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Review on Schiff bases and their metal complexes as organic photovoltaic materials

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ABSTRACT

Solar energy sources, having the potential to provide energy services with zero emissions of air pollutants, have become more economically attractive with technological improvements. Organic Solar cells promise to be a significant contributor to our future energy system with suitable efficiencies and low cost. The foundation, basic principles, material requirements and device operation mechanism of organic solar cells has been already reviewed by various authors. This paper highlights the use of Schiff bases and their metal complexes as Photovoltaic materials. Schiff bases having potential Photovoltaic characteristics are also discussed in this paper. Major developments in this field over the past few years and recent research have also been briefly discussed.

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1. Introduction

The ever-swelling exploitation of fossil fuels by humans has ruined the environment, and has made everyone realize now that, return to pre-industrial era is impossible. To solve our problems, a sustainable development is needed. The use of novel technology to harness renewable energy efficiently to supplement our traditional energy must be designed. Renewable energy sources have the potentiality of providing energy services with zero or close proximity to zero emissions of both air pollutants and green house gases. Among the various renewable energy sources available, solar energy conversion systems have attracted much attention by the researchers and engineers, due to their abundant availability of their source, the solar radiations. The Earth receives 120,000 TW of electromagnetic radiation through solar irradiation, and will continue till the death of our Sun some 5 billion years from now. Beginning with a hint from nature, A.E. Becquerel in the year 1839, for the first time observed the photovoltaic effect [1]. Photovoltaic devices convert solar energy directly into electrical energy without any emissions. For a single gigawatt—hour of electricity generated by solar photovoltaics, more than 1000 t of CO_2 emission is being reduced. Since the discovery of photovoltaic effect research has bloomed in this field, with development of photovoltaic devices using organic, inorganic and hybrid materials. Though inorganic materials have so far been very promising in the development of this field, organic materials as photovoltaics are also showing great hope.

Higher cost and complex production procedure involved with the inorganic photovoltaic devices, has crippled its extensive use in domestic and other commercial applications. However, organic photovoltaic devices with their low cost, easy reproducibility and

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non-toxic nature tend to be potential future energy source globally. Though organic materials are cheaper and have ease of reproducibility, their efficiencies have not yet reached the level deemed as necessary for commercial use. Newer organic materials that could overcome the drawbacks faced by the present conventional materials, is the latest trend on research. Schiff base compounds have been tried as substituent, and their possibilities have also been reported by various researchers.

In this context, this paper brings in the various works done in this field, and discusses their prospects. Schiff base and their metal complexes that have optoelectic properties and could be used in photovoltaics with improvements have been listed. Schiff base compounds are very promising because of their biodegradability, non-toxicity, good electrical conductivity in conjugated compounds, and cheaper and easier production.

2. History

After the discovery of the photovoltaic effect by A.E. Becquerel, in 1906, Pochettino observed photoconductivity for the first time in anthracene, an organic compound [2]. With this as the starting note, photoconductivity of various organic materials was studied in the 1950s with the aim of using them as photoreceptors. It was during this time that, in the year of 1959, Kallmann and Pope observed photovoltaic effect in a single crystal of anthracene sandwiched between two identical electrodes when it was illuminated from one side. Later on, photovoltaic effect was observed in many common dyes, such as methylene blue and was also observed in many important biological molecules such as carotenes, chlorophylls and other porphyrins, as well as the structural related phthalocyanines (PC) [3,4].

The first generation of organic photovoltaic solar cells were based on single organic layers sandwiched between two metal electrodes of different work functions [4]. The power conversion efficiencies reported were generally poor (in the range of 0.001 to 0.01%), but reached remarkable 0.7% for merocyanine dyes in the early days [5]. In this case, the organic layer was sandwiched between a metal–metal oxide and a metal electrode, thus improving the Schottky-barrier effect [6]. A major breakthrough in the field came in 1986 when Tang fabricated a thin film, two-layer organic photovoltaic cell, from copper phthalocyanine and a perylene tetracarboxylic derivative and discovered that the output power could be greatly increased if two materials were used instead of just one [7]. It was the first known heterojunction organic solar cell.

Later on the organic solar cell development gained momentum in the past years with the conversion efficiencies reaching 4%, with the development of new designs such as, (i) the evaporated bilayer devices [8,9] in which thin film layers are coated through thermal evaporation process; (ii) the bulk heterojunction polymer–fullerene devices [10–17] in which the donor polymers are blended with the fullerene and coated in between the electrodes; (iii) the co-evaporated molecular devices [18–21] in which two materials that are to be used for the application are mixed and evaporated together; and (iv) the organic–inorganic hybrid devices [22–24], which are at present the more efficient type of devices. Recent progress achieved using organic single-crystal, multilayered thin film and blended network technologies permit one to expect a very fast increase in the conversion yield of organic solar cells. This will possibly make them a competitive alternative to the various forms of silicon cells.

3. Operation of organic solar cells

The organic solar cells produce electric energy directly from solar radiation through a chain process. The operational mechanism of these devices is illustrated in Figs. 1 and 2.

These are the productive events of the PV process.

(i) Photons from the solar radiation enter inside the device and are absorbed by an electron in the highest occupied molecular orbital (HOMO) of the organic material.
(ii) The electron which has absorbed the photon, gets excited to the lowest unoccupied molecular orbital (LUMO), creating an exciton (bound electron–hole pair).
(iii) The created exciton diffuses to the interface of two materials, the electron donor and electron acceptor, and carriers are generated from the exciton dissociation.
(iv) The generated carriers are collected by the electrodes and driven into the external circuit to produce power and do work.

4. Challenges

Though organic solar cells have reached the benchmark of 10% efficiency [26], they still face a number of obstacles that are preventing them from moving beyond the laboratory. After the demonstration of the first donor (D)–acceptor (A) heterojunction by Tang [7], there has recently been a rapid increase in cell efficiency. The simultaneous researches in the field of organic LEDs have influenced the development of efficiencies of organic solar cells since organic light-emitting devices often employ materials and device structures that have direct application to light detection [27].

To reach an approximate upper bound of obtainable efficiency of 20%, at 100% conversion efficiency across the visible spectrum, Stephen R. Forrest has listed few challenges that must be overcome [27].

- The cell must have an efficient response across the entire solar spectrum.
- Couple most of the light into active heterojunction by surpassing the exciton diffusion bottleneck in tandem solar cells.
- Reduce the cell resistance in transporting the power from its generation site to the load by creating low-optical loss, high-conductivity contacts.

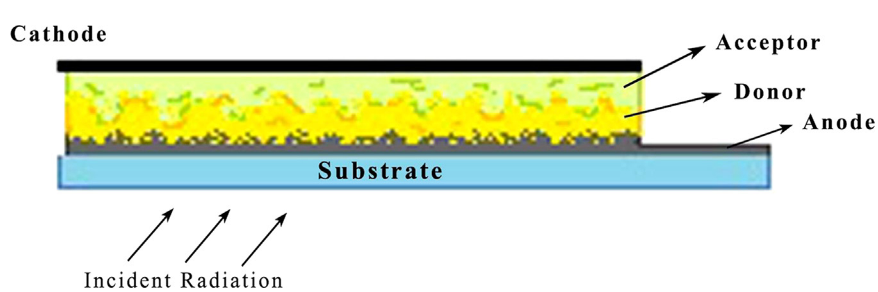

Fig. 1. Schematic diagram of a thin-film organic solar cell and its components.