.6   Junction box

It is considered as an electrical cabinet which houses all the current-carrying parts in order to:

Protect the PV module against the effect of shading using the bypass diodes and reduce the risk of fire and electric shock [16]
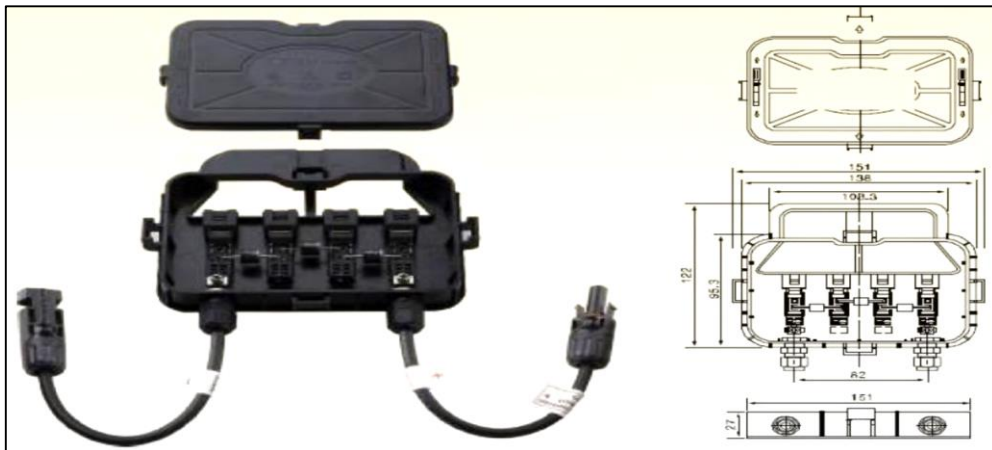
Figure II.13: Junction box

II.6.7   Cutting the welding tapes

The soldering tapes are made of copper and tin, and the operating instructions are;

- Use the cutting machine to cut welding bumps (interconnection and tape).
- Classify and package the cut welding tape according to their sizes
- Immerse the ribbons in an acid solution (Flux bath)

Figure II.14: Cutting the welding tapes

II.6.8 Welding of the cell

- Adjust the temperature of the electric soldering iron and heating plate, according to the thickness of the cells and ribbons.

- Choose the appropriate iron head, and turn on the electric soldering iron and heating plate.

We weld down the ridge with a regular uniform speed (the welding time is average 3 ~ 5 seconds for each bar. [17]
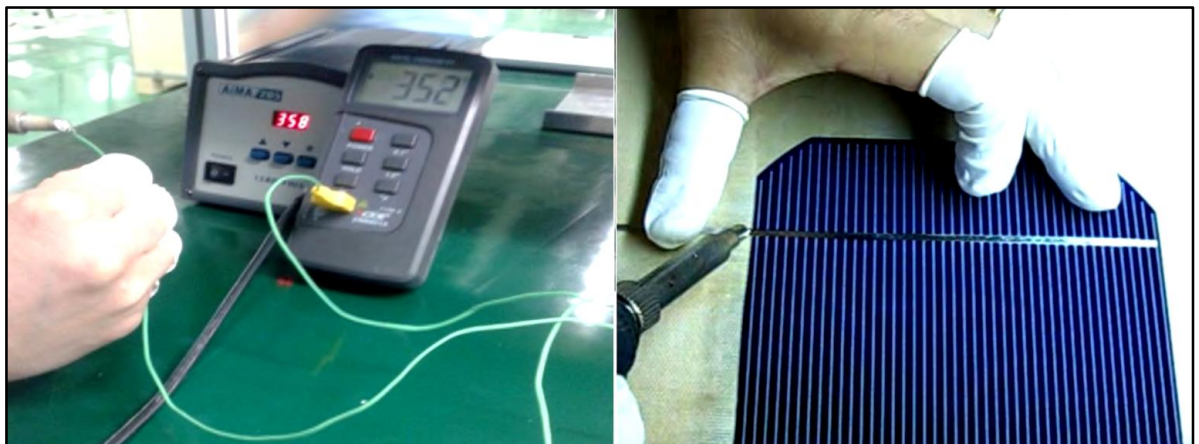
Figure II.15: welding of the cell

II.6.9 Connecting cells

- Connect the single welded cells in series, to transmit the current.

- Do serial welding.

- Solder the positive outgoing wire, and then align with the gauge placing the strip.
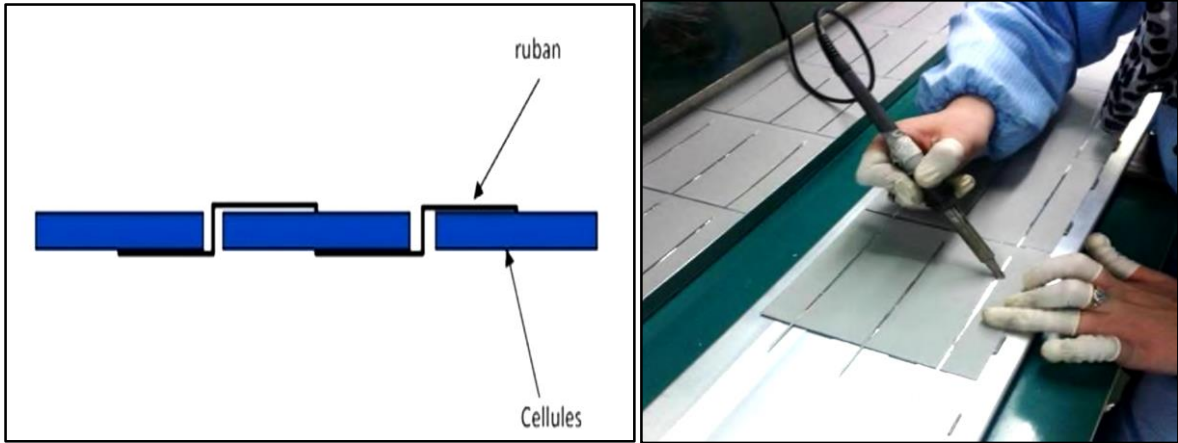
Figure II.16: series welding of cells

