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OLED-OPD Integrated System: Technological Development and Application

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Abstract. Because the materials of organic light-emitting diodes (OLED) and organic photodetectors (OPD) are complementary and the processes are relatively similar, the OLED-OPD integrated system can achieve both display and light sensing functions on the same flexible substrate. This makes consumer electronic devices thinner, lighter, bendable, and more functional. Through improvements in new materials and structural designs, such as the use of phosphorescent materials and perovskites, and the adoption of pixel-level embedding and vertical stacking methods, the device efficiency, spectral response, and space utilization have been significantly enhanced. Its applications include full-screen biometrics, automatic dimming, non-contact gesture interaction, and continuous health monitoring. Particularly in wearable medical devices, it can be used to measure blood oxygen, heart rate, and non-invasive blood pressure. However, there are still some difficulties at present, such as complex manufacturing processes, insufficient flexibility reliability, inaccurate data, and high production costs. In the future, with technological advancements, these problems are expected to be gradually resolved, making devices more durable, feature-rich, and even opening up entirely new application areas.

Keywords: OLED-OPD integration, flexible electronics, biometrics, health monitoring, organic optoelectronic devices

1. Introduction

Consumer electronics are rapidly evolving towards multi-functional integration and flexibility. While smart devices strive for a thin and light form factor, they also need to integrate display and sensing functions. In this trend, organic light-emitting diodes (OLED) and organic photodetectors (OPD) show great potential due to their complementary properties. Display technology has developed rapidly, from the earliest bulky cathode ray tubes (CRT) monitors to later technologies such as plasma (PDP), liquid crystal (LCD), field emission (FED), and so on. In recent years, organic light-emitting diode displays have attracted increasing attention. They do not require backlighting and can emit light on their own. OLED not only have high brightness, strong contrast, and fast response, but also offer wide viewing angles and no visual restrictions. They are becoming a new hotspot in the display field [1]. OLED offer self-luminescence, high contrast, flexibility, and tunable spectra; OPD, on the other hand, feature high sensitivity, wide spectral response, low power consumption, and ease of large-scale manufacturing. These characteristics make them well-suited

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for integration. Technological integration is becoming increasingly important, with the main goal of combining display and light sensing into a single unit, reducing the number of hardware components, such as for under-screen biometrics, and promoting their application in health monitoring and environmental perception. The fundamental reason for the development of consumer electronics towards thinness, flexibility, and multi-functionality is the limited hardware space but increasing functional demands. Traditional silicon-based sensing and display modules stacked together have problems such as large space occupation, optical interference, material rigidity, and high costs due to different processes. This has driven the need for technological innovation.

In this context, organic optoelectronic technology offers the possibility of integration on flexible substrates due to material similarity and process compatibility. OLED, as an efficient and spectrally tunable light source, and OPD, as a wide-spectrum detector, are naturally complementary in function. This integration not only reduces the hardware volume but also redesigns the system, enabling the display interface to simultaneously output information and receive environmental signals, thereby supporting functions such as full-screen biometric recognition, continuous health monitoring, and immersive interaction. This is an important technical route for consumer electronics to achieve sensing capabilities. This article will comprehensively introduce the OLED-OPD integration technology from the perspectives of technical foundation, product application, challenges faced, and future trends.

2. OPD application research

Recent years have witnessed significant progress in OPD application research, which is closely related to the continuous innovation in materials and integration technologies of OLED and OPD. In the field of OLED, the application of phosphorescent materials and thermally activated delayed fluorescence materials has significantly improved the luminous efficiency. Compared with inorganic materials, organic photosensitive materials have a greater variety and their band gaps are easier to adjust. Therefore, they are particularly suitable for making OPD with narrow spectral response. Nowadays, with the continuous development of information technology, OPD with narrow spectral response, due to their advantages such as good shape customization, simple process, light weight and portability, and strong color discrimination ability, can better meet the increasing application demands of the present and future than inorganic devices [2].

In terms of integrated structure design, researchers have explored various strategies. The monolithic integration approach achieves optical path optimization by sharing the substrate and some functional layers; pixel-level integration embeds tiny OPD units into OLED pixels, although it sacrifices a certain degree of brightness, it significantly improves the spatial utilization efficiency; the vertical stacking structure separates light emission and signal reception through optical filter layers, avoiding mutual interference between OLED and OPD, providing a feasible path for high-performance optoelectronic integration systems. The continuous maturity of these technologies is driving the application of OLED and OPD in fields such as biosensing, medical detection, and wearable devices to a new stage.

