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# *Fabrication of Flexible Transparent Electrodes (FTE) and Their Application in Organic Solar Cells*

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***Abstract.*** With the rapid advancement of consumer electronics like smart wearables and flexible displays, the demand for portable, deformable energy systems has surged. Traditional rigid solar cells and ITO electrodes fail to meet flexibility requirements, driving the development of FTEs for OPVs. This study systematically reviews three major FTE material systems: metal grids, silver nanowires, and conductive polymers. Metal grids offer high conductivity (down to 0.5 Ω/sq) and low cost, but face surface roughness issues. Silver nanowires form flexible conductive networks with 90% transmittance and retain over 94% PCE after 1000 bends, yet suffer from dispersion and cost challenges. Conductive polymers have good processability and achieve 7.7% PCE in OPVs, comparable to ITO, but require harsh treatment. Performance data shows optimized FTEs enhance OPV efficiency: modified Ag grid OPVs reach 1.36% PCE, AgNW-based small-area OPVs hit 16.1%, and conductive polymer OPVs match ITO efficiency. Suggestions include optimizing sintering for metal grids, developing green synthesis for AgNWs, and milder treatments for polymers.

***Keywords:*** Flexible Transparent Electrodes (FTEs), Organic Solar Cells (OPVs), Metal Grids, Silver Nanowires, Conductive Polymers

## 1. Introduction

With the rapid development of consume electronics, noval requirement, such as smart/wearable device, flexible displays, and implantable medical monitors have emerged, there is an increasing demand for portable and deformable energy supply systems. Traditional rigid solar cells are too heavy and lack the flexibility, making them hard to meet the needs of these devices. However, flexible solar cells, with their light weight, bendable and easy-to-cut features, can effectively solve the energy supply problem for flexible electronics [1]. Among them, organic solar cells/organic photovoltaic (OSCs/OPVs) have advantages like low cost, solution processability, and potential for large-area production, making them an ideal choice for flexible energy systems. The active layer of organic solar cells can be prepared on flexible substrates through printing, coating and other technologies, which can theoretically integrate seamlessly with various flexible electronic devices [2,3].

The performance of electrode materials is particularly important for the flexible application of organic solar cells. The traditional transparent electrode material, indium tin oxide (ITO), has high light transmittance and low sheet resistance, but it is brittle and has poor mechanical stability. It is

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easy to crack when be bent or stretched, leading to a sharp drop in conductivity, which could not meet the long-term use needs of flexible devices [4]. In addition, the scarcity of indium also limits its large-scale application. Therefore, developing high-performance flexible transparent electrodes (FTEs) is necessary to promote the practical use of flexible organic solar cells. FTEs not only need to have photoelectric properties comparable with ITO (high light transmittance, low resistance), but also excellent mechanical flexibility, bending resistance, and compatibility with solution processing technology [5]. This kind of material has broad development and application prospects.

To realize the flexible application of organic solar cells, they must be integrated with flexible transparent electrodes (FTEs) to form truly flexible devices. The performance of FTEs directly determines the efficiency, stability and large-scale potential of flexible organic solar cells: light transmittance affects light absorption efficiency, resistance is related to charge transmission loss, and mechanical properties determine the stability of devices when bent or folded [6]. In recent years, researchers have developed various FTE systems such as metal nanowires, metal grids, conductive polymers, each with its own advantages and disadvantages [6]. For example, silver nanowires (AgNWs) achieve high light transmittance and low resistance through a three-dimensional network, with excellent flexibility, but they have problems like high contact resistance between wires and easy oxidation; metal grids have excellent conductivity, but their grid structure may cause light scattering and affect light absorption [7].

This article will systematically sort out the main preparation methods and material systems of flexible transparent electrodes, focusing on analyzing the characteristics and application scenarios of ITO alternative materials (such as metal nanowires and metal grids), comparing the performance (efficiency, stability, etc.) of different FTEs in flexible organic solar cells, and discussing the challenges and solutions in their large-scale production. The specific structure is as follows: the first part introduces the core performance requirements and research background of FTEs; the second part elaborates on the definition, characteristics of various FTE materials and the reasons why they are selected as flexible transparent conductive films; the third part analyzes the integration methods and performance impact of different FTEs in organic solar cells; finally, it summarizes existing research results and puts forward future development directions.

