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degradation of materials used in solar

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Dedication

I dedicate this modest work particularly to: My dear parents, who have devoted their lives to building mine; My fiance, my companion in life "Oussama"; My dear brothers and sisters; My fellow professors.



Thanks

My gratitude is extended to my thesis chair, **Dr. Elfahem Sakher**, who offered a lot of encouragement, patience, and invaluable support through every stage of this process. His expertise has greatly influenced me as a learner, a teacher, and a researcher. I would also like to thank Head of the department and deputy head of the department **Dr. Isaac** and **Dr. Bouraiou Ahmed.** Additionally, I would like to **Rector of the University** and the Faculty of Material Sciences, including students and teachers.

Abstract

Abstract

In recent years, scientists and researchers have focused very much on the rise of renewable energies of all kinds, especially solar energy, and Adrar is considered among the best regions in the world that have the appropriate conditions for solar energy production, but the solar panels that are used in the conversion and production of electrical energy are exposed to damage with time by influence of external factors such as wind and heat, and this causes a deterioration in the level of energy production. During this research, we will focus on the microscopic causes of the types of degradation that affect the components of solar panels, we do this microscopic study based on XRD and electrical resistance (ER).

Key words:

Renewable energies, solar energy, solar panels, degradation, microstructural, X-ray diffraction, electrical resistivity

الملخص:

ركز العلماء والباحثين خلال السنوات الاخيرة تركيزا كبيرا جدا على الطاقات المتجددة بكل انواعها، وخاصة الطاقة الشمسية، وتعتبر ادرار من بين افضل المناطق في العالم التي تتوفر على الشروط الملائمة لإنتاج الطاقة الشمسية، ولكن تعرض الالواح الشمية التي تستخدم في تحويل وانتاج الطاقة الكهربائية الى التلف مع مرور الوقت وتأثير العوامل الخارجية كالرياح والحرارة، يسبب ذلك تدهور في مستوى انتجها للطاقة، خلال هذا البحث سنقوم بالتركيز على الاسباب المجهرية لأنواع التدهور التي تصيب مكونات الالواح الشمسية، نقوم بهذه الدراسة المجهرية بالاعتماد على حيود الاشعة السينية والمقاومية الكهربائية

الكلمات المفتاحية:

الطاقات المتجددة، الطاقة الشمسية، الألواح الشمسية، التدهور، الدراسة المجهرية، حيود الأشعة السينية، المقاومية الكهربائية

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List of Terms

PV: Photovoltaic.

Si : Silicon

Ge : Germanium

Cd : Cadmium

h: Planck's constant (J.s).

c: the speed of light.

v: the frequency (Hz).

 λ : the length wave (μ m).

UV: Ultraviolet band.

IR: Infrared band.

E: Energy (J).

Eg: the band-gap energy .

Ec: Energy conduction band.

Ev: Energy valence band.

eV: electron volts.

EVA: Ethyl Vinyl Acetate.

DC: Direct Current.

TPT: Tedlar -polyester- Tedlar film.

PET: Polyethylene Terephthalate.

PVF: Poly Vinyl Fluoride.

T: Temperature (K).

σ: the conductivity.

q: is the charge of the electron.

n and p: The densities of electrons and holes,

List of Terms

 μ : The coefficient, which, at a given temperature, connects the average drift speed of the carrier to the applied electric field.

Rs: Series resistance of the module (Ω) .

Rsh: Shunt resistor which models the leakage currents of the junction (Ω) .

Isc: Short circuit current of a cell (A).

Im: Current at PPM point (A).

Vco: Open circuit voltage of a cell (V).

Vm: PPM point voltage (V).

Pm: Maximum power or peak power (W).

Iph: Photovoltaic current (A).

Io: doide saturation current (A).

FF: Form factor.

 η : Diode ideality factor.

S: surface of the cell (m^2) .

SiO₂: Silicon dioxide.

ER: Electrical Resistivity.

XRD:X-ray diffraction.

General Introduction

General introduction:

The world faces many challenges in energy production, especially with the prospective studies that threaten the end of traditional energy such as oil and gas, and also with the great progress in technology and industry, our planet has been affected by polluting emissions from factories, and that is why scientists are now focusing on replacing old traditional energy with renewable energy, It compensates for its loss and reduces the negative effects on the environment.

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.

With the passage of time, the solar panels are exposed to damage caused by natural external influences such as wind and heat, and this leads to a decrease in the yield of energy production. Several types of deterioration appear on the solar panels, where we can navigate the change in the color of the solar panels and the appearance of air bubbles inside them, as well as the breaking and cracking of glass, These macroscopic observations are the product of microscopic changes at the level of molecules and even atoms, and for this we are conducting a microsructural study of the degradation of the knowledge of the internal and deep causes **Chapter 01: Generality on pannier solar photovoltaic.**

Chapter 01: Generality on pannier solar photovoltaic.

I.1 Introduction:

Photovoltaic energy results from the direct transformation of sunlight into energy electricity; this transformation is one of the means of exploiting the solar field. The production of electricity by clean means has become an essential necessity in a world where the environment is threatened by pollution and the greenhouse effect. Photovoltaic (PV) is a clean energy and not exhaustible. It is an essential component of renewable energy that can help the world to meet its ever-increasing energy needs, while limiting increasing greenhouse gas emissions and reducing air pollution the environment. In other words, photovoltaic is an intermittent energy. It is an attractive solution as a replacement or supplement to conventional sources of supply electricity because of its many advantages:

- It is a reliable means, which requires little maintenance.

- It provides electricity with free and renewable energy from the sun.

- It requires no fuel.

- It is silent and non-polluting, respectful of the environment.

- Lifespan of approximately 25 years [1].

Indeed the word "photovoltaic" comes from the Greek "photo" which means light and from "voltaic " which originates from the name of an Italian physicist Alessandro Volta (1754 -1827) who contributed a lot to the discovery of electricity, then photovoltaic means literally the "light electricity" [2].

In this chapter, we carry out a brief reminder on the photovoltaic system

I.2. Renewable Energy:

Renewable energy is a source of energy that renews itself rapidly to be considered inexhaustible on human scale. [3]

Renewable energy sources are characterized by their ability to be exploited without depleting their source. Renewable energy is what we obtain through energy streams that are repeated in nature automatically and periodically [4].

By "renewable energy" we also mean electricity that is generated from a variety of long-term sources, Renewable energies are divided into 5 categories:

- Hydraulic energy (92.5% of electricity from renewable energies)

- Wind energy (0.5%)

- Biomass energy (5.5%)

- Solar energy (0.05%)
- Geothermal energy (1.5%) [5]

I.3. Sun:

The sun star is of gaseous constitution, of spherical shape, It consists mainly of 80% hydrogen, 19% helium, the remaining 1% is a mixture of more than 100 elements [6]. It is the energy of nuclear fusion that provides the sun with its power, it is now accepted that the sun is a hydrogen thermonuclear bomb – helium transforming every second 564 million tons of hydrogen into 560 million tons of helium; the reaction-taking place in its nucleus at a temperature of about 25 million of degrees Celsius. Thus, every second, the sun is lightened by 4 million tons dispersed in the form of radiation. Its light, at a speed of 300,000 km/s, puts about 8 minutes to reach the earth, its spectral distribution of the atmosphere is presented a maximum for a wavelength of 0.5 μ m [7, 8]. **Table I.1:** Main Characteristics of the sun

Diameter (Km)	14.10 ⁵
Mass (Kg)	2.10^{30}
Area (Km ²)	6,09.10 ¹²
Volume (Km ³)	$1,41.10^{18}$
Average density (Kg/m ³)	1408
Speed (Km/s)	217
Distance from the center of the milky way (Km)	2,5.10 ⁴⁷

I.4. Solar Energy:

Solar radiation is the most widely shared energy resource on earth and more abundant. The amount of energy released by the sun and captured by planet earth for one hour could be enough to cover the world's energy needs for a year [9].

