

Comparison of organic solar cells and inorganic solar cells

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To cite this article:

Askari Mohammad Bagher. Comparison of Organic Solar Cells and Inorganic Solar Cells. *International Journal of Renewable and Sustainable Energy*. Vol. 3, No. 3, 2014, pp. 53-58. doi: 10.11648/j.ijrse.20140303.12

Abstract: The fluctuating price of energy, due to a variety of reasons ranging from geo-political constraints to national and international economic issues, and the fact that these energy resources are finite, can be seen as the main incentives to make a transition to a clean energy society. Solar energy is just one of many ways to make this transition a reality, and of the raft of clean energy technologies available, solar energy technology does offer appealing prospects. With the fact that solar energy offers an inexhaustible supply that is literally pollution-free, and coupled to the fact that the planet receives more sunlight in one day than what is required to meet the energy demands of the world for one year, utilizing this resource will undeniably be good for the business community and for the public. While solar energy has been harnessed for centuries, the modern approach has been to construct solar cells and solar module arrays using silicon; with the experience garnered from its use in the semiconductor industry, silicon was a natural choice for use in converting sunlight into usable electricity.

Keywords: Organic Solar Cells, Inorganic Solar Cells, Solar Energy

1. Introduction

The technology used for the manufacture of solar cells is predominantly silicon based an inorganic material. The semiconductor industry developed a deep understanding of the properties of this material, allowing for an easy transfer for use in the solar cell as a solar cell practically mimics the operation of a semiconductor wafer, in that it allows for the transport of an electric current. Initially starting out as organic pigments for use in certain applications, and then with the introduction of semiconducting polymers, these carbon-containing organic compounds were determined to be suitable for solar cell development. Early research indicated that the incorporation of these organic semiconducting polymers had a positive effect on the efficiency rate of the solar cell, so both industry and academia focused on accelerating the development of these novel solar cells. As there is always a trade-off between efficiency and cost, so it is with the utilization of organic solar cells. The main difference, and somewhat a significant difference, is in the lower efficiency rate compared to an inorganic semiconducting solar cell, such as the traditional silicon-based versions. With organic solar cells, the charge carrier mobility is low and this leads to a lower efficiency rating. In spite of this, and despite possessing an optical

band gap of 2 electron volts (eV), organic solar cells are promising due to their affinity for chemical modification (via chemical synthesis techniques), their low manufacturing cost, and the potential for large-scale manufacture. These three reasons have led to the push for organic solar cells.



Fig 1. www.energiemanagementberater.com

2. How Do Organic Solar Cells Work

The first organic solar cells were based on an active layer made of a single material. By the absorption of light, strongly Coulomb-bound electron hole pairs were created, singlet excitons. As described in part zero, these have to be

split in order to finally generate a photocurrent. In order to overcome the binding energy, one has to either hope on the thermal energy, or dissociate the exciton at the contacts. Unfortunately, both processes have a rather low efficiency: under normal conditions, the temperature is not high enough, and the sample thickness is much thicker than the exciton diffusion length. Early morning in North West Spain The consequence: excitons are mostly not dissociated, but recombine instead. This leads to luminescence, and light emitting solar cells do not belong to the most efficient... there is just not enough current output. The introduction of a second layer was a quantum leap in terms of power conversion efficiency (though still on a low level): organic bilayer solar cells, presented in the mid eighties [1]. The light is usually absorbed mainly in the so-called donor material, a hole conducting small molecule. The photogenerated singlet excitons now can diffuse within the donor towards the interface to the second material, the acceptor, which is usually strongly electronegative. A prominent example for an electron acceptor material is the buckminsterfullerene (C₆₀). The energy difference between the electron level of the donor and the corresponding acceptor level has to be larger than the exciton binding

energy, in order to initiate a charge transfer from donor to acceptor material. If an exciton moves – by diffusion, as it is neutral – towards the donor-acceptor heterojunction, it is energetically favorable if the electron is transferred to the acceptor molecule. This charge transfer, or electron transfer, is reported to be very fast (can be faster than 100fs in polymer-fullerene systems) and very efficient, as the alternative loss mechanisms are much slower [2]. The hole stays on the polymer: the exciton is dissociated; the charge carriers are now spatially separated. Even though residing on two separate materials now, electron and hole are still Coulomb bound, even though the recombination rate is clearly lowered (lifetime: micro to milliseconds) as compared to the singlet exciton (lifetime: nanoseconds). Therefore, a further step is necessary for the final charge pair dissociation. Here, an electric field is needed to overcome the Coulomb attraction, opv-generation-recombination-scheme.jpg and this dependence becomes manifest in the typical, strongly field dependent photocurrent of organic solar cells, also influencing fill factor and short circuit current. The basic steps from light generation / exciton generation to photocurrent are shown in the figure.

