# Application of Organic Field-Effect Transistor in Flexible Electronics and Wearable Devices

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**Abstract.** Organic field-effect transistors (OFETs) have firmly established themselves as pivotal components in the development of next-generation flexible electronics and wearable devices. Their exceptional attributes, including remarkable mechanical flexibility that allows them to endure repeated bending and twisting without compromising functionality, feather-light weight ensuring unparalleled comfort for extended wear, straightforward processing via solution-based methods like spin-coating and inkjet printing, excellent biocompatibility making them ideal for direct skin contact, and cost-effective manufacturing, render them indispensable in these rapidly evolving technological landscapes. This review meticulously compiles the latest groundbreaking advancements and the vast array of applications of OFETs within the domains of flexible electronics and wearable technology. It delves into the significant structural evolutions of OFETs, such as vertical OFETs that open new avenues for miniaturization and performance optimization, and polymer nanowire OFETs, which have made remarkable strides in enhancing carrier mobility and overall device performance. The review also comprehensively explores the diverse applications of OFETs, spanning from highly sensitive OFET-based sensors to the backbone of portable electronics—flexible circuits, and their role in display systems. Their outstanding performance underscores the immense potential of OFETs in practical wearable applications, including electronic skins, healthcare monitoring devices, environmental sensing solutions, and multifunctional flexible displays. Finally, the paper offers forward-looking insights into future research directions, aiming to further enhance the performance of OFET-based devices and make them more adaptable to the exacting demands of the flexible electronics and wearable markets.

## INTRODUCTION

Organic field-effect transistors (OFETs) have become a promising technique in the fields of flexible electronics, materials science, and wearable devices. Unlike conventional inorganic field-effect transistors, OFETs utilize various organic materials in the organic semiconductor layer. The use of Organic semiconductor materials gives OFETs many unique advantages, including mechanical flexibility, lightweight, biocompatibility, tunable optoelectrical properties and low-price large-area manufacturing techniques (spin coating and Inkjet printing) [1][2]. These advantages make OFETs more suitable for many promising applications in flexible electronics and wearable devices. In such applications, traditional electronics may meet their limitations in terms of comfort, flexibility and adaptability [1].

Over the past few decades, developments in organic semiconductor materials have significantly improved the performance and stability of OFETs. For early-generation organic semiconductors, low charge carrier mobility, low On/Off current ratio, high environmental sensitivity, and power dissipation are the main limitations [1]. However, these problems are improved by the advancements in materials such as small molecular semiconductors, conjugated polymers, and hybrid organic-inorganic composites. The enhanced charge transport improved operational stability, and more effective manufacturing processes of the high-performance organic materials provide more chances for integrating OFETs into commercially feasible flexible electronic products.

In the field of flexible electronics, new applications like rollable displays, electronic skin, flexible sensors, and foldable electronic devices are developed based on OFETs [1][2]. Compared to traditional rigid components, OFET-based components have the ability to be integrated on complex or moving surfaces because of their mechanical flexibility. For example, OFET-driven flexible displays have demonstrated the potential for bending and folding without degrading device performance, showing the potential for next-generation applications. Moreover, utilizing OFETs in wearable devices has significantly expanded the ways in which flexible electronics benefit daily life. OFET-based devices meet the requirements of wearable devices, such as lightweight, stretchable, and biocompatible [1]. They also provide good user experiences and seamless integration with the human body. For example, OFET-based wearable sensors and electronic textiles have shown impressive progress in health monitoring, such as tracking physiological parameters like heart rate, respiration, body temperature, and sweat analytes. These applications have the potential to change health monitoring methods. They can provide continuous, real-time monitoring of personal health data outside the clinic. Such functions help their users to make reasonable decisions and take proper actions before their health condition becomes worse.

