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# An overview on basics of organic and dye sensitized solar cells, their mechanism and recent improvements

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ABSTRACT

Organic and dye sensitized solar cell devices have attracted a significant attention during last few years in scientific community due to their advantages such as low cost, easy processibility, large scale manufacturing and efficient conversion of solar energy into electrical energy. The main aim of this review is to provide torchlight for organic chemist willing to start exploration in the field of solar cell as it includes an overview of organic and dye sensitized solar cells. This review covers detailed history for development of solar cell, some basic terminologies used in organic and dye sensitized solar cells. The review article gives attention toward synthetic utility of organic molecules for different types of solar cell such as single layer, double layer and bulk heterojunction solar cells, their mechanisms and type of materials which are generally used for solar cell device fabrication. The review specially gives focus on the up to date information about improvements in Organic Solar Cells (OSCs) and Dye Sensitized Solar Cells (DSSCs) which will be a handy tool for young budding researchers to explore the molecular engineering opportunities in terms of designing and synthesizing more efficient exotic materials for solar cell.

## 1. Introduction

Over the past decade, the thrust for renewable energies have came in limelight due to the world's ever increasing demand for energy [1]. Different forms of renewable energies like biomass, wind, hydroelectric, marine tidal, geothermal and solar energy are recognized as alternatives for traditional sources [2]. Among these renewable energies, solar energy is a key technology obtained from sunlight which includes utilization of sun energy in different manner. Sunlight is inexpensive, non-polluting, abundant, unique natural resource of clean energy [3]. Earth receives $1.75\times10^{17}$ W of energy from the sun which is enough to satisfy the annual energy demand of world in less than hour. This fascinating fact of sunlight is pinching researcher worldwide regarding its utilization for mankind by making interfaces which convert sunlight energy into the electrical energy. The commercially existing solar cells are currently based on the inorganic silicon semiconductors which will result proliferation of silicon demand in next decade and price of silicon will rise dramatically [4]. Due to this, Organic Solar Cells (OSCs) also known as Organic Photovoltaics (OPVs) has gained considerable attention from industry and researchers in recent past. Use of OSCs in place of conventional inorganic semiconductors plays vital role due to their easy synthesis, low manufacturing costs, large area coverage and flexible surface [5]. Additionally, attraction towards OSCs is due to easy modulation in optical band gap and energy levels with respect to various conjugated building blocks, compatibility with other deposition technologies for device fabrication [6]. For an efficient OSCs following five processes are important:

1. Light absorption followed by excitons generation
2. Excitons diffusion towards active interface
3. Then charge should be dissociated and separate
4. Separated charge should be easily transport
5. Collection of charge

## 2. Objectives of the review

Based on above mentioned principle steps, many researchers worldwide researching different types of conjugated organic donor and acceptor materials including small molecules and polymers to produce world class highly efficient organic photovoltaic devices. For the advancement of mankind, in recent years, worldwide thrust for

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newer, efficient, safer and greener energy sources has been increased tremendously. Moreover, sun light is the most reliable and affordable energy source for our planet. If we learn to harvest maximum energy provided by sunlight, we can bring lot of ecological, environmental and energy efficient technological benefits to the mankind to the level which were never achieved before. This is a great need for the society and therefore, scientists are focusing how to trap the energy from sunlight in a more cheaper and safe way. In this review, we have tried to focus on some of the recent advances taking place in OSCs and DSSCs research field with some fundamental knowledge using basic terminologies. Knowledge of historic development of OSCs and DSSCs technology along with current happenings in this domain will be helpful to the solar cell research community for their strategies and future work plan. Also, this review complies some basics of OSCs and DSSCs, their mechanism, type of materials involved, molecular engineering aspects attributed with various properties and recent cutting edge research happening in this field. Main objective of this review is to be a pathfinder for young growing communities and early stage researchers who wants to explore energy harvesting materials and devices for future work.

