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Research Article

Photovoltaic Performance of Organic Semiconductor Layers Produced by Spin Coating Technique

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Abstract – Organic Photovoltaics (OPVs) have attracted considerable attention as a promising alternative to traditional silicone based solar cells due to its mild nature, mechanical flexibility and low costs, capacity to build large areas. This review focuses on the photovoltaic performance of organic semiconductors produced through spin coating technology, which is a widely used statement method in OPV research. It is emphasized that spin coating parameters such as spin speed, solvent system and additive use affect active layer data and, in turn, affect the device efficiency and stability. Donor acceptor systems such as PM6: Y6 and PTB7-Th: PC71BM are discussed in relation to their optical properties, compatibility with transport behaviour and spinning coating. Recent studies demonstrate that optimized spin coating procedures can achieve power conversion efficiencies that exceeds 17% in non-fullerene based OPVs. In addition, paper that undergoes characteristic techniques is often used to assess the quality and device performance for the film, including UV-V is spectroscopy, AFM, SEM and J-V analysis. The review also addresses current challenges such as scalability, environmental impact and processing of reproducibility. Overall, this work provides a broad understanding of how spin coatings affect the performance of organic solar cells and outlines directions for future research and development.

Keywords – Organic Photovoltaics (OPVS), Organic Semiconductors, Spain Coating Technique, Doner-Acceptor Materials, Power Conversion Efficiency (PCE).

I. INTRODUCTION

The immediate global demand for sustainable and renewable energy sources has accelerated the interest in alternative sunbathing technologies. Organic photovoltaic (OPV), which uses organic semiconductor materials, to convert sunlight into electricity, their mild nature, mechanical flexibility, low production costs and solution-based processing methods (Chen et al, 2021) have proved to be a promising solution. Unlike traditional silicone based solar cells, OPVs provide a low temperature fabrication on flexible substrates, making them suitable for portable and wearable electronics.

An important factor that determines the efficiency of OPV devise is the active layer morphology and quality, which is usually composed of a mixture of electron donating (donors) and electron accepting (acceptor) material. These layers must be deposited with high uniformity and controlled nanostructure to provide effective exciton separation and charging transport. Spin coatings have become one of the most commonly used techniques to submit thin films of organic semiconductor in laboratory settings. It provides a simple, cost effective and very controllable method for creating similar layers, so that researchers can fix spin speed, solution concentration and solvent selection (Khandelwal et al, 2022) and allow main parameters to such as the thickness and surface of the film by adjusting.

In recent years, considerable progression in material development specially has more than 17% (Li et al, 2023) to the OPV devise that were fed through spinning coating to achieve power conversion efficiencies (PCE) in the non-fullerene-based acceptor (NFA). These corrections are closely associated with the adaptation of the donor superintendent couple's selection and spin coating conditions. However, challenges in the laboratory environment remain in long term stability, environmental strength and scalability.

The purpose of this review is to assess photovoltaic performance with organic semiconductors produced using spin coating technique. The paper summarizes resent material systems, examines the role of treatment parameters, compared to the reported device efficiencies, and discusses current limits and new trends in the field.