## 2. Case

### 2.1. Metal mesh

Metal mesh is a conductive structure made by arranging thin metal wires or strips into regular patterns like square or hexagonal. It is widely used as flexible transparent electrode in large-area flexible organic solar cells, combining electrical conductivity and optical transparency . Its metal lines conduct electric current while the gaps between lines allow light to pass through for the active layer to absorb sunlight. Key properties can be adjusted by tuning grid parameters narrowing metal line width or increasing gap size boosts light transmittance while making the grid denser lowers sheet resistance. Silver mesh is commonly used due to its high conductivity and it has better mechanical bending durability than brittle indium tin oxide, fitting well with flexible substrates like Polyethylene Terephthalate (PET). Some composite electrodes based on it have achieved low sheet resistance and high transmittance enabling flexible organic solar cells with good power conversion efficiency. Silver mesh is common for high conductivity and more flexible than brittle indium tin oxide, fitting flexible substrates. But it may have surface roughness (smoothed by polymers like PH1000) and high preparation costs. Some composite electrodes have achieved low sheet resistance, high transmittance, and enabled efficient flexible organic solar cells.

DOI: 10.54254/2755-2721/2025.GL27354

### 2.2. Nanowire

Typical metal nanowires have an aspect ratio of more than 1000, so they are usually called one-dimensional materials. They show excellent conductivity, light transmittance and flexibility due to their unique one-dimensional structure. They can form randomly overlapping conductive networks on flexible substrates through solution coating (such as blade coating, inkjet printing). Their light transmittance comes from the small-size effect of nanowires, while their conductivity depends on the close contact between nanowires. The three-dimensional network formed by random overlapping of nanowires can deform with the bending of the substrate without breaking, endowing the electrode with excellent mechanical flexibility. The resistance change is still small after thousands of bending times. At the same time, the solution processing technology makes it suitable for large-area and low-cost preparation.

### 2.3. Conductive polymers

Conductive polymers are a special group of organic polymers that can conduct electricity, unlike most traditional polymers which are insulators. They get their conductive ability mainly from their conjugated molecular structures, long chains of alternating single and double bonds that let electrons move freely through the material. These polymers are not just good at carrying electric current; many also keep some typical polymer perks, like being lightweight, flexible, and easy to shape or process into thin films using solution-based methods. For example, a common conductive polymer blend is widely used in devices like organic solar cells or touchscreens because it has decent conductivity, lets visible light pass through, and can fit onto flexible substrates. But they do have downsides: compared to metals or oxides like ITO, their conductivity is usually lower, and some can be less stable when exposed to air or moisture over time. Also, their performance can change if the polymer chains aren’t arranged evenly, which matters a lot for making large-area, reliable devices.

## 3. Analysis and challenge

### 3.1. Metal grid

The fabrication of the metal grid electrode focuses on an ITO-free hybrid structure. First, grooves with 3 μm width and 3 μm depth are etched on a polyethylene terephthalate substrate. Silver ink is filled into these grooves and sintered to form a hexagonal silver grid with 130 μm diagonal. The structure can be referred to the corresponding diagram in Figure.1. Then highly conductive PEDOT:PSS (PH1000) is spin-coated on the PET/Ag-grid at 600 rpm. It is vacuum-baked at 50 °C overnight to form a 150 nm thick film. A 35 nm thick PEDOT:PSS-4083 buffer layer is further spin-coated at 3500 rpm. The active layer is a mixture of P3HT and PCBB-C8 with 1:1 mass ratio dissolved in chlorobenzene. It is spin-coated at 700 rpm without thermal annealing to avoid damaging the PET. Finally LiF/Al is evaporated as the cathode and the device’s effective area is 1.21 $cm^2$. A modified electrode is also prepared by mixing a small amount of PH1000 into the silver ink before sintering. Characterization includes J-V testing under AM1.5 illumination with 100 $mW/cm^2$ intensity, UV-Vis transmittance testing and scanning electron microscopy morphology observation [8].

