# Applications of Two-Dimensional Organic Materials in the Field of Optoelectronics

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**Abstract.** This article looks into the quickly advancing landscape of two-dimensional organic products and their transformative function in optoelectronics, driven by developments in nanotechnology and chemistry. At the leading edge of this exploration are three essential materials: Graphene and its analogs, conjugated polymer nanosheets, and fullerene derivatives. Each of these materials presents unique characteristics and difficulties, offering a complex view of the potential and difficulties in this innovative domain name. Graphene and its analogs, renowned for their outstanding electric conductivity and mechanical stamina, stand as pillars in the advancement of sophisticated optoelectronic devices. Conjugated polymer nanosheets, with their flexible properties and tunable electronic characteristics, open new avenues for wearable technology and flexible displays. Fullerene derivatives, understood for their electronic flexibility, are key to creating high-efficiency solar batteries and sensing units. This extensive evaluation browses with the elaborate procedure of synthesizing these materials, emphasizing the synthesis obstacles while highlighting the techniques that have actually shown promise in conquering these barriers. The research study likewise forecasts the capacity of these materials in ushering in a brand-new period of optoelectronic devices, identified by boosted effectiveness, lowered environmental impact, and more comprehensive application scope, consisting of in renewable resource and wise innovation. In synthesizing these understandings, the research aims to offer a much deeper understanding of the current state and future trajectory of two-dimensional organic materials in optoelectronics. It emphasizes the vital of interdisciplinary collaboration in material science, engineering, and industry to utilize these innovations for useful applications, thereby forming the future landscape of modern technology and sustainability.

**Keywords:** Two-dimensional; Organic; Optoelectronics.

## 1. Introduction

In the modern society, optoelectronics is one of the most practical, sustainable and useful subjects. Research and Application in the realm of optoelectronics are rapidly increasing due to the burst of modern nanotechnology and chemistry. Two dimensional material, which is included in the study of optoelectronics, is under the condition of fast development. Fascinatingly, the study of two-dimensional (2D) materials is in a phase of ongoing development, with the collection of known 2D materials expanding annually as fresh materials are discovered each year. For example, presently, the catalog of graphene includes over 150 distinct materials. Beyond the remarkable properties of graphene, these emerging 2D materials demonstrate exceptional promise for applications in various fields such as biomedicine, sensor technology, transistor development, light-emitting diodes (LEDs), and catalysis [1]. Conjugated Polymer Nanosheets are primarily composed of carbon and hydrogen, sometimes including elements like nitrogen or sulfur. Their planar morphology provides a high surface area, beneficial for applications like Light-Emitting Diodes (LEDs), photovoltaic cells (solar cells), and optical fiber communications. Poly (p-phenylene vinylene) (PPV) is a notable example used in the earliest conjugated polymer LEDs. The third material, Fullerene, particularly C60, is renowned for its excellent conductivity of conducting electrons and efficient charge separation at the donor/acceptor layers, making it a popular material in organic photovoltaics. Innovations like the zinc chlorodipyrrin derivative (ZCl) have been developed to enhance C60's light absorption in the visible spectrum, overcoming its low absorption disadvantage.

Currently, there are a few challenges in the realm of synthesis of two-dimensional organic material that researchers are going to counter with, such as the difficulty in achieving high-quality, defect-free structures and maintaining stability under varying environmental conditions. However, new breakthroughs in this field can be exciting, especially in the realm of optoelectronics because these materials are able to be used to develop more efficient and flexible electronic devices. Taking a panoramic picture of the development of optoelectronic, people are able to find out that the future of these materials in transforming the field of optoelectronics is promising. The potential of the materials is enabling the innovation of lighter and more energy-efficient equipment. Finally, revolutionization of this field can happen, and more flexible displays and advanced sensors can be manufactured. This review will significantly enhance the understanding of the device physics of three types of 2-dimensional materials (Graphene materials, Conjugated polymer nanosheets and Fullerene with its derivatives) in the realm of optoelectronics while also offering a general perspective for researchers interested in exploring these materials for diverse applications.

## 2. Graphene and its analogs

Graphene and its analogs are very useful materials that contain huge potential for application in today's society. Graphene is a two-dimensional optoelectronic material that has high mobility, high optical transparency, great flexibility, robustness, and environmental stability (with general chemical structure as shown in Figure 1). It is the ideal material for touchscreens, organic solar cells and organic light-emitting diodes (OLEDs). Its analogs are widely used in transistors and photodetectors due to different electronic properties, such as semiconductor properties. Except for the wide application of this material, the manufacturing part has also been developing continuously in the last thirty years.