## 3. History of photovoltaics (solar cell)

"The beginning" of the solar cell technology is the discovery of photovoltaic effect by a French physicist Alexandre-Edmond Becquerel in 1839. He used two electrodes coated with AgCl or AgBr as light sensitive materials and kept in a black box surrounding in acid solution. The increased electricity was observed after exposing it to the light. Then it took 1873 when Willoughby Smith discovered selenium photo conductivity followed by William Grylls Adams and Richard Evans Day discovery in 1876 that selenium harvests electrical current on exposing with sun light. But drawback of this was created solar cell was very inefficient and energy created by this was not sufficient to run any electrical apparatus. In 1893, Charles Fritts introduced the first solar cell from selenium wafer. Then in 1894, Charles Fritts coated a selenium with thin layer of gold and used as a light sensor, not as energy supply due to the low efficiency of about 1%. After this pioneer research in 18th century, German physicist Wilhelm Ludwig Franz Hallwachs in 1904 observed photosensitivity by combination of copper and cuprous oxide. Albert Einstein in 1905 discovered how exactly light caused photoelectric effect-essentially, photovoltaics. He stated that light travels as energy packets, he called them photons and energy fluctuates only with its frequency. This revolutionary theory gave well explanation to photon absorption with regards to light frequency. This theory was followed by Nobel Prize winning research by Robert Millikan in 1916. He worked on the photoelectric effect and measured charge of the electrons. Then Polish chemist Jan Czochralski reported a growth of single-crystal silicon which shows efficiency increment for silicon-based cells. Bell Labs produced solar cells in 1950 which can be utilized for space activities by discovering a silicon solar cell and this was the first cell which can run electrical devices using sunlight. This fascinating discovery by Bell Labs was resulted in the launch of Telstar communications satellite powered (14 W) by solar cells in 1962. Simultaneously, cadmium sulphide p-n junction was reported with 6% efficiency in 1954 and in 1960, Hoffman Electronics came up with a solar cell having 14% efficiency. The world's first photovoltaic research and development laboratory 'The Institute of Energy Conversion', University of Delaware is established in 1972 with primary objective of research and development on thin-film photovoltaic and solar thermal systems. Then in 1972, David Carlson and Christopher Wronski, RCA Laboratories prepared first amorphous silicon photovoltaic cells with 1.1% efficiency. University of Delaware in 1980 developed copper sulphide and cadmium sulphide thin-film solar cell which exceeds 10% efficiency. In 1981, Paul Macready made aircraft assembled with 1600 cells on its wings which produced a power of 3 kW and this aircraft flew from France to England. In 1989, solar cells using reflective solar concentrators were reported. In 1992, University of South Florida made of cadmium telluride thin-film photovoltaic cell with 15.9% efficiency. The first solar cell to exceed 30% conversion efficiency was reported by National Renewable Energy Laboratory in 1994 using gallium indium phosphide and gallium arsenide which was again crossed as 32.3% in 1999. Recently in 2007, university of Delaware achieved a 42.8% world record power conversion efficiency in solar cell technology. Since past few years, there has seen a huge investment in utility-scale solar plants and the efficiency record break is getting common due to advancement in sciences and critical mass working on these technologies. In 2012, "Golmud Solar Park" is in China came up with the largest solar energy plant with an installed capacity of 200 MW. This is perhaps exceeded by India's "Gujarat Solar Park" scattered around the Gujarat region in the form of solar farms, with installed capacity of 605 MW.

## 4. Conventional solar cell and organic heterojunction solar cells

Conventional solar cells (Fig. 1a) are based on the minority carrier diffusion process which creates the photovoltaic current. At p-n junction, a bunch of electrons move to the p-side, creating the built-in voltage. This electric field makes it easy for electrons to move from p to n, but impossible the other way around. A photon with enough energy will excite an electron from the p side to the n side causing interruption of electrical balance. Then application of external current drives electrons to the p side which will then combine with holes sent by electric field. This electron flow generate the current and the cell's electric field produces a voltage. This resulted current and voltage will give power.

However, use of two or more layers of different materials with different band gaps shows efficiency increment. Loading higher band gap material on the surface to absorb high-energy photons can result better efficiencies and this approach is used in multi-junction cells. The anode cannot be too large or it will block the incoming light. If it is too small, then it will not conduct well. A grid of some type is usually used. Additionally, an anti-reflective coating must be applied along with a glass cover to protect the cells. Organic solar cells (Fig. 1b) involve majority charge carriers since holes are located in the highly occupied molecular orbital (HOMO) of donor phase and electrons are present in the lowest unoccupied molecular orbital (LUMO) of acceptor phase and their movements result in photovoltaic current. Organic solar cells made up from blends of conjugated polymers or conjugated organic compounds (donor) and fullerenes (acceptor). Upon absorption of photon or light, the active layer made of donor and acceptor mixed morphology creates electron-hole bounded pair called as an exciton. Exciton diffusion lengths are quite small and excitons can only travel till 10–20 nm distance. Upon reaching exciton at the interface of donor-acceptor present in the active layer, it gets dissocited into the free charges such as holes and electrons. The nanomorphology of the active layer blend plays a vital role to assist exciton diffusion and exction dissociation into free charges, so the active layer morphology engineering is extremely important.

The active semiconducting materials used in organic or polymer solar cells is always carbon based organic compounds either in the form of small molecules, dendrimers or polymer which converts solar energy into electric energy. Such organic molecules with capability of light absorption induces the passage of electrical charges between donor conduction band to the acceptor conduction band of molecule. Such type of OSCs can be divided into three types as single layered, bilayer and bulk heterojunction (BHJ) structured cells.

### 4.1. Single layered solar cell

The first generation of OSCs were mainly constructed by single organic layers [7–9] placed between two metal electrodes (Fig. 2a)