In performance, the pure PET/Ag-grid has 0.5 Ω/sq sheet resistance and 85% transmittance at 550 nm. The transmittance spectrum can correspond to the literature diagram showing transmittance comparison between PET substrate and PET/Ag-grid. PET has 91% transmittance at 550 nm while

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PET/Ag-grid drops to 85%. The PET/Ag-grid/PH1000 hybrid electrode has 6.1 Ω/sq sheet resistance. Its corresponding OPV device has 0.58 V open-circuit voltage, 3.74 mA/cm² short-circuit current density, 0.32 fill factor and 0.69% power conversion efficiency. This efficiency is nearly three times that of the PET/PH1000 electrode which has 0.24% power conversion efficiency. The modified electrode's sheet resistance reduces to 4.5 Ω/sq and its device performance improves to 0.61 V open-circuit voltage, 5.45 mA/cm² short-circuit current density, 0.41 fill factor and 1.36% power conversion efficiency. The J-V curve comparison diagram of each electrode device can show performance differences between different electrodes. SEM observation confirms that mixing PH1000 fills silver line pores, smooths the surface, reduces micro-shorts, lowers series resistance and increases shunt resistance. Although its power conversion efficiency is still lower than the glass ITO device which has 2.46% efficiency this hybrid electrode suits large-area flexible OPVs [8].

From practical application, the metal grid electrode has low cost and good flexibility making it suitable for roll-to-roll manufacturing. However it has drawbacks. The surface roughness from grid grooves cannot be eliminated even with PH1000 modification, which may cause defects in large-area device active layers. Silver line pores and poor contact between electrode and active layer lead to lower performance than ITO. The PCBB-C8 acceptor selected to avoid annealing limits material options. Future efforts should optimize silver ink sintering to reduce pores, develop ultra-smooth buffer layers and composite the silver grid with nanowires.

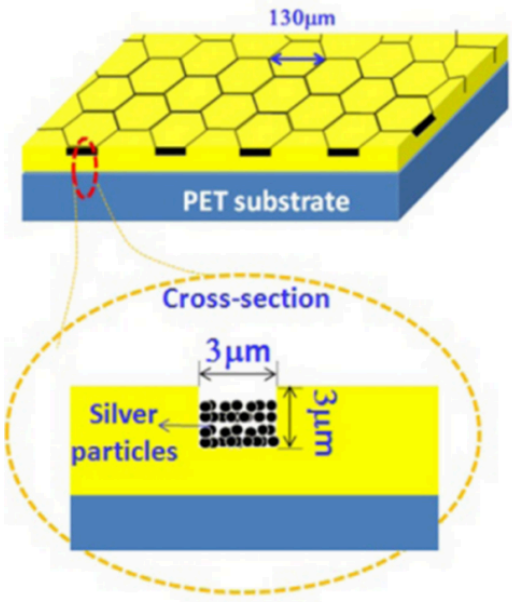



Figure 1. High-resolution Ag-grid embedded in PET based substrate. Black line represent Ag-grid, yellow areas are pastern, blue areas are PET substrate [8]

## 3.2. Nanowire

The nanowire electrode uses a composite structure of silver nanowires (AgNWs) and zinc chelated polyethylenimine (PEI-Zn). AgNWs with a diameter of 30 nm and length between 30 and 50 μm are made into a 2 mg/mL ethanol solution. They are scraped and coated twice on a PET substrate pre embedded with a silver grid that has a sheet resistance of 1.1 Ω/sq. After each scrape and coat step annealing is done at 150 °C for 3 min before patterning with a femtosecond laser. PEI-Zn is prepared by dissolving 0.5 wt% PEI in methoxyethanol adding 75 mg zinc acetate dihydrate and

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stirring for 1 h. It is scraped and coated three times on AgNWs to form a 100 nm thick film. Annealing is then performed at 150 °C for 10 min. The OPV active layer is a mixture of PBDB-T-2F, Y6 and $PC_{71}BM$. It is spin-coated and annealed before $MoO_3$/Ag is evaporated as the cathode. The device structure can refer to the layered schematic diagram in Figure. 2 [9]. Characterization includes atomic force microscopy (AFM) for roughness, X-ray photoelectron spectroscopy (XPS) for interface analysis, Kelvin probe for work function and environmental stability tests.