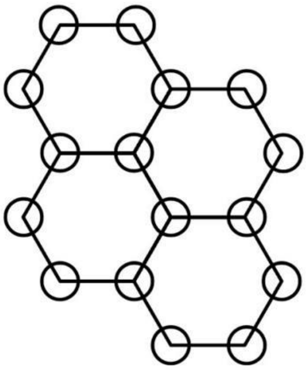

**Fig 1.** Brief view of graphene model, chemical bounds with circles that represent carbon atoms (original).

The manufacturing and production of graphene can be distinguished into mainly three methods: micromechanical cleavage, Liquid-phase Exfoliation (LPE), and chemical vapor decomposition.

For the method of micromechanical cleavage, people can just rub the layered graphene crystals with any other solid surface, and the obtained attachment flakes can be proven to have a single-layer structure after inspection by an optical microscope [2].

The method of Liquid-phase Exfoliation mainly contains six parts: choosing the appropriate material, dispersion, exfoliation, stabilization, separation/purification and post-processing. In the first procedure, proper graphite material should be selected as the source of graphene. Then, the selected material should be dispersed into a liquid medium. After that, the graphite material will be peeled off physically or chemically in order to get the graphene layers. At the same moment, surfactants or other chemicals may be added to help the graphene sheets disperse stably in the liquid. This is the process of stabilization. Through the above processes, we can get the graphene sample with impurities and unstripped graphite. Then, centrifugal separation, filtration or other method may be applied to obtain purer graphene. Finally, in order to get the expected properties, the resulting graphene might be dried or reduced, and that is the stage of post-processing.

Moreover, the Chemical vapor disintegration technique refers to the details treatment of synthesizing graphene by utilizing chemical vapor. This involves a catalyst-free inductively coupled radio frequency plasma-enhanced chemical vapor deposition, utilizing a blend of methane (CH4) dissolved in hydrogen (H2). The conformation of these nanosheets is feasible on numerous substratums using a diverse collection of deposition conditions, causing the advancement of flake-like structures with considerable wavinesses. The nanosheets possess a density of much less than 1 nm and exhibit a flawed graphite structure. The framework and morphology of the nanosheets were examined using scanning electron microscopy (SEM) and high-resolution transmission electron microscopy (HRTEM). The advancement price of graphene nanosheets was influenced by variants in methane content and substrate temperature level, although their density continued to be instead secure. The Raman spectroscopy investigation exposed a reduction in the crystallinity of the nanosheets as the methane web content or substrate temperature level boosted. Furthermore, the usage of Fourier transform infrared spectroscopy (FTIR) and thermal desorption spectroscopy (TDS) allowed for the identification of hydrogen gas absorption by the nanosheets. The convenience of this production strategy and its capability to be used on several surfaces enables a vast array of sensible applications and essential researches on graphene [3].

Another important aspect of two-dimensional material graphene is its application. Graphene is now widely used in almost every electrical cutting-edge technology. To be more specific, two of the main applications, light-emitting sources and photodetector will be illustrated. All the applications are based on the properties of graphene. OLED, which means organic light emitting diodes, is one representative technology that uses graphene as the main material for light source. The work function of graphene, at 4.5 eV, is comparable to that of ITO. Coupled with its potential as an affordable and flexible transparent conductive film (TCF), graphene emerges as a highly suitable choice for the anode in OLED applications [4].

With the evolution of nanotechnology, the light-emitting devices are also becoming more and more advanced. In order to make light sources more efficient, functional, and more stable, people have been looking for more advantageous manufacturing materials to make light-emitting components. Active materials based on graphene offer a forefront solution for creating two-dimensional, flexible, slender, and durable sources of light emission. The distinctive configuration of Dirac electrons in graphene, which are massless fermions exhibiting a linear dispersion relationship, along with a very wide plasmon bandwidth and modifiable surface polarities, presents numerous opportunities in the domains of optoelectronics and plasmonics [5].

The linear dispersion relation represented by the Dirac equation refers to the straight-line relationship between the energy and momentum of electrons in graphene. This is a key feature of Dirac fermions in graphene, which leads to unusual electronic properties like high electrical conductivity and electron mobility.

In addition, plasmons are collective oscillations of free electron density. Graphene, due to its two-dimensional nature and electron behavior, can support plasmons with a very wide range of frequencies (ultra-wideband). The surface polarity of graphene can be tuned, meaning that the way it interacts with electric fields can be altered. This is often achieved through external gating or chemical doping.