3. OLED application research

The OLED-OPD integration technology in OLED application research is significantly transforming the interactive experience of display screens. This technology combines the OLED display unit with the OPD, enabling the screen not only to emit light but also to sense light, thereby achieving a variety of innovative functions. OLED and OPD can be integrated into a single device to achieve

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two different functions: light emission and detection. This integrated design has obvious advantages: it can be made into flexible devices, make the device thinner and lighter, simplify the process, and be more conducive to large-scale production. Due to these characteristics, it has received extensive attention and interest from the scientific research community [3]. The molecules in the organic single-crystal semiconductor film are arranged neatly and orderly, with few impurities and defects. Therefore, its performance in transmitting charges is particularly outstanding. At the same time, it also has the characteristics of a super-smooth surface and dense molecular stacking, which not only improves the properties of the device interface but also effectively prevents the invasion of water and oxygen. Due to these advantages, organic single-crystals have become a promising material for charge transport layers. Currently, organic single-crystals are mainly used as the light-emitting layer in OLED, while related research on them as charge transport layers is still limited and has not been systematically carried out [4]. OLED are being increasingly applied, especially in the display field, and have gradually replaced the previous CRTs and LCD. By 2023, the market share of OLED in mobile phone screens had exceeded half, reaching 51%. Due to its ultra-thinness and flexibility, researchers have continuously expanded OLED technology to wearable devices and flexible display fields in recent years, and have made many significant advancements [5].

In the field of biometric identification and security, this technology enables full-screen multi-finger fingerprint recognition. Due to the presence of OPD sensors throughout the screen, users can press multiple fingers in any area to complete the identification, significantly enhancing the convenience and security of unlocking. At the same time, this technology also supports the live detection function: OLED can emit specific wavelengths of light, while OPD receives the light signals reflected back from the skin tissue. By analyzing biological features such as blood flow, it effectively distinguishes between a real human body and a forged image, preventing photo or model deception. To achieve true color and a wide color gamut for OLED displays, it is necessary to use organic luminescent materials with narrow emission spectra to ensure high color purity. However, currently, commercial materials generally have wide spectra due to strong molecular vibrations. Developing new narrow-spectrum luminescent materials has become an urgent need in the industry [6].

In terms of intelligent interaction, OPD can promptly sense the light intensity and color temperature of the surrounding environment, and automatically adjust the brightness and color performance of the OLED screen, making the display effect more comfortable and natural. Moreover, with its highly sensitive light perception ability, users can perform gesture operations without touching the screen. The changes in shadows formed by fingers moving in the air on the screen can be recognized by OPD as instructions, enabling non-contact interactions such as sliding and selection. This is particularly practical in certain scenarios where direct touch control is inconvenient.

This technology has endowed display devices with "visual" capabilities, driving the development of smartphones, tablets and other terminals towards greater intelligence and security. We hope you find the information in this template useful in the preparation of your submission.

4. Status of OLED-OPD integration technology

The integration of OLED and OPD is an important development direction in the field of wearable health devices. The core lies in miniaturizing and making flexible the light source and detector, and efficiently combining them to achieve non-invasive and continuous monitoring of various physiological parameters. In the area of health monitoring, a typical application is a blood oxygen and heart rate detection system: This system uses dual-wavelength OLED to emit specific light that

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penetrates the skin, while the OPD receives the light signals reflected by the blood, and then uses algorithms to analyze this optical information, ultimately calculating the user's blood oxygen saturation and heart rate values in real time. Another application is non-invasive blood pressure monitoring, which utilizes two OPD arrays to collect pulse wave signals from different parts and calculates the blood pressure value by determining the time difference between the two signals, avoiding the inconvenience of traditional inflatable cuffs.

In the field of medical equipment, this integrated technology also shows great potential. For instance, the photodynamic therapy patch uses OLED as the light source, which can activate the photosensitizers applied on the skin surface, and is used for precise treatment of conditions such as acne or skin cancer; while the flexible rehabilitation patch integrates both an OLED screen and an OPD sensor, enabling it to not only display real-time physiological data such as the user's heart rate and body temperature, but also provide feedback on the treatment progress, facilitating post-operative rehabilitation or chronic disease management.

Flexible forms are the key to achieving comfortable and sustainable wearable technology. Smart fabrics incorporate OLED and OPD into fibrous forms and directly weave them into clothing, enabling completely concealed health monitoring. Users can wear them almost imperceptibly. On the other hand, the stretchable structures designed with bending engineering allow the devices to repeatedly bend, stretch, and twist within a certain range, significantly enhancing the adaptability of the devices to daily human activities, thereby expanding their application potential in fields such as sports health and remote medical care. OLED adopts a top-emitting structure, with light emitted towards the opposite substrate side; while OPD is used to receive the light signals that enter from this side. The pixel circuits and reflective anodes of both can be fabricated simultaneously in the same substrate process [7].

Igor Titov's research presented the structure and fabrication method of OLED-OPD test chips used for rapid detection [8]. In the research, OLED and OPD form the detection unit, which is fabricated on a 25mm×25mm, 1mm thick glass sheet. Each glass sheet has 4 test chips, and then they are cut into 12.5mm×12.5mm sensing units. Each test chip contains 8 detection units. The green light OLED pixels are based on glass with a transparent conductive layer (ITO), and are fabricated by heating and evaporating organic materials. The transparent conductive layer is first treated to make an electrode 130nm thick; then multiple layers of organic materials are successively laid down, including two layers of charge transport films and a 20nm thick light-emitting layer - the light-emitting layer contains special substances to achieve efficient green light (with the maximum brightness wavelength of approximately 512nm). Then a 50nm thick film is laid down to transfer electrons and block excess charges; finally, a cathode electrode is made, consisting of 1nm thick lithium fluoride and 175nm thick aluminum. The effective area of the OLED pixel is the overlapping part of the transparent conductive layer electrode and the aluminum electrode.