Although OFET-based devices have made significant progress, challenges still exist. The critical challenges of OFET-based devices include ensuring uniform and stable device performance over large areas, enhancing long-term environmental stability, and further improving carrier mobility. Additionally, the commercial manufacture of OFET-based devices requires addressing scalability, reproducibility, and cost-effectiveness. Finally, the material degradation and interface instability under mechanical stress or long-term usage also result in problems that require continued research.

In the future, OFET technology still shows great potential because of the interdisciplinary research involving materials chemistry, physics, system-level integration and encapsulation. The OFET performance and reliability could be improved through molecular design optimisation, improved processing methods, and interface engineering. Moreover, the development of machine learning and computational modelling could accelerate material discovery and device optimization processes. By addressing current technological barriers and utilising emerging technologies, the broader commercialisation of OFET-based flexible electronics and wearable devices becomes possible.

This review explores the recent advances in the architecture of OFETs, such as vertical OFETs [3] and polymer nanowire OFETs [4]. Diverse applications in the area of flexible electronics and wearable devices such as high-sensitivity OFET-based sensors [5][6] and Organic light-emitting transistors [7] are also introduced. It also discusses existing challenges and provides insights into potential future research directions to encourage the development and integration of OFET technology in everyday life.

## ADVANCEMENTS IN THE STRUCTURE OF OFETS

Organic Field-Effect transistor is a type of field-effect transistor (FET) that utilise organic semiconductors as the channel material. Compared with conventional field-effect transistors which are typically based on rigid inorganic materials, the usage of organic semiconductor materials introduced many unique advantages, including good mechanical flexibility, low-cost solution-processable methods and ease of fabrication [8][9].

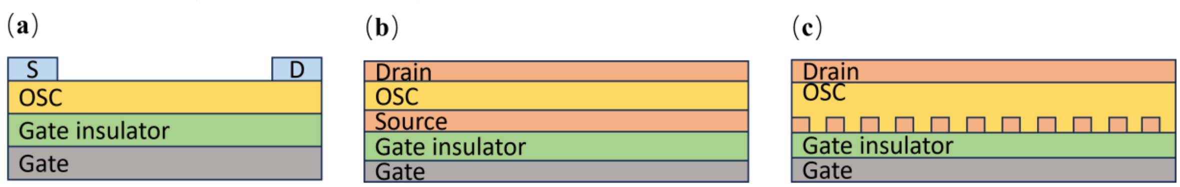


**FIGURE 1**. Schematic diagram of a) Traditional Planar OFET architecture (bottom gate top-contact). b) typical Vertical OFET architecture with a continuous source electrode. c) Vertical OFET with a weakly screening source electrode.

An OFET usually consists of five components: Gate electrode, Gate dielectric layer, Organic Semiconductor layer, Source electrode, and Drain electrode. OFETs are usually prepared by the bottom gate top-contact architecture. The Gate electrode layer is placed at the bottom of the device. The Gate dielectric layer is horizontally placed between the Organic semiconductor layer and the Gate electrode. The Source and Drain electrode are on the top of the Organic semiconductor layer (Figure 1a). OFETs prepared by this design are called Planar Organic Field-effect Transistors (POFETs) [9]. In POFETs, carriers accumulate at the semiconductor/dielectric interface upon gate voltage application, forming a conducting channel [9]. The charge mobility of POFETs could reach about 10 cm2V-1s-1 [9]. Planar OFETs introduce excellent flexibility, but the performance highly depends on the quality of semiconductor/dielectric interface. To address the low charge carrier mobility of the organic semiconductor materials, research about new fabrication architecture has driven more interest. Therein, a vertical architecture is first introduced by Ma and Yang in 2004 [3], which requires a vertical stacking of all device layers. A diode cell is positioned above a capacitor structure, where the bottom electrode functions as the gate of the transistor, and the top electrode operates as the drain.