LIRGO, which represents Laser-Induced Reduced Graphene Oxide, is a material used in the creation of a flexible LED device. Based on LIRGO, Jiang et al. created a flexible LED. They also proceed to do an uninterrupted 60-hour exposure to light in a vacuum with a pressure of 0.02 Pascal. In order to characterize the stability and longevity of the LIRGO emitter. Finally, it was determined that the LIRGO LED has a lifespan exceeding 60 hours under the conditions of a vacuum pressure of 0.02 Pa and a drive current of 0.01 A. In addition, by measuring LIRGO's power consumption and luminous intensity, it is possible to calculate its wall plug efficiency (WPE), which is an important indicator of its inherent electroluminescence (EL). The WPEs varied between 1.2% and 1.7%, averaging at 1.4%, for the five devices analyzed in the experiment. The compliance current was set at 0.01 A. This is considered a commendable figure [6].

## 3. Conjugated polymer nanosheets

Conjugated polymer nanosheets are a type of material composed of polymers that are highly interconnected in a planar structure. These materials are distinguished by their conjugated systems. To be more specific, the systems are a series of alternating double and single bonds along the polymer backbone. This internal conjugation allows for the delocalization of electrons, providing these materials with unique electronic properties. In addition, conjugated polymers are typically organic materials that are composed primarily of carbon and hydrogen, sometimes with other elements like nitrogen or sulfur incorporated into the structure. The planar or sheet-like morphology of these polymers grants them a high surface area, which is beneficial for a variety of applications. For example, light-emitting Diodes (LEDs), photovoltaic Cells (Solar Cells) and optical Fiber Communications.

As seen in Figure 2, poly (p-phenylene vinylene), or PPV, is soluble in both methanol and water. For a very long time, the first conjugated polymer light-emitting diode (LED) was made using PPV. Currently, a wide range of new PPV derivatives have been created that can dissolve in common organic solvents. This is due to the unsatisfactory quantum efficiency of PL and the high-temperature transformation of the forerunner to PPV. MEH-PPV can be readily synthesized from the corresponding monomer, 1, 4-bischloromethyl-2-methoxy-5-(2'-ethylhexyloxy) benzene. In addition, the presence of dialkoxy side groups modifies the bandgap of the polymer, resulting in a shift in the radiation color from the original yellow-green in color of the unsubstituted PPV to the color orange in a bathochromic manner. The initial development of high-efficiency polymer LEDs was achieved by utilizing MEH-PPV. When the 3',7'-dimethyloctyloxy group (MDMO-PPV) replaces the 2'-ethylhexyloxy side group, the emission color shifts slightly more toward red. In bulky 2, 5-bis (cholestanoxy) side groups in BCHA-PPV, the color shifts in the other way to orange-yellow [7].

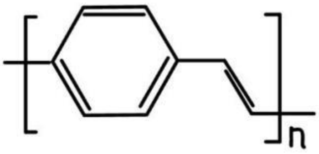

**Fig 2.** PPV structure graph (original).

In the context of polymer solar cells (PSCs), these devices typically consist of a photoactive layer made of a polymer blend, positioned between layers for electron and hole transport (ETL and HTL, respectively), and then connected to the anode and cathode. The structure enables the material to be one of the best choices for making photovoltaic cells. For ETLs, metal oxides like ZnO and TiO2 are often chosen due to their high electron mobility and conductivity. In addition, materials such as Poly (3, 4-ethylenedioxythiophene), polystyrene sulfonate (PEDOT: PSS) and MoO3 are frequently used for HTLs. Recent advancements have led to PSCs built on rigid glass substrates achieving power conversion efficiencies (PCE) of over 16%. In some studies, metal-oxide films are commonly used as ETLs. Nevertheless, the fragility of these films can limit the mechanical functionality of the gadgets. In contrast, organic materials, known for their great mechanical properties compared to inorganic materials, can act as potential alternatives for ETL materials in the development of PSCs because it has the properties of enhanced stretchability and flexibility. [8].

Devices in the field of polymer solar cells (PSCs) typically consist of a photoactive layer made up of a polymer mixture. This layer is located between layers specifically designed for electron and hole transport (ETL and HTL, respectively), and is then connected to the anode and cathode. The structure makes the material ideal for manufacturing solar cells. Titanium dioxide (TiO2) and Zinc oxide (ZnO) are typically utilized as metal oxides for ETLs due to their high electron mobility and conductivity. On the other hand, Poly (3, 4-ethylenedioxythiophene), polystyrene sulfonate (PEDOT: PSS), and MoO3 are frequently used as hole transport layers (HTLs). Recent advancements in the industry have led to power conversion efficiencies (PCE) of 16% in photovoltaic solar cells (PSCs) fabricated on rigid glass substrates. Metal-oxide films are commonly used as electron transport layers (ETLs) in numerous research studies. However, the delicate nature of these coatings can restrict the mechanical functionalities of the gadgets. Compared to normal inorganic materials, organic material usually possesses better mechanical properties. Thus, organic materials can have the potential to be used as alternative ETL (electron transport layer) materials in the development of PSCs (perovskite solar cells) with enhanced stretchability and flexibility [8].