Solar energy is transmitted to the earth through space in the form of photons and electromagnetic radiation. This energy can be captured and transformed into heat or in electricity thanks to adapted sensors. Compared to different forms of energy existing conventional systems, solar energy has the following advantages:

- After recovering initial installation costs, solar power is virtually free;
- The use of solar energy replaces unclean fossil energy;

• The use of solar energy makes it possible to significantly reduce emissions from greenhouse gas [10].

The sun continually discharges an enormous amount of radiant energy into the system solar energy; the earth intercepts a very small part of the solar energy radiated into space. An average of 1367 Watts reaches every square meter of the outer edge of the atmosphere terrestrial for an average earth-sun distance of 150 million km, this is what we calls the solar constant which is equal to 1367 W/m². The portion of energy received on the surface of the earth depends on the thickness of the atmosphere to cross. Solar energy is used mainly for two purposes: the production of heat and the electricity production [11, 12].

The sun's energy can be used in different ways by employing three major Technologies are, passive solar energy, active solar energy and energy Photovoltaic.



Fig I.1: Different forms of solar energy transformation

I.5. Photovoltaic energy:

0.6% of solar energy depends on the photovoltaic effect which consists of the emission of electrons by a material subjected to light clouds. This generated electricity (energy) can then be stored in batteries or converted using an inverter to distribute in the electrical grid. This makes it possible to create a direct electric current from electromagnetic radiation [13]. Through the use of photovoltaic panels, these solar panels consist of photovoltaic cells made primarily of silicon. Since the sun emits this type of radiation, this resource has the advantage of being inexhaustible and usable at any time in an area (at least for the next 4.6 billion years...) [14]



Fig I.2: Diagram showing the conversion of solar energy into electricity

I.6. Advantages and disadvantages of photovoltaic solar energy:

The most important advantages of photovoltaic energy are: [9, 11]

I.6.1 Advantage:

- ✓ Public acceptance
- \checkmark Suitable for hot countries and isolated sites.
- ✓ Independent energy, the fuel (solar radiation) is renewable and free.
- ✓ Generates the required energy.
- ✓ Reduces vulnerability to power outages.
- ✓ Expansion of systems is easy; the size of an installation can also be increased thereafter to follow the needs of the load.
- ✓ The resale of surplus production makes it possible to amortize the investments or even to generate revenues.
- ✓ Minimal maintenance.
- ✓ No noise.

I.6.2 Disadvantages:

- ✓ The manufacture of photovoltaic panels is high technology requesting a lot of research and development and therefore costly investments.
- \checkmark Yields from photovoltaic panels are still low.
- ✓ Requires backup system (batteries) for domestic installations.
- \checkmark The cost of investing in a photovoltaic installation is expensive.
- ✓ Lifetime of panels generally limited to 20 years.

I.7. Energy Storage History:

Some important dates in history less to power its union of photovoltaic:

<u>1839</u>; French physicist Edmond Becquerel discovers the process of the realization of sunshine to produce electric current in a solid material this is the effect photovoltaic.

<u>1883</u>; that the Becquerel's discovery was used by the American Charles Fritts to produce the first photovoltaic cell

1875; warmer von Siemens exhibits an article before the Academy of science in Berlin on the photovoltaic effect in semiconductors. But until the Second World War worldwide, the phenomenon still remains a laboratory curiosity.

1945: There American researchers, Chapin, Pearson and prince, develop a cell high-efficiency cup photovoltaic as the nascent space industry seeks new solutions to power its satellites.

<u>1958</u>; A cell with an efficiency of 9 is developed. The first satellites powered by solar cells are sent into space.

<u>1973</u>; The first house powered by photovoltaic cells is built University of law are [9].

<u>1983</u>; The first car powered by photovoltaic energy travels a distance of 4000 km in.

1990; Advances in photovoltaic cell production techniques and increase production volumes have led to a prices. Modules are produced in China (nearly 60% of production total), in Japan, in the USA, in Germany and in Europe [15].

<u>2013</u>: The production world of PV modules has grown to more than 18GWp.

2016: energy solar photovoltaic represented 1.6% of world production and produced 375 TWh against 246 TWh in 2015.

2017; production reached 500 TWh. Its renewable aspect is a significant attraction.

2050; The International Energy Agency predicts that the solar photovoltaic energy produced will reach 16% of global electricity production [16].

I.8. Solar radiation:

Although the radiation from the Sun's surface is practically constant, by the time it reaches the Earth's surface, it becomes highly variable, and this is due to its absorption and scattering in the Earth's atmosphere [17].

The solar spectrum is indeed composed of all kinds of energy radiations. and different colors, characterized by their wavelength range. Photons, grains of light that make up this electromagnetic radiation, are considered as carriers of energy, which is related to their wavelength by the following relationship [18]:

$$E = h.v = \frac{h.c}{\lambda} \qquad (I.1)$$

h: is Planck's constant.

v: the frequency.

c: the speed of light.

 λ : the length wave.

Namely that the shorter the wavelength, the greater the energy of the photon. note that the energy associated with this solar radiation breaks down approximately to [19]:

Table I.2: Wave length distribution

Ultraviolet band (UV)	9%	0,20μm<λ<0.4μm
Visible band	47%	0.4μm<λ<0.8μm
Infrared band (IR)	44%	0.8μ<λ<10μm



Fig I.3: Spectral distribution of solar radiation outside the atmosphere

I.9. Effect photovoltaic:

The photovoltaic effect is a process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight [20]. This effect makes solar panels useful, as it is how the cells within the panel convert sunlight to electrical energy. Edmond Becquerel first discovered the photovoltaic effect in 1839. When doing experiments involving wet cells, he noted that the voltage of the cell increased when its silver plates were exposed to the sunlight. Unfortunately, He was not able to explain the phenomenon theoretically, because certain characteristics of this effect could not be formalized with the classical theory of electromagnetism of the time [21].



Fig I.4. Principle of the photoelectric effect.

It was not until 1905 that the phenomenon was properly explained with quantum theory. After the "theoretical feat" achieved by Max Planck in 1900 on his interpretation of the spectrum of the black body, Albert Einstein in 1905 generalized the concept of loss of electromagnetic energy by quanta. This quantification of energy made it possible to understand and apply the concept of the photon as a particle carrying a finite amount of energy [22].

By applying the hypothesis of the existence of the photon, Albert Einstein was able to explain the quantum nature of the photoelectric effect and he was awarded the Nobel Prize in Physics in 1921 for his work. In summary:

- When a structure is exposed to light, it undergoes a bombardment of photons. These collide with the electrons present and can be absorbed.

- For the electron to be ejected, it must have enough energy to leave the structure.

- The photon must, upon collision, allow the electron to change state (state bound/free state) [23].



Fig I.5. Effect photovoltaic.

I.10. Basic Semiconductor Physics:

I.10.1 Semiconductor:

A semiconductor is a material that has a conductivity intermediate between that of metals (conductors) and insulators. The specificity of a semiconductor by compared to other materials lies in the following properties [24]:

a)- Conductivity:

For a semiconductor, it increases very rapidly with the temperature. In a metal, a one type of carriers, usually electrons, ensures the conduction. On the other hand there are electrons and holes.

b) - Photoconduction:

An illuminated semiconductor sees its resistivity decrease.

c) - Recovery:

In a semiconductor, current flows in one direction only.

d) - Semiconductor materials:

By analyzing the Mendeleev table, part of its elements, is considered to be made of semiconductors [25]

Table I.3: Location of semi-conductors in the periodic table

Chapter 01: Generality on pannier solar photovoltaic.