This electrode performs well. PEI-Zn fills gaps between AgNWs and reduces root mean square roughness (RMS) from 10.4 nm to 2.3 nm. The AFM comparison diagram can show surface differences of the AgNWs film before and after covering with PEI-Zn. The AgNWs film AFM image shows a height difference of about 100 nm and the surface becomes smooth after covering with PEI-Zn. XPS confirms electrostatic interaction between negatively charged groups on AgNWs surface and positively charged amine groups in PEI-Zn which enhances adhesion. The electrode has a work function of 4.20 eV suitable for electron collection and 90% transmittance in the visible near infrared region. The small area flexible OPV has a PCE of 16.1%. The 6 $cm^2$ and 10 $cm^2$ large area single cells have PCE values of 13.1% and 12.6% respectively. The 54 $cm^2$ module with 9 series connected sub cells has a PCE of 13.2%. Device J-V curves of different areas can show performance of various sized devices. When applied to QLED the external quantum efficiency (EQE) is 13.3% and the luminance is 14220 $cd/m^2$ which is twice that of ITO devices [9].

In terms of stability the resistance remains unchanged after 30 days at 50% humidity, 30 min of heating at 250 °C or 30 s of immersion in 0.1 mol/L $Na_2S$ solution. The bending test diagram can show that PCE remains almost unchanged after 1000 bends and the OPV still retains more than 94% of the initial PCE [9].

However this electrode faces commercialization obstacles. Uniform dispersion of AgNWs is difficult in large scale production which affects repeatability. Performance attenuation under long term thermal aging such as over 1000 h at 85 °C has not been verified. High purity AgNWs are costly. Future efforts should develop low cost AgNWs synthesis methods like solution phase reduction with green reducing agents, optimize PEI-Zn conductivity through $Al^{3+}$ doping and combine with roll to roll printing technology.

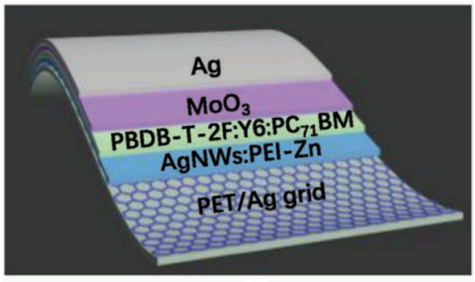



Figure 2. Structure of large-area flexible solar cell: PET(Ag-grid)/AgNWs:PEI-Zn/PBDB-T-2F:Y6:PC71BM/MoO3/Ag [9]

### 3.3. Conductive polymer

The conductive polymer electrode is based on sulfuric acid ($H_2SO_4$)-treated PEDOT:PSS, prepared via chemically controlled transfer printing. PEDOT:PSS is spin-coated on UV-ozone-treated quartz, dried at 120°C for 15 min, immersed in >95% $H_2SO_4$ for 10 min, rinsed, and redried at 120°C for 10 min, boosting DC conductivity (σdc) to over 4000 S/cm. Transfer (schematic in Fig. 3) uses a PDMS stamp; $H_2SO_4$ reduces PEDOT:PSS-quartz adhesion from 20 to 5.3 N/m, easing peeling.

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Films transfer to PEN/glass via annealing at 50-70°C for 2 min. following device structures were listed as below: flexible OPV (PEN/PEDOT:PSS/PTB7-Th:$PC_{71}BM$/Ca/Al, active layer 1:1.5 in chlorobenzene with 3 vol% 1,8-diiodooctane) and transparent OLED (glass/ITO/ZnO/PEI/P-PPV/$MoO_x$/PEDOT:PSS). The characterization includes 90° peel test, XPS, UV-Vis, and J-V/L measurements [10].