II.7   Assembly and manufacturing processes

The photovoltaic cell encapsulation process comprises 9 main steps as illustrated on figure 3.
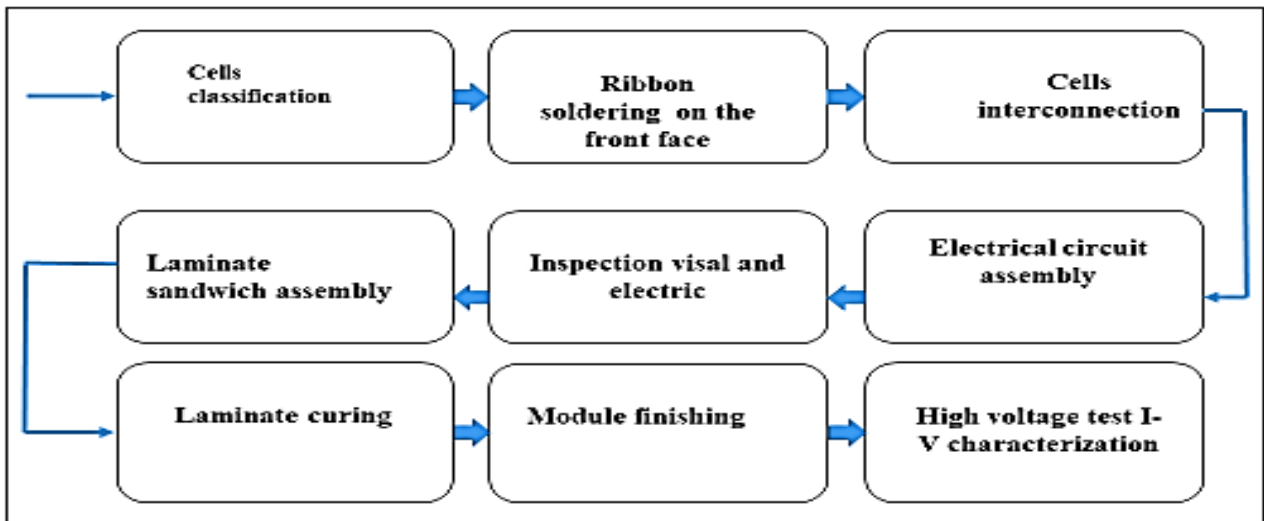
Figure II.17: Flow chart of the solar module fabrication process.

The lamination cycle is an empirically determined sequence of events. The main objective is to determine the shortest sequence which produces a good lamination without negative effects to any of the laminate components. The most critical part of the lamination cycle is the part prior to plastic melt of the sheet encapsulate. The amount of time the assembly is under vacuum, the

time at which pressure is applied, the temperature when pressure is applied, and the duration and quantity of pressure all affect the quality of the lamination. As the polymerization reaction is irreversible, the thermal treatment step is crucial in the solar cells encapsulation process. It is a decisive step for the quality of the module and for its lifetime. If a default (break, short circuit, string moving) happens during the polymerization, the module will be rejected. The lamination cycle is performed in Spire SPI SUN 240. It starts with the introduction of the laminate stack (cells and the encapsulate materials) in the lower chamber where the temperature is kept constant at $100 \, °C$. The upper chamber is under vacuum ($0.1 mm \, Hg$). The lamination operation is conducted in two phases (Figures II.17).

- In the first, the air inside the lower chamber is removed $during \, 5 \, minutes$. The pressure is then set at $0.1 mm \, Hg$ and maintained at this value during both the lamination and the polymerization cycles.[18]
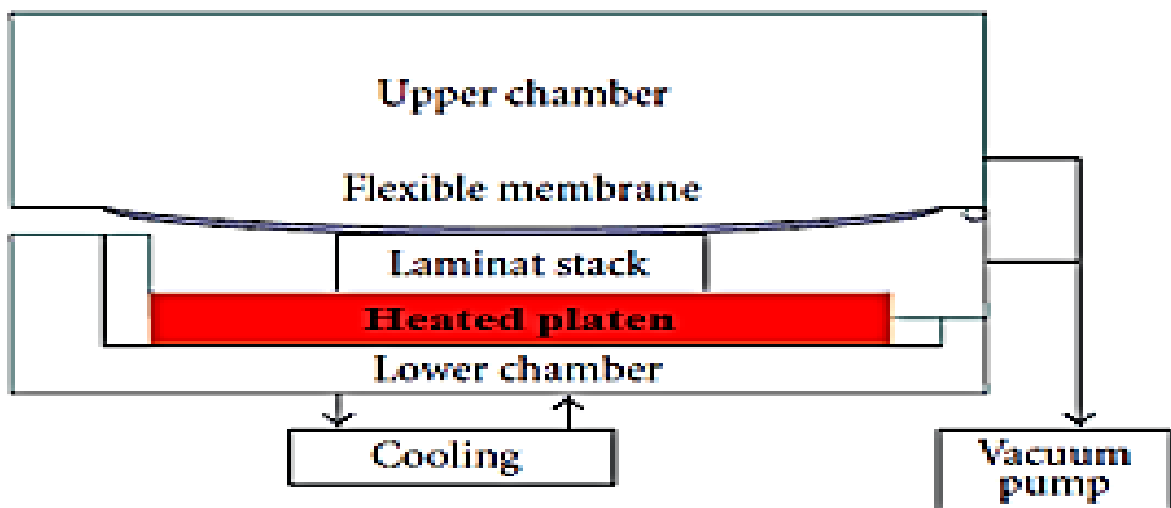
Figure II.18: Schematic of the laminator.

The curing is done at 156°C and lasts 15 mm. The EVA resin polymerization occurs during this step. The EVA crosslinks forming a chemical bond which hermitically seals the module components. At the end of this step we get a compact structure, the photovoltaic laminate. After cooling at 100°C, the lower chamber is at the atmospheric pressure and the upper chamber is at 0.1mm Hg. This is "the long cycle" of the encapsulation process which is conducted completely in the laminator (Figure 5). In the industry, the short or fast cycle is used for higher throughput. Its average duration is about 22 minutes if we do not take into account the time of load and unload of the module. The short cycle finishes with the lamination step (6 minutes). After setting the

laminator in unload conditions, the laminate is withdrawn from and placed in the curing oven for the required reticulation process. [19]

II.8 Degradation of a photovoltaic module

Degradation reflects the gradual deterioration of the characteristics of a component or system which can impair its ability to function within the limits of acceptability criteria and which is caused by the conditions of service. The degraded photovoltaic module can never lose its main function which is to generate electricity from sunlight, even if its use is no longer optimal. However, the degraded state of the photovoltaic module can be problematic when the degradation exceeds a critical threshold. According, manufacturers consider that the PV module is degraded when its power reaches a level below 80% of its initial value. In the following, we will present the different types of degradation of the most representative modules according to the literature The performance of photovoltaic modules can be degraded due to several factors such as:

- temperature,
- humidity,
- irradiation,
- dust,
- mechanical shock.

