

Short review about the development of organic photovoltaic cells

Abousaad Oumaima¹

¹School of Environmental Science and Engineering, Nanjing University of Information Science & Technology, Nanjing 210044, China;

Author email id: omaymaabousaad97@gmail.com; Tel.: +86-15651038715

Abstract: According to recent studies, the global energy demand could grow by approximately 50% in the next 25 years [1]. Currently, more than 80% of the world's energy is produced by burning fossil fuels such as oil, coal, and natural gas. These fuels produce greenhouse gases that are harmful to the environment. Moreover, the energy produced by these sources becomes expensive because of the exhaustion and, thus, the scarcity of these. Solar energy, abundant and non-polluting, can serve as an alternative to these sources and produce a significant contribution to global energy demand.

Renewable energies are an essential asset to solve ecological problems and satisfy the energy needs in constant increase. Among the various renewable energy sources in progress, solar photovoltaic energy, considered clean and inexhaustible, is one of the most promising as the energy of the future to replace other sources of fossil and nuclear energy.

Keywords: fossil energy, greenhouse gases, a global energy, photovoltaic energy, renewable energy.

1. INTRODUCTION

Fossil energy sources such as coal and oil provide chemical energy from combustion, converted into heat or electricity. Coal and especially oil are widely used all over the world as sources of energy (thermal and electric) for the industrial sector as well as for household use, but the gaseous emissions due to their combustion such as greenhouse gases (carbon dioxide; sulphur dioxide; nitrogen dioxide; methane) and certain toxic gases (the hydrogen sulfide; sulphur dioxide) caused acute air pollution and climatic disturbances due to the greenhouse effect as well as the destruction of the ecosystems and natural heritages especially by the lead rejected in water. This has led scientists around the world to search for other alternatives to fossil fuels, i.e., inexhaustible, cheaper, and non-polluting sources of energy such as hydroelectric power, wind power, fuel cells, water electrolyzers, animation based on the use of biogas and the thermal cracking of algae, geothermal energy and solar energy that can be converted into heat by thermal collectors or into electricity by photoelectric cells and photovoltaic cells.

These devices take advantage of photo-physical phenomena such as the photoelectric effect in metals and the photovoltaic effect in semiconductors, these two effects consist in generating a photo-current or a photo-electromotive force from the energy transmitted by the light, and they have been exploited for the manufacture of many opto-electrical devices and apparatuses such as photomultipliers, photoresistors, photodiodes, light-emitting diodes, optical sensors, photoelectrolysis, photovoltaic cells and organic photovoltaic cells based on the visual and electrical properties of semiconductors such as silicon which still dominates electronics and photovoltaics. Other materials can be considered to manufacture these cells, such as cadmium sulphide CdS, cadmium telluride CdTe and perovskites.

In recent years, electronics have undergone a radical revolution with the advent of molecular electronics and organic photovoltaics following the discovery of organic molecules' electrical conductivity and semiconductivity properties and polymers such as polyacetylene by Natta Heeger, McDiarmid and Shirakawa. This conductivity can be explained by the

presence in these molecules of highly mobile and delocalized π -electrons as well as by the phenomenon of conjugation, i.e., the alternation of π -molecular orbitals and σ -molecular orbitals. The photoelectric properties of the semiconducting organic molecules can be exploited for the development of organic photovoltaic cells.

By taking advantage of the electron donor (p-type semiconductors) and electron acceptor (n-type semiconductors) character, it is possible to implement a donor-acceptor heterojunction capable of transferring the charge carriers' photo-generated as a result of light absorption to the donor-acceptor interface via the electrodes. The anode-donor-acceptor-cathode stratification by acceptable methods of deposition and by using the assets of the nanotechnology and the physicochemical methods of characterization can make it possible to manufacture an organic photovoltaic cell of optimal optical and electric properties.

This Modest work is the fruit of theoretical reflections which do not claim to be exhaustive but trying to draw attention to this scientific and technological field which is in full development and full effervescence and known by its multidisciplinary starting from the subtleties of the organic synthesis to the physicochemical methods of analysis, separation, extraction and characterization by sketching.

2. STATE OF THE ART IN PHOTOVOLTAIC TECHNOLOGIES

Lower installation costs of solar systems and improved industrial conditions will allow photovoltaic technology to become a growing and economically and ecologically valuable energy source.

Photovoltaic electricity is obtained by directly converting solar radiation into electricity using conventional solar cells operating based on the photovoltaic effect.

The materials used in the beginning by these photovoltaic cells were essentially inorganic: today, the most commonly used material is still silicon, despite the increasingly tough competition from cadmium tellurides, chalcogenides, and other Gallium Arsenide.

Three leading technologies are currently implemented in the photovoltaic industry: the most important, use a very abundant material, silicon is the 1st generation. The "thin layers" technique combines various materials by projecting them in weak layers on support (2nd generation). The method of photovoltaic cells based on organic semiconductors (molecular; macromolecular; crystalline; liquid crystals) consists of directing up to 1,000 times the sun's light on partitions is the 3rd generation.

2.1. First generation

However, since the beginning of the '80s, a new type of material has emerged: the photovoltaic effect can indeed be obtained from organic molecules. These new materials hold great promise: they are inexpensive to manufacture in large quantities and open much higher production volumes than their inorganic cousins.