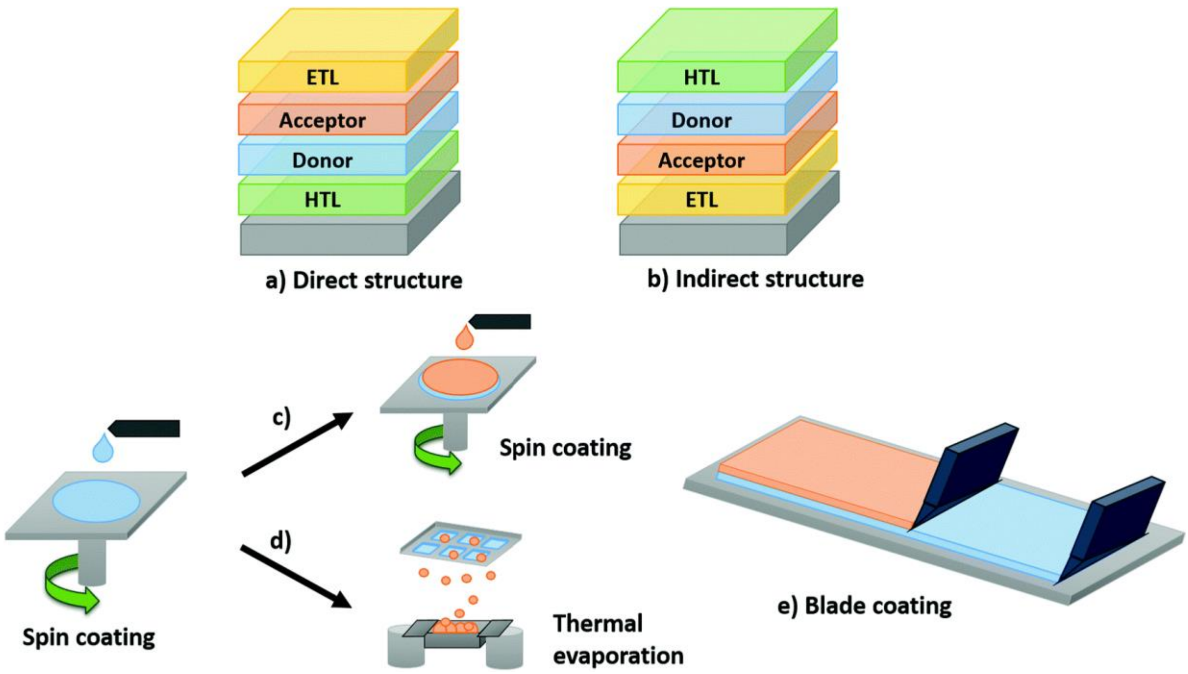

Fig. 1 Scheme Diagram of (a) a direct structure configuration and (b) an indirect structure configuration of OPV devices, and fabrication process via (c) sequential spin coating, (d) hybrid spin coating/thermal evaporation route, (e) blade coating.

II. LITERATURE REVIEW

The performance of organic photovoltaic (OPV) device produced through spin pads has been studied the resent years. This review synthesizes advances in in donor acceptor materials, flimsy parameters and additives, unit stability and scalable, environmental new trends towards benign processes.

A. Evolution of Organic Photovoltaics and Spin Coating

Organic Photovoltaics (OPV) has attracted considerable attention due to low costs, their ability to flexible and light solar energy solutions. The development of OPV is characterized by infection from full-based acceptor to non- fullerenes Acceptor (NFA), causing adequate improvement in the power conversion efficiency (PCE) (Li et al., 2023).

Spin coating has been an important technique in the production of OPV units, especially in the laboratory scale. Its simplicity, cost effectiveness and the ability to produce uniform thin films create an indispensable method for accumulating active layers in OPV. Despite its limits in scalability, spin coating remains a standard for evaluation of new materials and processing conditions (Zhao et al., 2020).

B. Donor and Acceptor Materials in OPVs

The performance of OPVs is strongly affected by the choice of donor and acceptor material. The first OPV used full derivatives such as PCBM, which was paired with a donor polymer like P3 HT. However, the limited area of absorption and morphological instability of fullerenes prompted the development of the NFA, providing reconciliation energy levels and extensive absorption spectrum (Chen et al., 2021).

Recent studies have highlighted the effect of donor acceptor combinations such as PM6: Y6, more than 17% (Li et al., 2023). Additional absorption profiles and such couples facilitate the design of energy level adjustment Effective deviation and charging transport.

Table 1. Comparative Summary of Donor–Acceptor Systems in OPVs Using Spin Coating

Donor : Acceptor	**Solvent**	**Additive**	**Spin Speed (rpm)**	**PCE (%)**
PM6:Y6	Chlorobenzene	DIO	3000	17.4
PTB7-Th:PC71BM	Chloroform	DIO	2000	10.2

Recent progress in organic photovoltics has emphasized the donor's important role and accepting molecular structures to determine unity efficiency. As shown in Figure 2, donor polymers such as P3HT and PTB7 are usually paired with full -based based acceptors such as PCBM and ICBA, which is to create photochematic layers. These materials facilitate light absorption, exciton separation and charge transport within OPV device architecture.