Each of these different factors cited can induce one or more types of degradation such as:

- discoloration,
- delamination,
- corrosion,
- cell breaks and cracks.

The degradation of the photovoltaic module can affect the different parts of it as shown in Figure different parts are: the glass, the interconnections between the cells, the encapsulating material which is generally made of Ethylene Vinyl Acetate (EVA), the protective polymer film which is generally made of Tedlar and the adhesives which ensure the adhesion between the various components of the module. [20]

II.8.1 Corrosion

Moisture entering the photovoltaic module through the laminated edges causes corrosion. Corrosion attacks the metal connections of the PV module cells, causing an increase in leakage currents and thus a loss of performance.

Figure II.19: a) border corrosion b): corrosion of the
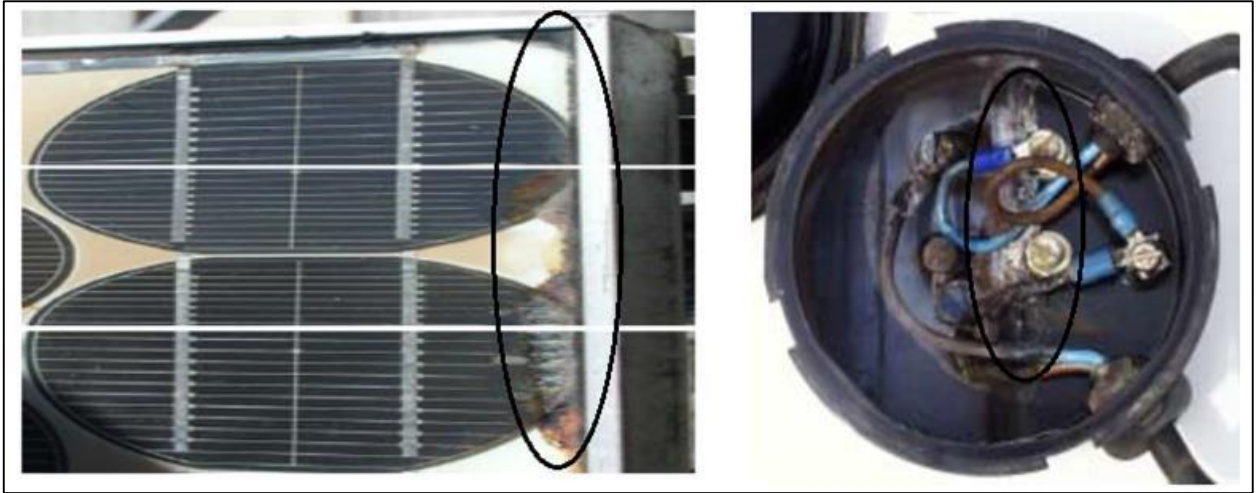
II.8.2 Delamination

Delamination reflects the loss of adhesion between the encapsulating polymer and the cells or between the cells and the front glass. It represents a major problem because it has two effects: the increase in light reflection and the penetration of water inside the structure of the module. [20]
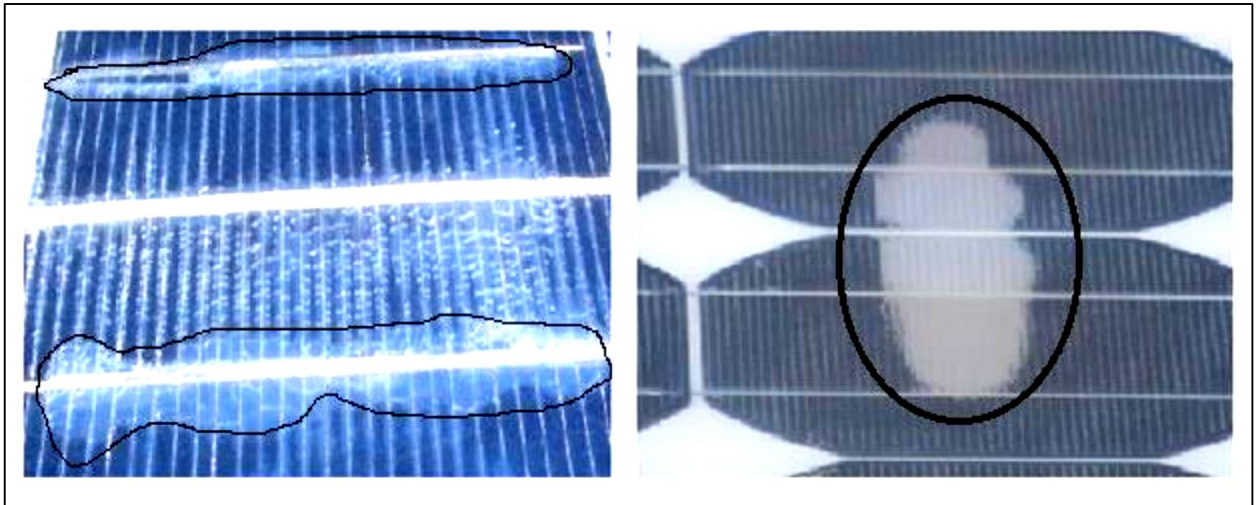
Figure II.20: Photovoltaic module with delamination