The silicon sector currently represents 99% of the photovoltaic module market. It is one of the most abundant elements on Earth, perfectly stable and non-toxic. There are several technologies for silicon photovoltaic detailed below; on the one hand, the cells are based on solid silicon (monocrystalline. Poly-crystalline. ribbons).

2.1.1 Monocrystalline silicon

It is made from a block of very pure silicon formed from a single crystal. The industrial process to obtain it is heavy and expensive, but it allows to obtain cells with 1720% (power of 170 to 200 Wp (watt-peak) per m²) of efficiency. The electrical circuit is placed on the back of the cell, which improves its performance. Monocrystalline solar panels have a higher efficiency in standard conditions, which can be meaningful only when the available space is reduced.

2.1.2 Polycrystalline silicon (multi-crystalline)

Most photovoltaic modules are based on polycrystalline silicon (poly-Si), more often called multi-crystalline silicon (mc-Si). The interest of multi-crystalline silicon is in the lower production costs with an efficiency of 16-18% (power of 160 to 180 Wp per m²), in the module's low cost and high efficiency. 180 Wp per m², due to casting ingots into blocks, is much faster and less expensive in energy than in the case of single-crystal synthesis. These cells are still the most widely used because of their better performance/price ratio than their monocrystalline counterparts [2]

2.2 Second generation

2.2.1 Thin-film technology

A solar cell in thin layers (TLSC), also called a photovoltaic cell in thin layers (TLPV), constitutes what one calls the 2nd generation of solar cells [3].

It is manufactured by depositing thin films of semiconductor materials with photovoltaic properties on a substrate such as glass, plastic or metal. It is used in several commercial technologies, including cadmium telluride (CdTe), copper indium gallium di-selenide (CIGS), amorphous silicon and thin film (a-Si, TL-Si). The interest in thin-film technology comes from the small amount of material needed to manufacture a cell compared to conventional cells. The thickness of the layers varies from a few nanometers (nm) to about ten micrometres (μm).

2.2.2 Amorphous silicon

The cells based on amorphous silicon are based on the basic stack consisting of a layer of type p, intrinsic undoped and noted I, and a layer of type n.

The amorphous silicon cells appeared in 1976 [3]. They mark a critical transition between the structures of the first generation and second generation. These entities are always composed of silicon but on a thickness of about $1\ \mu\text{m}$ only. Record efficiency of 13.4% has been achieved in the laboratory by LG Electronics with amorphous silicon solar cells, but commercial cells tend to have values between 6 and 8%. These efficiencies are certainly lower than those of crystalline cells, but amorphous silicon entities have some particularities that justify their use.

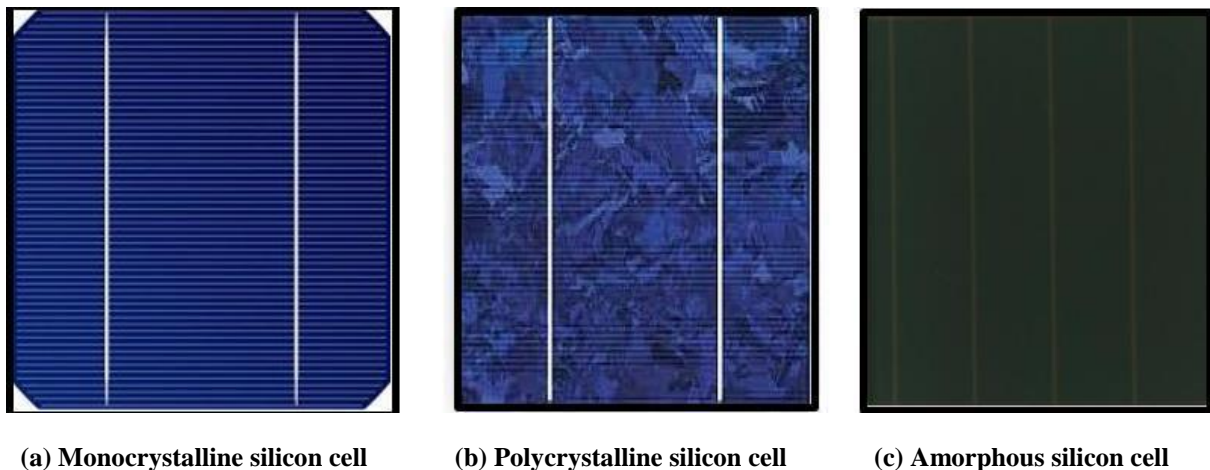


Figure 1: First and second-generation [2] [3]

2.3 Cadmium telluride cells CdTe

CdTe is a Group II-VI compound semiconductor with a direct gap band that converts light from the solar spectrum into electrical energy.

CdTe-based cells are also based on the p-n junction formation, but this time, we speak then of heterojunction by bringing two different materials into contact. The n layer is a semiconductor of a large bandgap (the CDS with the energy of the gap E_g 2,4 eV), which helps light to pass. One speaks then about the window layer. The photons are then absorbed by the layer of CdTe of type p, called absorber. The 1.5 eV value of the energy band gap of CdTe and the high absorption coefficient $> 5.10^5\ \text{cm}^{-1}$ of CdTe gives a high collection of incident photons in a wide range of wavelengths, which is ideally suited to the solar spectrum. The high value of the absorption coefficient makes that almost all the wavelengths of the spectrum are absorbed on a depth of $2\ \mu\text{m}$, thus authorizing the use of relatively impure materials, whose diffusion length of the minority carriers does not exceed a few μm [4].

