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Organic Solar Cells

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Abstract: As a low-cost photovoltaic solar energy device constructed of organic materials, organic solar cells (OSC) have shown considerable promise. This article provides an overview of what organic solar cells are, the materials they are made of the difficulties and constraints they face, their performance and efficiency, as well as their benefits and drawbacks. The stability and efficiency of organic solar cells are still being researched, with problems including their short operational lifetime and sensitivity to external conditions being addressed.

Index Terms: Organic Solar Cells, Low-cost photovoltaics, Solar Cell efficiency.

1 INTRODUCTION

Organic solar cells (OSC), dye-sensitized solar cells, quantum dot solar cells, and other solar photovoltaic technologies have all undergone substantial research and development as a result of the rapidly increasing demand for efficient and affordable solar photovoltaic (PV) technologies [1]. Among them, organic solar cells, which are shown in Fig.1 stand out because they have special benefits, including low cost, use of available earth components, simple production procedures, and adaptability to interact with various technologies [2]. Despite having an operating efficiency that is already more than 10% [5] compared to traditional silicon solar cells, organic solar cells still have a strong commercialization potential because of their unique advantages [2]. However, considerable technological obstacles still exist, including issues with stability and endurance, as well as knowledge gaps in the fundamental physics of devices [3,4]. A variety of materials with different efficiencies can be used to convert photovoltaic (PV) solar energy. No material or combination, however, has yet demonstrated sufficient cost-effectiveness to compete with energy produced on a massive scale using fossil fuels. Thin film technologies, particularly organic solid-state cells, have attracted significant interest as a potential long-term investment, while significant efforts are concentrated on lowering the cost of conventional inorganic devices. This review goes through materials used in organic solar cells, challenges and limitations, efficiency and performance, and advantages and disadvantages of the organic solar cell (OSC).

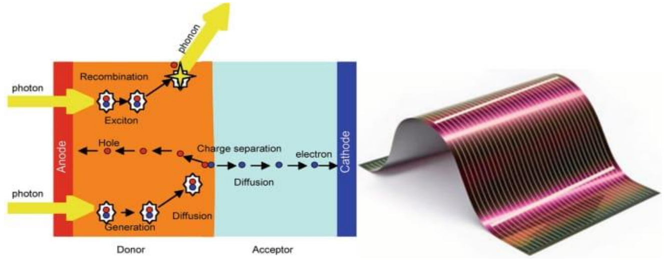

Fig. 1. Organic Solar Cell [2]

2 ORGANIC SOLAR CELL

An organic solar cell (OSC) is a variety of photovoltaic (PV) cell that employs organic semiconductors to transform sunlight into electrical energy [10]. Organic photovoltaic cells (OPVCs) are a type of polymer solar cell that converts sunlight into electricity by employing flexible polymers [13]. These organic semiconductors are composed of carbon-based substances, possessing electrical conductivity, albeit at a lower level compared to inorganic semiconductors such as silicon. Because of this, industry and researchers have recently given Organic Solar Cells (OSCs), also known as Organic Photovoltaics (OPVs), much attention. Over the last 30 years, there has been progress in the field of organic solar cell research. However, it is in the past decade that this research has garnered significant attention from both the scientific and economic communities. This increased interest has been sparked by a notable surge in power conversion efficiencies [12]. Organic solar cells (OSCs) are generally constructed using thin layers of organic substances, like polymers or small molecules [10]. These substances are placed between two electrodes, with one electrode being transparent to enable sunlight to penetrate the cell. When sunlight strikes the organic layer, it generates pairs of electrons and holes known as excitons [7,8,9]. These excitons subsequently move toward the boundary between the two electrodes, where they separate into free electrons and holes [7]. The electrodes then gather these electrons and holes, allowing them to pass through an external circuit and produce electrical power. The OPV technology is alluring because it promises to be extremely inexpensive, lightweight, made from abundant materials, and easily printed at high speed and on a wide scale using a standard roll-to-roll printing equipment system [12]. The power conversion efficiency (PCE) is now quite low (10%) despite optimistic estimates being made [14,15]. and stability is also thought to be inadequate. On the other hand, there are several obvious obstacles to overcome. The transition from laboriously created scientific instruments of square millimeter size in the lab to large-scale technical manufacture is another issue that has not drawn much attention [6]. Nonetheless, organic solar cells (OSCs) come with certain drawbacks. They typically exhibit lower efficiency compared to silicon solar cells and a shorter operational lifespan. Nevertheless, ongoing research aims to enhance the efficiency and longevity of OSCs, and they are anticipated to gain greater significance in the future solar energy market. Long-term reliability issues, as well as efficiency restrictions, continue to be major obstacles. Additionally, OPV modules' operational lifetimes are still much shorter than those of inorganic devices [7].

