

Research On the Properties and Applications of Organic Semiconductor Materials

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Abstract. Organic semiconductors, as a type of semiconductor material, have the advantages of good flexibility, tunable properties, and low cost. It can be applied in display devices and sensors. In recent years, organic semiconductor materials have attracted significant research interest due to their unique properties and wide applications. The purpose of this article is to provide a comprehensive overview of the properties and applications of organic semiconductor materials, which have gained significant popularity. Organic semiconductors are highly sought after due to their flexibility, low cost, environmental-friendly, tunable electronic characteristics, and a broad range of potential applications. Understanding these properties of the semiconductor materials is crucial to harness them. This work summarizes the research on the properties and applications of organic semiconductor materials. The advancements in organic semiconductor technology and its applications are discussed. The strengths and weaknesses of organic semiconductor materials are summarized. In addition, the current challenges in this field have also been discussed. The potential research directions for future organic semiconductor modification have also been pointed out.

Keywords: Organic Semiconductor; Properties; Application.

1. Introduction

Semiconductor materials have important research value. The rapid rise of semiconductor technology is an important reason for technology's rapid development and progress in the 20th century. Silver sulfide, as one of the semiconductor materials, was discovered by the British scientist Faraday in 1833. Its resistance is inversely proportional to temperature. In the 50s of the 20th centuries, the discovery and application of the first generation of silicon germanium led to the rapid development of semiconductors. In 1960, 0.75-inch monocrystalline silicon wafers appeared. However, the rise of the second generation of semiconductors has further promoted the semiconductor industry. GaAs, as a typical III-V compound semiconductor material, was first synthesized in 1929 by the German scientist V.M. Goldschmidt. In 1952, the German H. Welker discovered that gallium arsenide has semiconducting properties and proposed that III-V compounds are superior to first-generation semiconductors. With the wide and in-depth application of semiconductor compounds in microelectronics and optoelectronics, semiconductor technology has experienced rapid development.

Semiconductor materials are divided into organic semiconductors, inorganic semiconductors, and inorganic-organic hybrid semiconductors. An organic semiconductor refers to a semiconductor containing carbon bonds in the molecule. By doping, the conductivity and composition of organic semiconductors can be adjusted. Organic semiconductor exhibits the characteristics of flexibility, low cost, and environmentally friendly, making it an important member of the family of semiconductor materials. Therefore, research on the properties and applications of organic semiconductors is of great significance.

Firstly, this work introduces the basic properties of organic semiconductor materials. Subsequently, the applications of organic semiconductors in semiconductor technology are discussed. Moreover, the promising research directions of organic semiconductor materials in the future are elaborated.

2. The Properties and Preparation of Organic Semiconductors

2.1. The Flexibility of the Materials

Organic electronics have attracted a lot of attention due to their favorable properties including low cost, high throughput, lightweight, and high flexibility. Especially its excellent flexibility makes it a potential application in flexible wearable devices. However, the devices cannot survive repeated bending, creasing, abrupt folding, and even stretching against the surfaces of arbitrary complex-shaped objects. Extreme flexibility is required for these applications.

Research interest in flexible organic semiconductor electronics has increased since Heeger's group produced the first fully flexible polymer-based organic light-emitting diode (OLED) on a polyethylene terephthalate (PET) substrate in 1992 [1]. In 1994, Garnier et al. [2] created the first flexible organic field-effect transistor (OFET) made entirely of polymers using printing techniques. As a result, circuit matrices [4] and flexible OLED arrays [3] have been reported. In 2003, Forrest and colleagues presented the first biological write-once, read-many-times memory device [5]. In 2004, Aernouts et al. used highly conductive poly (3,4-ethylene dioxythiophene)/poly (4-styrenesulfonate) (PEDOT: PSS) as a flexible transparent anode to create flexible organic solar cell modules [6]. For the past few decades, scientific communities have been pursuing high-performance flexible organic semiconductor devices.

Organic semiconductor materials can be processed using a variety of techniques, including the solution method, vacuum evaporation, and inkjet printing, which makes them generally easier to work with. These materials can be manufactured in a variety of forms, including films, fibers, and granules.

2.2. Tunable Electronic Properties

Organic semiconductors have tunable electronic properties, which means that their electrical characteristics can be adjusted or modified by various methods. There are a few ways to alter the electronic properties of organic semiconductors.

2.2.1 Chemical modification

The electronic properties of organic semiconductor materials are influenced by their composition and structures. By changing the molecular structure of the organic semiconductor material, its electronic properties such as bandgap, charge carrier mobility, and energy levels can be altered. This can be achieved through chemical synthesis or functionalization. The HOMO–LUMO energy gap, IPs, EAs, and inner-sphere reorganization energies (λ_i) of organic semiconductors can all be varied widely by trifluoromethylation. It is known that λ_i is greatly decreased when the π -conjugation is increased. It is reported that inner-sphere reorganization energy considerably increases with the increase of the degree of trifluoromethylation on the same aromatic ring. Moreover, inner- and outer-sphere reorganization energies constitute the overall energy. It may be possible to modify the charge mobility of organic semiconductors by carefully regulating the interactions between molecules [7].

Doping can also alter the electronic properties. Adding dopant molecules into the organic semiconductor can modify its electronic properties by changing the concentration of charge carriers (electrons or holes) and thus affecting its conductivity.