The intermediate electrode, shared between the organic semiconductor layer and the gate insulator layer is the source (Figure 1b). However, the electrode screening effect introduced by the metallic source layer makes it very hard to transport charge in the organic semiconductor layer. To address this problem, several strategies have been developed. Using an ultrathin source layer and a supercapacitor, allowing very high electric fields at the source and organic semiconductor layer is a feasible solution [3]. Another method is utilising the perforated source electrode. For example, implementing metallic nanowires or photolithographically patterned metal layers (Figure 1c) [9]. By doing so, the gate-induced electric field could enter the organic semiconductor layer through the perforates structure [3]. By utilizing the superconductor and applying a bias between the gate and source electrodes (VGS), and the source and drain electrodes (VDS), the charge carriers could accumulate at the gate insulator and semiconductor interface and drift to the drain electrode [10], enabling vertical charge transport through nanoscale semiconductor channels. OFETs prepared in the vertical structure significantly enhance the current densities (>500mA $cm^{-2}$) and switching speeds at lower operating voltage. Demonstrating a huge potential for compact, high-performance, high-speed flexible electronics.

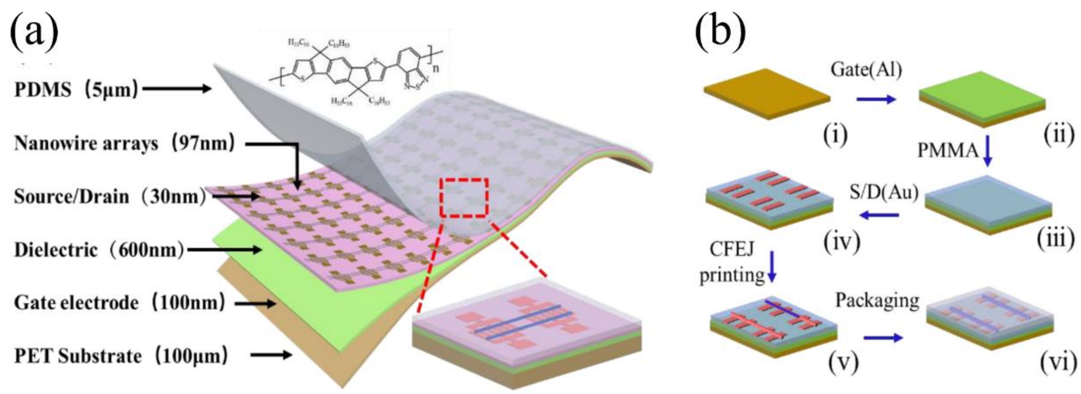


**FIGURE 2**. a) Diagram of structure for NW array based OFETs. b) Process diagram for NW array-based OFETs. (a-b) Reproduced with permission [4].

In 2023, a new candidate structure of high-performance flexible OFETs was introduced. The structure requires to integrate Polymer nanowire (NW) organic field-effect transistors on highly aligned large-area flexible substrates [4]. To fabricate this structure, a new technique called the coaxial focused electrohydrodynamic jet (CFEJ) printing technology is used to build highly aligned 90nm diameter polymer arrays [4]. The CFEJ printing method is a simple operation, high-resolution and material-saving technique which has the ability to fabricate highly aligned polymer arrays at room temperature without photolithography or transfer process [4]. The schematic of NWOFET (Figure 2a) shows a bottom-gate and bottom-contact structure. This structure requires the Gate electrode to lie on the substrate layer, the dielectric layer is sandwiched between the gate electrode layer and the source/drain layer. The nanowire arrays are printed on the source/array layer using the CFEJ printing method (Figure 2b). The OFETs fabricated from these printed polymer NW arrays show promising performance, including a high average hole mobility of approximately 1.1 $cm^2\ V^{-1}s^{-1}$ and a high current on/off ratio (about $1.93\times10^5$) [4]. Compared to the traditional thin-film OFETs with about 0.2 $cm^2\ V^{-1}s^{-1}$ hole mobility, the carrier mobility of OFETs with NW arrays is around 5 times higher, which indicates faster charge transport and better electrical performance. The high on/off ratio shows that OFETs with NW arrays have strong transistor switching characteristics and low leakage currents. Moreover, such devices demonstrate minimal hysteresis, ensuring stability and reliability for practical applications. Besides the above advantages, the printed polymer NW-based OFETs show consistent performance across arrays of devices (4×10 OFET arrays), confirming good scalability and uniformity of the CFEJ printing technique, indicating the capability for large-scale, high-resolution printing on flexible substrates. These advantages and good performance promise the printed polymer NW-based OFETs a future for being applied in flexible displays, wearable electronics, electronic skin(e-skin), biomedical sensors, and smart textiles.