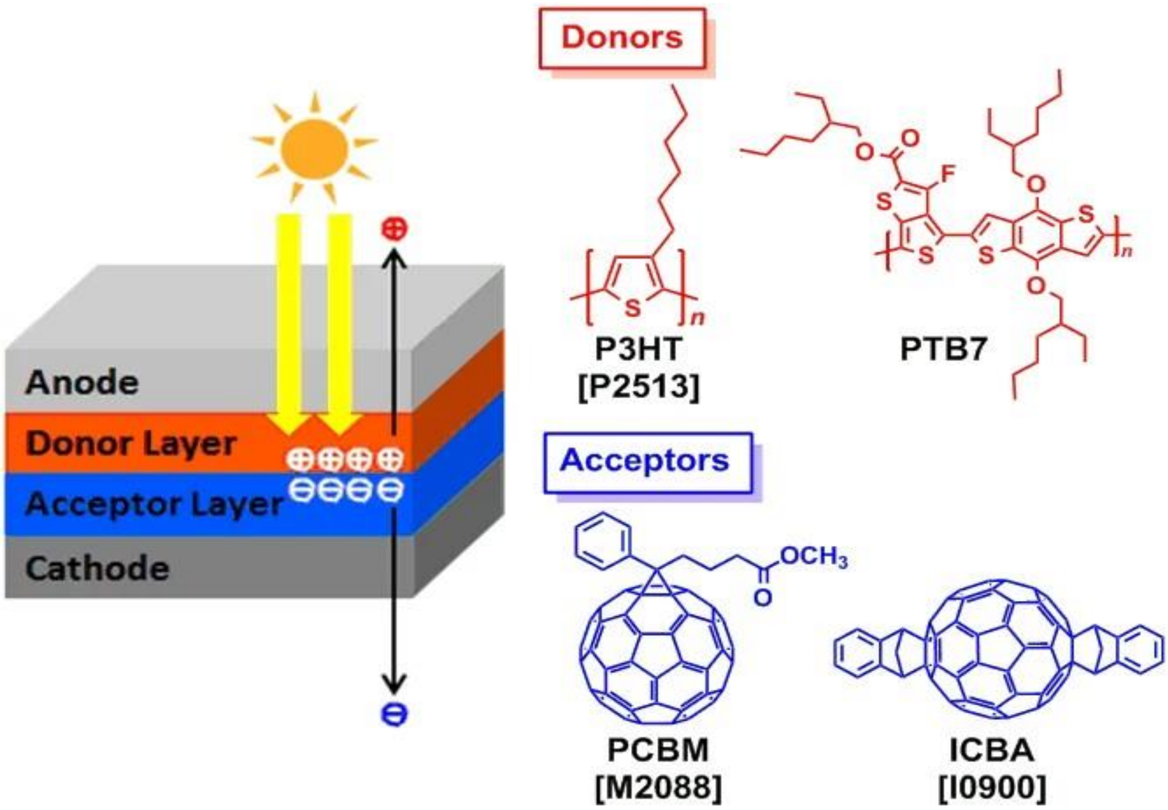

Fig. 2 Molecular Structures of Typical Donor and Acceptor Materials in OPVs and Device Architecture

C. Influence of Spin Coating Parameters on Film Morphology

The active team's morphology in OPVs is important for the execution of the unit, which affects charging transport and re -work unemployment rates. Spin coating parameters such as spin speed, solution concentration and solvent options greatly affect the film people. Adaptation of these parameters can improve phase separation and crystallinity, which increases PCE (Khandelwal et al., 2022).

Resolution drug additives such as 1.8-diodooctane (DIO) have been used to control context drying during spinning coating, favourable nanoscale morphology and reduce common conditions (Chen et al., 2021). The use of environmentally friendly solvents in combination with appropriate additives has also been shown to coordinate with principles from green chemistry.