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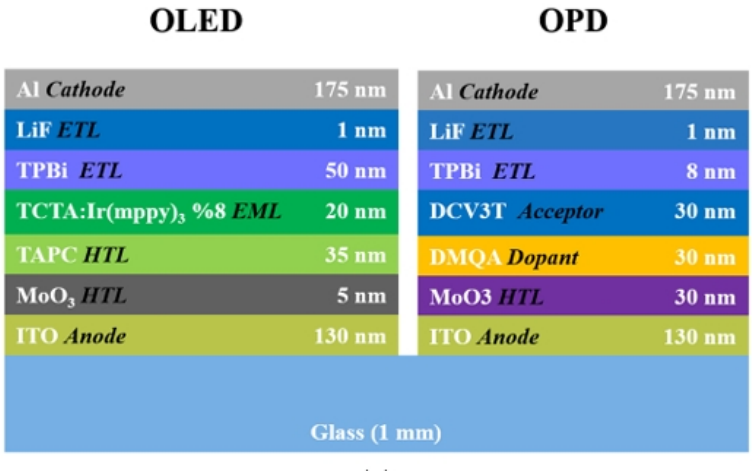

Figure 1. Thickness of the OLED-OPD test chip [8]

Figure 1 shows the layered stacking structure of OLED and OPD. This research achieved high-density integration of organic optoelectronic devices through microfabrication and vacuum evaporation processes, providing a hardware foundation for the development of compact and low-cost rapid diagnostic sensing systems. The data in the research are the core basis for device manufacturing, clearly defining the materials and precise thickness of each layer of OLED and OPD.

5. Outlook

Although the integrated system of OLED and OPD shows promising application prospects, its industrialization process still faces numerous challenges. Firstly, there are high barriers in manufacturing technology, especially in achieving large-area manufacturing with high resolution and uniformity, which imposes strict requirements on existing technologies. Secondly, the stability and packaging reliability of flexible devices during long-term use still need to be further improved, which directly affects the product's service life and user experience. In the medical and health field, the application requires highly accurate data, so not only does it need to continuously optimize signal processing algorithms, but also complete strict clinical certification procedures, which is a complex and time-consuming process. Moreover, cost control and large-scale production capacity are also key factors determining whether this technology can successfully enter the market.

The development of future technologies requires continuous breakthroughs in multiple aspects. At the material level, it is urgent to develop more efficient, stable and wide-spectrum-responsive organic semiconductor materials to meet the needs of different application scenarios. In terms of device design, the structure should be further optimized to reduce crosstalk between OLED and OPD, and improve integration and performance consistency. In the manufacturing process, developing high-precision and low-cost roll-to-roll production techniques will become an important way to achieve large-scale flexible electronic manufacturing. At the same time, it is also necessary to strengthen the combination of multi-sensor fusion technology and artificial intelligence algorithms to enhance the system's data acquisition and intelligent analysis capabilities.

The OLED-OPD integrated system is evolving from a single display function to a comprehensive platform featuring intelligent interaction, environmental perception, and health monitoring. With the continuous advancement of technology, this integrated system is expected to further blur the boundaries between consumer electronics and medical health devices, bringing revolutionary

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changes to human-computer interaction and health management methods, and ushering in a brand-new era of intelligent perception.

6. Conclusion

OLED-OPD integrated systems combine display and light sensing on a single flexible platform This technology makes devices thinner bendable and more versatile It supports functions like full screen fingerprint recognition health monitoring and non-contact gesture control New materials and structural designs have improved efficiency and sensitivity especially in wearable medical applications such as measuring blood oxygen and heart rate.

However, several challenges remain Manufacturing these systems is complex and requires high precision Flexibility and long-term reliability need improvement Data accuracy must be enhanced for medical use Production costs are still too high for mass adoption.

Future development depends on better materials especially organic semiconductors with broader light response and higher stability Smarter device designs can reduce interference between components Advanced manufacturing like roll to roll processing will help lower costs Combining multiple sensors with Artificial Intelligence will enable smarter data analysis.

This integrated technology is evolving from simple displays into multifunctional platforms for interactive health and environmental sensing It has the potential to redefine consumer electronics and medical devices creating new possibilities for human machine interaction and personal health management. OLED-OPD integration technology is upgrading traditional displays into multi-functional fusion interfaces, making devices lighter, more flexible and smarter. In the future, with the continuous breakthroughs in new materials and Artificial Intelligence, this technology is expected to create the next generation of devices that truly understand health, respond to gestures, and seamlessly integrate into life, reshaping the human-computer interaction experience and ushering in a new era of comprehensive health perception.

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