Two significant problems arise with this technology. Tellurium is a rare element (between one and five parts per billion in the earth's crust). It could come to miss or not be available in sufficient quantity to ensure the perennality of the dies that use it. Cadmium also raises questions because it is a toxic element that can accumulate along the food chain.

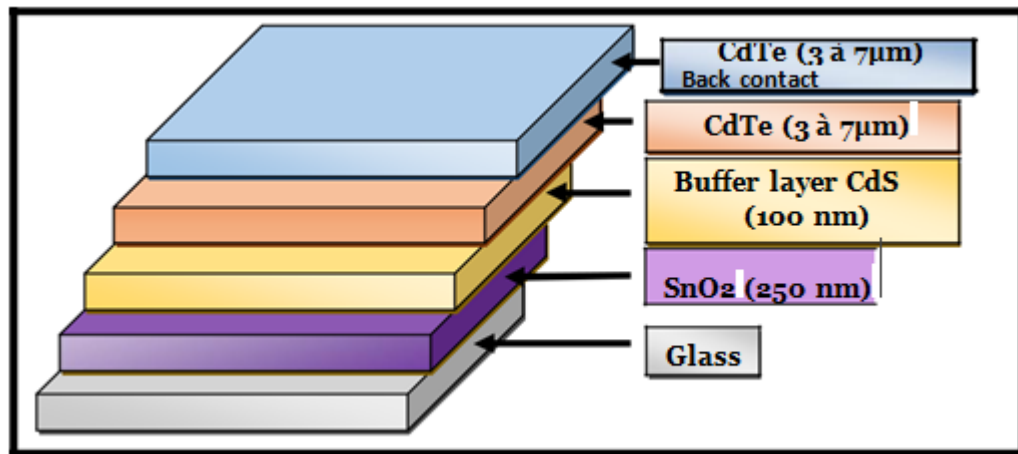


Figure 2: Structure of a CdTe photovoltaic cell [5].

2.4 Materials based on copper indium gallium selenide

Copper indium diselenide (CIS) is a very promising type I-III-VI compound material with a chalcopyrite structure since the theoretical yield of the (n)CdS-(p)CuInSe₂ heterojunction is around 25% [6]. The fabrication of CIS layers is more complex than those of CdTe due to their ternary or even quaternary character (with gallium, CIGS), which has required a longer development time. The positive counterpart of this complexity is excellent flexibility concerning the optimization of the properties. The gap is not the only one that can be fixed flexibly by partially replacing indium with gallium, aluminum or selenium with Sulphur; there are other properties (electron affinity, work function). CIGS-based thin-film solar cells are heterojunction cells. The p-type semiconductor, CIGS, is the cell's absorber (i.e. the area where electron-hole pairs are generated under illumination). The junction is formed with CdS/ZnO, which are n-type semiconductors. ZnO is called the window layer because it must let pass the radiation to the absorber. CIGS has a direct gap and thus a significant absorption coefficient: 2 µm thickness is sufficient compared to 200 µm for the Si homojunction. The structure of such a solar cell is presented in the figure below. At the back of the junction, the substrate is soda-lime glass, and the molybdenum forms the back ohmic contact collecting the holes. The 2 µm layer of CIGS is used to absorb the light. A 50 nm layer of CdS (called buffer layer, weakly n-doped) on this absorber performs the junction. An intrinsic ZnO layer of 50-100 nm high resistivity is usually inserted between the CDs and the doped ZnO. It allows a limitation of the electrical losses due to inhomogeneities in the absorber, preventing the defects of the CIGS from dominating the Voc. Then a layer of zinc oxide doped aluminum. Thus, strongly doped n forms the front window, conductive and transparent, to recover the electrons. An ohmic contact, like, a Ni/Al grid, can be added to collect the current more efficiently.

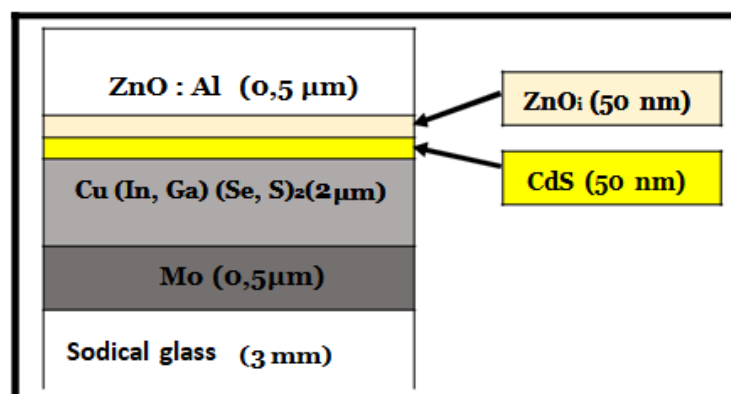


Figure 3: Cross-sectional structure of a CIGS cell.[6]

2.5. Cu₂ZnSnS₄ (CZTS)

CZTS is a semiconductor compound made of copper, zinc, tin and sulphur, which are sufficiently abundant in the earth's crust and are environmentally safe as long as they are used rationally. Although it is still a new material, results indicate that CZTS could be used as an absorber in thin-film solar cells.

