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# **A BRIEF REVIEW ON CURRENT NEED OF ORGANIC SOLAR CELLS**

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**Abstract:** Organic solar cell research has developed during the past 3-4 decades, but especially in the last two decade it has attracted scientific and economic interest triggered by a rapid increase in power conversion efficiencies. This may be achieved by the introduction of new materials, improved materials engineering, and more sophisticated device structures. Today, though efficiencies of these thin-film organic devices (~3%) have not yet reached those of their inorganic counterparts (~ 10–20%); the perspective of cheap production drives the development of organic photovoltaic devices further in a dynamic way.

**Keywords:** Solar Energy, Organic solar cells, Energy Conversion, Photovoltaic devices.

## **I. INTRODUCTION**

The world now uses energy at a rate equivalent to a continuous power consumption of 13 trillion watts, or 13 terawatts (TW). Even with aggressive conservation and energy efficiency measures, an increase of the Earth's population to 9 billion people, accompanied by rapid technology development and economic growth world-wide, is projected to produce more than double the demand for energy (to 30 TW) by 2050, and more than triple the demand (to 46 TW) by the end of the century. The fossil fuel reserves that currently power our society will fall short of this demand over the long term, and their continued use produces harmful side effects such as pollution that threatens human health and greenhouse gases associated with climate change. Alternative renewable fuels are at present far from competitive with fossil fuels in cost and production capacity. Without viable options for supplying double or triple today's energy use, the world's economic, technological, and political horizons will be severely limited. Sunlight provides the energy for almost all life on Earth. It is harvested by plants, including the microscopic algae living in water. Photons of sunlight enter the food-producing regions within the al-gal cell which act like solar panels. The molecules of the green pigment, chlorophyll, used to be arranged in clusters and absorb the energy of the photons. That energy is used to turn carbon dioxide and water into food, releasing excess oxygen. Algae are eaten by daphnia (water fleas) and these are caught by roach, small fish which are preyed on by herons. The heron ultimately depends on a vast number of algal cells to supply it with food. The scale of sizes in the painting gradually changes from the magnified part of a single algal cell, covering the lower third of the painting, to the Earth's atmosphere at the top of the painting. The oxygen in our atmosphere was itself created by ancestral forms of algae, beginning millions of years ago, when they were among the most advanced life forms on Earth. They changed the ancient atmosphere of the Earth, making it possible for oxygen-breathing animals to evolve. Even today, about 90% of all oxygen production and carbon dioxide use is carried out by algae living in the seas and freshwaters [1 – 3].

Currently, a very high degree of enthusiasm for solar cell technology originates from its superior viability as a clean energy source. Our society has finally started to acknowledge the environmental damage inflicted by the current usage of non-renewable energy sources. The knowledge, that energy needs will only increase, leads researchers and investors to explore innovative, environmentally friendly energy sources such as biogas, wind turbines and solar cells. Solar cells are an exciting clean-tech technology. Analyses of clean-tech efforts to reduce or eliminate use of non-renewable energy sources such as coal and oil indicate that photovoltaic energy converters are more reasonable than wind turbines and biofuels. Unlike wind turbines, solar cells employ no moving parts. Such solid-state devices are noiseless, don't interfere with flight paths as wind turbines do, and require almost no maintenance, once installed. To power our society

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in the future, biofuels would require more arable land than is currently available at present pace. The lower power density of biofuels requires three to four orders of magnitude more land area than oil fields for equal power production. The environmental and socio-economic damage from displacement of natural crops with biofuel crops and fertilizer runoff pollution could be worse than the consequences of using non-renewable energy. The most productive solar alternative is Brazilian ethanol from sugar cane, at a power density of  $0.45\text{W}/\text{m}^2$ . Corn ethanol only has a power density of only  $0.22\text{W}/\text{m}^2$ . To provide the amount of power India consumed in the beginning of this century for fuelled transportation alone, an area of land equal to all of India's arable land would have to be replaced with sugar cane, or twice our country's total arable land would have to be utilized for corn ethanol production. Of course, the growing conditions in India are not as fertile and isolated as in Brazil; biofuel crops would be grown around equator zones. Based on lessons learned in the past, it is best to supply our energy from within the borders of our countries to reduce such a fundamental dependency on other nations. If we relied instead on solar energy, without disturbing current arable land, unutilized isolated areas such as roof tops and deserts could provide all the India's power needs.

