Proceedings of the 2023 International Conference on Functional Materials and Civil Engineering
DOI: 10.54254/2755-2721/23/20230645

Graphene as advanced applied material in flexible display applications

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Abstract. Flexible display technology has grown in popularity as a study area in the electronics industry as a result of the quick development of flexible electronics technology. Transparent electrodes, the main element of flexible display technology, are crucial for high resolution, high brightness, low power consumption, and interference resistance. A new kind of transparent electrode material is urgently required because conventional applied transparent electrode materials have issues like expensive cost, difficult preparation, and low dependability. Due to its exceptional performance in terms of transparency, electrical conductivity, and flexible bendability, graphene has gained a much interest as an emerging material. In order to provide guidance on the future development of cutting-edge materials for flexible display applications, this paper investigates the use of graphene in flexible displays. It examines graphene's use as a transparent electrode material and a thin film transistor material in flexible displays, as well as its application prospects and development trends. It is found that graphene has a high transparency of 97.7% and high conductivity, which outperforms the generally used indium tin oxide and copper materials. However, further advancements in the mass production of graphene is necessary for the industrialization of graphene in flexible display applications.

Keywords: transparent electrodes, graphene, thin-film transistors, flexible displays, organic light-emitting diodes (OLEDs.

1. Introduction

With the rapid development of flexible electronics technology, flexible display technology has become a popular research field in the electronics industry. As the core component of flexible display technology, transparent electrodes play an important role in high resolution, high brightness, low power consumption and interference resistance. However, traditional transparent electrode materials such as indium tin oxide (ITO) have problems such as high price, complicated preparation and poor reliability, so a new type of transparent electrode material is urgently needed. Graphene, as an emerging material, has shown excellent performance in transparency, electrical conductivity, and flexible bendability, and thus has attracted much attention. This paper investigates the application of graphene in flexible display, explores the application of graphene as transparent electrode material and thin film transistor material in flexible display, and evaluates its application prospect and development trend in the field of flexible display, hope to give advice on the further development of the advanced materials for flexible display applications.

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2. Introduction of graphene

Graphene is a layer of two-dimensional honeycomb lattice structure formed by the hybridization of carbon atoms through sp^2. Its basic structure can be described as a ring of six carbon atoms hybridized by sp^2 to form sp^2 hybridization orbitals that form a hexagon in the plane. The formation of graphene requires exposing a section of pure carbon material to high temperatures to form a layer of carbon atoms, and then using chemical methods to peel out the graphene layer. After obtaining graphene, putting it into applications reveals that graphene has high electrical conductivity and transparency and can be used as a material in electronic components such as transparent electrodes, sensors and transistors. On the other hand graphene has high mechanical strength and flexibility, which can be used to prepare flexible electronic components, flexible batteries, flexible displays and smart wearable devices in other fields, such as sensors, biomedicine, and materials science. Graphene is successfully used in a range of devices such as biosensors, adsorption membranes, separation membranes, high temperature conductors, etc. with excellent adsorption properties, high temperature and chemical stability and chemical composition and structure similar to biological tissues.

Currently, the simplest technology for graphene preparation is the mechanical exfoliation method, which uses adhesive tape or mechanical exfoliation to separate single or multi-layer graphene from high-quality graphite crystals. This method has the advantages of simplicity, high efficiency and low cost, but there are also some problems, such as low production efficiency and difficulty in controlling the thickness of graphene layers. Chemical vapor deposition method [1], on the other hand, is used to form graphene on the crystal surface by introducing carbon source gas (e.g. methane, ethylene, etc.) into a high temperature reaction chamber and using metal catalysts (e.g. nickel, copper, etc.). Therefore, it has the advantages of controllable preparation scale and high production efficiency, but there are problems such as metal residues and pollution. There is also a chemical reduction method [2] to prepare graphene by reducing graphene oxides (such as graphene oxide, graphene oxide, etc.). So, it has the advantages of low cost and easy operation, but its preparation process requires the use of strong reducing agents, which is prone to environmental pollution and safety problems. In addition, the liquid phase exfoliation method [3] is a method to exfoliate graphene from a metal substrate. This method involves immersing a metal substrate containing graphene in a solution that separates the graphene from the metal substrate through a chemical reaction. This method results in larger area and higher quality graphene compared to the previous two graphene preparation methods. In addition, the liquid-phase exfoliation method can be used in large-scale production and can be applied to a variety of substrate materials, such as copper, nickel, iron, and aluminum.