CZTS is a p-type semiconductor with direct and tunable gap energy ranging from 1.4-1.6 eV. It is a suitable material for application in thin-film solar cells due to its high absorption coefficient ($> 10^4 \text{cm}^{-1}$) [7]. The structure of CZTS is derived from that of CIGS by the isoelectronic substitution of two atoms of In (or Ga, respectively) by one bit of Zn and one scrap of Sn.

As a result, CZTS has some properties similar to those of CIGS. One of its most significant advantages is that the structure of the CIGS cell can be maintained by simply replacing the CIGS with CZTS.

There is no evidence that adopting such a structure, i.e., combining CZTS with CdS and ZnO, will improve photovoltaic conversion efficiency. Still, it does mean that not much time is wasted searching for the structure that will work for CZTS.

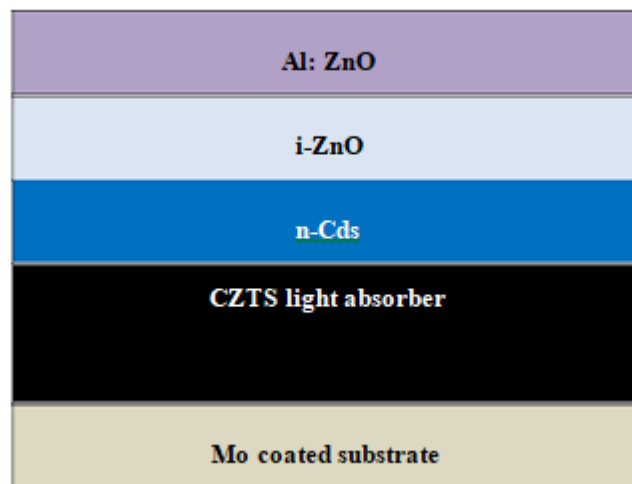


Figure 4: Typical schematic structure of a CZTS solar cell.[7]

This time could focus on the material's properties and its purification to make it better and better. The figure shows the typical schematic structure of a CZTS solar cell.

For all these reasons and the difficulties encountered, in the last few years, organic materials have been chosen and used to develop a new generation of cells, the organic photovoltaic cells. These new materials have particular advantages: they can be synthesized easily, by dry or wet process, with simple techniques from the microelectronics industry. Moreover, the quantities of materials used are relatively small, the films having thicknesses of the order of 100 nm.

An organic photovoltaic cell is generally manufactured on a glass substrate covered with ITO, which constitutes the cell's anode. Sometimes, the glass is replaced by a flexible plastic sheet also covered with ITO. The cells have dimensions of a few cm^2 , which is sufficient to characterize them.

The 3rd generation cells are more flexible, ultra-thin, and therefore more "agile" than silicon panels. They could be used on the roofs of trains and cars, blinds, or even military tents in the future. They can be transparent or coloured and integrated into the facades of buildings in thin plastic layers. Everyday objects could also be equipped with them, from sunshades to backpacks, including our clothes.

To improve the efficiency of cells, research is currently turning to several tracks; researchers have proposed several concepts for the realization of the cell of the future, which we will cite the most interesting as multijunction cells, concentration cells, nanocrystalline cells with dye, hybrid perovskite cells and organic cells [8].

2.6. III-V multijunction cells

The III-V multijunction cells stacking various III-V compounds, each optimized to effectively absorb a portion of the solar spectrum. The stacking, obtained by epitaxial growth [8][9], allows to capture of a large part of the solar spectrum and leads to a single cell composed in the reality of several cells in series, which are designed from several cells superimposed with different energy bands to absorb the maximum of the solar spectrum and thus to have the highest possible efficiency.

Due to the range of solar spectrum from which the photons are collected and the minimization of losses due to thermalization, these cells can achieve the records known to date in photovoltaic conversion. These cells were quickly considered as the best solution with a record efficiency that reaches 40% under concentrated light [10] in the laboratory. The manufacturing process and the materials used to manufacture these cells lead to an extremely high cost [11], limiting these materials to space applications.

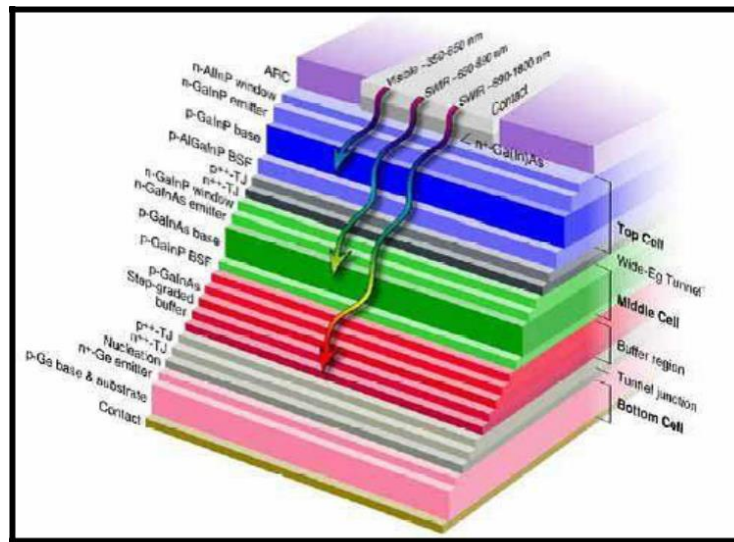


Figure 5: Multi-junction III-V cells [10].