Global power consumption by the year 2050 is estimated to be 30TW and the sun provides earth with 89,000TW at the surface. By these figures, one might suggest that the ultimate advantage of solar cells amongst other clean-tech options is that solar energy is solely capable of providing all human society's energy needs (if we are to eventually convert to 100% renewable energy). Wind-turbines and biofuels could not provide global energy needs without serious environmental impact (such as displacing all of our cities and arable land with biofuel crops) [4].

Solar cells use semiconductors to capture light. Each photon of light that is absorbed raises an electron in the semiconductor material to a high-energy state. The electron then drifts away from the net positive charge left behind (termed a 'hole') and this generates a current, which is drawn off as electricity. Silicon makes excellent solar cells – it's the right colour, absorbing across the visible and near infrared parts of the solar spectrum, and makes reasonably efficient cells. However, its efficiency has limitations: for silicon to absorb enough light, relatively thick slabs (typically 0.2 mm) need to be used. Semiconductor-grade silicon is an expensive material, too expensive to make the scale-up of silicon-based solar panels a feasible prospect. After the world-wide photovoltaic market more than doubled in 2010, the market grew again by almost 30% in 2011, despite difficult economic conditions. In 2011, the photovoltaic industry production reached a world-wide production volume of around 35 GW and another moderate increase is expected for years to come. Yearly growth rates over the last decade were on average more than 40%, which makes the photovoltaic industry one of the fastest growing industries at present [5 – 7].

## II. ORGANIC SOLAR CELLS

Solar cells remain too expensive to commercially replace other technologies at present except in the cases when they will be greatly subsidized. Solar cells today span three generations of technology. First generation solar cells are those seen as flat silicon panels on rooftops; these comprise 87% of the current solar cell market today. First generation solar cells operate using a single P-N junction. Second generation solar cells operate using multiple (tandem) P-N junctions that cover a wider spectrum for better efficiencies; but because of the high cost of these additional photolithographic steps, the first generation technology remains more practical when weighing both efficiency and cost. Finally, everything else that does not rely on P-N junctions is (at least for the time being) considered third generation solar cell technology. According to Wikipedia, this includes photo-electrochemical cells, polymer cells, and nano-crystalline material cells. All three could describe organic solar cells.

The term 'Organic Solar Cell' refers to the electrical power generation by organic molecules and polymers. The electrodes are typically made from metals or inorganic transparent conductive oxides, like Indium-Tin-Oxide (ITO). Organic solar cells have the ability to become less expensive than silicon-based cells. By using screen printing and other innovative techniques, start-up companies are giving first-generation (silicon tandem cells) and second-generation (thin-film tandem cells) serious competition. Nano-solar attributes the economic success of screen printed organic cells to the following key innovations: nano-structured components, printable semiconductors and electrodes, rapid thermal processing, low-cost thin-film substrate, and fast assembly through roll-to-roll processing. Although silicon solar cells may leverage the infrastructure of silicon-CMOS technology for cost benefits, poly-and single-crystalline silicon substrates are very expensive and will not be economical in the future for solar cell use. This is because the prices of silicon are skyrocketing; the price of poly silicon used to increase by a factor of 3 - 5% per year (present time). Part of the culprit is, surprisingly, silicon solar cells. The International Technology Roadmap for Semiconductors predicts that in the next few years, more silicon will be allocated to the solar cell industry than the chip industry. The growth of the

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silicon solar cell industry is due in part to the European Commission's stipulation that 20% of European Union energy usage come from solar cells. Countries such as Germany and Japan are huge proponents of solar cell technology; these countries and the U.S. heavily subsidize solar cell development and sales. Actual production costs for organic solar cells were not available to the author at this time; but it is predicted that, given these factors and the development of inexpensive organic solar cell thin-film printing technology, organic solar cells will be more economical in the future [8,9].