The following five procedures are crucial for an effective Organic solar cell [7].

1. Light absorption, then the production of excitons
2. Diffusion of excitons towards the active interface
3. Next, the charge should be separated and detached.
4. Easily transferring a separate charge
5. Charge collection

3 COMPARISON OF DIFFERENT TECHNOLOGIES.

The Table 1 shows the comparison between organic PV and Inorganic PV.

Table. 1. Organic PV versus inorganic PV [2].

Characteristics	Organic PV	Inorganic PV
Materials	Organic semiconductors, such as polymers and small molecules [10].	Inorganic semiconductors, such as silicon, cadmium telluride (CdTe), and copper indium gallium selenide (CIGS)
Efficiency	Typically, lower than 10%, with the best cells reaching over 20% [6].	Typically, 15-25%, with the best cells reaching over 30%
Cost	Lower manufacturing costs but higher material costs	Higher manufacturing costs but lower material costs
Weight	Lightweight and flexible	Heavier and less flexible
Durability	It is less durable, with a lifespan of typically 5-10 years [7].	More durable, with a lifespan of typically 20-25 years
Lifetime	10000 hours [7].	10 years
Transparency	Transparent	Opaque
Integration	easy	Not easy
Flexibility	Flexible	Not Flexible

When compared to inorganic photovoltaic cells a, Organic Photo Voltaic Cells have poorer efficiency because of their greater bandgaps [13]. Inorganic semiconductors exhibit favorable band gap energies that align well with the solar spectrum. However, a significant limitation is their lower light-absorbing capacity when compared to organic materials. Consequently, inorganic semiconductors necessitate the use of a greater number of absorbing layers, resulting in increased thickness. Furthermore, to enhance efficiency, the purity of inorganic semiconductors becomes a critical factor, contributing to elevated costs as purity levels rise [10]. Nonetheless, in the realm of inorganic semiconductors, the necessary binding energy for excitons (also referred to as exciton binding energy) to give rise to charge carriers is relatively low when compared to organic semiconductors, and it can be easily achieved at room temperature. For this reason, inorganic semiconductor devices typically exhibit higher efficiency when compared to organic solar cells (OSCs) [10].

Conventional inorganic semiconductors with crystalline structures can absorb a broad range of light frequencies and possess a stable three-dimensional lattice structure that enables excellent carrier mobility. For instance, a silicon-based solar cell with a bandgap energy of 1.1 eV equivalent to a bandgap wavelength of 1100 nanometers) can achieve a power conversion efficiency of 22% under AM1.5 conditions [8,11]. Poly(3-hexylthiophene) (P3HT) is used as the donor material to create the highest-performing polymer solar cells. P3HT can only collect up to 22.4% of the available photons [12]. Because of its 1.9eV (650 nm) band gap, which results in a maximum theoretical current density of 14.3 mA/cm2, the most popular acceptor substance (6,6)-phenyl-C61- butyric acid methyl ester (PCBM), is coupled with this compound.

The performance of a P3HT: PCBM system is approaching its 5% optimal level, which is less than one-fourth of the optimal level of a silicon solar cell [18, 19,20,21].

4 Different Material Uses in Organic Solar Cell

Organic photovoltaic cells (OPVs) represent a category of solar cells that harness organic semiconductors to transform sunlight into electrical energy. OPVs are constructed from carbon-based substances, which are readily available and cost-effective. Additionally, they possess a lightweight and flexible nature, rendering them appropriate for various applications.