## APPLICATIONS OF OFETS IN FLEXIBLE ELECTRONICS

With the development of organic semiconductors and their fabrication techniques, more and more OFETs based on different semiconductor materials have shown their unique properties. Considering this situation, OFETs have been applied in various fields, including flexible electronics, memory and logic circuits, Internet of Things (IoT) and smart packaging. Therein, flexible electronics is a realm with significant demand and enormous potential. Flexible electronics usually refer to a technique where electronic circuits and components are mounted on flexible, stretchable, or comfortable substrates. Flexible electronics can generally be bent, twisted, or stretched into unique shapes without degrading their performance. Based on this fact, OFETs are naturally suitable for applications in the realm of flexible electronics because of their good flexibility and stretchability, light weight, low-cost manufacturing, and high biocompatibility. This section will introduce the advances of OFET-based applications in flexible electronics, including flexible sensors, circuits and displays.

## Applications in Flexible Sensor

Flexible sensors, different from conventional rigid sensors, usually need to be fabricated on deformable substrates such as PI, PEN, and PDMS [11]. They are designed to maintain their functions under mechanical deformation, including stretching, bending, or twisting. Nowadays, flexible sensors have attracted increasing attention because they can be integrated into non-planar, wearable, and implantable platforms, ensuring promising applications in fields such as wearable and biocompatible electronics, robotics, electronic skin, and environmental monitoring.

Organic Field-effect transistors are naturally suitable for flexible sensors because they can be fabricated on stretchable substrates, and organic semiconductors offer intrinsic flexibility and low temperature processing. OFET-based sensor is a critical and popular research direction because such sensors provide high sensitivity and have the ability to detect various signals, such as chemical, biological and physical signals. Moreover, the tunable performance and flexibility make them ideal for large-area and low-cost sensing systems.

OFET-based sensor is an emerging topic; many applications have been developed to explore the possibilities of OFET. OFET-sensors function by transducing external stimuli, including gases, light, pressure, temperature, or biomolecules into electrical signals via modulations in charge carrier mobility, threshold voltage or drain current within the organic semiconductor. A flexible integrated electronic nose (e-nose) system has been developed for malodour classification [6]. This system integrates an OFET sensor array, a sensor readout interface (SRI), and a machine learning engine (MLE) on flexible substrates. The study compared the accuracy of flexible integrated smart system (OFET sensors and Flexible integrated circuit) and a validation reference system (OFET sensor and conventional Si-based microcontroller). The flexible integrated smart system reached an average goodness of prediction of approximately 50% for both male and female swatches, which is lower than the other combination (83% for female swatches and 71% for male swatches) [6]. However, the e-nose system's predictions are still as good as or better than half of the individual human panel assessors [6]. The flexible and low-cost fabrication processes still make it ideal for wearable sensors.