Organic solar cells have the potential to supersede the current inorganic semiconductor solar cells, and hence become the most important source of power for society by the end of this century. This may seem counterintuitive since the best production-scale organic solar cell ( $\eta=3\%$ ) is still four times less efficient than the cost-effective inorganic cell used for 87% of rooftop applications ( $\eta=12\%$ ). The best performer of current solar cell technology, rated at nearly 41% efficiency, is based on first-generation, photolithography-intensive, clean room-fabricated inorganic semiconductor heterostructures. These heterostructures are made from silicon to take advantage of the existing silicon-CMOS infrastructure for cost savings and throughput. Silicon, being the second most abundant element (after oxygen) in the earth's crust, would seem to be the ideal material for solar cells; however, the electronic grade silicon wafer substrate necessary for fabricating inorganic solar cells is expensive [10,11].

### III. LIGHT ENERGY CONVERSION IN TO ELECTRICITY

A worldwide search has been under way during the past decade to find other semiconducting materials that may provide cheaper solar cells. If we are to reduce the cost of deployment, we need to bring down the cost not just of the semiconductor materials used in the solar cell itself, but also of all the other materials used in the solar cell assembly, such as the substrate and how it is encapsulated in the panel. The best solution might be to print the entire apparatus – the active semiconductor layers, metal electrodes and tracks – directly onto a plastic film. And the fastest way to do this would be to use continuous roll-to-roll printing, in much the same way that newspapers are printed. Solar cells manufactured in this way would be lightweight, flexible and, crucially, much cheaper and easier to deploy than current systems enclosed within glass sheets. Roll-to-roll printing sets us some big challenges. It requires scientists to develop a completely new materials set, re-design the solar cell semiconductor architecture and build up the manufacturing skills that allow precise control of printed film thickness. For the necessary processes to generate electrical power four steps can be separated: Light absorption, Exciton diffusion, Charge separation and Charge transport.

### IV. NEW MATERIALS ROLL UP

Roll-to-roll printing requires semiconductor materials that can be handled as 'inks' and printed at room temperature – a very different world from the traditional high-temperature and high-vacuum processing world of silicon technology. While silicon readily liberates electrons from holes when a photon is absorbed, the excited electron generated in an organic semiconductor is very reluctant to leave its positively charged hole. Nature has already solved this problem in plants: in photosynthesis, the excited electron is generated at the interface between two semiconducting molecules that have different electron affinities. This causes the electron to move to the adjacent molecule, leaving the hole behind. Subsequent steps in photosynthesis use the reducing power of the electron and the oxidizing power of the hole to complete the chemistry. For solar cells, we have the simpler task of arranging that the separated electron and the hole can be collected at their respective electrodes to either side of the device. Plants use the natural process of photosynthesis to convert sunlight into chemical energy, where the first step in this process is the absorption of light by the chlorophyll molecule. Interestingly, chlorophyll pigments were also directly applied in a single layer solar cell [12]. Besides, the absorption of sunlight and (subsequent) creation of photo generated charge carriers, a second requirement for solar cell materials is the ability to transport these charge carriers. Both properties are commonly found for materials that have an extended delocalized electron system. Phthalocyanine is a representative of the *p*-type, hole-conducting materials that work as electron donor. The perylene and its derivatives show an *n*-type, electron-conducting behaviour, and they serve as electron acceptor material. Both of these molecules were often incorporated into evaporated solar cells. Because the optical band-gap of most organic materials is around 2 eV, the thermally excited, intrinsic charge carrier concentrations are rather low.