2.7. Nanocrystalline dye cells (Gratzel cells)

Nanocrystalline dye cells also called Gratzel cells after their inventor Michael Gratzel, they are composed of an inorganic semiconductor oxide.

Generally, titanium oxide is used for its large gap of 3.2 eV, with a liquid electrolyte in which the semiconductor oxide is embedded and an organic dye that serves as a photon absorber. This type of cell has a principle of operation utterly different from the other cells; once the stain gains enough energy through to the absorbed photon, this last one is going to emit an electron to the platinum electrode of the conduction band of a semiconductor oxide, which is going to regenerate after that the oxidized dye, the dye grafted on a layer of fine particles of TiO_2 . The solar radiation excites this sensitizer and brings it back to an excited state S^* , which allows it to deliver an electron directly to TiO_2 , thus playing the role of the cathode. The sensitizer is regenerated thanks to a mediator D ; itself revived at the anode.

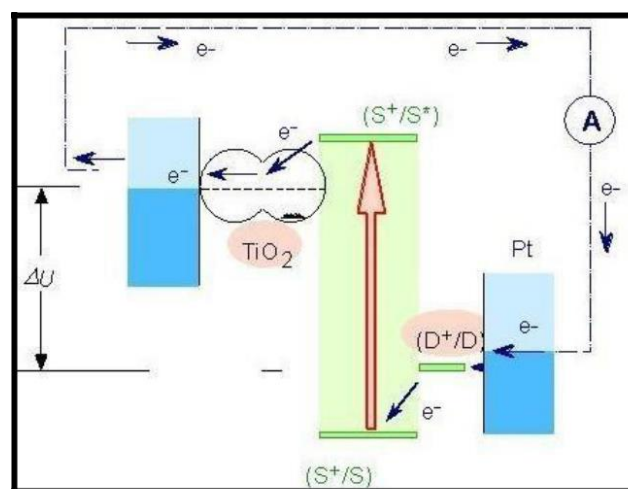


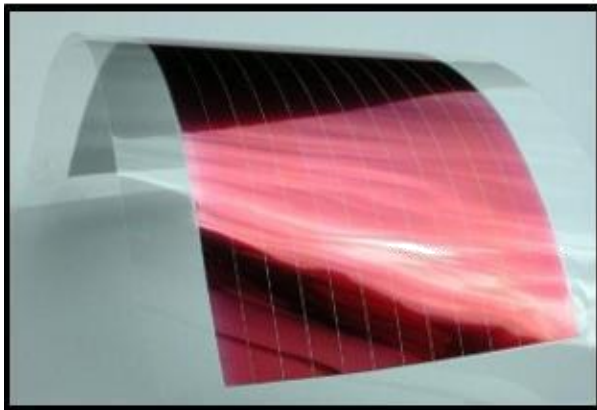
Figure 6: Schematic diagram of a nanocrystalline dye cell.

2.8. Organic cells

These modules are made of organic molecules. The semiconductor used is a polymer such as a polyacetylene [12]. The solar collectors are in the form of photographic type films, flexible, light, and easy to install. There are currently three types of organic photovoltaic cells: molecular, polymer and hybrid organic. These cells have a principle of operation based on the photo-induced transfer of electrons from one polymer to another, where one plays the role of donor and the other of the acceptor. These charges will be transported to the metal cathodes afterward. The potential interest of these technologies is to offer solar energy at a significantly lower price than first and second-generation technologies. However, they are still in the research and development stage. However, these cells are already used in some specific applications with low consumption and high added value, such as calculators or recharging mobile devices.

2.9. Concentrating Cells

This technology uses optical lenses that concentrate the light on small, high-performance photovoltaic cells. Their efficiency is higher than that of silicon. However, it is still necessary to be positioned facing the sun, which is possible by installing a "tracker" (mobile pivoting support). The concentration is obtained by a system of parabolic mirrors or Fresnel lenses, as on car headlights. This technology is currently only economically attractive in areas where direct sunlight is essential.



(a) Organic photovoltaic cell



(b) Concentration photovoltaic cell

Figure 7: Organic photovoltaic cell. [12]

3. PEROVSKITE HYBRID CELLS

Perovskite is one of the promising materials of the moment and could replace silicon in solar panels. Perovskite can be deposited in solution, which allows the realization of photovoltaic cells of large surfaces. The commercialization of perovskite cells is based on improving the installation cost compared to silicon and organic technologies.

Using light-absorbing materials and electrode materials deposited with low-temperature techniques, such as sputtering, printing [13], roll to roll and spin coating [14].

Perovskites have recently attracted much attention due to their high absorption coefficient, charge carriers' high mobility, carrier diffusion length, and high efficiency. The general formula of perovskite is ABX_3 .

A perovskite solar cell consists of a glass/FTO substrate on which is deposited the fluorine-doped tin oxide FTO, and on FTO is deposited the titanium dioxide TiO_2 .

TiO_2 is used to improve electron transport. The active layer consists of the perovskite material.