Many explorations have been conducted to improve the performance of OFET-based sensors. Recently, a study discussed the impact of silica particles modified with self-assembled monolayers (SAMs) on enhancing the performance of OFET-based gas sensors. By employing poly(3-hexylthiophene) (P3HT) blended with silica particles functionalized with different chemical groups, the sensitivity, selectivity, and stability of organic gas sensors towards harmful gases such as nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), and carbon dioxide ($CO_2$) were improved. Silica particles modified with SAMs of five different functional groups have been tested. These groups are Methyl group (C), Ethylenediamine (2N), Diethylenetriamine (3N), Thiol (S), and Bare hydroxyl group (O). The gas sensing performance towards $NO_2$, $SO_2$, and $CO_2$ were demonstrated. For $NO_2$ detection, 3N-functionalized silica achieves the highest sensitivity (responsivity of 0.143 at 10 ppm $NO_2$), which is three times higher than pure P3HT sensors [5]. The lowest limit of detection for 3N-functionalized silica is 0.00000417 ppb, indicating extremely high sensitivity. For $SO_2$ detection, S-functionalized silica shows the best performance, with the lowest limit of detection of 0.0000665 ppb [5]. Such high sensitivity is achieved by strong chemical interaction with thiol groups. Finally, 3N-functionalized silica exhibits the highest sensitivity for $SO_2$ detection, with the lowest limit of detection of 0.000178ppb [5]. Moreover, functionalize silica also significantly enhanced the long-term stability of OFET devices. After 42 days of ambient exposure, 3N and O-functionalized silica exhibits the highest recovery rate of 90% under vacuum conditions [5]. Such performance indicates that surface functionalization is an effective strategy to advance organic electronic sensors toward practical environmental and industrial safety applications.

## Applications in Flexible circuit

Flexible circuits, or Flexible printed circuits (FPC), are thin, lightweight, and deformable electronic circuits fabricated on mechanically flexible, bendable substrates. These circuits maintain electrical performance under physical deformation. Flexible circuits are an attractive research topic because of their interesting properties. Unlike rigid PCBs, flexible circuits can be integrated on non-flat and moving surfaces, enabling applications in wearable devices, soft robotics and curved displays. They are ultra-thin and lightweight, but can withstand repeated bending, folding, and stretching. Such advantages make flexible circuits the foundation of many next-generation electronic systems. OFETs are highly compatible with flexible circuits because of low-temperature fabrication and intrinsic mechanical flexibility. The low-cost fabrication process, such as inkjet printing and screen printing, also meets the requirements of flexible circuits. Moreover, OFETs can achieve various functions. In flexible circuits, they can act as logic elements, sensors, and amplifiers.

Developing materials is an important strategy to improve the performance of OFETs and broaden their applications. Recently, a material has been developed specifically for OFET arrays and showing a great potential for sensing applications, such as high-resolution UV imaging. The material (AZO-BTBT-8) combines a high-mobility benzo[b]benzo [4,5] thieno[2,3-d] thiophene (BTBT) backbone with photoresponsivity azobenzene (AZO) and flexible alkyl chains [12]. The AZO groups offer reversible photoisomerization upon UV and visible light exposure, creating intrinsic lattice strain within thin films [12]. The molecular lattice strain leads to optimized molecular packing, further enhancing crystalline ordering and significantly increasing carrier mobility (from ~0.015 $cm^2\ V^{-1}s^{-1}$ to ~0.141 $cm^2\ V^{-1}s^{-1}$) [12]. The devices also show robustness and flexibility under various mechanical stresses. A flexible array of 33 × 40 OFET devices was successfully fabricated, exhibiting reversible and stable light responses, enabling high-resolution optical sensing ability and the potential for applications in flexible sensing systems.

To address the need for devices capable of conforming closely to human skin and providing accurate monitoring of physiological signals without noise interference. An ultra-thin (270 nm), flexible, air-stable, self-adhesive organic electronic circuit has been developed. This device consists of gold (Au) electrodes sandwiched between layers of Parylene diX-SR, with organic semiconductor layers (DNTT for p-type OFETs, and PDI-8CN2 for n-type OFETs) [13]. The carrier mobilities for p-type OFETs achieved 0.11 $cm^2\ V^{-1}s^{-1}$ [13]. For n-type OFETs, this number is 0.007 $cm^2\ V^{-1}s^{-1}$ [13]. Devices showed stable electrical performance with minimal variations after mechanical deformation, indicating that the ultra-thin structure significantly enhanced the flexibility. The long-term air stability tests showed that OFETs encapsulated by ultra-thin parylene layers-maintained functionality over 5 years, although moisture and oxygen penetration introduced some degradation [13]. By utilizing the ultra-thin devices, the study demonstrated some amplifier designs. The organic pseudo-CMOS inverter (opCMOs) has gains up to 64.57 and a higher switching voltage (about 5V). The single-stage organic CMOS inverter (oCMOS) has gains up to 10.47, but a lower switching voltage (3V) makes it more suitable for bioelectronics applications. Finally, the five-stage oCMOS inverter significantly raises the amplification up to 2358, showing the capability for amplifying weak bio-signals [13].