Operation of Organic Solar Cell

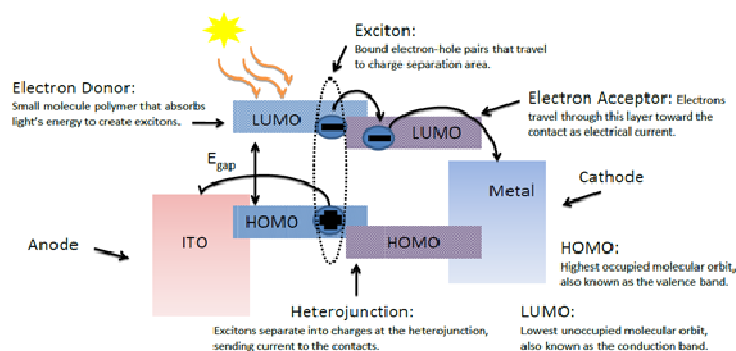


Fig 2. www.marblar.com

3. Advantages of Organic Solar Cells

Successful large scale commercialization of solar energy depends on three criteria in particular: efficiency, lifetime and cost. Much of the early excitement in organic photovoltaics arose from expectations that they could be very cheap. First, the chemicals industry already manufactures organic molecules by the kiloton and sells them cheap. Second, making an organic solar cell is wonderfully slapdash when compared to the care needed in making a silicon solar cell. However, efficiency and lifetime remain stubborn thorns in the side of advocates of organic photovoltaic: efficiencies waiver around 5% and ironically, although reasonably stable in the dark, organic materials tend to degrade in the light. Not only are the molecules easier to handle than atoms, it is also easy make new designs with molecules. Whereas it is difficult to build an entirely new

material when starting from atoms, almost anything can be built when starting from molecules. Indeed, the number of molecules that could potentially be used in an organic cell is limited only by the imagination of the synthetic chemist. This means that organic solar cells could be customized for a particular application or market. Massachusetts-based Konarka, for example, can manufacture cells with different color schemes including cells that are camouflaged for their military customers. More importantly, researchers hope that by careful design and with repeated tweaks, molecules can be developed that will satisfy all three criteria necessary for a successful solar cell: efficiency, lifetime and cost. One benefit of the huge molecular portfolio available to organic photovoltaic is the ability to choose molecules that absorb sunlight very efficiently. As a result organic solar cells can be made 1000 times thinner than silicon solar cells, thereby offering huge savings on materials. Furthermore, because they are thin, the cells are also flexible and could be printed

on a roll-to-roll process, transported easily and simply unrolled on the customer's roof. Konarka, amongst others, is also developing cells that can be incorporated into tents or clothes. Whilst organic photovoltaic may have cost advantages and whilst they may open up a range of other exciting possibilities, they also have shortcomings. To efficiently extract electricity from a solar cell, electrical charges need to be able to travel through it quickly. If charges move slowly they are likely to become stuck or recombine with other charges (of opposite polarity) and disappear altogether. As a result, the number of electrical charges available to do useful work, such as recharging a battery, is diminished. It is not hard to get charges out of a silicon solar cell because its atoms are neatly arranged into crystals and so charges can fly between them at enormous speeds. However, molecules are less ordered, particularly when printed, and so charges move much more slowly between them. To further compound the problem molecules hold onto a charge very tightly and are reluctant to pass it on to their neighbors. Because electricity can't flow easily, the efficiency of an organic solar cell is limited. Sadly, it's not only a problem of getting electrical charges out of an organic solar cell: it's also a problem of generating them. When a solar cell absorbs sunlight it gains energy but, being uncomfortable in this state, it attempts to discharge that energy. Ideally it does so by generating two charges but alternatively it may simply throw the energy away as heat. Solar cells are designed to favor the former process: silicon cells consist of two doped regions that attract positive and negative charges, and organic cells attempt the same effect using two different types of molecule. However, whilst the process is very efficient in silicon, it is less so in organic cells. Whilst poor generation and extraction of electrical charges limits the efficiency of organic photovoltaic, a further problem is lifetime. If you take the care to build a material from atoms, it will generally last a fairly long time. In comparison, molecules are fickle entities that will react with other molecules such as oxygen and water. In doing so, they change. They might absorb less light, or generate fewer charges, or actually trap charges and prevent them from being collected. It is an unfortunate, but ironic, fact that molecules are more likely to degrade in this way whilst illuminated.