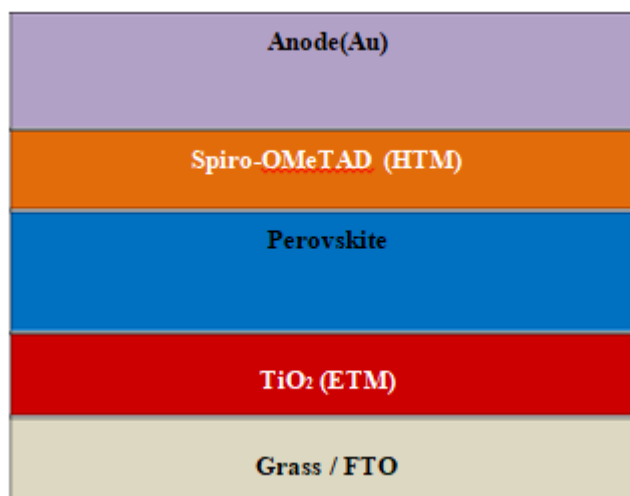


Figure 8: Structure of a perovskite photovoltaic cell.[13]

4. PHOTOVOLTAIC EFFECT AND PHYSICAL ASPECT

The photovoltaic effect is a radiation-matter interaction, i.e., the transfer of energy from light photons to electrons in the material. We can conceive the photovoltaic impact within the framework of classical physics as the result of the interaction between the electric field of the incident wave and the electrons in movement; the latter are accelerated by the electric field of the electromagnetic wave, hence the dependence of the kinetic energy of the electrons mobilized in the material vis-à-vis the amplitude of the incident wave. Photo means light in Greek voltaic adjective from the name of the Italian physicist Alessandro Volta the inventor of the first electric battery, the physicist Antoine Becquerel (father of the great physicist H.A. Becquerel discoverer of radioactivity) in 1839 discovered the photo-electromotive forces; he showed that by illumination one could produce electrical energy in material and he then found the "photovoltaic effect in an electrochemical cell made up of two metal electrodes plunged in an electrolytic solution (sulfuric acid), increasingly large quantities of electricity can be thus generated by subjecting the cell to solar illumination In 1875 Otto Von.

Siemens studied the photovoltaic effect in semiconductors, and in 1887 Heinrich Hertz discovered the photoelectric effect in metals; this phenomenon was studied in detail by Stoletov and Hallwasch. Later, Phillip Lenard showed experimentally that the intensity of the current produced is independent of the power of the incident wave. The kinetic energy of the emitted electrons depends somewhat on the frequency than the intensity of the incident light. These experimental facts are in flagrant contradiction with the electromagnetic theory of light. A coherent explanation of the photoelectric effect must be based on the corpuscular aspect of the morning. It means to consider that the electromagnetic energy is quantified and can be exchanged with the electrons only by packets which are the photons (Albert Einstein 1905). Also, the photovoltaic effect can be modelled by interactions between electrons and photons, which represent the particles associated with the electromagnetic waves (duality wave-corpuscle, Albert Einstein and Louis de Broglie). The studies of photo-electrochemistry, photo-galvanism and photo-electrolysis (photo-faradism) were born. This photo-electricity and photo-electronics developed amply in the '60s and '70s gratitude to the blossoming and emergence of silicon electronics and electronic components such as phototransistors, but this silicon electronics reached its limits. A breathtaking revolution in electronics was born, chemical electronics or molecular electronics based on the semi-conductivity and photoconductivity of organic molecules, either small molecules like polyenes or conjugated polymers. The organic photovoltaic cells appeared and heterojunctions based on recently discovered molecules such as carbon nanotubes, fullerenes, carbon foam and graphene, and polymers such as polythiophenes polyanilines, polyamines and polypropylenes.

5. DESCRIPTION OF THE OPERATING PRINCIPLE OF A SOLAR CELL

The organic cell is considered as a stratification of an active organic layer of a certain thickness. Still, this layer is inserted at the nanometric scale between the cathode and the anode, which must be transparent to allow the passage of photons in the active layer. The transformation of the light energy of photons into the electrical power of electrons and holes in these cells is based on the photovoltaic effect. The first step consists in the absorption of photons which interact with the

electrons π , causing their transition $\pi - \pi^*$ and this leaves a gap of positive charge called a hole, which by electrostatic attraction constitutes a pair with the electron called an exciton, which propagates along the molecule to reach the interface donor-acceptor, it is the diffusion of excitons due to the gradient of their concentration. Under the influence of the electric field prevailing at the donor-acceptor interface, these excitons dissociate to give electrons which diffuse towards the acceptor and holes which diffuse towards the donor, the transfer of charge can be carried out by resonance, that is to say, by delocalization on the bonds or by the exchange that is to say by conjugation or by the tunnelling effect. [15]

Interchain and intrachain conduction and conduction by polarons or bipolarons are also possible; the conductivity increases further with the interactions of the electrons with the phonons of the vibrations of the macromolecule chains.

The excitons which are generated in an inorganic semiconductor are excitons of large radius and low binding energy, thus much less stable; they are the Mott-Wannier excitons; on the other hand, the Frenkel excitons, which are generated in an organic material characterized by a low dielectric constant have a smaller radius of about 10\AA as well as the binding energy of the order of one electronvolt. Thus, they will be much more stable.