## Applications in Display Systems

In the realm of display systems, organic field-effect transistors play a critical role. Many OFET-based applications in display systems are continuously coming out, including Active-Matrix Organic Light-Emitting Diode (AM-OLED), E-paper displays, electrochromic displays, Organic Light-Emitting Transistor (OLET)-Based displays, and flexible displays. Therein, OLET is a topic with huge potential for next generation display techniques. Organic Light-emitting transistors are multifunctional devices that combine the switching functionality of an OFET with the light-emission capability of an organic light-emitting diode (OLED). In the conventional AM-OLED display systems, each pixel consists of three sub-pixels (Red, Yellow and Green). In each sub-pixel, one OLED emits light, and at least two thin film transistors, acting like switches, control the current flow to each sub-pixel [14]. This complex structure requires at least nine components to drive one pixel. OLET has the ability to hugely simplify the current circuit architecture and potentially reduce power consumption by allowing simultaneous electrical switching and light generation within a single component. Furthermore, the light-emitting function is achieved by the recombination of injected charge carriers so that the emission can be confined to the channel, and its intensity and color can be modulated. Such properties make OLET ideal for high-resolution displays. OLETs are structurally and operationally derived from OFET architectures. The advances in OFET materials and device architecture will directly influence the performance of OLET.

Recently, a study about nonvolatile memory organic light-emitting transistors brought OLET more possibilities. This multifunctional device, called ferroelectric organic light-emitting transistor (Fe-OLET), integrates nonvolatile memory, switching, and organic light-emitting capabilities within a single device. By utilizing the remnant polarization property of the ferroelectric polymer poly(vinylidenefluoride-co-trifluoroethylene) [P(VDF-TrFE)], the device achieves stable light emission even at zero gate bias. Such device addresses the challenge of limited pixel circuit integration density and aperture ratio in advanced AMOLED displays, potentially changing the design of pixel circuits.This device uses the bottom-gate configuration with an extended-gate architecture separating operation and sensing areas. The electrical and Optical performance of the device is excellent. Fe-OLET achieved a significant threshold voltage shift (ΔVth=46.6V) and a high ON/OFF current memory ratio of about 106 at zero reading voltage. The maximum luminance reaches 16520 cd $m^{-2}$ [7]. After optimizing the interface, the luminance can become five times larger. The field-effect mobility is also improved, reaching a high mobility of up to 20.1 $cm^2$ $V^{-1}s^{-1}$ after incorporating a UV-ozone treated PMMA buffering layer [7].

Moreover, Fe-OFET achieves reliable nonvolatile memory operation, demonstrating stable switching between On and OFF states without continuous gate voltage application [7]. The endurance tests showed a good retention performance, maintaining luminescence (about 150 cd $m^{-2}$) after 1000 seconds of continuous operation at zero gate bias [7]. Furthermore, Fe-OFET exhibited endurance with minimal deterioration after 100 program/erase cycles. It maintained luminescence brightness and a high ON/OFF ratio (larger than 104) [7]. Such promising results indicated that Fe-OLET technology not only improves conventional OLET performance in terms of luminescence and carrier mobility but also reduces the complexity of pixel circuits by removing the need for separate storage capacitors. This development opens the way toward higher integration density and simplified fabrication processes suitable for next-generation ultra-high-definition flexible AMOLED displays.