### V. PREPARATION TECHNIQUES

The two most common preparation techniques, viz. Evaporation and Wet Processing, for thin film production are in a

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way complementary for the choice of materials. Whereas for evaporation, thermal stability is required, materials for solution processing need to be soluble. Small molecules may be thermally more stable but less soluble than polymers, where solubility often is achieved by side-chain solubilization. Polymers will decompose under excessive heat and have a too large molar mass for evaporation. Hence for small molecules, evaporation is the best choice, whereas semiconducting polymers are mainly processed from solution. However, less soluble molecules like C<sub>60</sub> may become soluble when modified by attaching solubilizing groups (e.g., PCBM) and short polymers or oligomers may also be evaporated. Common to all wet processing techniques is the solving of organic materials in an appropriate solvent like water or any other polar or nonpolar organic solvent [13 – 15].

## VI. ORGANIC SOLAR CELLS BASED ON SMALL MOLECULES

Organic Solar Cells reached a certified efficiency of 6% (according to Heliatek GmbH). A lifetime of 30 years can be expected with proper encapsulation. Based on results of the TU Dresden, Heliatek GmbH develops new and innovative technologies for organic solar cells based on evaporable materials. As a consequence a successful market entry is mainly depending on the availability of production technology and materials. Beside of the meantime attractive efficiencies and lifetimes organic solar cells provide further features, which other technologies do not offer. As shown in fig. 1(a), transparent organic solar cells and modules are possible as well as solar cells with various colours (fig. 1b) and shapes (fig. 1c), which can be optimized to the customer needs.

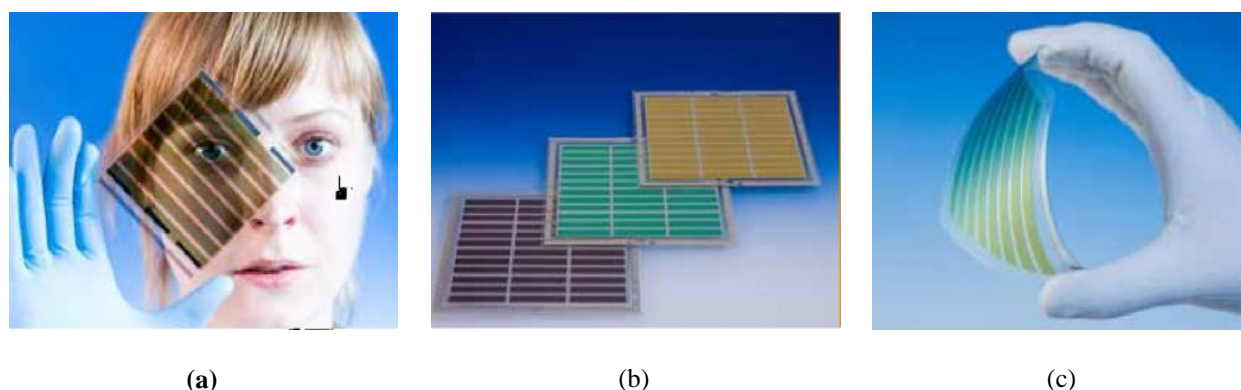


Fig. 1. Transparent Organic Solar Cells

## VII. CURRENT CHALLENGES AND ORGANIC SOLAR CELL DESIGN OVERVIEW

It was stated earlier that organic solar cell technology could supersede first and second generation solar cells (inorganic/ PN junction based technologies). However, in the current state, inorganic technology outperforms organics; the best efficiencies for commercial production organic and inorganic cells are 3% and 12%, respectively. In fact, organic solar cell technology was dormant for the first 30 years; only with recent advances during the last decade in nano science has it become interesting. Fundamentally, organics make excellent absorbers (usually two orders of magnitude more absorption than inorganic counterparts) that are hindered by poor current transport. Therefore, the most critical research advances will be concerning current transport and cost effective fabrication before organic solar cells become competitive functionally and economically [16].