Group	Ι	II	III	IV	V	VI	VII	VIII
			B	С	Ν	0		
			Al	Si	Р	S		
		Zn	Ga	Ge	As	Se		
		Cd	In	Sn	Sb	Te	Ι	

Quantum theory describes the differences between conductors (metals) and semiconductors using energy-band diagrams. Electrons have energies that must fit within certain allowable energy bands. The top energy band is called the conduction band, and the electrons within this region which contribute to current flow. The conduction band for metals is partially filled, which allows them to carry electric current easily, but for semiconductors at absolute zero temperature, the conduction band is empty, which makes them insulators [26].

The gaps between allowable energy bands are called forbidden bands, the most important of which is the gap separating the conduction band from the highest filled band below it. The energy that an electron must acquire to jump across the forbidden band to the conduction band is called the band-gap energy, designated Eg. The units for band-gap energy are usually electron volts (eV), where one electron-volt is the energy that an electron acquires when its voltage is increased by:

 $(1 \text{eV} = 1.6 \times 10^{-19} \text{ J}).$

$$Eg = Ec - Ev \qquad (I.2)$$



Fig I.6. Semiconductor energy diagram [27]

I.10.2. Doping of semiconductors:

A semiconductor material is a material whose electrical conductivity can vary depending on the conditions in which it is found. In order to improve the conduction of the latter, manufacturers inject foreign materials (impurities) into a semiconductor wafer, which have a number of peripheral electrons just below or just above the 4 electrons of the semiconductor (silicon) [28].

I.10.2.1. N -type doping:

N doping consists in adding to the semiconductor atoms having 5 peripheral electrons (pentavalent) such as Phosphorus. Four of these electrons will take part in the crystalline structure, and an additional electron will find itself free and able to move in the crystal. The semiconductor becomes N-type, i.e. the carriers mainly present in the crystal lattice are electrons [29].

I.10.2.2. P- type doping:

P doping consists in adding to the semiconductor atoms having 3 peripheral electrons (trivalent) such as Boron. These three electrons participate in the crystal structure, but each foreign atom creates a "hole" since it lacks a peripheral electron. That is to say that the majority mobile charges are (positive) holes in this region of the silicon. Mobile "electric charge carriers" is responsible for the conduction of a doped silicon wafer [30, 31].



Fig I.7. Impurities added to the lattice system: a) a donor impurity (antimonies) in silicon; b) an acceptor impurity (boron) in silicon

I.10.2.3. P-N junction:

When the two areas are brought into contact, some N-type semiconductor electrons pass towards the P-type material while the holes of the P-type semiconductor move at the same time in the opposite direction. The movement of these majority charges forms neutral electron-hole pairs, we then obtain a region called PN junction in which the conductivity gradually changes from P-type to N-type [6, 31].



Fig I.8. Formation of a space-charge region, when n-type and p-type semiconductors are brought together to form a junction.

I.11. Principle of operation of a photovoltaic cell:

The operation of the photovoltaic cell is based on the properties of semiconductors which, struck by photons, set in motion a flow of electrons. Photons are elementary particles that carry solar energy at 300,000 km/s and which Albert Einstein in the 1920 s called "grains of light". When they strike a semiconductor element like silicon, they strip electrons from its atoms. These electrons move, in a disorderly fashion, in search of other "holes" in which to reposition themselves [32].

But for there to be an electric current, these movements of electrons must all go in the same direction. To help them, we will combine two types of silicon. The side facing the sun is "doped" with phosphorus atoms, which have more electrons than silicon; the other side is doped with boron atoms, which have fewer electrons. This double face becomes a kind of battery: the side with many electrons becomes the negative terminal (N), the side with fewer electrons becomes the positive terminal (P). Between the two an electric field is created [22, 23].

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When the photons come to excite the electrons, these will migrate towards the N zone thanks to the electric field, while the "holes" go towards the P zone. They are recovered by electrical contacts deposited on the surface of the two zones before d go into the external circuit in the form of electrical energy. A direct current is created. An anti-reflective layer prevents too many photons from being lost by being reflected by the surface [33, 34].



Fig I.9. Principle of operation of a photovoltaic cell



Fig I.10. Working principle of a p-n junction.

I.12. Photovoltaic cell:

The PV cell is the smallest element of a photovoltaic installation, the size of each cell is a few square centimeters. It is composed of P-N type semiconductor materials, which produce an electric current under the effect light photons. This transformation is based on the following three mechanisms [35]:

Absorption of photons by the material constituting the device

Conversion of photon energy into electrical energy, which corresponds to the creation of electron pairs/holes in the semiconductor material.

Collection of particles generated in the device [36].



Fig I.11. The photovoltaic cell

The cells can be divided into three groups: Mono crystalline silicon cells Poly crystalline silicon cells Amorphous silicon cells

I.13. Photovoltaic module:

The most important component of any PV installation is the photovoltaic module, which consists of interconnected solar cells. These modules are interconnected to form fields to be able to different levels of energy needs. More and more powerful modules are available on the market, especially for network connection, but there is still a limit related to weight and handling [36].



Fig I.12. The photovoltaic module

I.14. Photovoltaic field:

The photovoltaic field is made up of photovoltaic modules interconnected in series and/or in parallel in order to produce the required power. These modules are mounted on a metal frame that allows the PV module to be supported with a specific angle of inclination. More and more powerful modules are available on the market, especially for network connection, but there is still a limit related to weight and handling [38].



Fig I.13. The photovoltaic field

I.15. Conclusion:

Photovoltaic panels are of great importance in the production of power in the world, especially in the islands, which have launched many projects. In this chapter, some basic and initial concepts about photovoltaic cells are presented that help us to know about the subject.

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Chapter 02:

Composition, Characteristic and degradation of Photovoltaic panels.

II.1. Introduction:

Solar panels are an alternative source of renewable energy [1]. Where solar panels consist of a number of small units called photovoltaic cells, which work to convert sunlight into electricity, and this is the basic principle of the work of solar panels [2]. The characteristics of these small units such as voltage and electric current determine the amount of energy released by the solar panels in sunlight conditions and the amount of heat, although the types and forms of solar energy are different, but there is a common basic component between them is silicon [3].

II.2. Composition of Photovoltaic panels:

Photovoltaic panels (or solar panels) are devices that convert the sun's light energy into electrical energy [2].

The majority of solar panels consist of several components, including organic and inorganic [4], that are placed in the form of multi-layer panels carefully arranged, which are wrapped with two layers of plastic in one unit in order to protect them and protect the wires that connect them together electrically from external weather conditions and factors [5], these layers are protected at the top With a layer of tempered glass that prevents reflection of light and allows maximum penetration of sunlight, in addition to an aluminum frame on the sides in order to ensure the protection and stability of the structure [6,7], followed by a layer of photovoltaic solar cells and then another layer of packaging and finally a back layer connected to the junction box. Fegure.1 [8, 9].



Fig II.1: Composition of Photovoltaic panels

II.2.1 Glass:

Glass is used in photovoltaic units as a protective layer for the elements from external conditions and climatic factors [10]. In the thin film technology, it acts as a substrate on which photovoltaic materials and other chemicals are deposited. Glass is also the basis for using mirrors to focus sunlight in general 90%-92% [11], so the material used as a front surface for photovoltaic solar panels must have a high transmittance for the passage of wavelengths that can be used in photovoltaic cells in the range of 400 nm to 1100 nm [12]. Most commercial bottles are oxide-based glass with a similar chemical composition



Fig II.2: Chemical component of glass[13].

In addition, the front surface material with low reflectivity should be impermeable to water and should be stable under prolonged exposure to ultraviolet rays and have low thermal resistance. The ingress of water or water vapor into the photovoltaic panel may cause corrosion and rusting of metal wires The junction between the cells and thus will greatly reduce the expected work of the panels. There are many materials that can be used in the upper surface of the panels but toughened glass with thicknesses of 3.2mm and 4mm is commonly used with low iron content of 0.008% and 0.02% because it is low Cost-effective, sturdy, stable, highly transparent, has

good self-cleaning properties, and has good sunlight transmittance [11,13,14].