Thin film photovoltaic cells based on solution processable organic semiconductors have attracted remarkable interest as a possible alternative to conventional, inorganic photovoltaic technologies. The following key advantages of organic photovoltaic devices have been identified:

1. Low weight and flexibility of the PV modules.
2. Semitransparency.
3. Easy integration into other products.
4. New market opportunities, e.g. wearable PV.
5. Significantly lower manufacturing costs compared to conventional inorganic technologies.
6. Manufacturing of OPV in a continuous process using state of the art printing tools.
7. Short energy payback times and low environmental

impact during manufacturing and operations.

Most of the advantages listed above do also apply to solar cells based on vapor-deposited small molecule absorbers. This suggests that OPV does have the potential to be a disruptive technology within the PV market [3].



Fig 3. www.enterprise.cam.ac.uk

4. How Do Inorganic Cells Work

Solar (or photovoltaic) cells convert the sun's energy into electricity. Whether they're adorning your calculator or orbiting our planet on satellites, they rely on the photoelectric effect: the ability of matter to emit electrons when a light is shone on it. Photovoltaic cells are made of special materials called semiconductors such as silicon, which is currently used most commonly. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely. PV cells also all have one or more electric field that acts to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use, say, to power a calculator. This current, together with the cell's voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce. Silicon is what is known as a semi-conductor, meaning that it shares some of the properties of metals and some of those of an electrical insulator, making it a key ingredient in solar cells. Let's take a closer look at what happens when the sun shines onto a solar cell. Sunlight is composed of minuscule particles called photons, which radiate from the sun. As these hit the silicon atoms of the solar cell, they transfer their energy to lose electrons, knocking them clean off the atoms. Freeing up electrons is however only half the work of a solar cell: it then needs to herd these stray electrons into an electric current. This involves creating an electrical imbalance within the cell, which acts a bit like a slope down which the electrons will flow in the same direction. Creating this imbalance is made possible by the internal organization of silicon. Silicon atoms are arranged together in a tightly bound structure. By squeezing small quantities of other elements into this structure, two different types of

silicon are created: n-type, which has spare electrons, and p-type, which is missing electrons, leaving 'holes' in their place. When these two materials are placed side by side inside a solar cell, the n-type silicon's spare electrons jump over to fill the gaps in the p-type silicon. This means that the n-type silicon becomes positively charged, and the p-type silicon is negatively charged, creating an electric field across the cell. Because silicon is a semi-conductor, it can act like an insulator, maintaining this imbalance. As the photons smash the electrons off the silicon atoms, this field drives them along in an orderly manner, providing the electric current to power calculators, satellites and everything in between. Before now, our two separate pieces of silicon were electrically neutral; the interesting part begins when you put them together. That's because without an electric field, the cell wouldn't work; the field forms when the N-type and P-type silicon come into contact. Suddenly, the free electrons on the N side see all the openings on the P side, and there's a mad rush to fill them. Do all the free electrons fill all the free holes? No. If they did, then the whole arrangement wouldn't be very useful. However, right at the junction, they do mix and form something of a barrier, making it harder and harder for electrons on the N side to cross over to the P side. Eventually, equilibrium is reached, and we have an electric field separating the two sides. This electric field acts as a diode, allowing (and even pushing) electrons to flow from

the P side to the N side, but not the other way around. It's like a hill -- electrons can easily go down the hill (to the N side), but can't climb it (to the P side). When light, in the form of photons, hits our solar cell, its energy breaks apart electron-hole pairs. Each photon with enough energy will normally free exactly one electron, resulting in a free hole as well. If this happens close enough to the electric field, or if free electron and free hole happen to wander into its range of influence, the field will send the electron to the N side and the hole to the P side. This causes further disruption of electrical neutrality, and if we provide an external current path, electrons will flow through the path to the P side to unite with holes that the electric field sent there, doing work for us along the way. The electron flow provides the current, and the cell's electric field causes a voltage. With both current and voltage, we have power, which is the product of the two. There are a few more components left before we can really use our cell. Silicon happens to be a very shiny material, which can send photons bouncing away before they've done their job, so an antireflective coating is applied to reduce those losses. The final step is to install something that will protect the cell from the elements often a glass cover plate. PV modules are generally made by connecting several individual cells together to achieve useful levels of voltage and current, and putting them in a sturdy frame complete with positive and negative terminals.