## 4. Fullerene and its derivatives

Fullerenes, also known as buckyballs, are a class of carbon allotropes characterized by a closed-cage structure consisting of carbon atoms interconnected in hexagonal and pentagonal rings, forming a spherical, ellipsoidal, or tubular shape. The most famous Fullerene is C60, which is very famous and being widely used by chemistry and physics researchers. C60 resembles a soccer ball-like shape and was the first to be discovered in the catalog of Fullerenes. Also, it is actually an allotrope of graphene. Subsequently, numerous variants of fullerene have been artificially produced and examined for their distinct characteristics such as electron accepting qualities and high electron mobility, as well as their potential applications.

C60, a derivative of fullerene, is a highly utilized material known for its exceptional characteristics such as robust electron conductivity and efficient charge separation at the interface between the donor and acceptor. C60 is commonly used in organic photovoltaics because to its demonstrated efficacy with various donor materials. To further the advantages of C60, scientists developed a zinc chlorodipyrrin derivative (ZCl) substance that exhibits a remarkable ability to absorb visible light. The limited light absorption in the optical range of the electromagnetic spectrum of fullerene C60, which is commonly employed, is a notable disadvantage. The feature stems from the inherent prohibition of symmetry in the lowest energy electronic transition, occurring at a wavelength of 670 nm. The significant optical density seen in the 400–500 nm region of a pristine C60 film is ascribed to an intermolecular charge-transfer (CT) absorption. ZCl was utilized to amplify the absorbing capacity of the electron-acceptor surface. The current density of organic photovoltaics (OPVs) based on C60, with and with no chemical sensitizer, is 4.03 and 3.05 mA/cm2, accordingly. The OPVs have a fill factor (FF) of 0.44 and an opening-circuit voltage (VOC) of 0.88 V [9].

Furthermore, there are numerous novel research avenues for Fullerene and its derivatives in the realm of organic photovoltaics that have developed in recent years. The new field necessitates a robust electron-donating capacity, significant polarity, or exceptional water permeability, all of which could be attained by novel design methodologies. Fullerene and its derivatives can be stimulated to generate organic hybrid perovskite solar cells (PSCs) due to their heightened electron attraction, superior electron mobility, and less rearrangement energy.

## 5. Conclusion

Currently, scientists and researchers are working to innovate more applicable materials and optimize known materials. Graphene, polymer nanosheets and Fullerene are three materials that have huge potential. In modern society, graphene can be designed to produce high-efficiency photoelectric conversion devices due to its excellent electrical conductivity and light transmittance. Conjugated polymer nanosheets, because of their tunable band gaps and high photoluminescence efficiency, can be used in Photonics and optical communication applications. Furthermore, Fullerene derivatives and graphene can also have important applications in sensor and biomedical fields due to their large area of specific surface and biocompatibility. In summary, all of the three materials illustrated are essential for the modern world and able to createmore benefits for mankind.

Although challenges like the difficulties in mass production, stability under operational conditions are exist, exploration and innovation are still the dominant trends in this field. Interdisciplinary collaborations can be helpful in encountering this problem. For example, to increase the interaction of light with matter, it was demonstrated that researchers could increase the length, duration, and extent of interaction while maintaining a relatively small size. This operation involves an interdisciplinary collaboration between two disciplines: two-dimensional materials science and optical communications [10, 11].

The advancement and implementation of carbon-neutral technologies, such as solar power, solar fuels, and solar thermal energy, pose both a huge challenge and a promising opportunity for the global society. Projections indicate that the global energy consumption rate is expected to increase twofold from 13.5 TW to 27.6 TW between 2001 and 2050. Furthermore, by the year 2100, it is anticipated that the consumption would quadruple, reaching a total of 43.0 TW. Despite solar technology's current lower-than-expected popularity, it has the potential to be the most effective solution in achieving the carbon-neutral goals of 15TW and 30TW [12]. In the future, the government's promotion of advanced two-dimensional optoelectronic materials and global research efforts may potentially resolve the energy challenges faced by the Earth. Additional two-dimensional optoelectronic materials will be discovered and utilized.

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