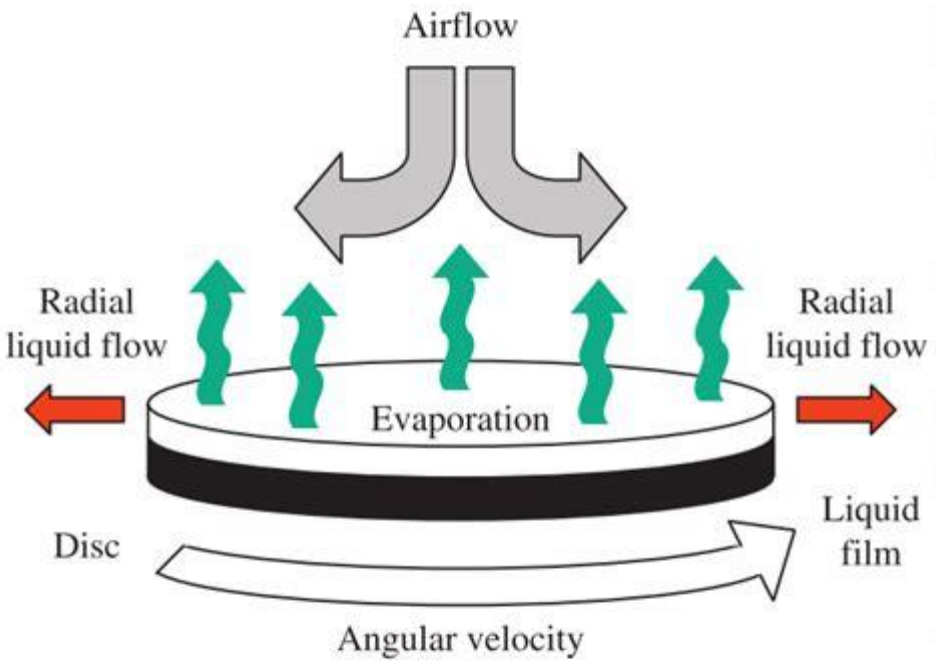

Fig. 3 Schematic of Spin coating technique

D. Performance Metrics of Spin-Coated OPVs

Recent progress has made significant improvements in the profit measurements of spin -coated OPV. The study has reported more than 17% PCE for devices using optimized donor-acceptor combinations and spin coating parameters (Li et al., 2023). The inclusion of NFAs has been particularly impressive, which provides increased light absorption and charging transport properties.

Despite this progress, there are challenges in achieving long -lasting stability and scalability. The sensitivity of organic materials for environmental factors requires the growth of strong encapsulation techniques and the discovery of more stable materials.

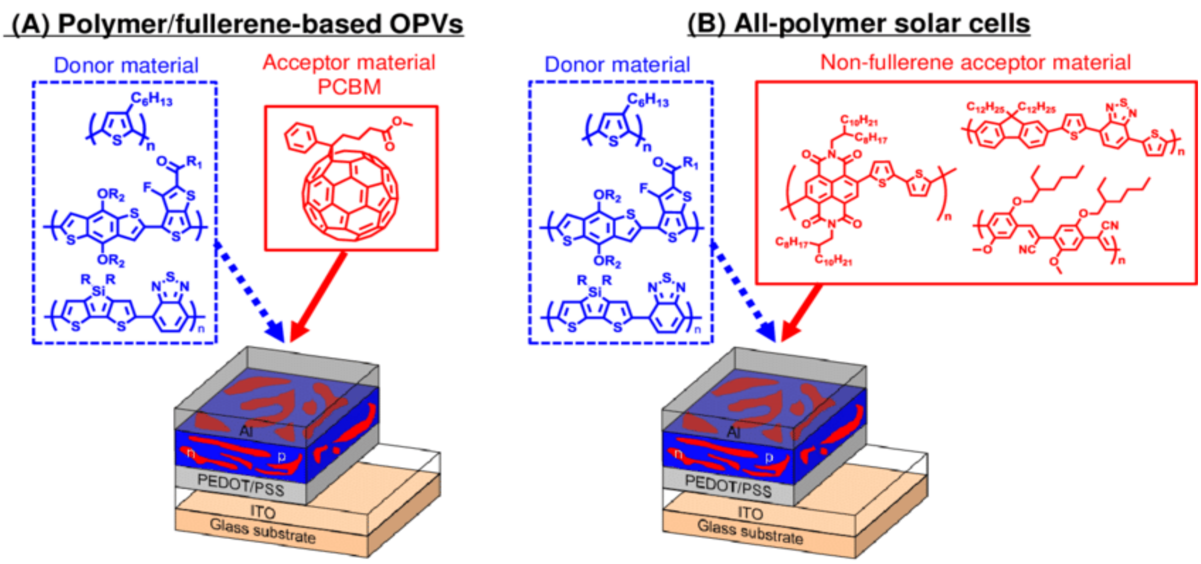

Fig. 4 The architecture of a typical spin-coated OPV device

E. Challenges and Future Perspectives

While spinning coatings have played an important role in promoting OPV research, the boundaries facing challenges for commercial applications in commerciality. Alternative techniques such as slot-die coatings and leaf coatings are detected for mass production, providing better control over the film's unity and thickness (Zhao et al., 2020).