3. Flexible display technology

3.1. The characteristics of the flexible display

Flexible display is a new type of display technology characterized by the ability to display images and text on flexible and bendable substrates. Compared with traditional rigid display devices, flexible display devices have high durability, low power consumption and better display effects. Flexible display devices can use flexible substrates, such as plastic film, paper, etc., which can be thin and flexible and can be bent while still having a good display effect. In addition, the flexible substrate of flexible display devices is more durable than the traditional glass substrate, not easy to break or damage, can maintain a good display effect in a longer period of time while having a higher contrast and wider viewing angle range and lower power consumption.

3.2. Principles of flexible display technology and current status

The principle of flexible display technology is mainly realized through the use of flexible substrates, bendable electronic devices and polymer encapsulation materials, etc. Its core lies in the control of the physical or chemical properties of electronic devices to achieve the display of images. At the same time, flexible display technology also needs to overcome the refractive index of the substrate, conductivity and other issues, and needs to have good flexibility in packaging materials, durability and other

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characteristics to meet the needs of users for flexible display devices. For example, now widely used OLED technology, OLED, also known as flexible organic light-emitting diode [4] technology is an organic compound film-based electroluminescence technology, with high brightness, high contrast, wide viewing angle and low power consumption and other characteristics. Compared with the traditional liquid crystal display technology, OLED technology has higher response speed and higher color saturation, so it is widely used in mobile devices, TV displays, lighting and automotive displays. Then flexible OLED technology is based on the traditional OLED technology, using a flexible substrate to replace the silicon substrate, making OLED displays have higher bendability and flexibility. Through the use of flexible substrates, OLED displays can achieve bending, curling, folding and other deformations, so as to better adapt to a variety of complex application scenarios. The previous article has mentioned that the traditional liquid crystal technology has defects, then the application of flexible materials to liquid crystal technology is flexible liquid crystal display technology. This technology is a display technology based on liquid crystal molecules in the electric field under the action of changing the orientation and thus adjust the light transmission rate. It can be made of liquid crystal materials on a flexible substrate, making the display with flexible, thin, transparent and other characteristics, widely used in smart phones, tablet PCs, wearable devices and other electronic products. Compared with flexible OLED technology, flexible liquid crystal display technology has the advantages of low power consumption, fast response time and low cost, suitable for large-area preparation and mass production. The common Kindle e-book use of flexible electronic paper display technology [5].

The basic principle of flexible electronic paper display technology is to use the characteristics of electrochromic materials, under the action of the external electric field, to adjust the degree of absorption and scattering of light material so as to achieve the display effect. Among them, electrochromic materials mainly include electrochromic polymers, electrochromic liquid crystals, electrochromic organic molecules, etc. These materials can be made into thin films or microcapsules and other forms and used in combination with flexible substrates to form flexible e-paper displays, making the displays flexible, thin, curlable and other characteristics, similar to the look and feel of traditional paper. Flexible e-paper display technology has the advantages of low power consumption, high contrast ratio, and wide viewing angle, making it suitable for long time reading and outdoor use.

Flexible display technology is one of the current research hotspots of display technology. With the demand for high-definition, large-screen and thin features of consumer electronics, the development of flexible display technology is gradually attracting attention. At present, flexible display technology has been developed considerably, which includes a variety of technologies described above. Among the flexible display technologies, the application of graphene has attracted much attention. As a new type of transparent conductive material, the excellent performance of graphene transparent electrodes provides new possibilities for the development of flexible display technology.

4. Application of graphene in flexible display

4.1. Graphene transparent electrode

There are two main methods to prepare graphene transparent electrodes: mechanical exfoliation method and chemical vapor deposition method. Among them, the mechanical exfoliation method refers to the preparation of graphene transparent electrodes with high transparency and low resistivity by mechanical force exfoliation of graphene monolayer. This method is suitable for the preparation of graphene transparent electrodes with small areas. And the chemical vapor deposition method refers to the deposition of graphene precursors (such as methane, ethylene, etc.) in gaseous state on the substrate to form graphene transparent electrodes with high transparency and low resistivity. This method is suitable for large-area graphene transparent electrode preparation. The performance of graphene transparent electrode is excellent, compared with the traditional ITO (Indium Tin Oxide) transparent electrode, the transmission rate of graphene transparent electrode is as high as 97.7%, which is higher than that of ITO electrode, and the conductivity of graphene transparent electrode is better than that of ITO electrode, and its resistivity is about 1/30 of that of ITO electrode [6]. They can be used in flexible electronic

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products such as flexible display devices. On the other hand, the preparation process of graphene transparent electrodes is simple, and the materials are widely available, and the quality of the prepared electrodes is stable and reproducible. It can be seen that the nature and function of graphene transparent electrodes determine its important application prospects in flexible display devices, organic solar cells, touch screens, light emitting diodes (LEDs) and other fields.