II.8.3 Discoloration

The discoloration of the photovoltaic module results in a change in color of the material used for its encapsulation which is generally made of Ethylene Vinyl Acetate (EVA) or of the adhesive material between the glass and the cells. This color change can result either in yellowing or in browning of the encapsulating material. It causes a modification of the transmittance of the cell encapsulate and consequently the power generated by the module is reduced. [21]
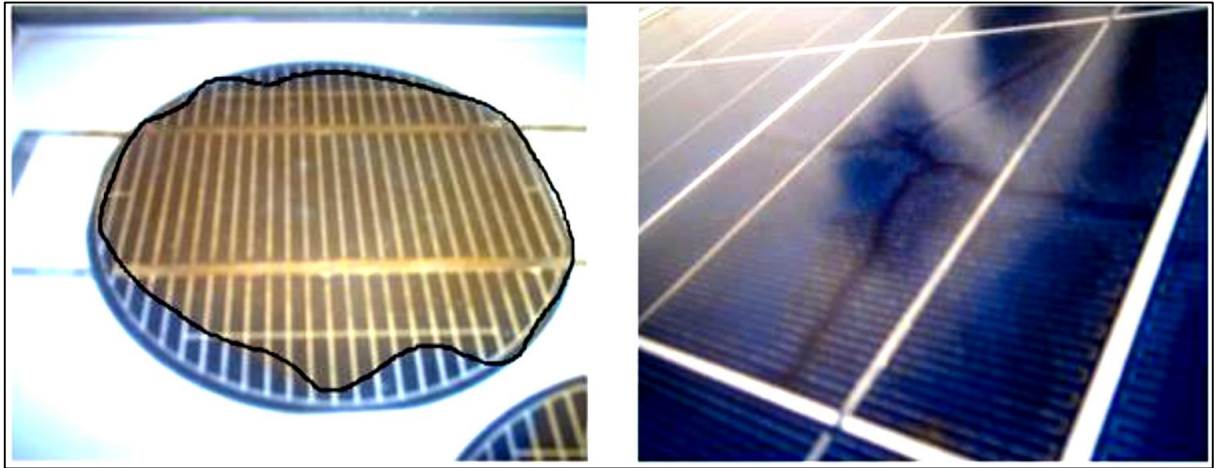
Figure II.21: Photovoltaic modules with discolored cells

II.8.4 EVA degradation

For the last few decades, Ethylene vinyl acetate (EVA) has remained the most dominantly used encapsulate material in crystalline silicon photovoltaic modules due to its reasonable cost and ease of manufacture. It provides an adhesive bond at different interfaces (glass, cell, and back sheet) of the packaged module assembly. Some of its other important functions are to provide; coupling between various layers, insulation to electrical circuit, and mechanical strength with a good optical transmission. However, environmental factors like ultraviolet (UV) radiation intensity, ambient humidity, and operating temperature can affect the durability of the EVA operation al Certain additives like, UV absorbers , anti-oxidants, hindered light amine stabilizers . are added in EVA formulation to protect it from the environmental stressors. However, under field operating conditions, EVA degradation has been identified to be a major cause of loss in performance in PV modules installed worldwide. The most commonly reported EVA degradation are discoloration and delamination.[22]
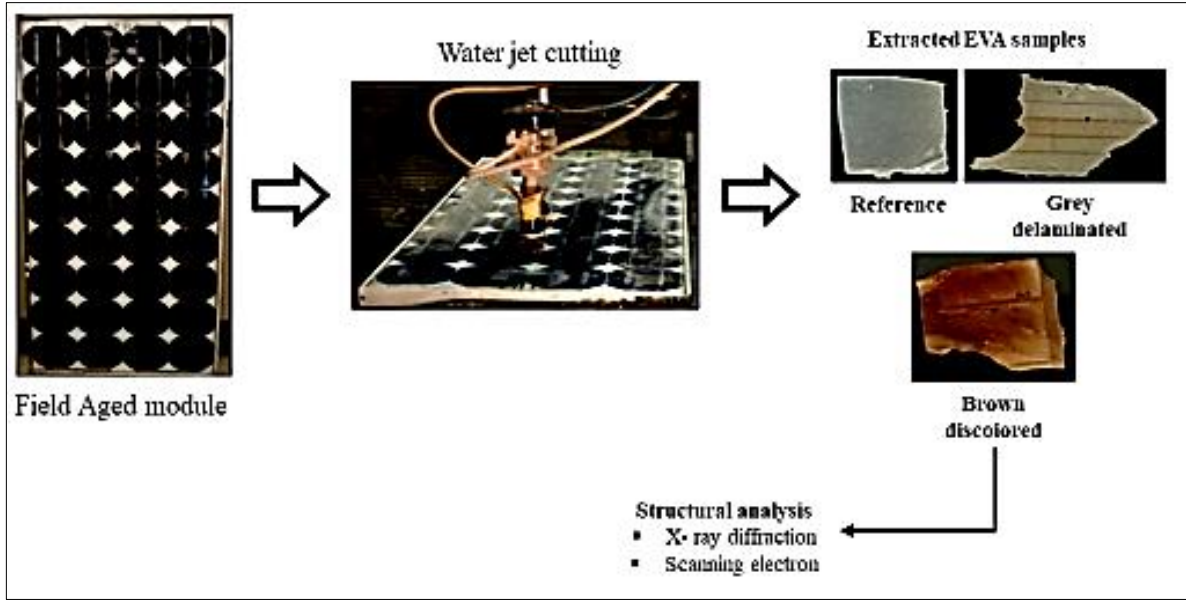
Figure II.22: Schematic of the methodology used in the work.

This work presents a systematic approach for investigation and analysis of the effects and impact of dominant EVA degradations, structural analysis was performed using X-ray diffraction (XRD) and scanning electron microscopy (SEM) technique. in the chapter three

II.8.5 Cracks and broken glass

Glass breakage and cracks are an important factor in the degradation of PV modules. They occur in most cases during installation, maintenance and especially transport of the modules to the installation sites. However, the module with cracks or breaks can continue to produce energy. [23]

Figure II.23: Photovoltaic module with broken glass

II.9   Lifetime testing of PV Modules

The typical lifetime of PV systems is about 25 years. In these as little maintenance as possible should be required on the system components, especially the PV modules are required to be maintenance free. Furthermore, degradation in the different components of that

the module is made should be little: manufacturers typically guarantee a power between 80% and 90% of the initial power after 25 years. During the lifetime of 25 years or more, PV modules are exposed to various external stress from various sources:

- Temperature changes between night and day as well as between winter and summer,

- mechanical stress for example from wind, snow and hail,

- stress by agents transported via the atmosphere such as dust, sand, salty mist and other agents,

- moisture originating from rain, dew and frost,

- humidity originating from the atmosphere,

- irradiance consisting of direct and indirect irradiance from the sun; mainly the highly-energetic UV radiation is challenging for many materials. [24]

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CHAPTER III:

Experimental part

III .1 Introduction

in the chapter This Delamination and discoloration are the most commonly observed encapsulate degradations in crystalline silicon photovoltaic modules under field conditions. In this work, a comparative analysis of brown discoloration and front side grey appearing delamination of ethylene vinyl acetate (EVA) has been presented, to understand

their basic effects and modes of degradation. For this purpose, both type of degraded EVA samples from fieldaged PV modules have been investigated, for finding the difference in their spectral response, chemical constituents, structural change, and impact on module electrical performance. These investigations have been performed using $X - ray\ diffraction$ (XRD), and scanning electron microscopy (SEM).