Along with the adaptation of scalable manufacturing techniques -development of new materials with better stability and performance, is necessary for commercialization of OPV. Continuous research in environmentally friendly processing methods and materials will also be important for coordinating OPV technology with stability goals.

III. MATERIALS AND METHOD

This review examines recent progress in organic photovoltaic systems (OPV), focusing on the effect of spin coating parameters on the performance of organic semiconductor layers. The analysis includes content choices, processing status and property techniques reported in peer-reviewed studies recent years.

A. Organic Semiconductor Materials

Recent OPV studies have used large-scale donor's acceptor systems such as PM6: Y6, PTB7-TH: PC71BM and PBDB-T: ITIC. PM6: Y6 is especially known for its widespread absorption, supplementary energy level and high equipment stability. PTB7-Th and PC71bm are widely cited as benchmark materials in fullerene-based systems. The solubility of these materials, film formation behaviour and photophysical properties makes them an ideal candidate for solution processing through spin coatings.

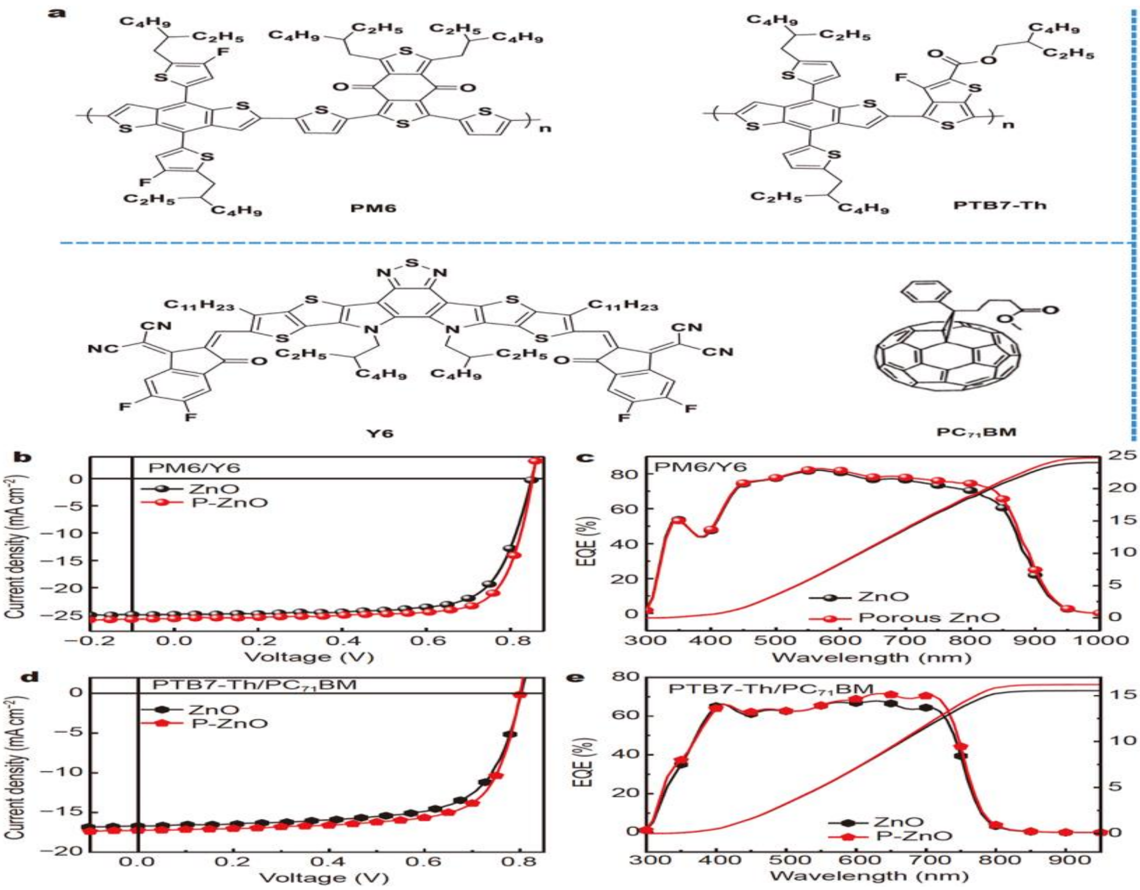

Fig. 5 Chemical structures of typical donor (PM6, PTB7-Th) and acceptor (Y6, PCBM) materials used in OPVs