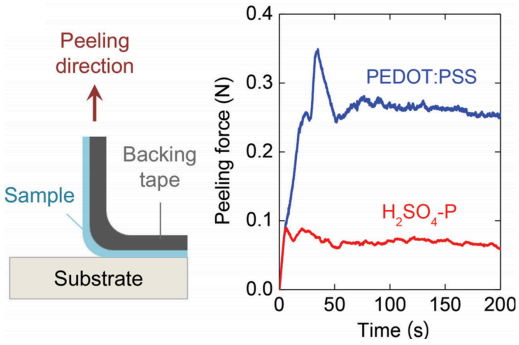



Figure 3. Chemically controlled adhesion of PEDOT:PSS. Experimental scheme and force-displacement curve for 90° peel tests applied to PEDOT:PSS films coated on quartz substrates, before and after $H_2SO_4$ treatment. The average peeling force per unit width was used to quantitatively estimate the adhesive strength of the film [10]

During the characterization, XPS confirms excess PSS removal and improved crystallinity. Flexible OPV PCE is 7.7% ($V_oc$=0.77 V, $J_sc$=14.22 mA/cm², FF=0.70), comparable with ITO's 7.6%. It retains >96% PCE after 1000 bends (radius 4 mm), vs. ITO's 200x resistance jump after 1 bend. Transparent OLED has 91.6% transmittance at 540 nm, ~3 V turn-on, 5500 cd/m² max luminance [10].

However, harsh $H_2SO_4$ treatment needing strict cleaning; PDMS transfer struggles with large-area (>100 cm²) uniformity; untested long-term environmental stability (humidity/oxygen) and PEDOT:PSS oxidation. Future work might including milder post-treatments, optimized PDMS for large areas, $Al_2O_3$ barriers, and composites with metal nanowires/grids to lower resistance.

## 4. Summary & suggestion

Table 1. Comparation of various FTEs

| Type | advantages | disadvantages |
|---|---|---|
| Metal grid | - high conductivity<br>- good mechanical stability in some cases | -hard for fabrication<br>-visible grid lines may affect optical uniformity |
| Ag Nanowires | - high conductivity<br>- excellent optical transparency<br>- good flexibility for bending | -prone to oxidation<br>-relatively high cost for large scale production |
| Conductive polymer | - good solution processability<br>- flexible and lightweight | -lower conductivity compared with metal-based materials<br>-limited long-term stability under harsh environments |

The advantages and disadvantages were concluded and shown in Table. 1. Metal grids stand out as a vital type of FTE, boasting remarkable high conductivity, some silver grid electrodes even

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achieve a sheet resistance as low as 0.5 Ω/sq. They also offer good mechanical bending durability, making them more compatible with flexible substrates like PET compared with brittle ITO. Moreover, their low-cost nature makes them suitable for roll-to-roll manufacturing, unlocking great potential for application in large-area flexible OPVs. However, this type of electrode has obvious shortcomings. The surface roughness caused by grid grooves cannot be completely eliminated even with PH1000 modification, which easily leads to defects in the active layer of large-area devices. Additionally, silver wire pores and poor contact between the electrode and the active layer result in lower device performance than ITO electrodes. Moreover, the selection of the PCBB-C8 acceptor to avoid damaging the PET substrate limits the range of material options. To address these issues, future efforts should prioritize optimizing the silver ink sintering process to reduce internal pores in silver wires and enhance electrode density. Meanwhile, developing ultra-smooth buffer layer materials is essential to improve the flatness of the electrode surface and reduce the defect rate of the active layer. Furthermore, attempting to composite silver grids with other conductive materials such as nanowires could help compensate for the performance deficiencies of a single structure through synergistic effects.