Fig II.3: Tempered glass

II.2.2 Packaging material (Encapsulant):

Packaging materials are used to ensure that the solar photovoltaic cells adhere to the top surface and back surface of the panels for mechanical protection, electrical insulation and protection from environmental damages (rain, snow, dust...). Breaking this layer can lead to discoloration of the board, corrosion of metal parts and loss of adhesion strength in addition to energy loss [15]. Therefore, the packaging material used must be characterized by stability at high temperatures and low thermal resistance, continuous exposure to ultraviolet rays and low water absorption. It is also transparent with high transmittance [16]. Currently, ethyl vinyl acetate (a copolymer of ethylene and vinyl acetate) is the most widely used material as a coating material in the photovoltaic panel industry. The EVA layer comes as a thin sheet that is inserted between the solar photovoltaic cells and the upper surface and between the photovoltaic cells and the lower surface and then this layer is heated to a temperature of up to 150 °C to polymerize the EVA material and bond the photovoltaic panel materials together [11,12,17]



Feg II.4: EVA [18]

Table II.1: Characteristics and requirements for the encapsulant ethylenevinyl acetate (EVA)

Glass transition temperature	<-40 °C
Total hemispherical emissivity	>91% of the incident light
Hydrolysis	No hydrolysis at80 °C and
	100% RH
Water Absorption	< 0.5 wt% to 100% RH
Resistance to thermal absorption	Stable above 80 °C
Liquidity mechanics	No fluidity at 50 °C
Shear modulus	< 20.7 MPa (3000 psi) at 25 °C
Manufacturing Temperature	≤ 171 °C
Pressure lamination manufacturing	$\leq 1 \text{ atm}$
Inertia chemical	No reaction at 90 °C
Degradation by UV absorption	No wavelength > 350 nm
Clouding	None at 80 °C and 100% RH
Odor, toxicity	None
Gel content (after curing)	>70% (higher is better)

II.2.3 Solar cells:

Photovoltaic cells convert the solar radiation falling on them with a constant current DC; these electrical cells are connected together inside the photovoltaic panels [19]. The cell is known as the smallest piece of semiconductor [20], the most common material for the production of solar cells is silicon [21,22], obtained from sand, so it is called silicon solar cells. Solar cells are classified into monocrystalline silicon, polycrystalline silicon, and thin film solar cells [23, 24, and 25].



Fig II.5: Solar cells

II.2.4 Back sheet:

The solar back layer is the last layer at the bottom of the solar PV panel and is usually made of polymer or a blend of polymers.

A high-quality solar back - coating should protect against:

UV rays, which are harsh on most polymer materials

Moisture and steam penetration.

Drought, wind, dust, sand and chemicals [26]

Besides, it should be scratch-resistant, especially during installation and maintenance. It should also be stable at a temperature of between -40° C and $+85^{\circ}$ C.

In two-phase solar photovoltaic panels, which are designed to allow sunlight to enter from both sides of the photovoltaic cell, the solar back layer must be optically transparent [27].

Development and testing ensure that the solar panel back cover film will last long and keep the electrical components inside protected from the environment.

Most solar panel manufacturers use TPT for solar backlight. TPT is the acronym for Tedlar -polyester- Tedlar film. PVF and refers to Poly Vinyl Fluoride, a thermoplastic fluoropolymer. PET stands for Polyethylene Terephthalate, a common thermoplastic polymer [28, 29, 30].



Fig II.6: Back sheet [31]

II.2.5 Aluminum Frame:

The metal frame is one of the last parts that are assembled during the manufacturing process of photovoltaic panels. It complements the role of the metal frame in ensuring the durability of electrical panels mechanically to protect them from harsh conditions to withstand wind and rain and to

withstand external force [31]. The frame is usually made of aluminum [32], because it has some special properties that facilitate the process of using it, and aluminum can be easily deformed to get the best shape, in addition to being low-cost [33,34].



Feg II.7: Aluminum Frame [11]

II.2.6 Junction boxes

The role of junction boxes in photovoltaic panels is the delivery of electrical connections from inside the panels to the outside [35]. The junction boxes contain diodes whose main function is to prevent the formation of hot spots that could damage the photovoltaic cell [36].



Fig II.8: Junction boxes [22]

II.3. Characteristic of Photovoltaic panels:

II.3.1 Silicon:

Since ancient times, silicon has been of great importance to humanity, but the great affinity between it and oxygen led to the delay of its isolation as a free element until 1823 by the Swedish chemist Jacob Berzelius [37]. The word silicon originated from the Latin word silicon, which is what was commonly called hard rock. Silicon is one of the most common elements after oxygen, and its mass represents 25.7% of the Earth's mass [38].

Silicon is not found free in nature, but it exists in the form of gray solid oxides [39].

Silicon is obtained with a purity of between 90% - 99% from reducing silica from quartz, rock crystal, flint or sand SiO_2 to pure carbon, finely powdered is mixed with coke and heated in a electric furnace.

The reaction is: $SiO2 + 2C \rightarrow Si + 2CO$

Magnesium powder is used instead of coke as a reducing agent.

The reaction is: $SiO2 + 2Mg \rightarrow Si + 2Mg$ [40]



Fig II.9: Silicon [38]

Silicon belongs to the semiconductor, as it is a material in which electric current is difficult to transport [41]. The silicon atom has 14 electrons, as there are 4 valence electrons in the outer electron shell because it is located in the fourth column of the periodic table, and therefore the silicon atom can

achieve the eight rule by forming 4 covalent bonds to give compounds of the SiX_4 pattern.

II	III	IV	\mathbf{V}	VI
	B ⁵	C ⁶	\mathbf{N}^{7}	O ⁸
Mg^{12}	Al ¹³	Si ¹⁴	P ¹⁵	S ¹⁶
Zn^{30}	Ga ³¹	Ge ³²	As ³³	Se ³⁴
Cd^{48}	In ⁴⁹	Sn ⁵⁰	Sb ⁵¹	Te ⁵²
Hg^{80}	Tl⁸¹	Pb ⁸²	Bi ⁸³	Po ⁸⁴

Table II.2: Excerpt from the periodic table of chemical elements chimiques [42]

The silicon exist in different structures, amorphous silicon in which the arrangement of the atoms is random , or crystalline Silicon [43], 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, 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 [44].

II.3.2. Crystalline Silicon (Si):

In such a lattice, the atoms are arranged in a certain pattern that repeats itself. The lattice thus has long-range order and symmetry. However, the pattern is not the same in every direction the bonds between the atoms are of covalent type with an inter atomic distance of 2.35 A° and a lattice 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 E = 1.12 e at room temperature. [45].



cubic crystal

crystalline silicon

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 [46].



Fig II.12: (a) monocrystalline and a (b) multicrystalline silicon wafer

II.3.3. The diamond structure:

The diamond structure is adopted not only by crystalline carbon, but also by silicon and germanium, making it one of the most important crystal structures in the study of semiconductor [47].



Fig II.13: Conventional unit cell of the diamond crystal structure.

Silicon is a cubic diamond crystalline structure, each unit cell having 8 atoms. There are 4 atoms in the center region of the cell, 1 on each face of the cell, and 1 on each corner. However, the corner and face atoms are shared and the corner atoms only contribute 1/8 to the unit cell and the face atoms contribute1/2. Adding these values up the total number of atoms equal: 8.(1/8) + 6.(1/2) + 4 = 8 [48]

The band structure of Silicon has been the subject of many studies. The minimum conduction band of the silicon is in the direction [010] and the refore, by symmetrically, also in the directions [010], [001], [001], [100], [100] or in total six minimums (located in the faces the cube) [49].