III.2   The Hall effect

The Hall effect was first observed by an American scientist, E. H. Hall, in 1879, is a phenomenon that occurs when a conductor or semiconductor carrying a current is placed in a magnetic field perpendicular to the current. This causes the charge carriers in the conductor to be deflected by the magnetic field and give rise to an electric field, due to the induced voltage by the separation of positive and negative carriers, known as the Hall field. This field is perpendicular to both the current and the magnetic field. The Hall Field can point along either direction of the axis it resides on. Note that, at sufficient temperature, the net current in a semiconductor is made up of counteracting currents of p-type and n-type carriers. [1]

III.2.1   The Hall effect in semiconductors

Semiconductors have important characteristics which have led to their crucial role in the electronics revolution of the last 50 years. Although they have lower room temperature conductivity than metals, their conductivity increases as temperature increases, unlike metals, and both electrons and positive carriers ('holes') may contribute to the conductivity. Semiconductors can be chemically 'doped' so that there is an excess of either electron ('n-type') or holes ('p-type') participating in conduction. Doping alters the conductivity of the semiconductor and offers many possibilities to control the behavior of the material and is the main reason for the importance of semiconductors in modern electronic devices. The relative contribution of electrons and holes to the conductivity changes as a function of temperature and the behavior of the Hall voltage with temperature can be used to examine the type of charge carriers which dominate in different temperature regions. [2]

III.2.2 Resistivity

is a material parameter that is a measure of the resistance to current. The resistivity is defined as the resistance of the sample times the cross sectional area of the sample divided by the length of the sample,

$$\rho = R * \frac{A}{l} \qquad (1)$$

The resistivity has units of m and it is inversely proportional to the conductivity of the sample,

$$\sigma = \frac{1}{\rho} \qquad (2)$$

III.2.3 Conductivity and Hall Effect Versus Resistivity

The first extensive experimental study of basic electrical properties when polycrystalline Si containing B and P, conductivity and the Hall effect in silicon The properties were measured at temperatures constant , where the measurement was determined for the sample length l and area A

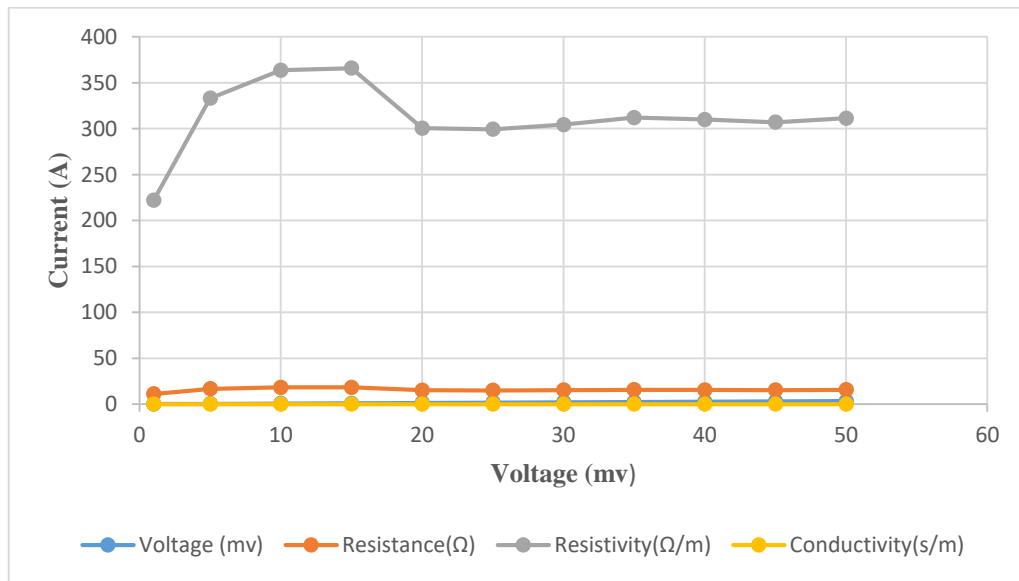| Voltage (mv)	1	5	10	15	20	25	30	35	40	45	50
Current (A)	0.09	0.3	0.55	0.82	1.33	1.67	1.97	2.24	2.58	2.93	3.21
Resistance($m\Omega$)	11.11	16.66	18.18	18.29	15.03	14.97	15.22	15.6	15.5	15.35	15.57
Resistivity(Ω/m)	222.2	333.2	363.6	365.8	300.6	299.4	304.4	312	310	307	311.4
Conductivity(s/m)	0.004	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003

Figure III. 1: conductivity versus resistivity in polycrystalline Si at room temperature : and Current (A) a variable ,Voltage constant (mv)

III.3 Introduction to X-rays

Discovered in 1895 by the German physicist Rontgen, $X - rays$ are the basis of different analysis techniques such as radiography, spectroscopy and diffractometry. These electromagnetic radiations have a wavelength on the order of Angstrom ($1 \text{ Å} = 10 - 10 \ m$).