I. Active layer materials

Conjugated polymers: Conjugated polymers are a specific category of polymers characterized by a sequence of alternating double and single bonds among their carbon atoms [15]. This structural feature grants them distinctive electronic characteristics, rendering them well-suited for application in Organic Solar Cells (OSCs) [9,10,22]. Some common conjugated polymers used in OSCs include,

Poly(3,4-ethylenedioxythiophene) (PEDOT)
Poly(3-hexylthiophene) (P3HT)
Poly(phenylenevinylene) (PPV)
Poly(indenofluorene) (PIF)
Poly(benzothiadiazole) (PBT)

Organic solar cells employ materials categorized as organic semiconductors due to their capacity to absorb light and facilitate charge conduction, either within the molecular structure (e.g., in conjugated polymers) or through a molecular network. Conjugated polymers investigated for photovoltaic applications encompass polythiophenes, poly-phenylene-vinylenes (PPVs), polyfluorenes, and polycarbazoles [8,11]. In contrast [22], non-polymeric (referred to as 'small molecule') organic semiconductors used in organic photovoltaic devices comprise functionalized fullerenes, phthalocyanines, perylene derivatives, and pentacene [8,15].

Small organic molecules: Another category of materials suitable for the active layer in OSCs comprises small organic molecules. Examples of frequently employed small organic molecules in OSCs encompass [12,13].

- Fullerenes, such as phenyl-C61-butyric acid methyl ester (PCBM)
- Non-fullerenes, such as indacenodithiophene (IDT) and 2,2'-bithiophene (BT)
- Perovskites, such as methylammonium lead iodide (MAPbI3)

II. Electrode materials

Indium tin oxide (ITO): Indium tin oxide, often referred to as ITO, serves as a transparent semiconductor commonly employed as the anode in organic solar cells (OSCs) [25]. It possesses excellent electrical conductivity and boasts a high work function, facilitating the efficient extraction of electrons from the active layer [18,19,23].

Aluminum: Aluminum is a common cathode material in OSCs. It is a good conductor of electricity and has a low work function, which helps to extract holes from the active layer.
Other materials, such as molybdenum trioxide (MoO3) and poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS), can also be used as electrodes in OSCs [23].

III. Other materials

Hole transport materials (HTMs): HTMs are substances that facilitate the movement of electron vacancies, known as holes, from the active layer to the anode. Several typical HTMs employed in organic solar cells are,

- PEDOT:PSS

- Poly(triarylamine) (PTAA)
- Poly(3-hexylthiophene-2,5-diyl) (P3HT)

Electron transport materials (ETMs): Electron Transport Materials (ETMs) are substances designed to facilitate the movement of electrons from the active layer to the cathode. Examples of frequently employed ETMs in Organic Solar Cells (OSCs) comprise:

- PCBM
- [6,6]-phenyl-C61-butyric acid methyl ester (PCBM)
- C60

Interfacial layers: Interfacial layers refer to slender material layers strategically positioned between the active layer and the electrodes. Their primary function is to diminish resistance between these two components, thereby enhancing the efficiency of the solar cell [21]. Several typical interfacial layers employed in organic solar cells encompass:

- Poly(ethylene oxide) (PEO)
- Lithium fluoride (LiF)

IV. Emerging materials for OSCs

Scientists are consistently working on creating new materials for OSCs, aiming to enhance their effectiveness, durability, and affordability. Among the noteworthy materials under investigation are:

Carbon nanotubes: Carbon nanotubes are elongated structures made of carbon atoms, forming one-dimensional cylinders, and they exhibit impressive electrical and thermal conductivity. These nanotubes have the potential to enhance the transmission of electrical charges and overall efficiency in organic solar cells [24].

Perovskites: A class of materials known as perovskites has a special crystal structure that makes them perfect for use in OSCs. A power conversion efficiency of approximately 25% has been attained by perovskite solar cells, which is on par with silicon solar cells [25].

Graphene: Graphene, a thin layer composed of carbon atoms arranged in a two-dimensional structure, possesses excellent conductivity [24,25]. It has the potential to serve as a material for creating transparent electrodes in organic solar cells (OSCs).