. Fig II.14: Minimal Silicon condition band representation minima.

II.3.4. Silicon properties:

II.3.4.1. The height of the band prohibited:

The band gap energy (Eg) gives important electrical characteristics to each semiconductor. Experimental results show that the band gap width temperature (Feg II.15).

These variations can be roughly described by the universal function:

$$Eg(T) = Eg(0) - \frac{aT^2}{T+b}$$
(II. 1)

Table II.3: Parameters of the variation of the forbidden band as a functionof the temperature [50]

Semi-conductor	Eg(0) (ev)	a (ev/K)	b (K)
Si	1,170	4,73.10 ⁻⁴	636

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Fig II.15: Variation of the forbidden band of Si and Ge as a function of the temperature

We can notice that band gap energy strongly depends on the temperature. Indeed, for higher temperatures, there is a significant decrease in the width of the forbidden band [49].

II.3.4.2. Conductivity of silicon:

The electrons of the two outer regions called the valence band and the conduction band determine the conductivity of materials.

The electrons in the valence region do not have enough energy to separate from the nucleus, but can begin to flow around two nearby nuclei, resulting in the formation of a covalent bond. In the crystal lattice, we can see the four covalent bonds of a silicon atom. These bonds are what maintain the crystal unit of this semi-conductor [48].

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Fig II.16: 2D representation of how Silicon atoms covalently bond.

Electrons in the conduction region have a fairly high energy, which allows them to separate from their nuclei. It rotates in a chaotic manner between all the atomic nuclei of matter. They are called free electrons. They easily move in an electric field, forming a current. Only valence electrons are represented. As the electrons collect, each atom sees its full terminal layer (8 electrons), and pure silicon bonds to an insulator (the conductivity is zero at 0 K, i.e. infinite resistance). When the temperature rises, some of the electrons move quickly forming filled holes. Energy is represented in a similar way to that of an atom [50]



Fig II.17: Fermi-Dirac diagrams showing how the number of quasi-free electrons increase and overcome the Fermi level as the temperature increases.

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

$$\sigma(T) = q \left(n \mu_n(T) + p \mu_p(T) \right)$$
 (II.2)

q: is the charge of the electron.

n and p: are the densities of electrons and holes,

 μ : is the coefficient, which, at a given temperature, connects the average drift speed of the carrier to the applied electric field [49].

II.3.4.3. Silicon properties :

Atomic Mass	28.0855+ 0.00034
Atomic radius	110pm
Covalent radis	1.11A°
Van der wals raduis.	210
Crystal structure	Diamant
Electrical configuration	3s2 3p

Table II.4: Table of atomic properties of Si [49].

Table II.5: Table of physical properties of Si [18].

Name	Silicon
State	Solid
Melting point	1414 °C
Boiling point	2223 °C

Melting energy	50.55 Kj / mol
Evaporation energy	384.22 <i>K</i> j / mol
Molar volume	$12.06 * 10^{-6} \text{ m}^3/\text{mol}$
Vanor pressure	Vapor pressure 4 77 P
Sound snood	8.422 m/s at 20.8C
Sound speed	8.433 III/S at 20 °C
Specific heat	700 j/Kg.K
Electrical conductivity	2.52 *10 ⁻⁴ m/S
Thermal conductivity	148 W/m.K
Density	2.328 g/cm^3
Dielectric constant	11.9
N _e	$2.8 * 10^{19}$
N _V	1.04 *10 ¹⁹
Electron affinity	4.05
Gap energy	1.12 <i>e</i> r
Intrinsic concentration of carriers	$1.45 * 10^{10}$
Minority life	2.5 *10 ⁻³
Mobility of electrons	$1500 \text{ cm}^2.\text{v}^{-1}.\text{s}^{-1}$
Refractive index	3.44

II.4. P-V and I-V Characteristics of Solar Cell:

Solar cell is the basic unit of solar energy generation system where electrical energy is extracted directly from light energy without any intermediate process. The working of a solar cell solely depends upon its photovoltaic effect, hence a solar cell also known as photovoltaic cell. A solar cell is basically a semiconductor p-n junction device [51]. When sunlight falls on the solar cell, photons with energy greater than band gap of the semiconductor are absorbed by the cell and generate electron hole (e-h) pair. These e-h pairs migrate respectively to n- and p- side of the pn junction due to electrostatic force of the field across the junction. In this way, a potential difference is established between two sides of the cell. A semiconductor pn junction is in the middle of these two contacts like a battery. If an external circuit connects these two sides, current will start flowing from positive to negative terminal of the solar cell. This is basic working principle of a solar cell. For silicon, the band gap at room temperature is Eg = 1,1 eV and the diffusion potential is UD = 0.5V to 0.7 V [52].

II.4.1. Equivalent circuit of a cell:

Modeling the behavior of a PV cell uses the properties of the solar radiation and those of semiconductors. There are several mathematical models of a photovoltaic cell whose purpose is to obtain the current-voltage (I-V) characteristic for the analysis and evaluation of the performance of photovoltaic modules. These models differ from each other by the chosen structure of the PV panel and the number of parameters involved in the calculation of the current-voltage pair. The model at a diode is the most classic and the most commonly used model [53]. It involves a current generator for modeling the incident light flux and a diode for the cell polarization phenomena. To take physical phenomena into account cell level, two series resistors and shunt Rs and Rsh respectively complete the model. The series resistance is due to the contribution of the base resistances, the edge of the junction and the front and rear face contacts.

The shunt resistance characterizes the currents of leakage from the junction along the periphery of the cell: it is reduced because of the penetration of metallic impurities into the junction (especially if it is deep), during deposition the metal grid or contact sockets on the diffused face of the cell. The represents the electrical equivalent diagram of a cell. This figure shows that the current generated by a cell is equal to the sum of three currents [54].

II.4.2. Parameters of a photovoltaic cell:

The behavior of a solar cell is generally studied from of four main quantities I_{SC} , V_{co} , I_{m} , and V_{m} :



Fig II.18 : Circuit équivalent d'une cellule PV

- Maximum current and voltage

The maximum power of a photovoltaic cell under illumination is the essential parameter, it is the ideal point of the current-voltage. The voltage (V_m) and current (I_m) values such that, also called maximum voltage and current, are also important

$$P_m = I_m \times V_m \qquad (\text{II. 3})$$

We have plotted on the following figure the current-voltage characteristic under light from a solar cell, the values of the parameters used to generate the curve I - V.

The point located at the elbow of the characteristic, is said point of maximum power [55].

- Short circuit current

Is the current value when (V = 0), in the ideal case $(R_s = 0 \text{ and } R_{sh} \text{ infinite})$ this current is merges with the photocurrent I_{ph} . the approximate expression of short-circuit current is then:

$$I_{SC} = \frac{I_{ph}}{1 + \frac{R_s}{R_{sh}}} \qquad (II.4)$$

For a silicon cell for maximum illumination Isc = 30A/cm [56].

- Open circuit voltage :

This is the voltage for which the current delivered by the generator photovoltaic is zero ($I_{ph} = 0$) (the maximum voltage of a solar cell or photovoltaic generator).

$$V_{CO} = \frac{K.T}{q} \ln(\frac{I_{SC}}{I_0} + 1)$$
 (II.5)

 I_0 : doide saturation current [57].



Fig II.19: I-V and P-V Curves of Solar Cell [51].

- The form factor FF :

FF it efficiency of the solar cell, it is obtained as follows:

$$FF = \frac{I_m \cdot V_m}{I_{SC} \cdot V_{CO}} \qquad (II.6)$$

- energy conversion efficiency η :

This is the ratio of the maximum power generated and the power of the incident solar radiation.

$$\eta = FF.\frac{I_{SC}.V_{CO}}{P_0} \qquad (II.7)$$

If S is the surface of the cell and E is the illumination, the energy efficiency is written [57]: $P_0 = E \times S$ (II.8)

So
$$\eta = \frac{I_m \cdot V_m}{E \cdot S}$$
 (II. 9)

II.4.3. Influence of illumination and temperature:

Temperature and illuminance modify the I-V characteristic of the solar cell, not in its general form, but for dc I values, and the product [54, 57].