A crystal is an arrangement of atoms, ions or molecules, with a pattern repeating periodically in three dimensions. The interatomic distances are of the order of Angstrom, of the same order of magnitude as the wavelengths of $X - rays$: a crystal therefore constitutes a 3D network which can diffract $X - rays$

In 1913, William Lawrence Bragg and his father Sir William Henri Bragg used this radiation to determine the crystal structure of $NaCl$ and then of many other metal salts. They jointly received the Nobel Prize in Physics in 1915 for their contributions to "the analysis of the crystal structure by means of $X - rays$"[3]

III.3.1   X-ray production for diffraction

The production of $X - rays$ is generally done according to the same process as that used in medical imaging. Electrons torn from an electrically heated tungsten filament are accelerated under the effect of an intense electric field (voltage of 50 kV) to bombard an anode (or anticathode) made of different materials depending on the intended applications. $X - rays$ are emitted by the anode [4]
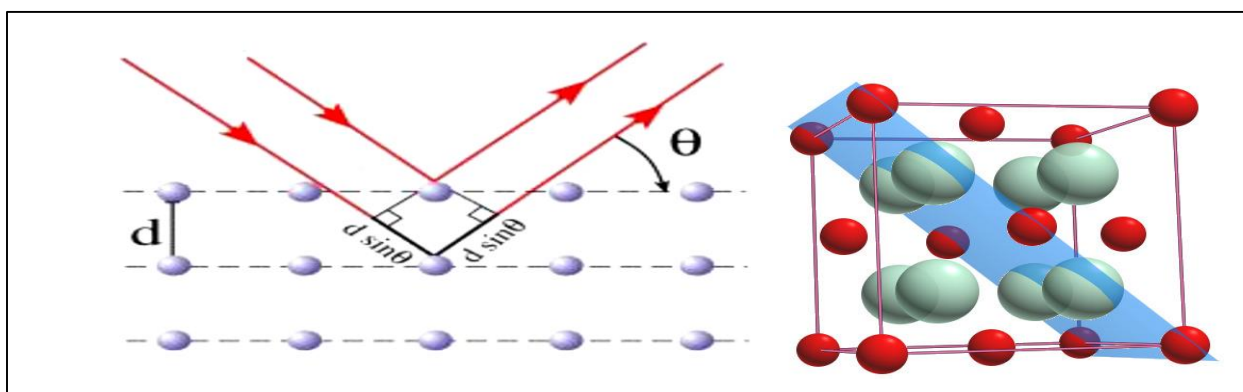

Figure III.2: Determination of lattice spacing using Bragg's law.

The material commonly used for the anode is copper, which produces X-rays of wavelength $\lambda = 1.54 \text{ Å}$

III.3.2 Principle of the powder method

Today, powder diffraction methods are used to study crystallized materials. These methods allow in particular to characterize the material studied, both from a qualitative point of view and from a quantitative point of view without requiring the synthesis of single crystals. From a qualitative point of view, powder diffraction techniques allow:

- determine the chemical composition of the powder by comparing the spectrum obtained with those contained in a database.
- to detect the presence of impurities.
- to test the crystallinity of the material ...

From a quantitative point of view, these methods make it possible to study:

- the crystalline parameters $a, b, c, \alpha, \beta, \gamma$.
- in simple cases the atomic positions and the space group.
- mixtures of powders, solid solutions.
- the presence of any structural disorder. [5]

This method was invented by P. Debye and P. Scherer. A monochromatic X-ray brush is diffracted by a sample composed of a large number of microcrystals random orientations. The size of the microcrystals is in the range of 0.01 to 0.001 mm. Given the very large number of microcrystals (from 107 to 1013) contained in the sample, there are There is always a large number for which a family of reticular planes (hkl) makes with the incident beam the angle θ defined by the Bragg relation: $\lambda = 2 \cdot d \, (h \, k \, l) \cdot sin \, \theta$
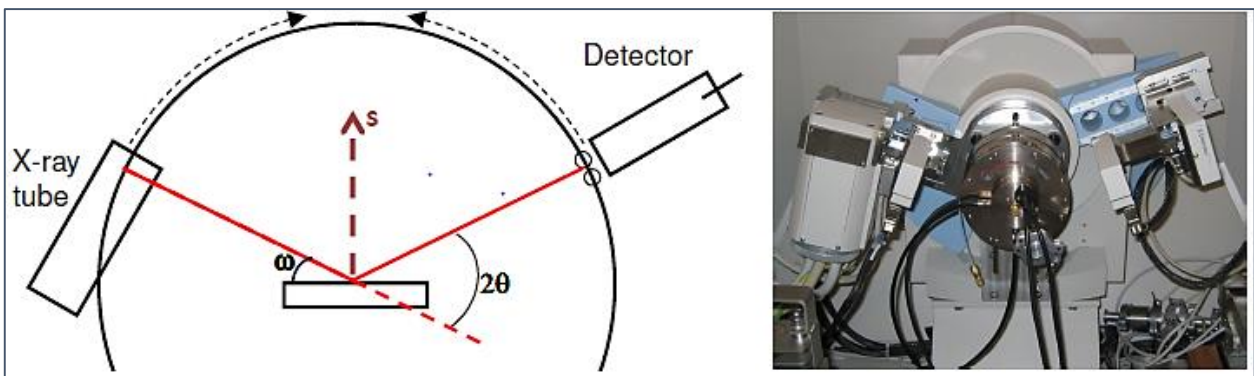

Figure III.3: powder diffractometers

III.4   Experimental methodology

This work presents a systematic approach for investigation and analysis of the effects and impact of dominant EVA degradations using experimental based techniques. The schematic of methodology used in this work is shown in Figure II.21: structural analysis was performed using $X-ray\ diffraction\ (XRD)$ and scanning electron microscopy (SEM) technique.

III.4.1   X-ray diffraction (XRD)

The structural analysis of the degraded samples has been performed using XRD technique. It is primarily used to analyse the crystallinity of a material. The XRD spectra in this work was measured using a 3 kW Smart Lab X-ray diffractometer from Rigaku equipped with $Cu\ (K\alpha = 0.154\ nm)$ target. The measurements were done for 2θ angle between 5° and 90° in an interval of 0.01°. The instrument was operated at 40 kV and 30 mA. The measurement was repeated for each investigated EVA sample, to ensure the repeatability of the trend.