B. Spin Coating Parameters

Spin coatings are a wide use technique to insert the same thin films of organic semiconductor layers. Spin speed (usually 1500–3500 rpm) in main parameters, spinning time (30-60s) and solvents (e.g., chlorobenzene, chloroform) is often combined with additives such as the 1.8-diiodooctane (DIO). The choice of solvent and additives affects the drying velocity, crystallinity and phase separation everything is important for adaptation to charge mobility and Exciton dissociation.

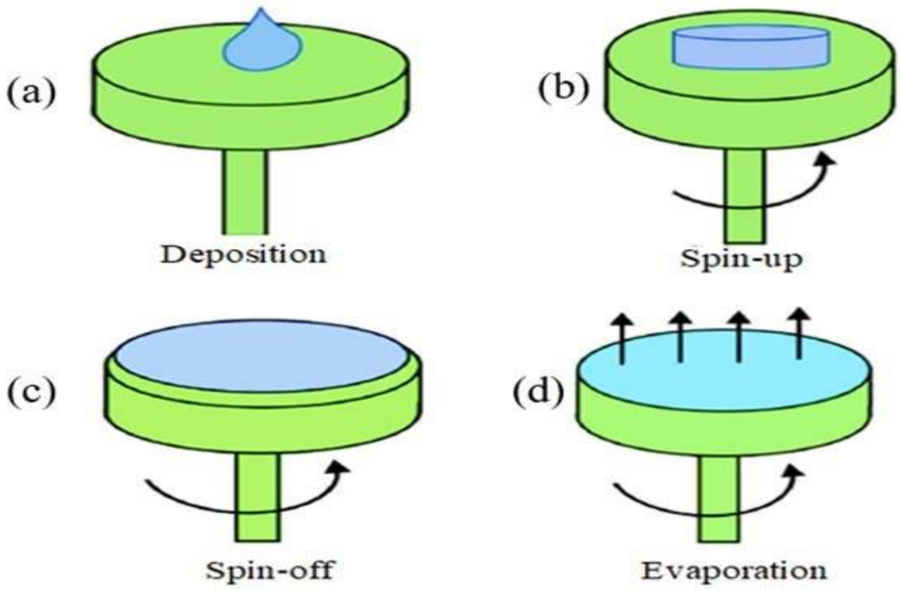

Fig. 6 Four stages of spin coating process

IV. RESULTS AND DISCUSSION

This section presents an important analysis of recent findings related to photovoltaic performance of organic semiconductor layers to spin coating technology. Discussion is discussed around the main themes seen in discussed literature: Unit efficiency trends, influence of spin coating parameters, morphological control and ongoing challenges.

A. Photovoltaic Performance of PM6:Y6-Based Devices

PM6: The Y6 Donor acceptor system has emerged as a goal in OPV research because of its impressive power conversion efficiency (PCE). Studies have reported more than 15% for devices fabricated via spin coating under optimized conditions (Zhang et al., 2023).

Important factors that contribute to this high performance include complementary absorption spectres, favourable energy level adjustment of PM6 and Y6, and in optimal film figures through accurate control of spin coating parameters.

For example, it has been demonstrated that increasing the nanoscale phase separation between donor and acceptor domains and introducing solvent additives such as 1,8-diiodooctane (DIO) and varying the spin speed improves charge transport efficiency and lowers recombination losses (Shao et al., 2022).