II.4.3.1. Influence of illumination:

Illustrates the variation of the power delivered by the generator as a function of the voltage for different values of illumination, which allows us to deduce the influence of illumination on the P(V) characteristic.

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Fig II.20: Characteristic $I_{PV} = f(V_P)$ with variable illumination and constant temperature



Feg II.21: Characteristic $P_{PV} = f(V_P)$ with variable illumination and constant temperature

II.4.3.2. Influence of temperature:

It is essential to understand the effect of changing the temperature of a solar cell on I=f(V) characteristic. The current depends on the temperature since the current increases slightly as the temperature increases, but the temperature negatively influences the circuit voltage opens. As the temperature increases the open circuit voltage decreases. Therefore, the power maximum of the generator undergoes a decrease.



Fig II.22: Characteristic $I_{PV} = f(V_P)$ at constant illumination and variable temperature



Fig II.23: Characteristic $P_{PV} = f(V_P)$ at constant illumination and variable temperature

II.5. Solar Panel Degradation:

Some things get better as they age, but there are also things, which get deteriorated as they have a finite life span such the machinery and electronic device. Although crystalline solar power panels are often sold with 25- to 30-year lifespan guarantees [59], those 30-year-old modules won't be performing as well as they did on Day 1. Performance declines as solar cells experience degradation due to unavoidable circumstances like UV exposure and weather cycles, temperature, irradiation, machinal shock ... etc. [60].

Just like a lot of other equipment, solar panels don't perform at 100% for their entire life and then just stop working in year 30. Instead, solar panels at a very slow rate produce less electricity as they age. This process is called degradation.

Because of solar panel degradation, most panels' production warranties change as they age. Manufacturers typically guarantee 90% of the panels' production until the first ten years. After ten years, that percentage drops back to 80% for the remaining 15 - 20 years [61].

All solar panels slowly degrade over time, which means they're producing less electricity from the same amount of sunlight.

Each of different degradation 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 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 [62].

II. 5.1. Yellowing and browning:

This usually consists of a degradation of the EVA or the adhesive material between the glass and the cells. It is a col-our change in the material from white to yellow and some-times then from yellow to brown. It causes a change in the transmittance of the light reaching the solar cells and thus a decrease in the power generated. [63] Oreski and Wallner (2009) determined that the main cause of this defect in EVA and in ethylene copolymer films, is UV radiation and water exposure combined with temperatures above 50 °C that cause a change in the chemical structure of the polymer [64].



Fig II.24: Yellowing and browning of photovoltaic panels

II.5.2. Corrosion:

Moisture entering the photovoltaic module through the laminated edges causes corrosion. The retention of moisture in the module envelope increases the electrical conductivity of the material. Corrosion attacks the metal connections of the PV module cells causing an increase in leakage currents and thus a loss of performance. Corrosion also degrades the adhesion between the cells and the metal frame [65].



Fig II.25: a) Corrosion b) Junction box failures [60].

II.5.3. 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 leads to two important effects, i.e., the increase in light reflection and the penetration of water inside the structure of the modul [66].



Fig II.26: Delamination of the paking layers [62].

II.5.4. Cracks and broken glass:

Glass breakage and cracks are an important factor in the degradation of PV modules. In most cases, they occur during installation, maintenance and especially transportation of modules to installation sites. However, the module with cracks or breaks may continue to produce energy [67].



Fig II.27: Broken glass [65].

However, the risk of electric shock and moisture penetration becomes higher. Breakage, glass breakage and cracks are usually followed by other types of degradation such as corrosion, discoloration, delamination.

II.6. Conclusion:

In this chapter, the most important components of photovoltaic panels were briefly identified, then detailed the principle of operation and the various characteristics, in addition to the most important deteriorations that occur to the panels over time.

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Chapter 03:

Experimental technical characterization of solar panels

III.1. Introduction:

The problem of the degradation of the photovoltaic module is still a question for the monitoring and development of the photovoltaic industry. In this chapter, we are interested in studying the deterioration of the photovoltaic panel, where we present the materials and methods used during our study, this study is divided into two parts, the first part is concerned with describing the electrical properties (Electrical Resistivity (ER)) of photovoltaic panels and the second part deals with the analysis of the deterioration of photovoltaic panels by rays DRX and its study with the Xpert highscor program

The various tools and devices used in this study will be presented, and the steps and stages of the experiment will be explained in detail. 1 The study was carried out in the research laboratories of Ahmed Deraya University, Adrar.

III.2 Steps of the experiment:

1- At first, we brought photovoltaic panels that suffer from deterioration, such as broken glass or discoloration. ...etc. monocrystalline photovoltaic cells.



Fig III.1: a) Circular solar panels b) Square cell solar panels.

2- We cut the boards using special scissors and took all measures and precautions for protection by wearing glasses, gloves and aprons.



Fig III.2: Cutting solar panels

3- We chose 4 different degraded samples for study and compared them



Fig III.3: Samples

4- Separate the components of the four samples carefully using the pickup, starting with the broken glass, then separating the EVA film that had colored spots, then removing the broken solar cells into pieces of different sizes, and finally the back film, which was stickier in the photovoltaic panels with circular cells.



Fig III.4: Separating the components of solar cells

5- We chose suitable sized pieces from different cells in order to study their electrical properties, and the rest crushed by a special masher until we got a powder.



Fig III.5: Suitable size pieces



Fig III.6: Crushing cut cells

6- In addition to the crushed solar cells, we took small pieces of the various components of the previous panels and encoded them in a simple way.



Fig III.7: Coding of different solar panel components

7- We measured the dimensions of the photovoltaic cells and then carried out an experiment to study the electrical properties of the four pieces of solar cells. We installed an electrical circuit containing the cells, provided them with different values of electric current at different temperatures (27, 50 and 75 °c), measured the voltage at each current, and then deduced the value of the electrical resistance.



Fig III.8: Experimental setup for measuring cell voltage and current

8- We analyzed various x-ray encoded samples and transferred the results and analyzed them with the program X'Pert Highscor.

III.2.2. X'Pert Highscore:

X'pert High score is a computer program that processes X-ray diffraction data, and it contains for a diverse database we can get many information on different crystal structures. X'pert High Score program is able to match the information provided to it from the X-ray diffraction chart of the studied sample and that from its databases, giving the required crystal structure.

III.2.2. Origin Lab:

Origin Lab is designed to make analyzing and presenting data easier. To that end, you can even update the update process automatically whenever certain parameters change. You have color managers who do smart planning to simplify the process at every stage

III.3 Characterization technics:

III.3.1 Electrical Resistivity (ER):

Resistivity or Coefficient of Resistance is a property of substance, due to which the substance offers opposition to the flow of current through it. Resistivity or Coefficient of Resistance of any substance can easily be calculated from the formula derived from Laws of Resistance [1].

Laws of Resistancemm:

The resistance of any substance depends on the following factors,

Length of the substance.

Cross sectional area of the substance.

The nature of material of the substance.

Temperature of the substance [2].

Definition of resistivity across a block of side length L with an applied current I and potential drop between opposite faces of V. (B) Electrical circuit equivalent, R is a resistor The resistivity technique is based on the

principle that, when a current, I is passing through an electrically uniform cube of side length L (Figure 1), the material within the cube resists the conduction of electricity through it, resulting in a potential drop, V between opposite faces. The resistance R (Ω) is proportional to the length L (m) of the resistive material and inversely proportional to the cross-sectional area, A (m2): V = I.R (III.1)

Where V is voltage, I is current, and R is resistance.