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CHAPTER IV:

Results and discussion
Experimental part

IV.1: Results and discussion

This section presents the findings from the investigation and analysis on the grey delaminated and brown discolored EVA degradation samples, EVA sample should have resulted in the browning of the sample due to its vulnerability to UV radiation in absence of UV absorber additive. However, due to delamination, excess moisture and air ingression must have taken place in these areas of the module. Such conditions in the absence of anti-oxidants could have caused the photo-bleaching of the discolored EVA. This phenomenon of photo-bleaching is commonly observed close to the edge regions in cells with discoloration [1]
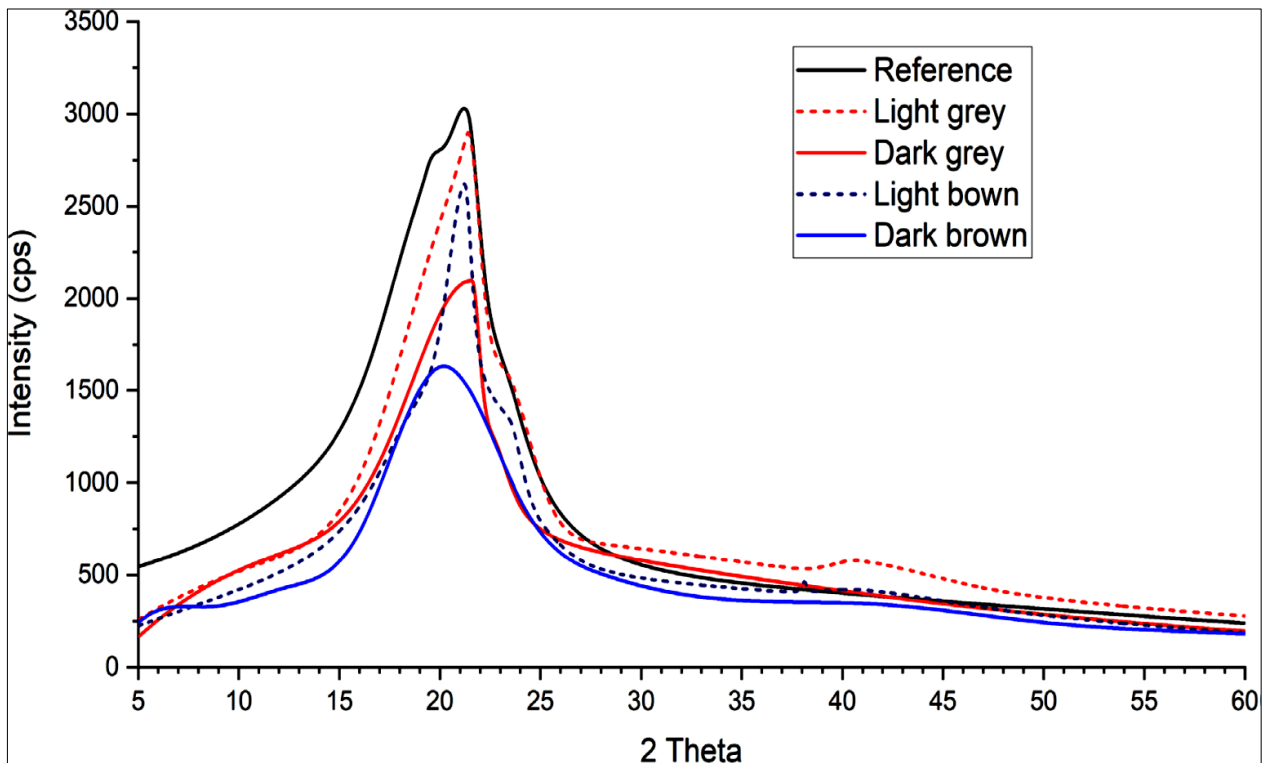
FigureIV.1: XRD spectra of darkest and a lighter shade sample of both type of EVA degradations.

## IV.2: Structural analysis

In order to examine the change in structural aspects of the degraded EVA samples, X-ray diffraction (XRD) spectroscopy was performed. The XRD spectra for the darkest and a lighter shade of each type of EVA degradation is shown in FigureIV.1. The peak centred around 20° in the spectra of standard EVA is usually attributed to the amorphous nature of the EVA due vinyl

acetate (VA) content in the EVA chain. The decrement in amorphous nature i.e. increase in crystalline property can cause loss of mechanical properties namely, surface hardness, stiffness, and susceptibility to external stress which directly contributes to EVA degradation. As mentioned above, any reduction in the peak around 20° for delaminated and discolored EVA samples, could be due to the loss of VA content in EVA chain caused by deacetylation reaction [2]