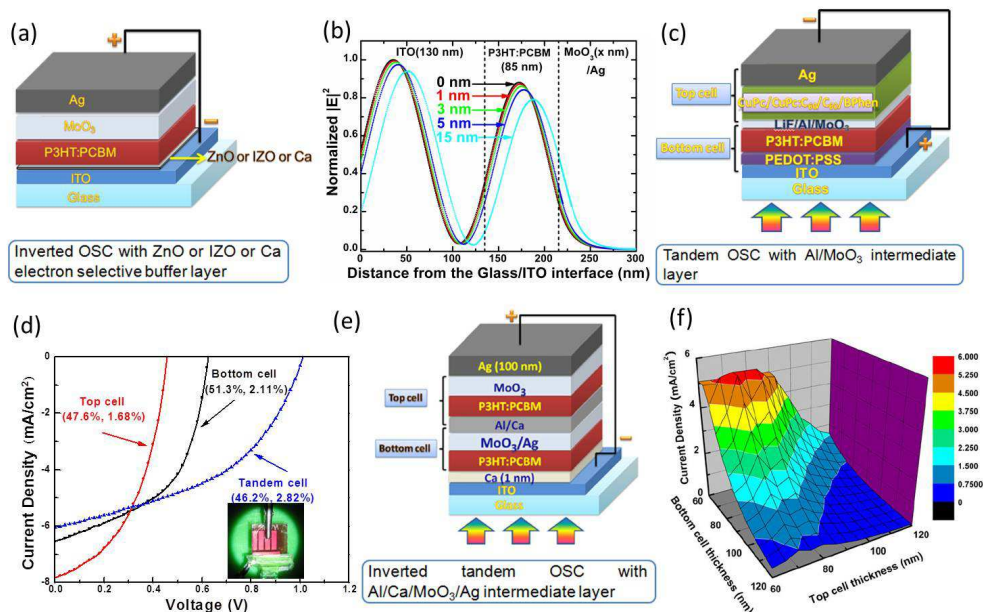


Fig 4. www.luminous.eee.ntu.edu.sg

5. Advantages of Inorganic Solar Cells

In solid state configuration remarkable efficiencies higher than 8% have been reported for innovative devices structures, where PbS absorber acts as HTM [4]. Similarly, extremely thin absorber (ETA) solar cells use a thin layer of inorganic absorber to sensitize a mesoporous

semiconductor. Sb₂S₃ has achieved excellent solid state efficiencies in this configuration due to its low band gap and high extinction coefficient. Nevertheless problems such as high recombination have not been overcome yet, limiting its maximum efficiency to 6.3% when combined with the appropriate polymer and fullerene derivative [5]. Other inorganic materials have also been employed as sensitizers for TiO₂ including CuInS₂ (CIS), achieving

efficiencies of 5% [6].

Since late 2012, organic/inorganic halides with the perovskite structure have strongly attracted the attention of the photovoltaic community when efficiencies close to 10% were first achieved in solid state cells [7] and [8]. The excellent properties and the innovative device possibilities in perovskite-structured organ metal halides has resulted in a frenzied increase of publications reporting high efficiencies [9] and [10], Recently 15% efficient solar cells were reported with $\text{CH}_3\text{NH}_3\text{PbI}_3$ [1] target efficiencies of 20% identified as a feasible goal [11]. Inorganic solar cells are usually chemically and thermally stable devices. Power conversion efficiencies of modern inorganic solar cells reach 30% barrier. This is a major advantage of inorganic solar cells over organic devices. However, inorganic solar cells also possess their own drawbacks. Their production is costly and energy consuming because it requires thorough purification procedures. Therefore, inorganic cells still cannot provide cost-efficient alternative to other 'green' energy sources, such as hydropower. While all four have their pros and cons and are directly advancing the field of organic solar cells, research has also focused on either improving or replacing the two electrodes with better or more suitable material. One such example is the use of carbon, a fairly inexpensive and ubiquitous raw material. Carbon, in either its form of graphene or as carbon nanowires, has recently pushed organic solar cells from a novel and niche idea to one that could realistically make the switch to mainstream applications. The switch will not be on electrical efficiency rates but more on the manufacturing costs. By reducing the costs even further by using carbon, organic solar cells should find widespread interest for low-level applications and (low-cost) niche applications. [12]