2.2.2 Physical modification

The electronic properties of organic semiconductors are often temperature dependent. By controlling the temperature, it is possible to tune parameters such as conductivity, mobility, and bandgap.

Modifying the interfaces between different layers or materials in an organic semiconductor device can influence its electronic properties. This can be done through surface treatments, interfacial layers, or device design.

Organic semiconductors can exhibit interesting electronic properties under external stimuli such as light, electric field, or mechanical stress. By applying these stimuli, the electronic properties of organic semiconductors can be tuned for specific applications. Organic semiconductors can exhibit

interesting electrical properties when they are subjected to external stimuli such as light, an electric field, or mechanical stress. By applying these stimuli, the electrical properties of organic semiconductors can be modified for specific applications. The development of organic semiconductors that are both moisture- and air-resistant is essential for the creation of organic solar cells, organic light-emitting diodes, organic thin-film transistors, and molecular electronics [8]. The HOMO–LUMO gaps, electron affinity, ionization potential, reorganization energy related to charge transfer, the energy levels of the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO), are crucial parameters for the design of the devices. Being able to alter these parameters increases the chances of discovering new materials.

Overall, the tunable electronic properties of organic semiconductors offer flexibility and versatility in designing electronic devices with tailored performance characteristics for various applications in optoelectronics, flexible electronics, and organic electronics.

2.3. Preparation and Manufacture

Till now, commercialized Si-based semiconductors display high efficiency. However, the preparation, purification, and manufacturing of silicon crystals still need to be improved in order to achieve higher performance. Organic semiconductors have promising applications in flexible electronics, wearable devices, optoelectronics, and other fields. Sustained growth in market demand can promote the large-scale production of organic semiconductors.

One method for lowering the cost of synthesizing high-performance solar materials is to synthesize photovoltaic materials with straightforward structures, such as poly(3-hexylthiophene) (P3HT). Poly[(thiophene)-alt-(6,7-difluoro-2-(2-hexyldecyloxy) quinoxaline)] (PTQ10), a low-cost conjugated polymer donor with a high overall yield of 87.4% was prepared by two steps of synthesis [9]. Simplifying the reported synthesis process of high-performance photovoltaic materials can also cut costs. Choosing the right catalysts, devising a more straightforward synthetic route, and streamlining the purification procedure are the methods to achieve this goal.

3. Applications of Organic Semiconductors

Organic light-emitting diodes have been considered one of the most promising technologies for future displays since Kodak's breakthrough in 1987. Numerous materials have been developed and improved to meet the requirements of this application. The structure of these materials and the process by which the electroluminescence is generated are different from each other. Due to their potential to replace liquid crystal displays or cathode ray tubes in flat-panel displays, organic light-emitting diodes have received a lot of attention over the past 20 years.

For next-generation full-color displays and lighting applications, fluorescence-based organic light-emitting diodes are an attractive option due to their long operational lives, excellent color purity of electroluminescence, and potential for low production costs. The use of thermally activated delayed fluorescence molecules as assistant dopants, which enable the efficient transfer of all electrically generated singlet, enables the high performance of fluorescence-based organic light-emitting diodes. This exciton harvesting method allows organic light-emitting diodes to select emitters freely from a large range of typical fluorescent compounds [10].

It is reported that an organic light-emitting diode display can be used in large-screen display applications. In this way, the high parasitic capacitance of the OLED device itself can be overcome in a common anode configuration, thus achieving the required minimum seam.

In addition, solar cells based on organic semiconductors will also become an important application field. The growing interest in renewable energy sources is driven by the need to address the global demand for fossil fuels, which are becoming scarcer, and a better understanding of the long-term impacts of CO₂ and other greenhouse gas emissions. Projections indicate that global energy consumption will rise from around 17 TW in 2010 to about 27 TW by 2040. In the energy era, organic semiconductors will become the preferred choice for functional materials. The future of organic solar

cells as a pervasive technology for portable power will largely rely on their economic potential [11]. This depends on several intricate factors, such as efficiency, manufacturing cost, lifetime, form factor, weight, scalability, and sustainable manufacturing.

4. Conclusion

Organic semiconductors play a crucial role in the field of electronics due to their unique characteristics. They are promising candidates in the field of developing flexible and lightweight electronic devices. Flexible displays, wearable electronic devices, and organic photovoltaics may be prepared by using this material. The application potential of organic semiconductors extends to fields such as healthcare, sensing technology, and energy harvesting. Their versatility and adjustability make them suitable for a wide range of applications, opening up new possibilities for innovation and technological progress. In terms of semiconductor technology, organic semiconductors provide a promising alternative to traditional inorganic semiconductors. Their compatibility with large-scale, low-cost manufacturing processes and their potential for integration with existing semiconductor technologies make them a valuable asset in driving the next generation of electronic devices. Continuous research on device design and manufacturing processes is crucial for addressing existing challenges. By further understanding and optimizing the characteristics of organic semiconductors, researchers can improve their performance, stability, and scalability, paving the way for further application in various fields. In summary, organic semiconductors have significant significance and potential applications in advancing semiconductor technology. Continuous research and development in this field is crucial for fully utilizing the capabilities of organic semiconductors and promoting innovations in the electronics industry.

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