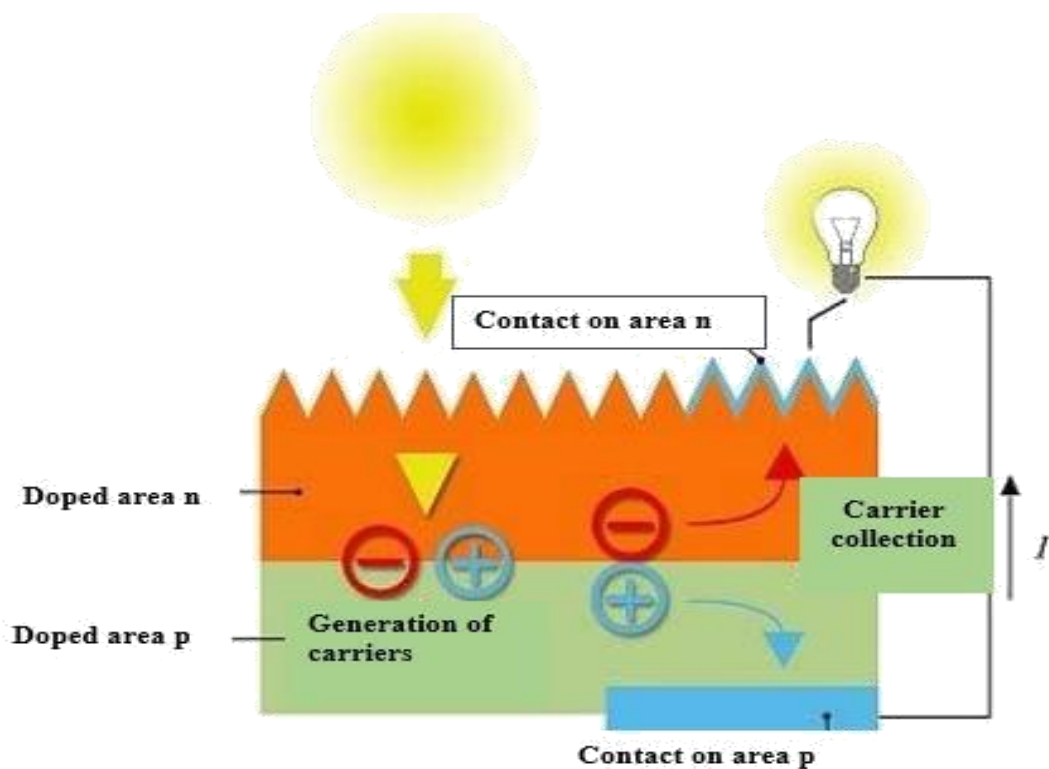


Figure 9: The functioning principle of a photovoltaic cell [15].

6. PHYSICAL PROCESSES OF THE ORGANIC PHOTOVOLTAIC EFFECT

When the incident photons hit the surface of the photovoltaic material, there will be a creation of carriers in the different zones n, p and the space charge zone.

The behaviour of the carriers will depend on the region:

At the n or p zone, the minority carriers which reach the site of load will be sent back by an electric field either in the p zone for the holes or in the n zone for the electrons. Their accumulation will create a photo-current of diffusion.

At the space charge zone level, the excitons resulting from the incident photons will be dissociated by the electric field, from where the electrons will go towards the n region and the holes towards the p region.

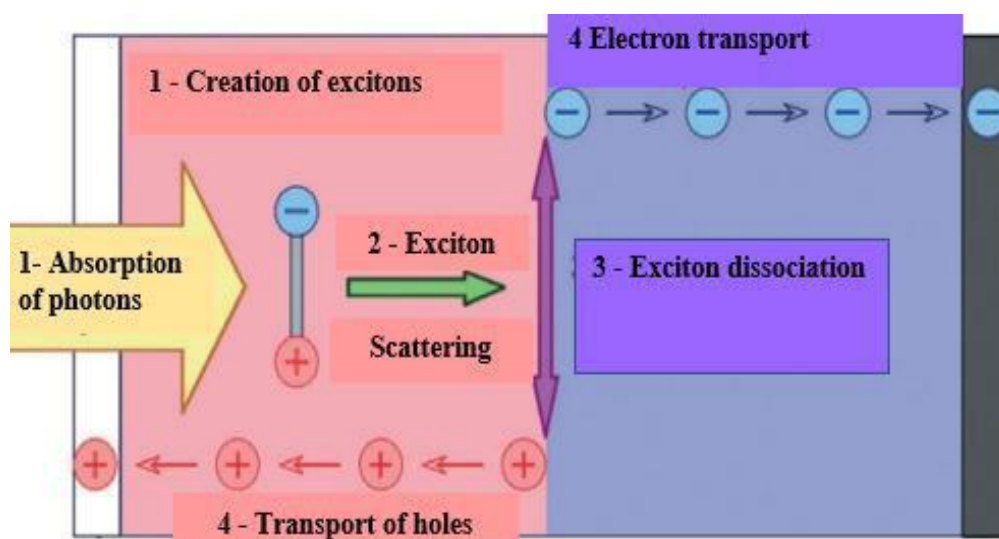


Figure 10: The different stages of photovoltaic conversion.[15]

6.1. The absorption of photons and the generation of excitons

Absorption of photons in solid material such as an organic semiconductor, for example, results in a contribution of energy to the π electrons, so that these electrons pass from the HOMO level to the LUMO level it is the transition

$\pi - \pi^*$ This leads to the creation of a hole which remains linked to the electron and which both form an exciton. This photonic absorption manifests the interaction radiation-matter, that is to say, that the interactions of the electric field of the incident wave associated with the photon with the dipole moment, either induces in the molecule of the oscillations of this dipole thus the emission of radiation, it is the radiative transition, or stimulates the creation of the exciton [16].