The value of the R varies according to the dimensions of the material such as, length (L) and cross-sectional area (A), measured in meters. The electrical resistivity value, ρ can be acquired by the relationship [3], [4]:



 $\rho = R.A/L$ (III.2)

Fig III.9: Parameters-used-in-defining-resistivity-A-Definition-ofresistivity-across-a-block-

III.3.2 X-ray diffraction (XRD):

XRD has been used extensively for the examination of materials and thin films. Its effective use depends uponaving a crystalline material. The technique is a bulk sensitive analytical method, but can be used to provide information relevant to surface changes in suitable circumstances. For example, XRD can provide useful information on the extent to which surface treatment of a carbon system has affected the bulk of the material. It is possible to use XRD in a thin-film mode, employing very small take-off angles, to derive some surface information, but generally speaking it must be regarded as a bulk structural technique. Examples of the application of XRD

to the study of carbon fibers can be found in the author's own work (Xie and Sherwood [5].

III.3.3 Bragg's law:

If we calculate the directions in which we have signal, we see that we get a very simple law: if we draw parallel imaginary planes passing through atoms, if we call d the distance between these planes(or "inter-reticular distance"), then the interferences are constructors if:

$$2d_{hkl}.Sin\theta = n.\lambda$$
 (III.3)

Where d_{hkl} is, half the deviation, n is an integer call "diffraction order", and λ is the wavelength of the X-rays (remember that we work in monochromatic). It is here Bragg law [6].



Fig III.10: Bragg diffraction of X-rays (Reflection of X-ray from two planes of atoms in a solid)

If the beam of rays which illuminates the sample is punctual (or at least is a cylinder), there is then a symmetry of revolution around the axis of the beam. The diffracted rays therefore form cones whose axis is the incident beam. In the case of a Debye room that impress the film are the traces of these cones [7].

III.3.4 X-ray system:

In order to characterize in situ and in real time the dynamics of the formation of solidification microstructure, the SFINX device is equipped with an X-ray system which has three main parts

> The X-ray source:

The X-ray source is a micro-focus source with a 3 μ m focal point manufactured by the company "Fine Tec Fine Focus Technologies GmbH". This source emits a beam X divergent (170° aperture cone).

The target used is molybdenum, which was chosen because the energy of its lines characteristics $K\alpha = 17.4$ keV and $K\beta = 19.6$ keV gives a good compromise betwee1n the transmission and contrast for Al-Cu alloys.



Figure III.11: Diagram of the device SFINX X-ray imaging

> The detector:

The transmitted X-rays are detected by a "Vosskuhler 11000" digital camera, containing a 24mm x 36mm sensor with a pixel size of 18µm. She is adapted to the collection of X-rays thanks to fine optical fibers which protect the sensor CCDs. The camera is equipped with a scintillator placed in front of the optical fibers and positioned 2mm inside the camera from its surface. The scintillator converts x-rays into visible light. The camera captures the radiation visible, and transforms it into an electrical signal to form an image. A Peltier-type cooler and a fan on the CCD camera are used to cool the camera to prevent image quality deterioration when the system is hot during solidification experiments.

> The procurement system:

The camera and the recording of images are controlled by an acquisition system. This system can acquire images with a size of 2012 pixels x 1340 pixels (2.7 million pixels) uncompressed in 16 bits, which corresponds to a level of gray for each pixel ranging from 0 (black) to 65536 (white). Note that the camera has a background noise whose gray level value is around 3000. The exposure time for recording an X-ray in the device can vary from 10 ms to 1500 ms. For solidification experiments, the tim typical exposure time is 300-500 ms, giving a temporal resolution of around 2 to 3 frames per second [4,5].

In the case of a Bragg-Brentano diffractometer, the X-ray detector records a maximum when it is on a cone. (In the image below, the cones should of course be truncated the sample because X-rays are absorbed by the sample and the sample holder [5]. By Bragg law, we can therefore associate each peak with an imaginary atomic plane. We know that these plans can be designating by Miler indices (hkl). We can therefore also associate these indices (hkl) with diffraction peaks. We are talking about peak indexing [6].

III.3.5 The definition of a powder:

The powder is defining more precisely in crystallography as a polycrystalline sample, which by definition is forming, by a large number of crystallites oriented randomly with respect to each other. Each crystallite is a monocrystalline entity [7].

III.3.6 Bragg- Brentano diffract meter:

This is the most common assembly. The sample looks like a blister; it may actually be a solid wafer, or a cup filled with powder with a level good plan. In the configuration, the sample is horizontal and stationary, the tube and X-ray detector move symmetrically. If 2θ hkl is the deviation of the beam, the angle between the horizontal and the tube is therefore equal to θ_{hkl} as is the angle between the horizontal and the detector, hence the name of the



assembly.



As the X-ray tube is the heaviest part, we often prefer to keep the tube fixed and move the sample and the detector. We then have the assembly said (θ hkl, 2 θ hkl), since the plane of the sample makes an angle θ with the incident beam, and the detector makes an angle 2 θ hkl with the same beam.



Chapter 03: Experimental technical characterization of solar panels

Fig III.13: Installation of 0hkl and 2 0hkl

The Bragg-Brentano montage has the advantage of harvesting the most intensity; indeed, the beam comes out divergent you tube and because of the geometry, it converges on the detector. Indeed, the convergence is not perfect (we would need a curved sample and not a plane one), we therefore speak of approximate focusing (parafocussing). There are at least two motors, one for positioning the detector, and one for the sample holder (θ hkl, 2 θ hkl) or for the X-ray tube (θ hkl, 2 θ hkl). This device is calling a "goniometer", since it is using to adjust the angles of incidence and diffraction [8].



Fig III.14: goniometer of machine.

III.3.7 Position of the diffraction lines:

A diffraction pattern is characteristic of a compound. The angular position θ_{hkl} of the diffraction lines obeys the Bragg relation. From the knowledge of the angles, we thus deduce the inter-reticular distances d_{hkl} we can then qualitatively determine the phases involved by comparison of the inter-reticular calculated with those stored in the databases (JCPDS file for example) if the compound is already known and lists.

III.3.8. AXRD benchtop powder diffraction system Apparatus:

III.3.8.1 Description:

The PROTO AXRD Benchtop powder diffraction system provides a lowcost alternative for powder diffraction. With an achievable FWHM peak resolution of $< 0.04^{\circ} 2\theta$, and an angular accuracy of $< \pm 0.02^{\circ} \Delta 2\theta$ over the full angular range, the AXRD Benchtop provides the necessary level of performance for even the most demanding x-ray diffraction material investigation. Phase identification, Rietveld refinement, Crystallite size and strain, thin films and coatings, Glancing incidence, Quantitative phase analysis, Percent crystallinity, Structure analysis, rocking curves.



Fig III.15: the apparatus XRD/XRF "The AXRD Benchtop powder diffraction system" [9].

III.4. Conclusion:

In this chapter, we have adopted in our study on the experimental side a set of steps in order to separate the components of the panels for several samples and prepare them in order to expose them to x-rays and analyze the results X'Pert Highscore. On the other hand, we measured the electrical resistance in terms of temperature

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Chapter 04:

Results and descution

IV.1. Introduction

After the experiments that we conducted in the laboratory of Adrar University (physics lab), we obtained satisfactory results. In the first experiment, we relied on Determining the components of the solar panels. In the second experiment on an x-ray with Geiger-Muller to see the effectiveness of the protection.

IIV.2. Results and descution:

IV.2.1. Electrical Resistivity (ER):



The Sample No: 01

Fig IV.1: Graph of change in voltage in terms of electric current for sample 1 at a temperature of 27°C.



Fig IV.2: Graph of change in voltage in terms of electric current for sample 1 at a temperature of 50°C.