Silver nanowire electrodes exhibit excellent performance thanks to their unique one-dimensional structure. The three-dimensional conductive network they form not only achieves high light transmittance (up to 90% in the visible to near-infrared region) and low resistance but also possesses outstanding mechanical flexibility. After 1000 bending cycles, the PCE of OPV devices with these electrodes can still retain over 94% of their initial value. The solution coating process also makes them suitable for large-area preparation. For instance, composite electrodes based on silver nanowire and zinc-chelated polyethyleneimine (PEI-Zn) can achieve a PCE of 16.1% in small-area flexible OPVs, while 6 $cm^2$ and 10 $cm^2$ large-area single cells reach PCE values of 13.1% and 12.6%, respectively. When applied to QLEDs, their performance even outperforms ITO devices. Nevertheless, this electrode faces challenges in commercialization. Uniform dispersion of silver nanowire is difficult in large-scale production, affecting the repeatability of device performance. The preparation cost of high-purity Silver nanowires is relatively high, and the performance attenuation under long-term thermal aging (e.g., over 1000 hours at 85 °C) has not yet been verified. In response, it is suggested to develop solution-phase reduction methods involving green reducing agents to lower the synthesis cost of Silver nanowires. Optimizing the conductivity of PEI-Zn through $Al^{3+}$ doping can further enhance the overall photoelectric performance of the electrode. At the same time, combining with roll-to-roll printing technology will help solve the problem of dispersion uniformity in large-area preparation and promote its industrial application.

Conductive polymer electrodes, represented by sulfuric acid ($H_2SO_4$)-treated poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), see their direct current conductivity (σdc) increased to over 4000 S/cm after treatment. They combine good solution processability, flexibility, and lightweight properties . Flexible OPVs based on this electrode achieve a PCE of 7.7%, which is comparable to the 7.6% of ITO electrodes. After 1000 bending cycles (with a radius of 4 mm), they can still retain more than 96% of their PCE, far superior to the bending stability of ITO electrodes. They also deliver excellent performance in transparent organic light-emitting diodes (OLEDs), achieving 91.6% light transmittance and high luminance. However, this type of electrode has obvious limitations. The harsh $H_2SO_4$ treatment process requires strict cleaning, and the polydimethylsiloxane (PDMS) transfer method struggles to ensure uniformity in large-area (>100 $cm^2$) preparation. Additionally, long-term environmental stability (impacted by humidity and oxygen) and the oxidation issue of PEDOT:PSS have not been fully verified. In the future, improvements can be made in three aspects: developing milder post-treatment processes for

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PEDOT:PSS to replace the harsh sulfuric acid treatment; optimizing the structure and performance of PDMS stamps to enhance the uniformity of large-area transfer; and introducing barrier layers such as $Al_2O_3$ to improve environmental stability, while attempting to composite them with metal nanowires or metal grids to further reduce electrode resistance.

From the overall development of flexible transparent electrodes and flexible organic solar cells, future research should revolve around the four core goals of "performance improvement, cost reduction, stability optimization, and industrial adaptation." On one hand, it is necessary to strengthen the research and development of multi-material composite systems, leveraging the complementary advantages of different materials—such as the high conductivity of metals, the flexibility of polymers, and the high light transmittance of nanowires, to construct new FTE structures that combine high photoelectric performance and excellent mechanical stability. On the other hand, breakthroughs in green manufacturing technology are needed to develop low-toxicity, low-cost material synthesis and device preparation processes, reducing the environmental and economic costs of large-scale production. At the same time, a more comprehensive long-term stability evaluation system should be established, and standardized testing methods should be developed for complex environmental factors such as temperature, humidity, and light in practical applications to provide data support for the practical application of FTEs and flexible OPVs. Ultimately, through the collaborative innovation of materials, processes, and evaluation systems, flexible organic solar cells will be promoted to find wide application in fields such as smart wearables, flexible displays, and implantable medical devices, meeting the market demand for portable and deformable energy supply systems.

## 5. Conclusion

This study centers on the application of flexible transparent electrodes (FTEs) in organic solar cells (OPVs). Through experimental testing and performance analysis, it systematically explores the characteristics, advantages, and existing bottlenecks of three core FTE material systems, metal grids, silver nanowire, and conductive polymers, providing key insights for optimizing the performance of flexible photovoltaic devices and advancing their industrialization.