5 Efficiency and Performance of Organic Solar Cell

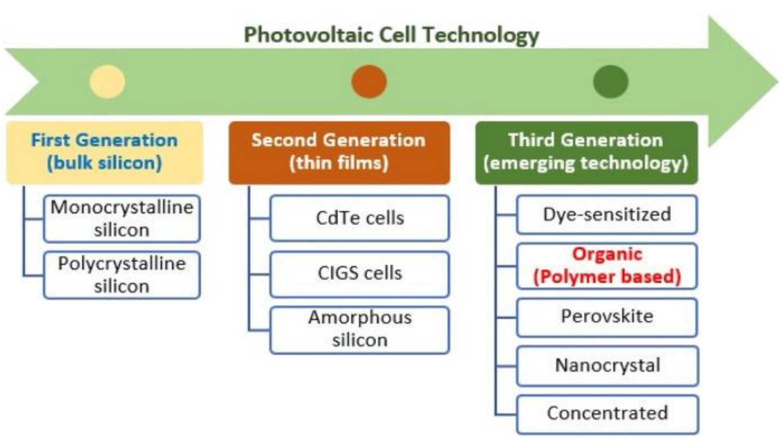

Fig. 1. Photovoltaic Cell Technologies

In recent years, the field of organic solar cells (OSCs) has experienced significant advancements in terms of efficiency and performance. OSCs have emerged as a promising and sustainable solution for harnessing

solar energy due to their potential to reduce the overall cost of solar energy systems and provide clean and green energy sources. However, to compete effectively in diverse photovoltaic (PV) technologies and address the world's growing energy needs, it is crucial to continually improve the efficiency of OSCs through the analysis of novel materials and the optimization of donor-acceptor material arrangements [26].
One of the primary factors contributing to the remarkable progress in OSC efficiency is the constant innovation in active layer materials and the engineering of charge-transfer interfaces. These developments have enabled OSCs to achieve power conversion efficiencies (PCEs) that have surpassed 18%. The active layer materials are critical components of OSCs, and their properties significantly impact the overall performance of the solar cells. The careful selection and development of these materials have played a central role in improving PCEs [29]. Another area of focus in OSC research is the tuning of the morphology of bulk-heterojunction (BHJ) blend films. This involves controlling the molecular orientation, crystallinity, domain size, and purity within the active layer. The morphology of the BHJ blend films has a profound effect on several key aspects of OSC performance, including exciton diffusion, exciton dissociation, charge transport, and recombination. Researchers have employed various strategies to fine-tune phase separation and film morphology, including the use of solvent additives, thermal annealing, and solvent vapor annealing. These techniques have contributed to the enhancement of photovoltaic performance in OSCs [28].
A relatively recent development in OSC research is the utilization of volatile solid additives (SADs) to optimize film morphology and enhance photovoltaic performance further. SADs represent a promising class of materials with diverse working mechanisms that can improve OSC efficiency. These mechanisms can be categorized into three types as shown in Fig. 2. [27]

- The first type of SADs induces ordered and condensed intermolecular packing, creating a favorable morphology through strong charge-quadrupole or sigma-hole interactions. This results in enhanced photovoltaic performance.
- The second type of SADs reduces the adsorption energy of acceptor materials, improving pi-pi stacking through attractive interactions between SADs and acceptors. This enhances light absorption and electron mobility in OSCs.
- The third type of SADs, characterized by high crystallinity, facilitates well-developed nanoscale phase separation. By restricting the over-self-aggregation of acceptor materials during film formation, these SADs allow the donors to access the remaining space of SADs during thermal annealing, ultimately improving OSC performance [27].

While these strategies involving SADs have shown promise in enhancing OSC performance, there remains a need for a fundamental understanding of the relationship between SAD structures, active layer morphology, and OSC performance. Continued research in this area will be crucial for further optimizing OSCs [27].

Additionally, the conformation of organic compounds plays a fundamental role in determining their physicochemical properties. Achieving a planar conformation is essential for attaining high-charge transport mobilities in organic and polymeric semiconductors. Researchers have explored various methods, both covalent and non-covalent, to manipulate the conformation of organic compounds, aiming to improve the performance of optoelectronic devices, including OSC [28].

OSCs have made significant strides in recent years, with PCEs exceeding 18% through innovations in active layer materials, charge-transfer interfaces, and the optimization of film morphology. The introduction of volatile solid additives has opened up new avenues for performance enhancement. However, challenges such as stability against moisture and air, as well as the need for efficient encapsulation, persist. The ongoing research and development of OSCs hold great promise for addressing the world's energy needs and advancing the field of renewable energy [29].