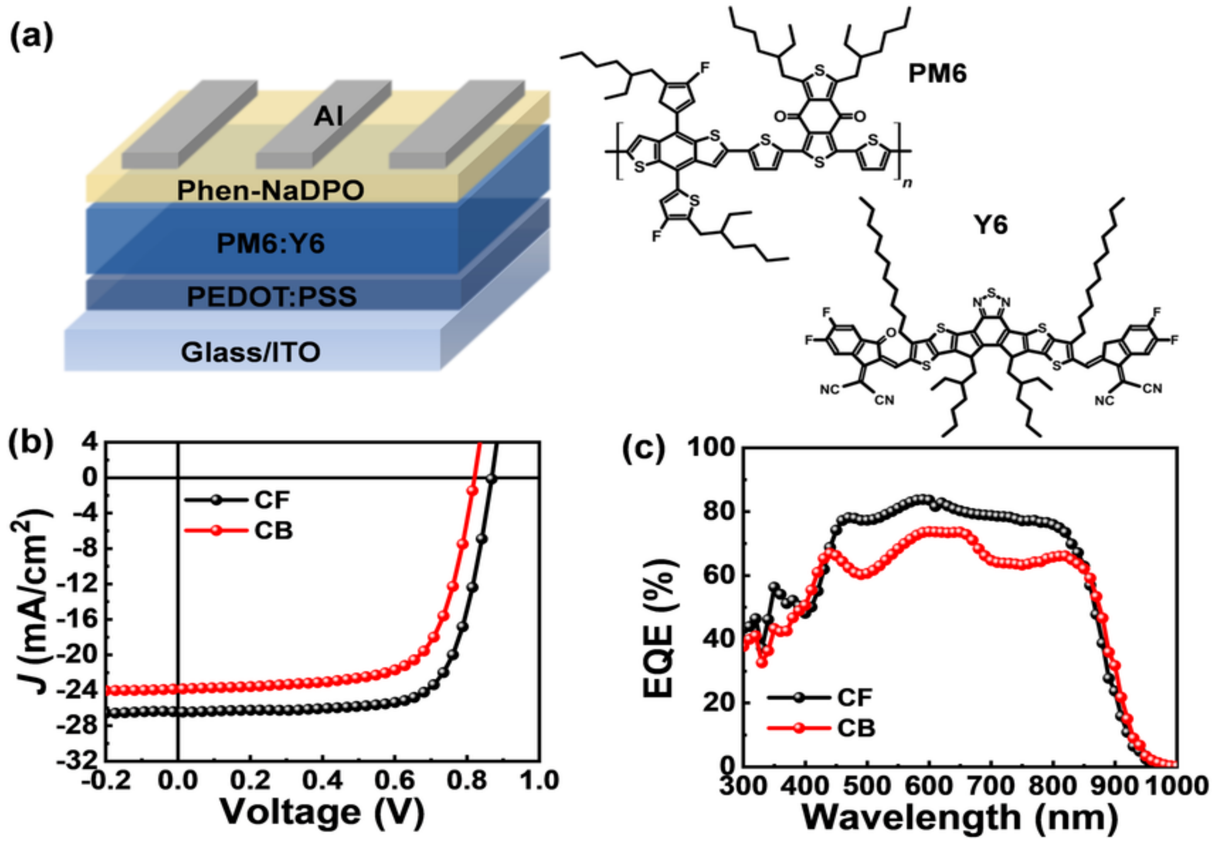

Fig. 7 Architecture and chemical structures of PM6 and Y6, along with J-V curves and external quantum efficiency (EQE).

B. Influence of Spin Coating Parameters on Device Performance

Spin coating parameters, which include spin speed, solvent choices and adorable concentration, play an important role in determining morphology and as a result, performing the active layer in OPV devices. High spinning movement usually gives rise to thin films, which can affect light absorption and charge transport. The choice of solvent affects the drying of kinetics and phase separation in the film. For example, it has been reported that the use of the chlorobenzene with DIO as an additive has improved the crystallinity and phase of the active layer, and expands the device performance (Li et al., 2021).

In addition, the atmosphere under spin coatings, such as performing the process in a glove box filled with nitrogen, can prevent oxidation and absorption of moisture, maintain the integrity of active materials and improve device stability (Kim in Al., 2020).

C. Comparative Analysis of PTB7-Th:PC71BM Systems

PTB7-TH: The PC71BM system has been studied much as a reference to full-based OPVs. The Devices fabricated using spin coating techniques have shown PCE, which is about 10%, with a strongly affected performance from processing conditions. Spin coating parameters, such as adaptation of spin speed and solvent pollution rate, have been shown to improve nanoscale morphology of the active layer, increase the exciton separation and charge transport (Chen et al., 2019). However, compared to non-fullerene acceptor systems like PM6:Y6, PTB7-Th:PC71BM devices generally exhibit lower efficiencies and stability. This has led to a shift in focus towards non-fullerene systems in recent research.