In terms of material performance, all three FTE types demonstrate unique value for flexible scenarios. Metal grids, with a low sheet resistance of 0.5 Ω/sq and cost-effectiveness, emerge as a promising option for mass-producing large-area flexible OPVs. Their compatibility with roll-to-roll manufacturing further lowers the threshold for large-scale application. The three-dimensional conductive network formed by AgNWs achieves 90% light transmittance and retains over 94% of its power conversion efficiency (PCE) after 1000 bending cycles. It delivers high-efficiency performance in both small-area (16.1% PCE) and large-area OPVs (12.6% PCE for 10 $cm^2$ devices), and even outperforms traditional indium tin oxide (ITO) electrodes when applied in quantum dot light-emitting diodes (QLEDs). Conductive polymers, such as sulfuric acid ($H_2SO_4$)-treated poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), offer a viable solution for lightweight flexible devices, boasting a direct current conductivity of over 4000 S/cm, OPV efficiency comparable to ITO (7.7%), and excellent bending stability.

However, the study also identifies common and specific challenges that the three materials urgently need to overcome. The surface roughness of metal grids easily causes defects in the active layer; AgNWs face issues of uneven dispersion in large-scale production and high costs; and conductive polymers are limited by harsh sulfuric acid treatment processes and unproven long-term environmental stability. The strategies proposed in this study—such as optimizing sintering processes, developing green synthesis technologies, adopting mild post-treatment methods, and

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creating multi-material composites—have been initially verified to effectively improve material performance.

In summary, this research not only clarifies the current development status of FTE materials but also defines the core direction of synergistic optimization across "performance-cost-stability-industrialization." It lays a theoretical and experimental foundation for future research on the practical application of flexible OPVs in fields like smart wearables and flexible displays.

## References

[1] Fukuda, K., Yu, K., & Someya, T. (2020). The future of flexible organic solar cells. Advanced Energy Materials, 10(25), 2000765.
[2] Li, Y., Xu, G., Cui, C., & Li, Y. (2018). Flexible and semitransparent organic solar cells. Advanced Energy Materials, 8(7), 1701791.
[3] Krebs, F. C. (2009). Fabrication and processing of polymer solar cells: A review of printing and coating techniques. Solar energy materials and solar cells, 93(4), 394-412
[4] Ye, S., Rathmell, A. R., Chen, Z., Stewart, I. E., & Wiley, B. J. (2014). Metal nanowire networks: the next generation of transparent conductors. Advanced materials, 26(39), 6670-6687.
[5] Sun, Y., Chang, M., Meng, L., Wan, X., Gao, H., Zhang, Y., ... & Chen, Y. (2019). Flexible organic photovoltaics based on water-processed silver nanowire electrodes. Nature Electronics, 2(11), 513-520.
[6] Liu, C., Xiao, C., Xie, C., & Li, W. (2021). Flexible organic solar cells: Materials, large-area fabrication techniques and potential applications. Nano Energy, 89, 106399.
[7] Zeng, G., Zhang, J., Chen, X... & Li, Y. (2019) Breaking 12% efficiency in flexible organic solar cells by using a composite electrode. Sci. China Chem. 62, 851–858 .
[8] Li, Y., Mao, L., Gao, Y., Zhang, P., Li, C., Ma, C., ... & Chen, L. (2013). ITO-free photovoltaic cell utilizing a high-resolution silver grid current collecting layer. Solar energy materials and solar cells, 113, 85-89.
[9] Qin, F., Sun, L., Chen, H., Liu, Y., Lu, X., Wang, W., ... & Zhou, Y. (2021). 54 cm2 Large-Area Flexible Organic Solar Modules with Efficiency Above 13%. Advanced Materials, 33(39), 2103017.
[10] Kim, N., Kang, H., Lee, J. H., Kee, S., Lee, S. H., & Lee, K. (2015). Highly conductive all-plastic electrodes fabricated using a novel chemically controlled transfer-printing method. Advanced Materials, 27(14), 2317-2323.