4.2. Graphene thin-film transistors

Graphene thin-film transistors are a kind of transistors based on graphene material with excellent electrical and mechanical flexibility properties, which have wide application prospects in the field of flexible electronics. High-quality graphene films can be prepared from single graphene crystals by mechanical exfoliation and transferred to the substrate to form transistor structures. Or graphene precursor gases (e.g., methane, ethylene, etc.) can be deposited on the substrate by chemical vapor deposition to form graphene films, and then transistor structures can be prepared by processes such as photolithography and electron beam lithography. Graphene oxide can also be reduced to graphene films by chemical reduction, and then transistor structures can be prepared by processes such as electron-beam lithography [7].

Graphene thin-film transistors can reach a carrier mobility of 200,000 cm2/(V-s), one of the highest known mobility transistors, and are suitable for high-speed, high-sensitivity electronic devices. Graphene thin-film transistors also have excellent low-noise performance and can be used in sensitive sensors and preamplifiers. With graphene thin-film transistors, good electrical properties can be maintained under bending and stretching, making them suitable for flexible electronic devices and flexible display devices. Graphene thin-film transistors also have good high-temperature stability and can work stably under high-temperature conditions, making them suitable for electronic devices in high-temperature environments. High-performance and flexible organic light-emitting diodes can be prepared using graphene thin-film transistors, and the technology has been widely used in smartphones, wearable devices, virtual reality and other fields. In addition, graphene thin-film transistors can also be used for the preparation of biomedical sensors, such as in cholesterol sensors, DNA sensors and protein sensors, which can improve the sensitivity and specificity of the sensors. [8].

4.3. Other applications of graphene

In addition to applications in the field of flexible displays, graphene has a wide range of promising applications. For example, in the energy field, graphene can be used as an electrode material for batteries, supercapacitors and solar cells. In the sensor field, graphene's high sensitivity and selectivity make it an ideal sensor material for gas sensors, biosensors and chemical sensors. In addition, graphene can be used in high-strength composite materials, thermally conductive materials, anti-corrosion materials, and water treatment materials. The application of graphene in these fields is still in the early stage of continuous exploration and development, and there is still much room for future development.

5. Advantages and challenges of graphene in flexible display

5.1. Advantages of graphene in flexible displays

When introducing graphene, it is already known that graphene has a high transparency, measured as high as 97.7%, which is several times higher than traditional transparent conductive materials such as indium tin oxide (ITO). This allows flexible displays that use graphene as a transparent electrode to have higher light transmission and contrast, resulting in a clearer display. And the electrical conductivity of graphene is also very high, more than 200 times that of copper. This allows flexible displays using graphene as the conductive material to have lower resistance and higher current transfer efficiency, making the display more responsive. Another point is that graphene has excellent mechanical properties and can be bent and stretched without breaking. This makes it possible to prepare flexible displays with better portability and plasticity by using graphene as the base material for flexible displays.

5.2. Challenges of graphene in flexible displays

The application of graphene to various fields requires a large number of high-quality finished graphene products, but the large-scale preparation technology still needs to be improved, and the way and method of graphene preparation requires not only the use of expensive instruments and equipment but also the use of expensive raw materials, resulting in high costs. And due to the difficulty of controlling various parameters in the preparation process, the quality of graphene crystals prepared in large areas has the problem of instability, which makes it difficult to be applied in certain fields. Graphene transparent electrodes have many advantages in fields such as flexible displays, but there are still some shortcomings. Among them, the main problem is that their conductivity may be degraded by oxidation, chemical contaminants, dust, etc., which reduces transparency and reliability. In graphene thin-film transistors, the lack of stability of graphene thin-film transistors can lead to problems such as leakage and thermal runaway during prolonged use due to the high electrical conductivity and thin-film structure of graphene. [9] In addition, there are defects and impurities in the preparation process of graphene transistors, and these factors also affect the stability of the devices. The method of making high-quality graphene transistors still needs to be explored [10].

6. Conclusion

With the rapid development of flexible display technology, graphene, as an excellent flexible material, is widely used in flexible displays. Graphene transparent electrodes, graphene thin film transistors, graphene sensors, graphene flexible optoelectronic devices, flexible graphene batteries, graphene flexible organic light-emitting diodes, etc., are all applications of graphene in flexible displays. In the future, the application of graphene in the flexible display will be more widely developed. On the one hand, the preparation process of graphene thin film transistors will be continuously optimized, while more new materials will be compounded with graphene to improve its flexibility and stability. On the other hand, with the increasing demand for wearable devices and bendable devices, the application of graphene in the field of flexible electronics will usher in more opportunities. Meanwhile, the applications of graphene in biomedical and environmental monitoring fields will also be expanded, providing more possibilities for the application of graphene in flexible displays.

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