Creating a hole that remains linked to the electron and which both form an exciton. The photon-electron or photon-matter interaction can be treated either by the mathematical formalism of the dipolar approximation, which treats the matter in a quantum way and the radiation in a classical way, or the interaction can be described by a purely classical model, i.e. the orientation and the deformation of the electronic clouds and the creation of the dipolar moment induced by the electric field of the incident wave, This absorption can be treated through the theory of perturbations. The photon-matter interaction is reduced to the first order for the dipole moment and the second for polarizability. If the electron is d the hole localized on the same monomeric site in the exciton in question, the electron-hole distance is thus tiny. The binding energy is significant, and this confers a lifetime largely sufficient for the excitons to diffuse towards the donor-acceptor interface without dissociating under the influence of the thermal agitation; for the case of the inorganic materials, the exciton can be of weak energy, and that is because the electron and the hole are localized on two different sites, the exciton will be thus less stable. It will not have a time necessary to reach the interface D/A, which represents a difficulty for the inorganic materials regarding the diffusion of the excitons. The internal electric field at the D/A interface leads to the dissociation of the exciton by overcoming the Coulombic interaction, i.e. the interaction force between the internal electric field and the electric charges of the electrons and holes will be greater than their mutual interactions; this leads to the deformation of the exciton, that is to say, the deformation of the electronic cloud or rather the creation of an induced dipole moment proportional to the polarizability of the pair electron-hole, thus the acceleration of the movement of the electron in the coulombic field of the hole and the lifting of the degeneration of the excitonic levels, and consequently, the dissociation of the excitons into electrons and holes. The diffusion of the excitons is a function of their life which is of the order of a few nanoseconds, if nothing occurs, the electron and the hole recombine again, and the energy of the exciton transformed into a photon or a phonon is transmitted to the molecule if the electron and the hole are not localized on a molecule during the life of the exciton, they can diffuse on a length called the length of diffusion which does not exceed a few tens of nanometers. there is a necessary condition so that the diffusion of the excitons is possible is these last ones must be generated at a distance lower than their length of distribution, in other words, the inter-distance interface donor-acceptor and the exciton must necessarily be lower than the length of distribution, this quantity is a function of the time of distribution:

$$L_D = \sqrt{D\tau_D} \quad [1]$$

One could also estimate the lifetime of the exciton from the Heisenberg uncertainty principle based on its effective mass:

$$\tau_E \sim \frac{\hbar}{\Delta\mu^* v_g^2} \quad [2]$$

6.2. Dissociation and diffusion of excitons.

When the excitons diffuse towards the donor-acceptor interface under the influence of their concentration gradient, there is a separation of charge due to the internal electric field; the electrons overcome the junction or the interface to reach the donor. But the potential well created by the polar groups or the groups polarized by the internal electric field generates positive and negative polarons. The positive polaron comprises the hole plus the potential well, and the negative polaron contains the electron plus the potential well. The polarons can give pairs of bipolarons by electrostatic interaction [17].

The condition for the establishment of the charge transfer process according to the energies of the HOMO and LUMO orbitals is that the charge transfer energy must always be equal to the difference between the ionization energy of the donor and the electron affinity potential of the acceptor, and it must always be less than the binding energy of the exciton. So, the energies of the separate electron and hole must be less than the energy of the exciton for charge transfer to be possible. So, there is a transfer of electrons from the donor to the acceptor that means the excitons were generated in the donor; on the other hand, if they are developed in the acceptor, it is the hole that will pass from the acceptor towards the electron donor, i.e., from the PCBM towards the P3HT. Once again, the energy of transfer of charge is lower than the energy of the exciton [18].

6.3. Transport of the photo-generated charge carriers

The next step involves carrying the photo-generated electric charges towards the electrodes, the electrons towards the cathode, and the holes towards the anode. To be facilitated, the electron and hole mobilities must be high, but the problem is that these materials are endowed with dielectric properties; the mobility values always depend on the methods used to measure them. We can apply Mott-Gurney's law to determine the mobility of charge carriers. Knowing the effective masses and the drift times of the electrons and holes in the material, one can deduce the mobility in the framework of the Drude-Sommerfeld model adapted to semiconductors.

For some oligo-thiophenes and pentacenes, which can be organized or associated with forming columnar networks as Perylenes, which confer to the electrons and the holes rather considerable mobility, generally, the mobility of the electric charges depends on the coordination or the crystalline order, the more the molecule is ordered, the more the mobility is high, and that depends of course on the conditions of deposition as well as on the needs of purification of these materials since the impurities which can exist in the molecules like oxygen for example or other contaminants limit the mobility of the charge carriers by creating potential traps.

7. CONCLUSION

The range of existing technologies for the manufacture of photovoltaic cells using different materials, especially organic materials, has been possible only through to the deep understanding of the physical processes governing the mechanisms of electrical conduction in these materials and a careful study of the photovoltaic effect that has served to access a rational interpretation of the optical and electrical properties of the materials used about their electronic structures as well as their organization and morphologies. All this theoretical knowledge on the physicochemical properties of materials with photovoltaic characteristics has been valuable and very useful for all these technological developments of inorganic and organic photovoltaic which have constituted a starting point for the development of different types of photovoltaic cells that have conquered all sectors of energy, optoelectronic applications, microelectronics.

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