Organic solar cells can be generally described in five layers as shown in Fig. 2. The first layer, the solar cell substrate, can be made of a heat-resistant transparent substrate such as glass, or flexible materials such as polyester. Whereas conventional solar cells allow light to enter through a conductive grid anode on the opposite end as the substrate, organic devices generally admit light through a transparent substrate top layer coated with Indium Tin Oxide (ITO) [17]. ITO is a commercially available glass coating and is widely used as the conductive electrode second layer of organic solar cells because of its transparency in thin films and carrier injection properties that can be enhanced using film treatments. ITO allows for carrier injection into the organic layer of the solar cell. Between the cathode material and active layer, a layer of poly (3, 4-ethylenedioxythiophene)-poly (styrenesulfonate) (PEDOT-PSS) can be deposited to

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form the third layer. The fourth layer of organic solar cells is a donor/acceptor-blend active layer. After this layer, the anodic fifth layer is deposited. The anode can be made from any conducting material; aluminium, gold, silver, and even calcium can be employed. In practice, a layer of lithium fluoride can serve as a protective barrier between the active and anodic layers. There is a fundamental limit to how many layers can be added however. Adding more layers increases processing cost and limits device applications as thicker chips are more prone to breakage and cannot be fabricated on films [18–20].

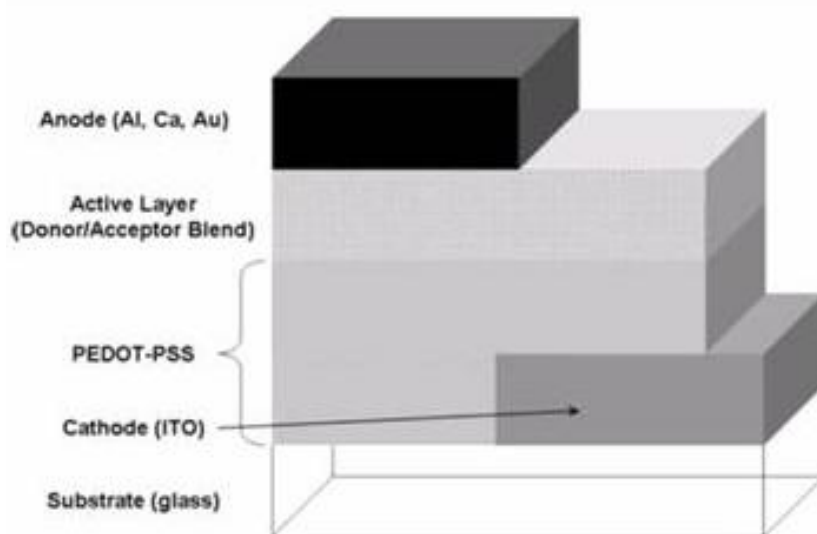


Fig. 2: A conventional organic solar cell structure

## VIII. CONCLUSIONS

The solution to enable organic solar cells to become cost competitive with non-renewable energies would be to increase the efficiency of the current silicon P-N junction based technology. This could be accomplished by adding more layers to these commercially available, monolithically integrated devices which are based on silicon technology. These cascading layers of differing material band gaps would absorb sunlight from shorter to longer wavelengths as they propagated through the device. If everything goes as per planned, our society will be powered primarily by organic solar cells within a couple of years. Rather than seeking more efficiency from the current, silicon P-N junction commercial technology, innovative new organic semiconductor devices can reduce material and production costs so much that efficiency is no longer the important figure of merit. Although efficiencies can further improve and possibly match that of the inorganic counterpart, organic solar cell area in the future will be far less expensive than silicon solar cells and so efficiency could be compensated by increasing area while the devices remain cost competitive with non-renewable energy sources.

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