6 ADVANTAGES AND DISADVANTAGES

Organic Photovoltaic (OPV) cells hold the promise of providing a sustainable and environmentally friendly alternative to conventional solar cells, offering advantages such as cost-effective production and design versatility. However, they also encounter several hurdles in terms of efficiency, durability, and competition from established renewable energy technologies [28]. The strengths of OPV cells, including their affordability and adaptability in design, render them an appealing choice for a wide array of applications, encompassing consumer-oriented products and emerging industries. The opportunities arising from the surging demand for renewable energy sources, supportive government policies and incentives, and the escalating awareness among consumers regarding sustainability and environmental impact all serve as drivers that could propel the expansion and adoption of OPV cells in the foreseeable future [30].

Nonetheless, it is imperative not to overlook the weaknesses and threats confronting OPV cells. Their comparatively lower efficiency and durability, when juxtaposed with traditional solar cells, pose a considerable challenge to their commercial feasibility. Moreover, the competition stemming from well-established renewable energy technologies may curtail their market presence. Furthermore, the intricate technological limitations and research challenges that OPV cells face necessitate substantial investments and research efforts, potentially impeding their rate of adoption and commercialization. Lastly, the regulatory landscape for renewable energy technologies is susceptible to changes that might introduce uncertainty and risk to the prospects of OPV cells [29].

7 SWOT analysis for OPV cells [30].

7.1. Strengths

- Flexibility and Lightweight: OPV cells possess a thin and flexible structure, rendering them suitable for diverse applications, including wearable technology, integration into building materials, and the creation of solar-powered fabrics. Their flexibility also enhances resistance to wind and impact, setting them apart from rigid solar panels [10].

- Cost-Effective Production via Printing Techniques: OPV cells can be manufactured using cost-efficient roll-to-roll printing and other low-cost printing methods. This approach significantly reduces manufacturing expenses and facilitates scalability. Additionally, the utilization of printing techniques allows for customization, enabling the design of unique shapes and patterns [12].

- Eco-Friendly and Easy Disposal: OPV cells are crafted from non-toxic materials, such as carbon-based polymers, and do not incorporate rare or costly components like silicon and metals. This characteristic not only aligns with environmental sustainability but also simplifies the disposal process at the end of its lifecycle. Furthermore, OPV cells can be recycled to create new cells or other products [14].

- Modular and Scalable: OPV cells can be produced in various shapes and sizes, offering versatility in design. They can also be interconnected to form modules or arrays, enabling scalability and the customization of solar panels to suit specific applications and installation sites [8].

- Enhanced Performance in Low-Light Conditions: OPV cells exhibit greater efficiency when subjected to low-light conditions, surpassing the performance of traditional silicon-based solar cells. This feature enhances their suitability for regions with limited sunlight and indoor applications, such as powering smart buildings and IoT devices [10].

7.2. Weaknesses

- Lower Efficiency Compared to Silicon-Based Solar Cells: OPV cells have a lower conversion efficiency when compared to traditional silicon-based solar cells. Typically, OPV cells achieve an efficiency range of 10–20%, while silicon-based solar cells surpass this rate. This efficiency gap limits the power output of OPV cells, which may not meet the requirements of certain high-demand applications [28].

- Durability and Stability Issues: Durability and stability challenges are apparent in organic photovoltaic (OPV) cells, which do not match the robustness and resilience of conventional solar cells. These cells may experience a decline in performance as they are exposed to elements such as UV light, moisture, and various environmental factors over time. It is imperative to focus on strategies for encapsulating and safeguarding OPV cells tto improve their lifespan and dependability significantly [28].

- Limited Production Volume: OPV cells are manufactured in significantly smaller quantities compared to traditional silicon-based solar cells. This limited production volume diminishes their commercial viability, restricting their availability in the market and potentially leading to higher costs [20].

- Sensitivity to Temperature: OPV cells operate within a narrower temperature range in comparison to silicon-based solar cells. Elevated temperatures can lead to degradation or malfunction, resulting in reduced efficiency and a shortened lifespan for OPV cells [17].