Intrinsically white organic polarized emission semiconductor materials are important for reducing complexity and miniaturising the light-emitting devices, such as OLET. However, the lack of proper materials and effective preparation methods is the key limitation of this technique [15]. In 2024, a study broke this bottleneck by developing a white organic polarized emissive semiconductor single crystal (WOPESSCs) [15]. A highly polarized bule-emitting material, 2,6-diphenylanthracene (DPA), was chosen as the host because of its excellent optoelectronic properties [15]. Green-emitting tetracene (Tc) and red-emitting pentacene (Pen) were used as guest dopants to be enabling efficient energy and polarization transfer [15]. The grown high-quality single crystals show a photoluminescence quantum yield (PLQY) of 38.3% and a charge mobility of 4.9 $cm^2$ $V^{-1}s^{-1}$ [15]. The degree of polarization (DOP) ranges from 0.69 to 0.96 across the visible spectrum, with emission tunable from bule-white to yellow white based on polarization angles [15]. WOPESSCs also achieved precise Commission Internationale de l'Eclairage (CIE) coordinates of (0.3258, 0.3396), very close to standard white-light emission [15]. With such good and consistent performance, WOPESSCs-based Organic polarised light-emitting transistors (OPLETs) are developed. Such devices show high mobility (up to 4.9 $cm^2$ $V^{-1}s^{-1}$), strong polarized emission, and electroluminescence tunability from yellowish to bluish white through voltage adjustments [15], highlighting a great potential for flexible, multifunctional applications in flexible electronics and wearable displays. This study advances the integration of polarized emission in OFETs, the achieved high mobility and stable white-light emission are particularly suitable for flexible circuits and multifunctional displays.

## APPLICATIONS OF OFETS IN WEARABLE DEVICES

As a part of flexible electronics, wearable devices are a class of lightweight, flexible systems designed for continuous operation while directly interacting with the human body. Wearable devices are a crucial and special research topic because they are continuously and directly in contact with the human body, and are required to provide continuous tracking of physiological parameters such as heart rate, body temperature, respiration, or movement. The special operating environment requires wearable devices to be stretchable, biocompatible and comfortable. Energy efficiency is also essential for continuous battery-free operation. The properties of OFET largely meet these requirements, making them highly suitable for wearable devices.

By the nature of the working environment of wearable devices, water is a factor that cannot be ignored. To improve the performance of OFET-based sensors and explore their potential for wearable electronic applications, a high-performance waterproof-breathable fully flexible tactile sensor has been developed [16]. This tactile sensor integrates piezoelectric materials with OFET technology. The material, β-phase polyvinylidene fluoride (PVDF) nanofiber membranes, was fabricated through an electrospinning process [16]. The highly porous membranes provide excellent breathability and water resistance, and the 2,6-diphenylanthracene (DPA) utilized by OFET provides the signal application, enhancing the sensor's detection capability [16]. Such materials make the tactile sensor exhibit high sensitivity of 7.94 $kPa^{-1}$, low detection limit of 48.54 Pa, and rapid response/recovery time (about $10^5$ms) [16]. Furthermore, the linear, stable, and repeatable response to applied pressures from 10 to 200 grams shows a high device reliability [16]. Based on this sensor, real-time monitoring of various human motions has been demonstrated [16]. The excellent breathability and waterproof properties also significantly improve the users' comfort for long-term physiological monitoring applications, offering considerable potential for advanced wearable devices, such as wearable electronic skin.