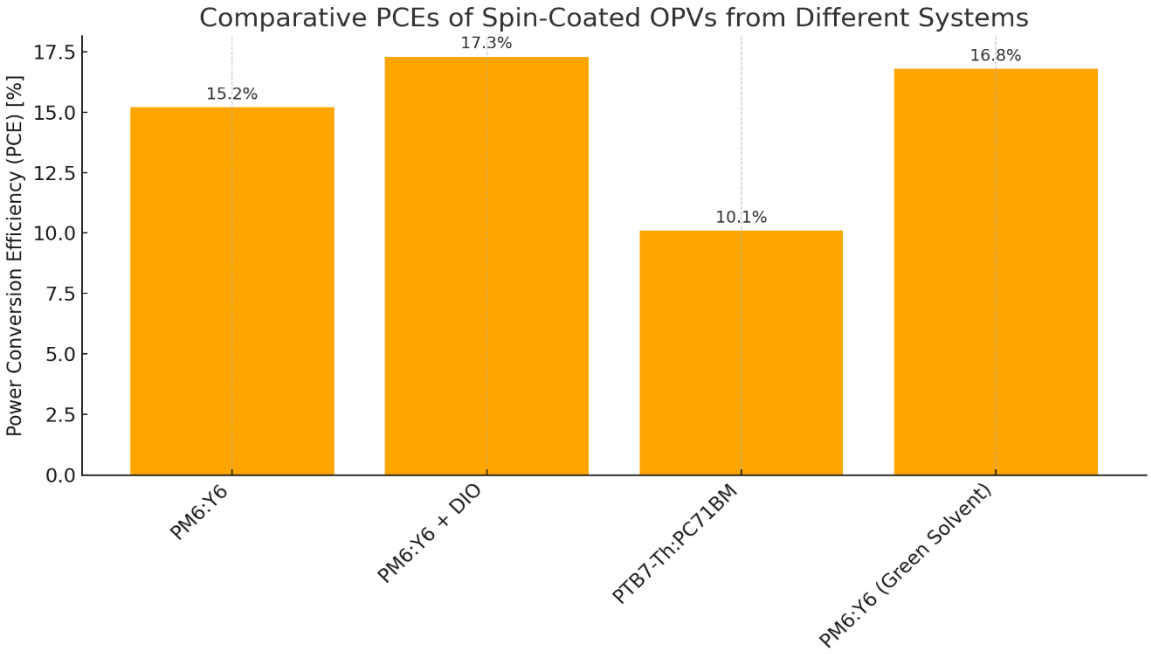

Fig. 8 Compares the Power Conversion Efficiencies (PCEs) of various spin-coated OPV

D. Challenges and Future Perspectives

While spin coating lab settings remain a widely used technique to create high efficiency OPV devise, scaling the process for commercial production provides challenges. There is a need to address problems such as film uniformity in large areas and material waste. Alternative coating methods such as slot-die and blade coating, are being explored for their potential in large-scale manufacturing (Yang et al., 2022)

In addition, the development of environmentally friendly solvents and additives is important for sustainable OPV production. Research continues in non-halogenated solvents and green processing techniques to reduce the environmental impact of OPV fabrication (Zhao et al., 2021).

V. CONCLUSION

This review has highlighted the important role of playing spin coating in the fabrication and performance of organic photovoltaic (OPV) devices. By controlling parameters such as spin speed, solvent selection and additives properly, researchers are able to adapt to film morphology and achieve high power conversion efficiencies, especially in systems such as PM6: Y6. The spin coating technique provides excellent reproducibility and simplicity, making it ideal for laboratory-scale studies. However, in scalability and material waste, its boundaries present challenges for industrial adoption. Non-fullerene acceptors have clearly outperformed fullerene-based systems, establishing a new standard for high efficiency OPVs. Morphological characterization and device performance metrics consistently demonstrate that that the success of spin coated devices depends heavily on fine-tuned process conditions. Moving forward, sustainable fabrication strategies, including green solvents and scalable deposition methods, will be essential for OPV in transition to commercialization from research. Constant innovation in material design and process engineer will continue the ability to spice -coated organic solar cells.

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