- Shorter Lifespan: OPV cells have a shorter lifespan when contrasted with traditional silicon-based solar cells, typically lasting around 10–15 years. This shorter lifespan may make them less suitable for applications that demand long-term reliability and durability [222].

7.3. Opportunities

- Advancements in New Materials: Progress in developing novel materials for OPV cells has the potential to enhance their performance and stability significantly [21].

- Increasing Demand for Renewable Energy Sources: The increasing focus on curbing carbon emissions and shifting towards renewable energy sources creates a significant opening for organic photovoltaic (OPV) cells. They provide a sustainable and eco-conscious substitute for conventional solar cells [7].

- Favorable Government Policies and Incentives: Governments across the globe are implementing subsidies, tax incentives, and various financial backing measures to promote the adoption of renewable energy technologies. These policy initiatives foster a favorable climate for the advancement and utilization of OPV cells [19].

- Rising Consumer Awareness and Demand for Sustainability: Consumers are growing more mindful of the environmental consequences of their decisions. This heightened awareness has resulted in an increased desire for products that are sustainable and environmentally friendly. As a result, there exists a potential for OPV cells to capture a larger market share and be integrated into a variety of consumer-oriented products [23].

- Emerging Markets and Industries for OPV Cells: OPV cells present novel prospects across a range of industries, including agriculture, transportation, and architecture. In agriculture, they have the potential to energize irrigation systems and devices used.

- for monitoring crops. Within the transportation sector, OPV cells can serve as a source of energy for electric vehicles, boats, and drones. Moreover, in architecture, they can be seamlessly incorporated into building exteriors, windows, and roofing to supply solar power and curtail overall energy consumption [16].

- Collaboration and Investment from Major Companies: Numerous prominent corporations are dedicating resources to the advancement and manufacturing of OPV cells. This creates a prospect for collaborative initiatives and the exchange of expertise, which can propel the technology forward and boost its adoption. However, it remains crucial to confront issues related to the enduring dependability and resilience of OPV cells in particular applications.

7.4. Treads

Challenges and Threats to the Adoption of OPV Cells:

- Competition from Established Solar Cells and Other Renewable Energy Technologies: Well-established traditional silicon-based solar cells and other renewable energy technologies like wind and hydropower offer higher efficiency and reliability compared to OPV cells. This competition poses a threat to the widespread adoption and commercial viability of OPV cells [28].

- Technological Constraints and Research Challenges: OPV cells encounter various technological limitations and research hurdles, such as the need to enhance their efficiency, durability, and stability. Addressing these challenges demands substantial investment and research efforts, potentially slowing down the adoption and commercialization of OPV cells [23].

- Regulatory and Policy Uncertainties: The regulatory landscape for renewable energy technologies is susceptible to change, introducing uncertainties and risks to the adoption of OPV cells. Alterations in government policies and regulations could potentially impede the development of the OPV cell industry [24].

- Vulnerabilities in the Supply Chain: OPV cells have a complex supply chain encompassing material production, manufacturing, and distribution. Any disruptions, such as shortages of materials or components, have the potential to impact their availability and cost [30].

- Economic Risks: The commercial success of OPV cells hinges on factors like production costs, market demand, and competition. Changes in these economic variables can jeopardize the industry's adoption and commercialization efforts [28].

8 CONCLUSION

In conclusion, the emerging field of organic solar cells (OSCs) offers a compelling alternative in the world of photovoltaic technologies, offering a range of benefits like affordability, use of plentiful eco-friendly materials, streamlined production processes, and adaptability in integration with different technologies. Even though OSCs have already outperformed conventional silicon solar cells in terms of efficiency, they still face significant challenges in terms of stability, endurance, and a complex grasp of basic physics. In order for OSCs to function, light must be absorbed in order to cause the creation of excitons, which are then captured and turned into electrical power using precise charge-collecting techniques. While OSCs now exhibit poorer efficiency and a shorter operational lifespan than their silicon-based equivalents, continuing research efforts aim to boost these characteristics. This portends increased significance for OSCs in the future solar energy market. The widespread commercialization and acceptance of OSCs, however, are constrained by persisting long-term reliability and breaking through efficiency barriers, which are crucial issues that demand specialized solutions. The trajectory shows how crucial it is to continue with research and development projects to get over these challenges and finally realize the enormous potential of organic solar cell technology.

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