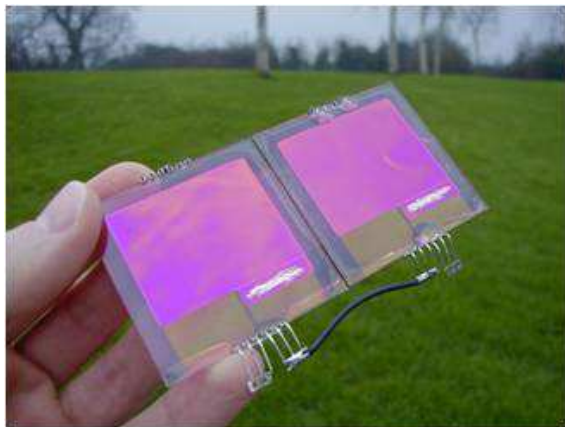


Fig 5. www.phy.cam.ac.uk

6. Comparison Organic Solar Cells and Inorganic Solar Cells

Inorganic semiconductors are better matched in their band gap energies to the solar spectrum, but have lower absorptivities than organic materials, requiring thicker absorbing layers, and high purities (and high costs) to

insure efficient operation. Another key difference between OPVs and conventional inorganic solar cells is in the exciton binding energy. In both systems excitons (excited states) are formed upon photon absorption. In inorganic semiconductors the energy required to dissociate these excitons into charge carriers is quite small (a few milli-electron volts, easily achieved at room temperature). In organic semiconductors the "exciton binding energy" can be as high as 0.5 eV or higher, requiring the formation of a D/A heterojunction (see below) to provide the internal electrochemical driving force for exciton dissociation to occur. Inorganic solar cells can be very efficient because a single inorganic material can be used with an exciton binding energy is negligible at room temperature. The physics of organic solar cells very different because the exciton is strongly bound. You need to have an acceptor and donor component with as much interface as possible between them in order that the formed excitons can quickly reach the interface to disassociate. Once the excitons have disassociated into two separated species, the electron and the hole, they must move efficiently toward the electrodes. Remember that the more you can order your material, in general, the better the mobility will be. The faster the electrons and the holes can move away from each other, the more efficient their separation will be.

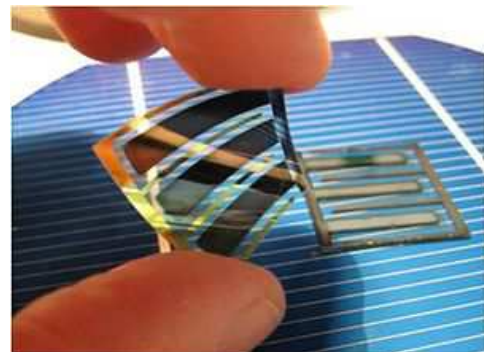


Fig 6. depts.washington.edu

7. Result

Solar energy is clearly part of the solution to the problem of dwindling fossil-fuel reserves. It's increasingly cheap; it's the target of huge quantities of investment and entrepreneurship, thanks to innovations like CSP (Concentrating Solar Power). But if you flinch at the idea of a world dominated by flat panels and vaguely sinister solar receiver towers, take heart: many designers are looking at the natural world for inspiration. Adapt to all surfaces and reduce production costs; these are the two main advantages of organic photovoltaic solar cells, a technology that could revolutionize the way we produce the energy we consume. Light, translucent and sensitive to low light levels, photovoltaic solar cells open a whole new range of possibilities which traditional solar cells cannot offer. These attractive properties make them one of the most appropriate technologies for the development of

photovoltaic power production units integrated into our daily lives. That being said, their efficiency levels are still below that of standard solar cells and scientists are working to improve this crucial aspect in order to commercialize this new technology. The organic solar cells have a similar function but their architecture is 2000 times thinner (about 100 nm), blending different layers of organic materials and semiconductors. The notable advantage in these organic solar cells is that they are much cheaper to produce than conventional solar cells, a huge advantage for its possible commercialization. However, the high manufacturing cost and the rate of converting sunlight into electricity (known as the electrical energy conversion efficiency rate) are drawbacks that have impeded the widespread use of solar energy technology. Other factors exist as well, such as the time constraint associated with sunlight and the availability of the raw materials, but these are either impossible to change (number of hours of available sunlight) or tied into the main drawbacks of cost and efficiency (raw material availability). Improvements, therefore, are both warranted and necessary [12]. Thankfully, improvements have been made in order to reduce the manufacturing costs and improve the efficiency rate. From first generation silicon solar cells, which can be considered the technological backbone of the solar energy industry, second and third generations have been developed and deployed. One particular third-generation solar cell, the organic solar cell, is slated to offer a reduction in the cost of manufacture.



Fig 7. www.plusplasticelectronics.com

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