Fig IV.3: Graph of change in voltage in terms of electric current for sample 1 at a temperature of 75°C.



Fig IV.4: Graph of change in electrical resistivity in terms of temperature for sample 1.

The Sample No: 04



Fig IV.5: Graph of change in voltage in terms of electric current for Sample 4 at a temperature of 27°C.



Fig IV.7: Graph of change in voltage in terms of electric current for sample 4 at a temperature of 50°C.



Fig IV.6: Graph of change in voltage in terms of electric current for sample 4 at a temperature of 75°C.



Fig IV.8: Graph of change in electrical resistivity in terms of temperature for sample 4.

Through what we reached from the results of the analysis of the various samples, we found that:

- 1. The amount of the produced voltage is directly proportional to the amount of current passing through the cell.
- 2. The voltage produced by the cell increases with the temperature of the cell.
- 3. The increase in electrical resistivity is directly proportional to the different temperatures adopted during the experiment so that The higher the temperature, the higher the electrical resistivity of the solar cell

IV.2.2. Structural and microstructural Study by XRD

The different diffractograms of panel samples powders are shown in **Figure 09**. Each diffractogram is arbitrarily shifted vertically to allow good observation. As is apparent,

It is clear that there are many differences in the X-ray diffraction pattern of different samples, including the following:

The diffraction pattern represents the crystalline materials that can be seen from the peaks.

- The presence of the same peaks in all samples with the change in the intensity of each of them, which is specific to the Si.

- The presence of a new picks in the samples 3 (2theta= 28.2925°) and sample4, which does not appear in the rest of the samples.

- Last Peak (2theta=76.4556°) characterized by high intensity in sample S4, knowing that it is present in the rest of the samples

All these differences may be due to the presence of different phases of each sample, and to know more details, we perform the Rietveld Refinement of the samples (**Figure.09**)



FigIV.9: XRD patterns of the ...

Rietveld refinement by the fitting of X-ray diffraction patterns is the ideal method for microstructural characterization, including qualitative and quantitative analyzes of multiphase materials as well as different panel samples. Several researchers have adopted the Rietveld method to determine the microstructural parameters of various systems.

The structural refinement method uses the minimization technique of least squares making it possible to approach the experimental diagram from a structural model. The minimized function, or residue, is written:

$$M = \sum_{i} w_{i} \cdot (y_{i} - y_{ic})^{2} \dots (IV.1)$$

Where y_i and y_{ic} are respectively the observed and calculated intensity, w_i is the weight associated with the intensity y_i . When refinement by least squares, w_i is taken equal to $1/y_i$.

From a structural model, each contribution y_{ci} is obtained by the combination of different Bragg contributions and continuous background:

$$y_{ci} = y_{bi} + \sum_{k} I_k \phi_k$$
 (IV.2)

Where I_k is the integrated intensity of the reflexion, ϕ_k is the profile shape function and y_{bi} a polynomial function reproducing the background.

The integrated intensity of the reflexion, is calculated according to certain structural and geometric parameters:

$$I = S_{c} |F_{k}|^{2} m_{k} \frac{(L_{p})}{(V_{c})^{2}} \dots (IV.3)$$

 S_c is the scale factor, F_k is the structure factor inclusive of the Debye-Waller factor and site occupancy, m_k is the multiplicity of the hkl reflection, L_p is the usual Lorentz-polarization factor, and V_c is the volume cell.

The profile shape function is the result of the convolution of instrumental and sample broadening:

 $\phi_k = \phi^S \otimes \phi^I \dots (IV.4)$

Where ϕ^{S} is the sample broadening and ϕ^{I} is the instrumental broadening. This last can be written as follows:

$$\phi^I = S \otimes A \dots \dots \dots \dots (IV.5)$$

Where S and A are, respectively, the symmetric and asymmetric components of the instrumental profile, determined by the particular geometry of the diffractometer. The asymmetric component is given by:

 $A = \exp\left[-a_s \left| 2\theta - 2\theta_0 \right| \tan(2\theta_0) \right].$ (IV.6)

Where a_s is the asymmetry parameter and θ_0 the Bragg angle of a $K_{\alpha 1}$ peak.

The Pseudo-Voigt function defined as the contribution of a pure Lorentzian and a pure Gaussian (which will be corrected for the asymmetry of the peaks):

$$pV(2\theta_i) = \sum I_{nt} \left[\eta L(2\theta_i) + (1-\eta)G(2\theta_i) \right] \dots (IV.7)$$

 I_{nt} is the scale parameter of the pV function, η is the gaussianity of X-ray peaks, L (2 θ_i) and G (2 θ_i) are the Gaussian and Cauchyian components, respectively, given by:

$$G(2\theta_i) = I_0 \exp\left[-\ln 2\left(\frac{2\theta - 2\theta_0}{\text{HWHM}}\right)^2\right].$$
 (IV.8)
$$L(2\theta_i) = I_0 \left[1 + \left(\frac{2\theta - 2\theta_0}{\text{HWHM}}\right)^2\right]^{-n} \text{n}=1; 1.5; 2 \dots (\text{IV.9})$$

Where $2\theta_0$ is peak position, I_0 is the peak intensity and HWHM is the halfwidth at half-maximum of the X-ray peaks.

The HWHM is given by the Caglioti formula [Sakher E, Loudjani N, Benchiheub M, Bououdina M. Influence of milling time on structural and microstructural parameters of Ni50Ti50 prepared by mechanical alloying using Rietveld analysis. Journal of Nanomaterials. 2018 Jan 14;2018.]:

 $FWHM = \sqrt{U \cdot \tan^2 \theta + V \cdot \tan \theta + W} \quad (IV.10)$

Where U, V and W, are coefficients of quadratic polynomial or the coefficients of Caglioti.

When using the HighScore Plus program to analyze samples, it has been proven to us that there are different phases (10 phases). Figure.010

shows the refined XRD patterns and quantitative analysis for old panel samples with different time of installation.

From the Rietveld analysis, we notice that the samples are completely different in terms of their different constituent phases, with the presence of Si in all samples with different percentages in each of them (**Figure 10**), Al is present in each of the samples S1, S2 and S3.

S3 is characterized by the three phases Si, Al and SiO2, this last phase is found only in this sample (Figure.10),

In sample S4, it shows presence of new phases is Ag with a ratio of 3.8 % and the Mo phases is 0.1 %. We also note that these two phases are found only in this sample.



Sample 01









Sample 04



Fig IV.10: Rietveld refinements for XRD pattern of (S1)....., (S2).....

General Conclusion

Conclusion General:

The increase in the cost of traditional energies on the one hand and the limited energies of its resources on the other hand, stimulated the consideration of photovoltaic energy as a solution among the promising energy options for several benefits such as abundance, the absence of any pollution and its availability in large quantities more or less at any time on the globe. However, its development is still limited due to the low yield due to several factors including optical loss caused by various degradations.

The degradation of PV modules is due to defects caused by solar cells, from packaging techniques and the impact of environmental factors.

Through the research that we conducted in the physics laboratory at Ahmed Draya University, and through the results and studies that were reached, we concluded that:

- Deterioration patterns recorded in the micro-electricity plant of Ahmed Draya University Adrar: discharge, discoloration, glass breakage and bubbles.
- The increase in electrical resistivity is directly proportional to the different temperatures adopted during the experiment so that The higher the temperature, the higher the electrical resistivity of the solar cell.
- > Various solar cells are made of a basic material, silicon.
- that the samples are completely different in terms of their different constituent phases.
- The diversity of materials present in the degraded samples varies from square- celled plates that contain Si in addition to Al, while plates with circular cells contain Si in addition to Mo and Ag.

Finally, we can say that the deterioration of the photovoltaic panels is due to the additional materials that contain the cells, which affects the electrical resistivity.