The performance of OFET-based wearable devices can be influenced by many different aspects, including the organic material, the structure of OFET, and the organic semiconductor deposition methods. Recently, the performance of OFET-based mechanical sensors for wearable devices has been studied. Such mechanical sensors are designed to detect anisotropic and isotropic deformation. The study compares two different electrode layouts (interdigitated and spiral-shaped) and two organic semiconductor deposition methods (drop-casting and meniscus-guided printing), evaluating their effectiveness in detecting specific deformation types [17]. The meniscus-guided printing was divided into two types: parallel and radial, based on the direction of crystal alignment. After recording the average threshold voltage and charge carrier values evaluated on a set of 5 devices for each configuration, the results show that the charge carrier mobility of Drop-casted devices is generally higher than meniscus-printed devices. Specifically, the charge carrier mobility of drop-casted OFET with interdigitated electrodes (i-OFET) is about $5.3 \times 10^{-2}$ $cm^2$ $V^{-1}s^{-1}$, which is lower than drop-casted OFET with spiral-shaped electrodes (about $9.2 \times 10^{-2}$ $cm^2$ $V^{-1}s^{-1}$), indicating spiral layouts improve charge collection efficiency [17].

Moreover, experiments are conducted to test electromechanical performance under anisotropic deformation and isotropic deformation. As for anisotropic deformation, devices were tested under two anisotropic deformation directions: parallel and orthogonal to channel length. The results show that parallel-printed interdigitated OFETs (p-i-OFET) show the highest sensitivity to orthogonal anisotropic deformation (about 15% relative current variation per 1% strain, almost double the sensitivity compared to parallel deformation), because of aligned crystalline domains [17]. Devices without aligned crystals or isotropic layouts had significantly reduced sensitivity, indicating the importance of matching crystalline orientation and electrode geometry to deformation direction. As for testing the tactile sensing performance (Isotropic deformation), a hemispherical indenter is used to simulate complex deformation. Drop-casted spiral OFETs (dc-s-OFET) show significantly higher sensitivity (1.2 N-1, relative current variation per unit force) for tactile sensing compared to all other device configurations [17]. This study indicates that OFET mechanical sensors should be specifically optimized based on their intended application, opening new opportunities for advanced applications in wearable devices, such as joint monitoring.

## CONCLUSION

In conclusion, organic field-effect transistors (OFETs) have significantly developed the field of flexible electronics and wearable devices, which depend on the remarkable structural improvements and expanded application domains. Recent developments in OFET architecture, such as utilising polymer nanowires, improving the printing technology, and optimizing the electrode layouts, have substantially improved the carrier mobility, mechanical flexibility, and operational stability. These advancements enhance the successful integration of OFETs into various applications, including flexible sensors, flexible circuits, and organic light-emitting transistors (OLETs). Such applications open the way for more comfortable, energy-efficient, and multifunctional electronic systems.

As for flexible electronics, OFETs offer flexible sensors high sensitivity and mechanical robustness. Enabling applications in healthcare monitoring, environmental sensing, and human-machine interactions. In the area of flexible circuits, the properties of OFETs (like lightweight and cost-effective fabrication processes) promise the potential for next-generation electronics in smart packaging and electronic textiles. Additionally, the emergence of OLET technology highlights the multifunctionality of OFETs, which demonstrate a future of high-resolution, energy-efficient display systems and advanced optoelectronic devices. Moreover, wearable devices have particularly benefited from OFET technology. Integrating OFET-based wearable devices with textiles and human skin promises real-time health monitoring, physiological data tracking, and better user comfort. Such benefits make them essential in the fields of personalised medicine and wellness.

Despite these developments, several challenges still exist. The carrier mobility is still an essential factor that could be improved. It can be enhanced by optimizing the existing OFET architecture, altering the organic semiconductor and electrode materials, or optimising channel morphologies. Limitations still exist in achieving consistent device performance and reliability in complex environments, such as those with high mechanical stress, exposure to moisture, or varying temperatures. Additionally, the scalability of OFET fabrication techniques and long-term environmental stability need further research and development.

Looking forward, future research could focus on enhancing the material properties, including developing organic semiconductors with improved charge mobility, enhancing device stability under complex environments, and improving the performance under long-term usage. Innovations in device design (like self-healing materials and biocompatible OFETs) are also critical for expanding OFET applications into the biomedical area. Finally, advancements in large-scale, low-cost printing techniques and environmentally friendly manufacturing processes will be essential for the sustainable commercialisation of OFET-based flexible electronics and wearable devices.

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