IV.3: Surface morphology analysis

To obtain further insight on the two type of EVA degradations, the physical morphology of the samples has been investigated using SEM imaging technique. The images of the front (in contact with glass surface) and rear side (in contact with front cell surface) of the darkest shade of grey delaminated, brown discolored, and reference EVA samples are given in Fig. 8. The reference sample (FigIV.2. (a)) and the front surfaces for both degraded EVA samples (Fig.IV.2(c) and (e)) appear to have a smoother morphology in comparison to those in contact with the cell surface (Fig. (b) and (d)). Moreover, the morphology of the delaminated EVA sample showed square indentations on its rear surface (Fig.IV.2 (b)). However, the indentations were not clear in the rear of the discolored EVA sample (FigIV.2(d)) as some portion of the EVA might have remained on the cell surface during its extraction owing to adhesion. This is in contrast to the delaminated EVA sample where the [3]
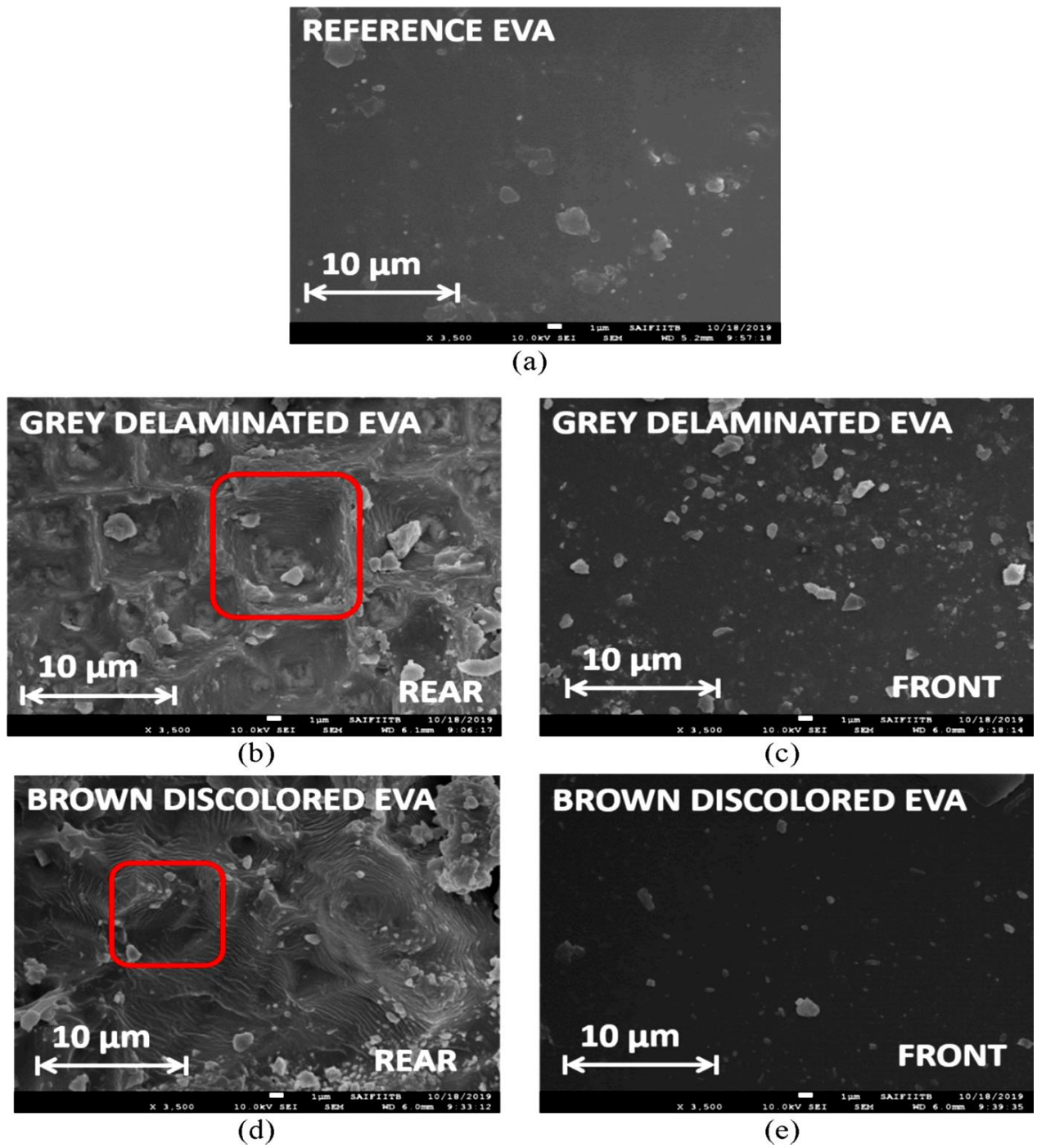
FigureIV.2: SEM image indicating morphology of (a) reference EVA sample (b) rear and (c) front side of delaminated EVA sample (d) rear, and (e) front side of discolored EVA sample.

phenomenon can cause increased reflection losses and seems to be the reason for grey appearance of EVA. This investigation highlights the comparative effects and impact of the dominant EVA degradations, which can be useful for the improvement of EVA formulation and manufacturing for PV module application. [4]

IV.4 Conclusions

This paper presents a comparative investigation and analysis of brown discoloration and front side grey appearing delamination of ethylene vinyl acetate (EVA). loss due to absorption at lower wavelengths, and reflection at higher wavelengths, were observed to be the dominant effects of brown discolored and grey delaminated EVA degradation respectively. The impact of these effects was seen as loss in short circuit current on the module performance, with an additional power loss due to mismatch in cells, loss in module output power of up to 40% has been observed, for the highest extent of degradation considered [5]

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GENERAL CONCLUSION

In this Master's thesis, we were interested in the development of a functional solar cell encapsulate The objective of this work was centered on the realization of an encapsulate Several techniques were used for the characterization of the samples: optical properties by UV-visible spectrophotometer, X-ray diffraction (XRD) for structural study. This thesis consists of four chapters in the first chapter, we will introduce the photoelectric effect as well as the manufacturing steps for the PV modules. Second, we will talk about the benefit of the solar cell encapsulation step and characterize the materials used for this purpose.

The photovoltaic conversion is based on the photovoltaic effect, that is, on the conversion of the light energy coming from the sun into electrical energy. To carry out this conversion, devices called solar cells are used, constituted by semiconductor materials in which a constant electric field has been created artificially (by means of a pn junction). Next, we will try to understand in a qualitative way how light is converted into electricity. This requires remembering some concepts of physics and chemistry. The semiconductor material par excellence is Silicon given its extraordinary abundance, 60% of the earth's crust is composed of silica that has a high content of it, in addition to its interesting electronic properties. 90% of the current solar cells are made of silicon, and the others are governed by the same physics, so we are going to study silicon. Silicon crystallizes in a network similar to that of a diamond. Through covalent bonds, very stable and strong, each silicon atom shares one of its four valence electrons with four other atoms (thus remaining in a stable structure, with its outer layer full, with 8 electrons).

Since electrons tend to occupy the lowest energy levels, most of them are linked, and at absolute zero temperature, all of them. At room temperature, some acquire enough energy to escape the bond and can then move through the material (conduction).

This behavior is not exclusive of semiconductors but is manifested in all materials; what is peculiar is the amount of energy needed to release an electron from the link.

Delamination and discoloration are the most commonly observed encapsulate degradations in crystalline silicon photovoltaic (PV) modules under field conditions. In this work, a comparative analysis of brown discoloration and front side grey appearing delamination of ethylene vinyl acetate (EVA) has been presented, to understand their basic effects and modes of degradation. For

this purpose, both type of degraded EVA samples from fieldaged PV modules have been investigated, for finding the difference in their spectral response, chemical constituents, structural change, and impact on module electrical performance. These investigations have been performed using, X-ray diffraction (XRD), and scanning electron microscopy (SEM).

was identified mainly in absorption and reflection loss respectively, under different wavelengths. Also, the impact of these degradations on module performance, due to mismatch loss within the module has been presented. The chemical constituent investigation, supported presence of delamination in grey degraded sample

due to absence of interfacial adhesive agent, in contrast to discolored sample. Findings from the structural investigation, corroborated a decrease in crystalline behavior of both degradations.

Furthermore, impressions from etched silicon cell were observed only in delaminated sample, which can be the reason of its grey appearance and more reflection. This work highlights the comparative effects and impact of dominant EVA degradations in terms of their characteristic aspects, which can be instrumental in improvement of EVA formulation.